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L.A.U.D.E: Learning Automata for Urban Development Exploration. The Case Study of Rome Urban System

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L.A.U.D.E.: Learning Automata For Urban Development Exploration The Case Study Of Rome Urban System

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ABSTRACT

Learning C.A. is a cellular automaton coupled with a classifier system, in order to discover the transition rules for the automaton from experimental data. This new model is applied for the first time to a real urban system. The paper discusses the problem of applying C.A. to an urban system in a realistic way, and it presents the first results obtained with the model.

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1. Introduction

This paper presents the application to a real case study of the theoretical-methodological work (firstly presented at the XVII Conference of Italian Regional Science Association; Papini and Rabino, 1996), concerning the development of a new generation of urban models, which can be called „intelligent“ simulators (in the sense of A.I.) of the urban systems evolution.

In chapter 2 the conceptual meaning of such theoretical proposal is reassumed, by identifying its roots in different veins of reasoning. In chapter 3, learning cellular automata are presented as operational proposal and the mathematical-computer details of the prototype are specified.

The following chapters describe the application carried out to the Rome urban system: chapter 4 presents the way in which the urban system was represented; chapter 5 describes the „design“ of the model, that is the learning mechanisms adopted in the case study; chapter 6 shows the results, which correspond to what the model (Laude) „discovered“ about the transformation factors working in the study area.

2. An Ambitious Project

In a moment apparently propitious for a relaunching of both theoretical and operational urban mathematical modelling (see Klosterman, 1994), the development of such activity and the proposal of new models request the consideration of at least four aspects: the (new) epistemological climate; the evolution of urban modelling in recent years; the (changed) computer context (from both the point of views of theory and tools); the always crucial connection with urban planning.

2.1. A different epistemological context

In the development of new urban models, the new epistemological climate and the „science of complexity“ cannot be neglected. A lot has been written and said about this „science“ (in the field of urban planning, see for instance Rabino, 1995 and Lombardo, 1995), so that we will remind here neither its phenomenology (irreversibility, selforganization, etc.) nor its principles, that must be taken into consideration in model building.

It must be stressed, however, a direction of analysis often neglected: that one which considers not only the representation of a complex reality in a model, but also the „location“ of the model itself in a more complex world. In other words, the idea is to reconsider firstly the relation model-model builder from the point of view of complexity.

In this sense, we can see that, starting from the model viewed as an „objective representation“ of the analysed system, a new idea is recently gaining ground, which looks at a model as an „organised system of knowledge“ about the studied system.

This change is discussed in Occelli and Rabino (1997); here we add that the new point of view allows in some way the model to have an autonomous life with respect to the model builder, therefore, it is not inappropriate to consider the model as a cognitive system (an intelligent system) observing a given reality.

2.2. *The recent evolution of urban modelling*

In recent years, urban modelling showed two main characteristics:

- a) a prevalent theoretical advancement, to the detriment of operativeness of models;
- b) the attempt to shift from „classic“ models to „evolutionary“ models (as evolutionism appeared to be the symbol of complex systems)

The former aspect will be treated in chapter 2.3. As to the latter, we can say that Allen's model (Allen and Sanglier, 1979) is the paradigmatic representative of the modelling change which counts contributions by several authors: Bertuglia, Diappi, Lombardo, Rabino, Reggiani, in Italy and Haag, Pumain, Wilson, etc. (beside Allen) in Germany, France, England.

Though Allen's model produced in the eighties a strong innovative drive, now we can in retrospect recognise in this model two substantial weaknesses (that can be found, however, also in the work of the other authors quoted) with respect to the modelling change mentioned above:

- a) the model, indeed, does not correspond to an evolutionary mechanism (that is a process of selforganization based on mutation and selection), as it provides a macro-description of urban change and the randomness elements are forcedly introduced in the model by means of an arbitrary additive random term;
- b) as a consequence, the selforganization is more apparent than real. Instead of a real emerging of super-structures, the model develops some elements already contained in the model itself, even if in an implicit form:

$y = f(x)$ explicit function, x is the independent variable, y is the dependent variable;

$y = f(x,y)$ implicit function, referable to the form $y = g(x)$, even if not by analytical way.

Therefore, the challenge for the theoretical urban modelling is still the development of really evolutionary models.

In addition, we can add that:

- the recent urban modelling work which uses cellular automata does not seem to distance itself from the classic approach (see for instance the Lowryan „philosophy“ of the model developed by White and Engelen, 1994);
- the applications to urban systems of neural networks have more the nature of statistical techniques than that of urban models;

- the recent model SIMPOP developed by Sanders and others (1997), though allows the „emerging“ of structures, contains them from the beginning;
- maybe, elements of true evolutionism can be found in some urban simulation games; but such elements can be traced more in the interactions between the players than in the „gaming desk“ (that is in the „model“ of the game).

2.3. The „computer explosion“ and the lesson of Artificial Intelligence (A.I.)

We cannot discuss the development of urban modelling without taking into account the development of computers, which cancelled all the elements of the „requiem for large scale models“ of the seventies (see Klosterman, 1994).

A new style of „management“ of the models has become inevitable: the elaboration of information through standard applications (e.g. Excel), the friendly use of the model by means of Windows-like menus, the cartographic mapping of data (GIS), etc.

However, it is to be regretted that, beside the direct exploitation of the new possibilities, little has been made in order to probe the new open fields of the interaction between modelling and computers (e.g. interactive modelling, interface between models and GIS, etc.).

The same can be said as to the application of A.I. tools to urban analysis and urban planning: in these fields, the use of Expert Systems, Neural Network and the like comes often to straight applications of such techniques.

