Towards the Interpretation of Emergent Spatial Patterns through GO Game: the Case of Forest Population Dynamics

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***Abstract*— In this paper we present the preliminary results of an ongoing research that aims at supporting ecosystem management in the study of forest systems according to a distributed modeling and simulation approach. The Cellular Automata For Forest Ecosystems (CAFFE) project is an interdisciplinary research involving computer scientists of the Department of Computer Science, Systems and Communication of the University of Milano–Bicocca and urban planners, biologists and ecosystem managers of the System Research Department of Austrian Research Center (ARC). In particular, we focus here on the part of CAFFE project that concerns the design of a method to support the analysis step of simulations of forests according to a distributed approach (such as those based on Cellular Automata or Situated Multi–Agent Systems). To this aim an innovative analysis method inspired by the Chinese Go game is under design. The originality of the approach concerns the detection within system configurations of known patterns whose interpretations are well–known by expert Go players. In this paper, after a brief presentation of the CA–based model of forests, we focus first on the set of Go patterns that we currently studied, then we present some preliminary results on experiments we conducted to validate the proposed approach to spatial patterns interpretation.**

I. Introduction

The CAFFE (Cellular Automata For Forest Ecosystems) project is an interdisciplinary research that involves computer science, biology, and ecosystem management. It started about one year ago and involves the Artificial Intelligence Lab (L.INT.AR.) of the Department od Computer Science, Systems and Communication of the University of Milano–Bicocca and the System Research Department of Austrian Research Center (ARC). The main aim of this ongoing research is the development of methods for sustainable afforestation and management of forests.

A central role is played in this project by computer supported simulations of the dynamics of the forest system. The modeling approach adopted by CAFFE for the forest system is based on Cellular Automata and describes the forest as the result of competition between heterogeneous vegetable populations. After a preliminary implementation of the CA–based model (see [1]), we are currently developing a software simulation platform for sustainable afforestation and management of forests in which both model improvements (i.e. a new model of the forest based on Multilayered Situated MAS [2], [3] is under design) and new software functionalities. One of these functionalities will concern an innovative interpretation approach for patterns that can be detected as emerging from the dynamics of forest systems.

In this paper, we focus on the part of the CAFFE project that aims at designing a method to support the analysis step of software simulations of vegetable populations in the forest model. This goal is particularly relevant (and ambitious) due to the distributed modelling approach that is at the basis of the forest system simulation and modelling. According to [4], we refer here to distributed modelling approaches in order to indicate all those approaches that allow the representation of complex systems (and problems) whose evolution (and solution) results from the interactions between autonomous and interacting entities (more often indicated as based on Multi–Agent Systems - MAS). For this reasons, analyzing the dynamics of complex systems modelled and simulated according a distributed approach is still a challenging issue. In fact in a simulation of a forest composed by a lot of different species, we have a very complex behavioral dynamics, and it is very difficult to recognize all the collective emergent behaviors occurring during the simulation.

The work here presented concerns the model of a forest system according to a Cellular Automata (CA) approach. CA can be considered a simple case of MAS in which each cell of the automaton represents an agent and the CA dynamics is based on the behavior (change of state of cell) and on local interaction among cells (transition function of CA cells usually includes the state of adjacent cells). Obviously CA can only be considered as a very simple class of reactive MAS. However, they can be a suitable and very promising approach for the aims of CAFFE project (both for modelling and simulation, but also for the design of a novel analysis method). The CA–based model of forests that has been adopted by CAFFE project is derived by the one presented in [5], in which different plant species can inhabit the forest area and compete for the same resources (i.e. water, light, nitrogen, and potassium). The area is divided into cells and it is reproduced by the CA. The state of each cell of the CA is defined by a flag denoting whether or not it contains a tree, the amount of each resource present in the cell, and a set of variables defining the features of the tree (possibly) growing in it. The update rule of the automaton mainly depends on the presence of a tree in a cell. In case a

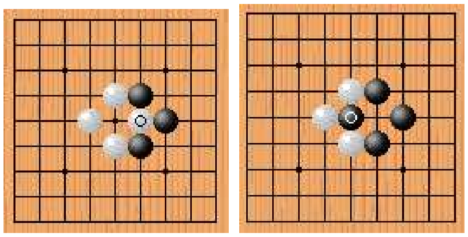

Fig. 1. The Ko rule in the Go game.