It is then necessary, beyond techniques, to work at an innovative use of such tools, which could catch their deep nature of „knowledge engineering methods“ (e.g. learning methods, forms of knowledge organisation, etc.) and provide the tools for the development of territorial „cognitive systems“ (that is, new models).

2.4. Models, planning, design

Apart from the opinions about the usefulness of mathematical models, their application is always associated with the analytical phase of the planning process, as a tool to build information and knowledge organisation (e.g., in the evaluation phase, in order to probe the effects of planning actions).

However, we can wonder whether modelling could be present also in the really creative moments of the planning process (e.g. problems individuation, the „invention“ of plan alternatives). Now it seems possible (Rabino, 1995), in fact the emerging idea of a model conceived as an evolutive cognitive system (selforganizing) stresses that the new focus is on the „creative processes“ (and therefore on the creative aspects of planning).

The development of a new modelling, then, seems to aim at a new and more relevant role in the context of urban and territorial planning and management.

2.5. Concluding comments

All the elements introduced in the previous chapters aim toward one goal:

to try to build really evolutionary (urban) models, where with „really evolutionary“ we mean a model able to produce by itself the emerging of new structures, a model, then, able to modify its equations by itself (obeying only to some general principles).

In the next chapter we try to traduce this ambitious goal in an operational project.

3. The Learning Cellular Automata

3.1. A general model

The development of a model with the characteristics said above requests to go over again the logical process of model building, in order to find the aspects of such process which can be modified in the wished direction. It can be found that in the connection between „real world“, that is the world of the observed phenomenon (the phenomenon to be modelled), and „formal world“, that is the world of the modelled phenomenon, there lies a cyclic mechanism of induction and deduction (of creative intelligence and of „building“ intelligence), as follows:

- a) starting from the observed phenomenon, an inductive step (eminently a creative one: the theoretical formulation of the model) allows to build the „mental model“ of the phenomenon (definition of the constituting entities, recognition of relation structures, individuation of the „laws“ ruling the phenomenon);
- b) then, a deductive step (mainly a building one: the model „resolution“) transforms the mental model in a „formalised model“, specified by using an appropriate formal language (usually mathematical);
- c) finally, an inductive/deductive step (the „model interpretation“, where both creative and building components of the intelligence are necessary) compares the formal model with the observed phenomenon, enlightening both of them and allowing to refine both the mental and formal model (by going over again points a, b and c.).

The building of a really evolutionary model (in the sense explained above) means that the process described above must be made endogenous in the model.

Obviously, in a researcher, such process is strongly influenced by his/her specific conditions: his/her knowledge on the topic, his/her general culture, his/her keenness, etc.. In the same way, in

the really evolutionary model, the problem is to define a specific context inside which „to invent“ the model; such context, in this initial phase of our ambitious project, will be necessarily a very limited dominion of knowledge.

In other terms, it is reasonable to aim at building a „mechanism“ which is certainly not able to invent a totally new model, but which is able at least to specify some elements of a model already outlined as to its general features. It means that we cannot aspire, for the moment, to reproduce all the formulation-resolution-verification cycle from its first iteration, but we can aspire to replicate such cycle starting from a first formulation of the model, exogenously given.

Therefore, the task is:

to integrate, in the process of formulation of the model, an inductive process (based on the comparison between the formal model and the observed phenomenon) able to specify with more accuracy the model itself.

In equivalent terms, we need that:

a „metamodel“ (a model outlined in its general features) be coupled with a learning algorithm, able to learn, by observing the phenomenon, what are the specific features that the model must have.

As to the metamodel, we will resort to the knowledge in the field of the existing urban modelling, as to the learning algorithms, we will look at the field of A.I. (neural networks, classifiers systems, etc.).

3.2. An operational prototype

In order to make operational the general model proposed in 3.1, cellular automata are specially suitable, for the following reasons:

- * cellular automata, as a tool for urban modelling, are gaining a big popularity, because they imply inputs and outputs in a qualitative and cartographic form, which is, for urban planners, more usual than numerical representations. In addition, this different form of representation allows an easy interface with GIS (as in our application), which show an increasing diffusion;
- * the working mechanism of cellular automata is relatively simple, because it consists mainly in the transition rules between one state and another of a cell, which depend on the state of the cell itself and of its neighbouring (appropriately defined). This simplicity makes operatively easier the connection with the „learning system“.

At this point, it is useful to remind briefly the way of working of „classic“ cellular automata:

- * a territory is subdivided in cells by means of an appropriate zoning (usually, a regular grid); the „state“ of each of these cells is defined (e.g. its land use);

* the model builder, on the basis of his/her urban planning knowledge, defines the transitions (or the transition probabilities) of each cell from one state to another, depending on the state of the cell itself, on the state of its neighbouring (e.g. the prevalent land use) and on other „local“ or „global“ characteristics of the analysed territory.

In the learning cellular automata, this latter operation is replaced by an automatic procedure of learning of the rules mentioned above.

There are two aspects to be specified:

- a) as to the „learning“, it is necessary to state a learning „general principle“ (with respect of what does the algorithm learn?);
- b) as to the automata, it is necessary to define the „ground structure“ of the rules to be learnt (the metarules, the metamodel).

As far as the former aspect is concerned, we assumed as a general principle „the ability to reproduce a given target“, operationally specified as a „target map“ of the territory: a map modified with respect to that assumed as the initial one by the model (the changes being induced by natural evolution or by a plan). In other words, it is necessary that the automaton - by means of the learnt transformation rules -, starting from the initial map, be able to reproduce at best the final map (target), which is the product of the reiterated application of the rules themselves.

As far as the latter aspect is concerned, two more aspects must be specified:

- b₁) the level of semantic complexity at which the rules to be learnt are expressed (e.g. as general urban planning principles or more specific modelling rules);
- b₂) the „form“ and the „criterion“ by which the fitting between the learnt map and the target map is evaluated (in other terms, the „sensors“ of the learning algorithm must be specified).

On the side of the semantic complexity, in this initial steps of our work, we adopted the simplest solution, that is the direct expression of the rules in the same form as they act in the CA.

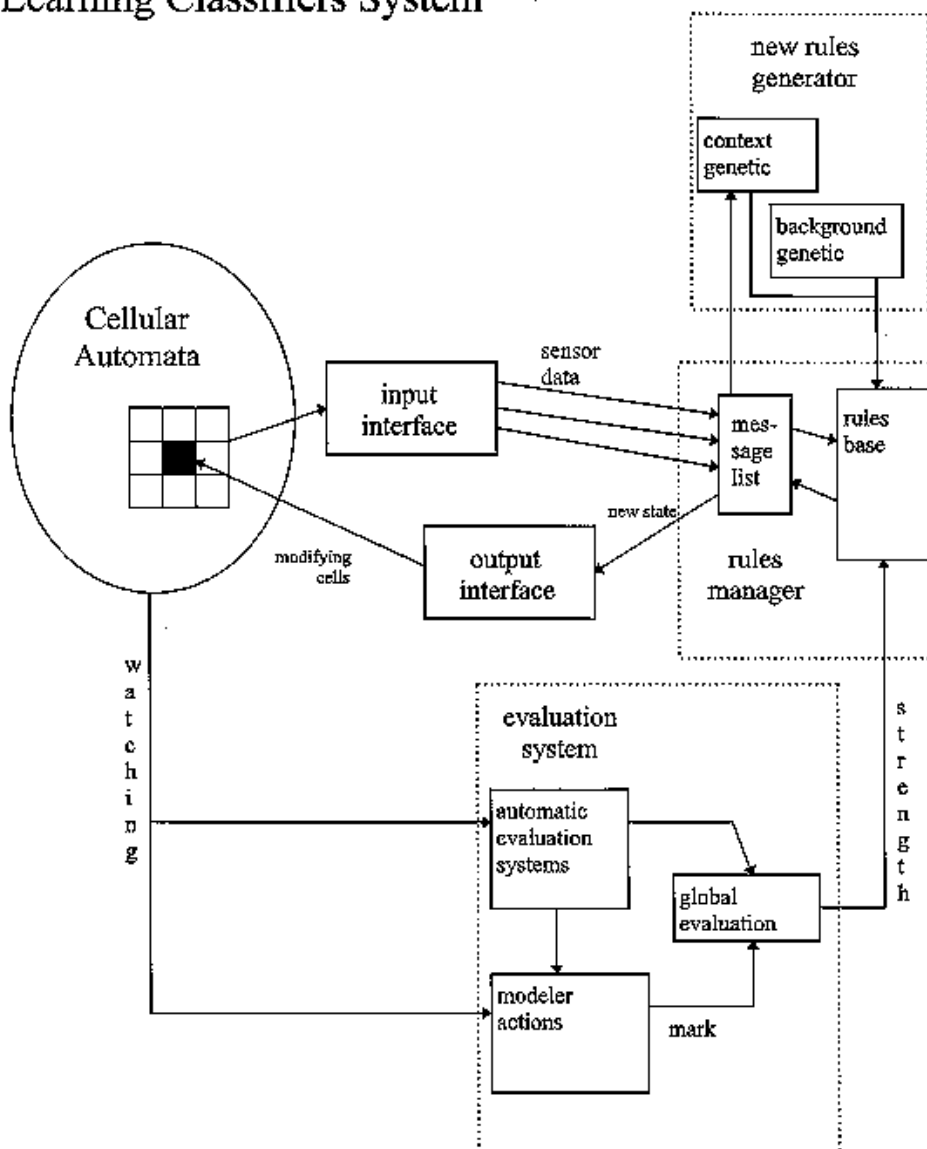
On the side of the sensors too, we choose the simplest solution, that is to accept or reject the rules depending on the matching (after their reiterated application) between the observed and the learnt state of a single cell of the automaton. More precisely, this matching (at single cell level) is analysed for a very great number of randomly selected cells and the rule is either prized (by increasing its level of „confirmation“ and then its „strenght“) or punished (by decreasing its „strenght“) depending on the goodness of fit.

3.3. The computer structure of the prototype

The flow chart which follows describes the structure of the outlined prototype. On the left hand side a classic cellular automaton can be recognised, while the right hand side presents the learning

system (a typical classifiers system), divided into its three components: a rules generator, a rules „evaluator“ and a module for the management of the system itself. The rules and the sensors are respectively the input and output interfaces of the automaton with respect to the classifiers system. Moreover, it is to be specified that the rules generator is a genetic algorithm which „invents“ new possible rules (to be evaluated) starting from previous rules, through the usual evolutionary mechanisms (random mutation, crossover, etc.). Therefore, the evolutionary character (beside that of learning) can be ascribed to the proposed cellular automaton (Laude).

The Cellular Automata Interfaced with a Learning Classifiers System



Finally, we recall that the rules introduced in the model are rules of the kind IF ...THEN ...

(condition-action rule, typical in classifiers systems) and codified by means of a bits string. The string defines the initial state of the cell, the state of its neighbouring, the presence (or absence) of other attributes of the cell and the final state of the cell, codified in the same way as the initial state.