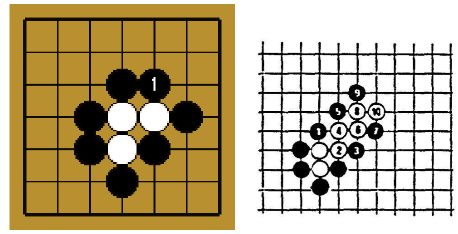

Fig. 2. Geta (on the left side) and Schicho (on the right side) in Go game.

tree is present, part of the resources present in it (and in the neighboring ones, if the tree is large enough) are absorbed by the tree. Every cell also produces at each update step a given amount of each resource (that in any case cannot exceed a maximum threshold value). The production of resources in the cells is determined by a set of global parameters, and reproduces environmental factors such as rain, presence of animals in the area, and so on. The effect of the presence of a tree in a cell on the neighboring ones has been modelled by making resources flow from richer cells to poorer ones (that possess less resources since a part of them is consumed by the tree).

In the following Section, we introduce the proposal for a method for pattern detection in the dynamics of forest populations based on the detection of spatial patterns whose interpretation is suggested by the ones of similar spatial patterns occurring on a Go board during a game. In Section III we then show first experiments conducted to validate the proposal. Some remarks and future works conclude the paper.

II. Go–based Interpretation of Spatial Patterns

Most of the available approaches to analyze the behavior of complex systems are based on statistics and probability theory and they aim at deriving macro level interpretations by aggregating and correlating variables of the micro level(s). Within the context of forest ecosystems for instance, the dynamics of the forest (e.g. biomass) is computed aggregating the features of living trees taking into account different age and dimensions of trees [6]. Another common approach to complex system analysis concerns the detection and interpretation of recurring patterns [7]. These approaches are of course domain independent for what concerns pattern detection (usually the focus is in the searching of structural similarities within system configurations). On the other hand, when the model concerns a real world system and the analysis of its dynamics is oriented to verify or anticipate peculiar phenomena (e.g., in the forest ecosystem domain, deforestation of a given area), it is inevitable the necessity of domain dependent interpretation of the detected patterns. In order to reconcile the need of defining domain independent method with the detection and interpretation of a specific natural phenomenon, we started from the latter. In particular we noticed that several simulation scenarios provided recurrent dynamic configurations that were very similar to specific situations occurring in the Go game. Go game, due to the simplicity of its playing rules but also to the complexity of possible configurations and the consequent complexity of playing tactics and strategies, has already inspired several models (e.g. in economy, military, art, semiology, culture, and many others [8]). In the Go game there are two populations (i.e. black and white stones) that compete for survival in a territory with limited space and resources. During the game, black and white stones situated on the Go board cannot move, but they can be put onto a board site, survive or die as result of a metaphorical competition on the local territory with neighboring stones. The effect of the death of the stone is its removal from its site. A key concept for the survival of Go pieces is the notion of *liberty*: if a group of pieces have no liberties (i.e. none of its elements is adjacent to a free site), it is removed from the game.

The analogies between Go game and the CA–based model of forests above sketched are going to be formalized. Very broadly in the CA–based model of forests, trees of different species live in a territory, compete for limited territory resources, can born, die, and they cannot change their position. Moreover, the concept of liberty for plants can refer to favorable conditions for growth and reproduction. Starting from this analogies, our proposal suggests to exploit this game to study emergent patterns in the dynamics of complex systems, by studying some spatial patterns well–known by advanced Go players [9], and to verify whether their interpretation can be suitably and fruitfully applied to interpret similar spatial patterns occurring in dynamics configurations of the CA–based forest model.