4. The Representation Of The Urban System

In the application of a learning cellular automata to an urban system, a particularly critical phase is represented by the writing out of the "textbook", that is of the contents and architecture of the information which are supplied for the automata. Such architecture must consist of an efficient and effective description of both the spatial and functional structures of the urban system, as well as of its evolution, so that Laude can "read", interpret and learn the evolution of such structures and deduce the rules which produced the transformation occurred in the considered time interval.

In this chapter, we describe the problems met in the description of such information structure and indicate the solution adopted in the application to Rome urban system: these solutions are quite different from those that can be found in the applications of classic cellular automata (i.e. not learning CA) to urban systems.

4.1. *The geometry of the cells*

In the models conceived and/or applied in the US (since Lowry model up to Cellular Automata) urban space has been always disaggregated by adopting orthogonal grids.

This choice originates from the morphologic structure of the urban texture of the American cities and from the corresponding shape of the statistical elementary zones.

This representation of space turns out very useful in many contexts of urban modelling, ranging from the computation of distances and routes (in general, everything connected with the use of graphs), to all computer graphics problems, in which each square or rectangular sub-area can correspond with one or more pixels.

In Italy, such urban textures can be found only in the parts of cities built after the middle of the 19th century. The remaining, which is the most part, presents a spatial organisation and shape of buildings which cannot be represented by means of an orthogonal grid unless operating spatial deformations and data approximations so strong to be unacceptable, especially when working at a small and detailed scale, inside the urban "*continuum*".

Also the structure of distances and accessibility, on a network resulting from the overlay of centuries, is more complex than a structure in which the orthogonal grid prevails, with its regularity of blocks and of their size.

Therefore, for the application of Laude, we abandoned the idea of adopting an orthogonal grid for

the representation of space, though aware of the increase of the level of complexity of the task, from both a semantic and a syntactic point of view. We then undertook the task of interfacing Laude with an algorithm which allows to represent a system in which cells be of any shape and assembled in any way.

By means of an appropriate software, it is then necessary to define and individuate adjacencies between such cells of any shape.

We tackled this task being aware that it would not be useful only for the present application problem, but it would produce other relevant advantages, that are:

- a) to extend the application of Laude to any kind of variables mapping, also at different scale, depending on the availability of data and on the level of detail which is to be adopted;
- b) to provide Cellular Automata with a wide transferability, in particular for C. A. built by different schools for different purposes.

4.2. The border problem

The problem of the identification of the boundaries of the system and that of its "closure" (i.e. how to model the relations between the "inside" and the "outside" of the system) is not new in urban modelling and has been always posed in the following terms:

- 1) *boundaries*: how to determine the boundaries of the system in such a way to ensure that the most part of the considered phenomena and processes take place inside the system and therefore interactions with the outside be weak enough.

The problem, which is included in the more general problem of the individuation of sub-regions, was often tackled by means of clustering techniques (e.g. as in Giangrande, Lombardo and Mortola, 1976).

In the individuation of clusters in the spatial (and not spatial) interaction modelling, the singling out of relatively independent sub-systems is based on the analysis and evaluation of interdependencies, mostly of a static nature, represented by means of the measurement of interaction flows in a determined time section.

In the case at study, the spatial and functional interdependencies (the "rules"):

- are "found out" by Laude,
- are rendered explicit only at the end of the learning process,
- refer to the whole system and not to the single cell (as in the SIA models),
- are dynamic, as they are derived by the observed evolution of the system.

On the basis of the spatial and functional interdependencies learned by Laude, it will then be possible to use this new kind of C.A. as a particular dynamic clustering technique.

To this end, we can outline the steps of a suitable procedure:

1. arbitrary choice of the boundaries of a subsystem;
2. application of Laude and identification of the transformation rules;
3. application of the rules, simulation, comparison between simulated and real evolution, evaluation;
4. if the fitting is not satisfying, modify the boundary (by adding or subtracting cells) and go back to step n. 2; as the boundary widens, the probability of the existence of local roots of the evolution decreases;
5. if the fitting is satisfying, an enough independent subsystem (cluster) is identified.

2) *"closure" of the system*: how to model the relations, however weak, which exist between the inside and the outside of the system.

In the field of the application of classic CA, the problem concerns the cells located on the border, and the solutions adopted most frequently are:

- the system is closed like a torus or
- "mirrors" are placed on the borders (Serra, Zanarini, 1990), in some cases, with different "reflecting capacity"

In the applications to urban systems, these solutions are not satisfying, because:

- a) the influence of the "outside" is not limited to the "border cells", on the contrary, it reaches to some distance from the "source" and then does not involve only the border cells (see, for instance, the application to Cincinnati carried out by White, Engelen and Uljie, 1993); this is also true as to the internal influences are concerned, therefore it is necessary to introduce some measure of the distance between cells in order to obtain a representation of spatial effects more realistic than that obtained by considering only the spatial relation between neighbouring cells;
- b) there is no reason to adopt (and there are many reasons not to adopt) the device of the introduction of "mirrors", which would imply to assume the existence of an improbable symmetry of the urban structure with respect to arbitrary points or axes.

In the application of Laude, then, we choose to adopt a solution similar to that used for SIA models (see for instance Giangrande, Lombardo and Mortola, 1977; Lombardo, 1988). It consisted in introducing "external zones": it was modelled their effect on the zones of the system, while it was not modelled the effect of the system on them.

As to Laude, this corresponds to the introduction of external "seeds" (Batty and Xie, 1994), which are "seen" by Laude, but don't change during the dynamic evolution of the system and belong to the class of "fixed cells" (see the following chapter).

4.3. The representation of land use

4.3.1. The choice of the relevant classes of land use

As in any representation of urban and territorial phenomena, the problem is to find the best compromise between the quality of the representation, which requests a satisfactory level of detail, and the possibility of "reading" the representation, which implies problems of size of the data base. In our application the limits derive from the CA "machine" which reads the rules, where a *rule is the specification of all the land use transformations* (and the number of transformations is proportional to the square of the considered land uses).

Therefore, the represented land uses must have the following requisites:

- a) to be in a number "bearable" by the algorithm;
- b) to be obtained by aggregations of urban activities homogeneous as to location behaviour
- c) such aggregations must not "hide" the changes occurred, that is they must allow to catch the (most part of) change.

4.3.2. The individuation of the prevailing land use

On the basis of the considerations developed above, we analysed and elaborated the 1981 and 1991 Rome Census data, referred to 5600 Census zones and to 674 types of activity.

The data analysis and elaboration were made more complex by the awareness that, for a relevant part of the urban area, it was not acceptable to define only one prevailing land use (this problem was stressed also in Batty, Couclelis and Eichen, 1997), but it was necessary to introduce mixed land uses of the cells. We then had to define appropriate indicators and develop statistical analyses aimed to the individuation of thresholds which allowed to define, for each cell, the prevailing land use or the different mixes of land uses.

This analysis was developed following four consecutive levels:

1st level. Individuation of the cells with only residential use (R), with only productive use (P), with mixed use (M).

Indicator: $I^R = \text{population} / (\text{pop.} + \text{total jobs})$

Thresholds: $I^R > 0.9 \Rightarrow R$; $I^R < 0.7 \Rightarrow P$; $0.7 < I^R < 0.9 \Rightarrow M$

2nd level. Classification of the cells with only residential use (R) as medium-high density cells (R^a), medium-low density cells (R^b) and empty cells (V).

Indicator: $I^{RD} = \text{inhabitants per hectare}$

Thresholds: $I^{RD} \geq 250 \Rightarrow R^a$; $10 < I^{RD} < 250 \Rightarrow R^b$; $I^{RD} < 10 \Rightarrow V$

3rd level. Classification of the cells with only productive use (P) for different economic activities (P_i); identification of further empty cells (V).

The economic activities were aggregated in such a way to satisfy the requisites described in chapter 4.3.1.:

- 1) TS: high tertiary
- 2) TI: common tertiary
- 3) IN: industry
- 4) SA: health services

Indicator: I^{P_i} = employed in activity i / total of employed

For each cell, it was identified the activity with the higher number of employed (P1) and the next one (P2).

Thresholds: $I^{P1} - I^{P2} > 0.1 \Rightarrow$ P1 is the prevailing activity, otherwise there is a mix of activities, identified in the next level.

4th level. Classification of cells with mixed use (M) for different mixes of activities (2 max).

The cells where there is a mix of residential and productive land use were identified at the 1st level and the economic activity with which residential land use is mixed is defined by the maximum value of I^{P_i} .

To identify the mix of economic activities, we assumed: $I^{P1} - I^{P2} \leq 0.1 \Rightarrow$ mix of P1 and P2.

As a consequence, the considered land use are 14 (see Table 1).

Figures 1a, 1b, 2a and 2b show the land use transformation occurred between 1981 and 1991; as the graphic representation of the transformations of 14 elements would require the use of 182 colours or textures, in the figures a synthesis of the transformations is presented, using the aggregate symbols indicated in Table 1.

In addition, again for readability reasons, in these figures, residential and productive activities dynamics are represented separately. It must be specified that, in figures 1a and 1b, the transformation indicated as $R \rightarrow R$ represents both the case of no change and the case of change of the residential density; similarly, in figures 2a and 2b, the transformation indicated as $P \rightarrow P$ represents both the case of no change and the case of change of the economic activity.

Table 1. The considered land uses

<i>Prevailing</i>	<i>Symbol</i>	<i>Mix</i>	<i>Symbol</i>
Empty	V	Residence+high tertiary	M
High density residence	R	Residence+low tertiary	M
Low density residence	R	Residence+industry	M
High tertiary	P	Residence+health services	M
Common tertiary	P	High tertiary+common tertiary	P
Industry	P	High tertiary+industry	P
Health services	P	Common tertiary+industry	P
		Ec. activities+health services	P

4.3.3. The "attributes" of the cells

It is to be considered that the general category here called "land use" includes land uses and/or characteristics (referred to points or to areas) which are fixed characteristics ("attributes") of the cells: they do not change, but influence the system dynamics.

Therefore, they are "seen" by Laude as only "active" characteristics and not as "active and passive" ones.

The considered attributes can be distinguished as follow:

a) *attributes referred to points*: they correspond to the presence in any cell of elements relevant from the point of view of accessibility; they are:

- 1) presence of railway or underground stations
- 2) presence of accesses to the highway ring

b) *attributes referred to areas*: they characterise the whole surface of the cell.