We introduce now some common spatial patterns that can emerge during Go games and that are well–known by Go players. Each spatial pattern is interpreted by Go players in terms of game competition, and we briefly describe how the interpretation of Go patterns can be applied to interprete spatial patterns that emerge from the evolution of the CA–based model of forests.

A. Spatial Patterns Emerging in Go Game ...

1) **Ko pattern.** Ko is the configuration of Go stones such that a little free territory (i.e. a set of board positions not occupied by stones) belongs to the influence zone of two or more pieces of the same team (see Figure 1).
2) **Geta pattern.** Geta pattern corresponds to the local capture of a group of adversary pieces by a set of stones that surrounds it (see the left side of Figure 2).
3) **Shicho pattern.** Shicho is pattern in which a group of stones expands itself towards another side of the Go board. Shico does not imply the movement of

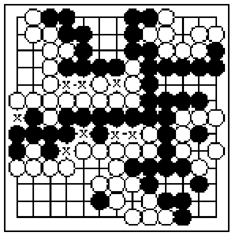

Fig. 3. Example of Go game. We can notice a lot of connected groups.

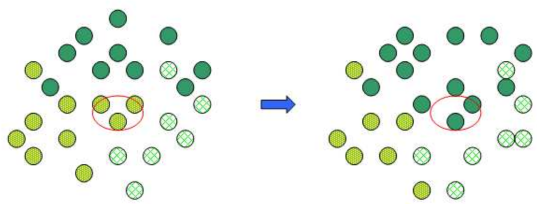

Fig. 4. Ko interpretation for forest ecosystems. Different species are competing for the domain in a little area

single stones that are part of the moving group. Group movement occurs in time–space that is, group movement is the result of stones removal from some positions and the positioning of others in adjacent ones (see the right side of Figure 2).

4) **Iki pattern.** A peculiar pattern that can emerge during a Go competition is Iki, a pattern that can not be captured by the adversary. Iki corresponds to a part of Go board surrounded by stones of the same color, with some free positions in its inner side to form two 'eyes', in Go jargon. This formation has two internal liberties that can not be occupied by adversary.
5) **The Tsugi pattern.** Tsugi is a Japanese word that means 'connection'. Connections are very important in Go competition, because two stones connected to form a group are stronger than they alone (see Figure 3). In fact, it is more difficult for the adversary to build a group able to surround connected stones (i.e. it may require a lot of stones).

B. ... Their Application to Interpret Forest Population Dynamics

1) **Ko pattern**. In a CA configuration similar to a Ko pattern (see Figure 4), none of the the involved species (in the example we considered only two plant species) can control the territory in a stable way. In this type of situations, it is usually observed a continuous replacement of trees by others of another specie.
2) **Geta pattern.** Similarly to Go game, we can consider that if a group of trees is surrounded by plants of another specie and it is forced to be limited within a little and close territory zone, sooner or later it will die. In fact, trees and plants that are forced in a little zone have little space to harvest the needed resources for survival and reproduction (see the left side of Figure 5).

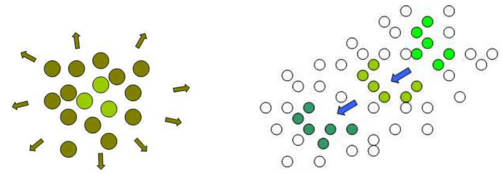

Fig. 5. Geta (on the left side) and Schicho (on the right side) interpretation for forest populations.

3) **Shicho pattern.** In forests Shicho occurs when an homogeneous group of plants is situated in a zone where resources are not suitable related to population requirements, or in an area that is controlled by another specie (see the right side of Figure 5). Since new born trees are more likely to survive if they grow up on suitable areas, we can observe as emergent phenomenon, a group shifting in space–time.
4) **Iki pattern.** A spatial pattern in forest dynamics similar to Iki is characterized by a strong group that can survive for long time assuring part of the territory to its individuals (see Figure 6). This pattern is particularly strong because plants on the group border have a lot of space in the inner side and this guarantees the availability of space and resources for their survival and reproduction.
5) **Tsugi pattern.** Tsugi phenomenon occurs in a natural way also in forests. Each group of plants expands itself by reproduction, and when two groups expand toward one another, there is the possibility to create a connection between them. As in Go game, two connected groups of plants are stronger because they can support each other. When a plant dies neighboring ones can replace it, and when two groups are connected, neighbors increase in number. Beside this aspect, an isolated little group of trees can easily fall in the Geta phenomenon but if it is connected to another group, it is no more possible to surround it.