Some of them correspond to not changeable land use, therefore the cell becomes a "fixed" cell; they are:

- 3) parks and not transformable areas (by the General Plan)
- 4) sea (see outside, see chapter 4.2)
- 5) other municipality (see outside)

Other attributes do not make the cell a "fixed" cell; they are:

- 6) adjacency to a cell which presents one of the 5 attributes listed above
- 7) historical centre (it influences attractivity and location costs)

The state of a (not fixed) cell is therefore defined by 12 bits:

- land use (4 bits)

presence/absence of:

- station

- access to highway

- historical centre

adjacency to:

- station

- access to highway

- historical centre

- park

- outside "seed"

4.4. Representation of distance effects

As said before, we think that it must be taken into consideration the fact that spatial influence reaches to some distance from the "source" and then does not involve only its adjacent cells. Therefore, unlike in the classic CA, in which spatial influence depends only on adjacency between cells, we introduced a continuous measure of the distance between cells, in such a way giving Laude the possibility of "studying" and possibly introducing the idea of radius of influence of a cell and of its land use.

Indeed, in some applications of CA to urban systems there were introduced "bands" of "preferable" distance for the relations between different land uses. In these applications, though, it corresponded to the introduction of an additional rule, while, for Laude, the distance matrix is an additional information whose role and importance is to be learnt.

However, as the use of a distance matrix with a size of 5600x5600 elements would produce difficulties in the computations and as it is likely that the spatial influences "studied" by Laude do not have relevant effects beyond a certain distance, we considered only distances not greater than 4 kilometres. In other terms, it correspond to the adoption of an "enlarged adjacency", while the strict adjacency is used only as far as the influence of "attributes" is concerned.

In the experiments, we adopted geometrical distances between cells, in order to simplify the task of the preparation of the data base

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5. Possible Structures Of Laude's Sensors, Or The Education Of Laude

In synthesis, Laude, on the basis of the information structure received, activates a procedure in which formulates a set of hypotheses about the rules responsible of the transformation from the

initial to the final map, tries to apply the hypothesised rules and is "punished" or "prized" according to the level of reliability of the applied rules. Such procedure is applied in an iterative way, excluding the "false" rules, while increasing the "strength" of the rules which demonstrate more efficient for the description of the transformations.

As in any organised learning process, the learning is to be driven each time toward selected typologies of phenomena and of structures, starting usually from simplified representations and then slowly increasing the level of complexity.

In our case, the problem is "to tune in" Laude's sensors, designing its structure in such a way that "he" is able to read and interpret different typologies of phenomena and of evolutive structures. Table 2 lists some examples of phenomena and of evolutive structures of the system, with increasing complexity, on which Laude's sensors can be tuned in.

In this first simplified application to Rome urban system, Laude was tuned in the recognition of both inertial and dynamic behaviours and in the effects produced on each cell by the status of adjacent cells (see the symbol "*" in Table 2), while the effect of a continuous measure of distance between cells was not introduced in the experiment described here.

Table 2. Examples of phenomena recognisable by Laude

Dynamic behaviour	* Inertia
	* Change
Local effects	* Imitative
	* Complementary
	Competitive
	Hierarchical

Field effects	Accessibility

Recognisable structures	Global level structures

6. The First Results, Or What Laude Has Learnt Till Now

About 300 rules of land use transformation were identified, each of them can be evaluated through its "strength" by ordering them according to decreasing values of such parameter. If we take into account the first 15 rules, we can say that Laude learnt, beside the existence of a certain level of inertia of the system, that the most part of the transformations took place in peripheral areas and that the urbanisation phenomena took place in the cells with a good level of access to the public

transport network and/or to the highways and in those with a good environmental quality (adjacency to parks).

The results of Laude's learning process can be synthesised in the following way:

	<i>Cells land use (1981):</i>	<i>in the neighbouring of:</i>	<i>changed as:</i>	<i>strength:</i>
A)	Empty Low density residence	# Railway stations #*Highway accesses * Parks # Other municipalities→	Low density residence Resid.+Com. tertiary	Very high Med. high
B)	Low density residence Low density residence Empty Empty	Sea	Industry Tertiary mix Residence+Industry Residence+Tertiary	Med. high Med. high Med. high High
C)	Empty	Parks Highway accesses	Health services	High

These rules concern mainly areas located in the periphery of the urban system; in particular:

A) The symbol „#“ indicates peripheral zones (identified by presence/adjacency to highway accesses) and some of them border on other municipalities. In this latter case Laude identified the trend of Rome urbanisation to trespass the boundaries of its municipal territory. Moreover, in these zones appears a mix of residence and tertiary, showing an evolution towards an urbanisation more „mature“ than in the other cases.

The symbol „*“ also indicates peripheral zones, but located in a good environmental context (identified by adjacency to parks). Such characteristic, coupled both with the relevance of the presence/adjacency to highway accesses and with the no relevance of stations, could correspond to classes of population with a medium-high income.

B) Coastal areas, that actually showed a certain liveliness as to change and urbanisation growth.

C) They are specific cases, concerning zones where hospitals were built in peripheral areas (identified by presence/adjacency to highway accesses) with in a good environmental context (adjacency to parks).

The evolution rules identified were applied by Laude to produce a simulation of the system. By

comparing observed and simulated urban structure, the following level of error can be observed:

- being 5374 the cells which could change, the errors made were 219, that is 4% of cells were wrongly simulated;
- the inertial behaviour of the system (i.e. „no change“) shows a level of error lower than the medium one;
- levels of error higher than the medium one are produced by an over rating of the new urbanisation phenomena (i.e. transformation from empty to residential land use) and by an over rating of the productive activities in some cells, where such activities become prevalent with respect to residence.
- the spatial distributions of the errors is quite even in the territory (see figure 3), therefore there are not parts of the system whose behaviour was misleading as to the learning process.

6.1. Concluding comments

In conclusion, in our opinion, this first experiment with a complex and totally new tool such as Laude produced very encouraging results, enough to contradict a recent statement made by Batty and Xie (1997):

. . . there have been a number of attempts to adapt such models [C.A.] to real systems (...). Such applications at present represent ways of "fine tuning" the predictions and parameters of CA models to realistic order of magnitude. It is unlikely that current approaches can really generate acceptable levels of performance in terms of the goodness-of-fit to existing patterns . . .

It must be considered, however, that Laude does not belong to the category of classic CA (*current approaches*) known by Batty and Xie.

As to the research prosecution, considering the simplifications adopted, not so much for the system representation as for the sensors' structure of the CA, it will be oriented to the re-designing of the sensors, aimed to their sharpening, in order to allow the recognition of more complex phenomena, such as those indicated in Table 2.

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Figure 1a.: Transformation from residential land use

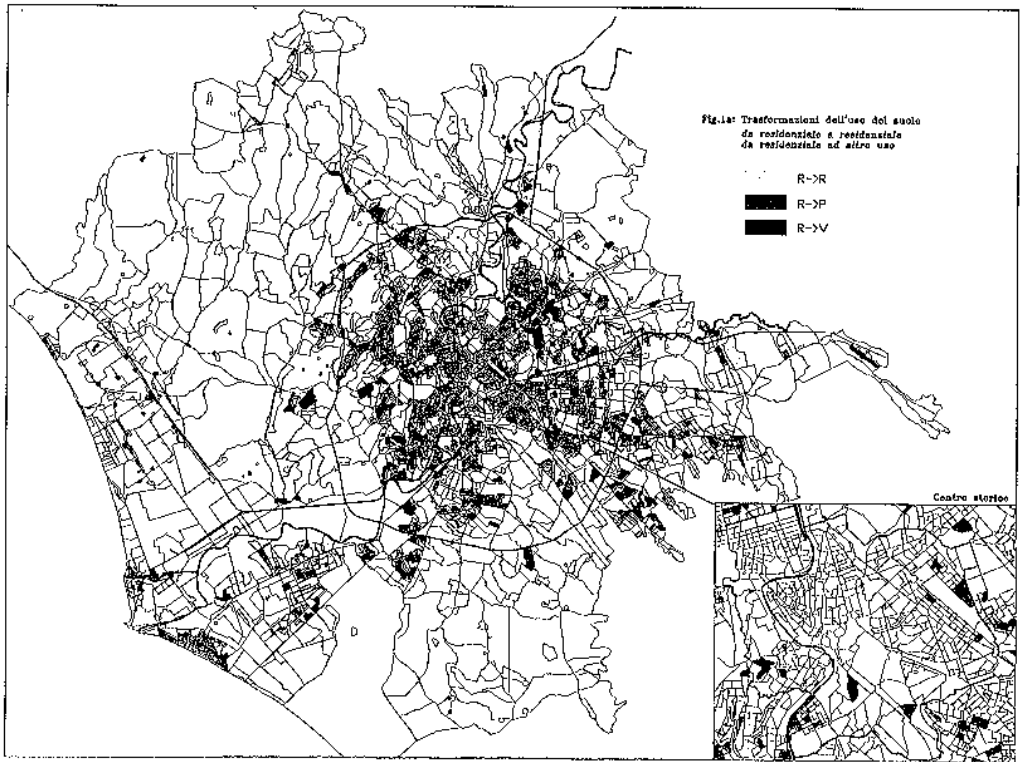


Figure 1b.: Transformation to residential land use

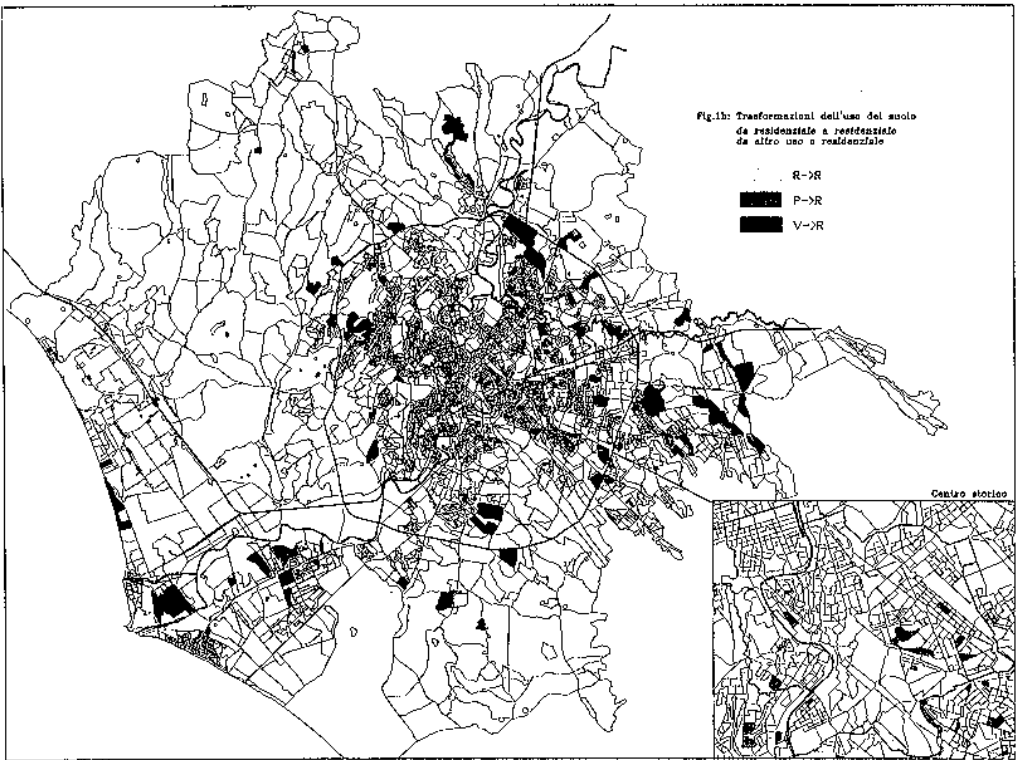


Figure 2a.: Transformation from productive (industrial, services, ...) land use

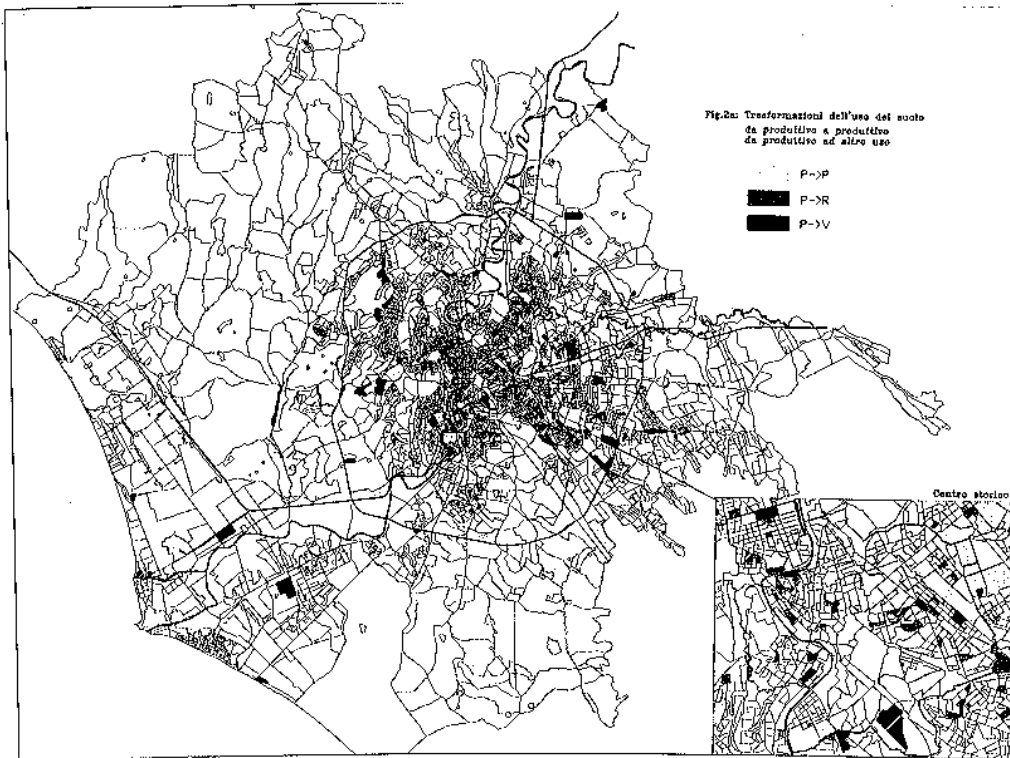


Figure 2a.: Transformation to productive (industrial, services, ...) land use

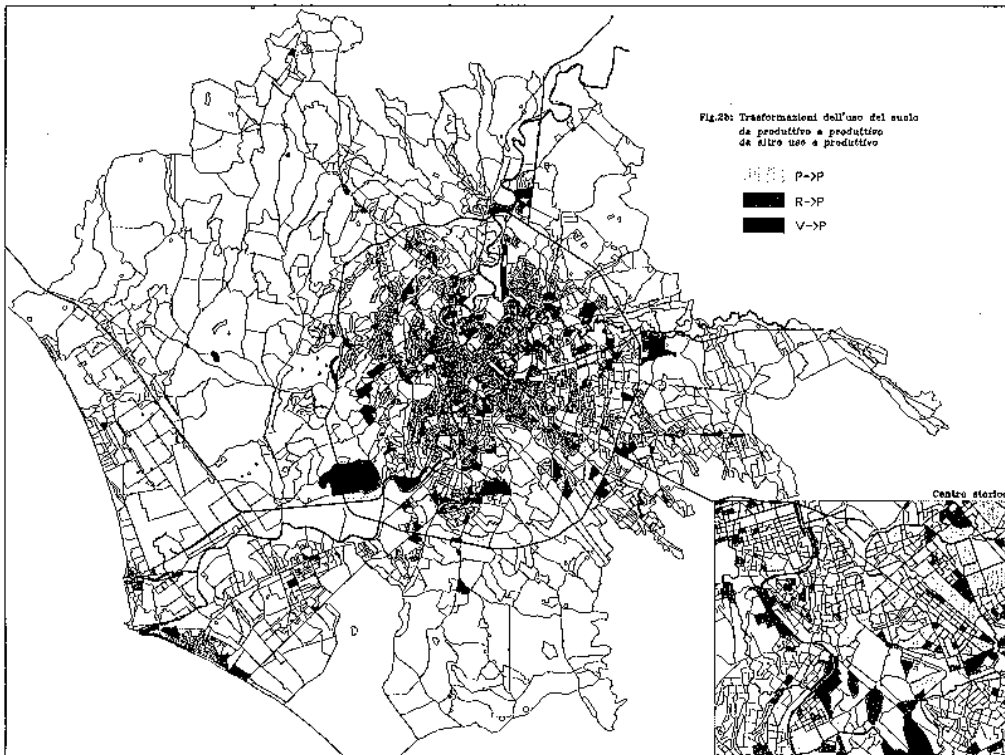


Figure 3.: Errors between observed and simulated land uses.