III. Experimentations

In this section we present some experiments performed in order to validate the proposed approach and in particular to verify wether the hypotheses on the evolution of forest systems based on Go spatial patterns are confirmed by experimental simulations. To this aim, we exploited FORESTE [1], a simulation software developed according to the CA–based model of vegetable populations presented in [5].

In order to verify the occurrence of a spatial patterns in the experiments we adopted a method mainly based on the concepts of group and neighborhood. If we refer to neighborhood of a cell i as the set N_i, and we consider a trivial group composed by only one element the set $\{i\}$. We define a *connection* between to cells t and s (i.e. t is connected to s, and vice versa) if $t \in N_s$. We indicate connection between t and s with $t \rightarrow k$. Moreover, given a cell t and a group of

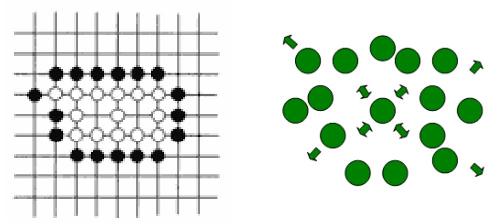

Fig. 6. Iki in Go game and its interpretation for forest ecosystems.

cells A, we say that t belongs to A (i.e. $t \in A$), if $\exists k \in A$ such that $t \rightarrow k$.

According to this model, the general aim of the experiments we conducted was to verify the correct evolution of Go–like patterns with reference to the forest simulation scenario. We define the starting conditions that represent a suitable situation for the occurrence of the pattern. Then we let start the simulation observing if the patterns evolve toward the final expected configuration. In this simulation experiment process we divide the patterns in two groups: static patterns (Geta and Iki), where it is easier to establish a good starting point for the phenomenon occurrence; and dynamic patterns (Ko, Shicho, Tsugi), where it is more difficult to find the initial situation that guarantees the occurrence of these phenomena.

A. Experiments on the Occurrence of Geta and Iki patterns

The aim of the first experiment we conducted was to verify the formation of Geta and Iki patterns. We consider the formation of Geta when it occurs the complete disappearance of surrounded specie. Geta pattern is perhaps the easiest pattern to study: starting from a given configuration, we can let evolve the CA and detect resulting configurations.

Three important elements can influence the Geta formation (i.e. involved populations, spatial dimensions of the pattern and resource distribution), and for each combination of them we conduct a set of simulations.

- *Involved populations:* we simulated Geta formation between both two groups of the same vegetal population and two heterogeneous species.
- *Spatial dimension of Geta pattern:* we considered a small (2×2), a medium (3×2) and a large (4×3) neighboring area. In general a small area is easier to attack, while a large one is more likely to survive.
- *Resources distribution on the territory:* we considered a uniformly favorable terrain and a less favorable one. The terrain resources state strongly influence the evolution of the specie competition.

According to the performed experiments we can conclude that Geta is a spatial pattern that occurs in all the studied cases. In Figure 7 we can see an example of simulations.

To verify the formation of Iki pattern, we started from an initial Iki pattern and we observe its evolution in time. We considered an Iki success if after 250 time steps we can establish that the specie involved has still a certain influence over the given territory area. We chose to consider 250 time steps because Geta complete its evolution in a maximum of 160 time steps. Therefore we think that this time period can be sufficient for a specie to take control over a territory. We consider four important elements that influence the Iki formation and we conducted experiments in all the conditions resulting from the combinations

As in the case of Geta, we considered important elements that can influence the Iki formation and we conducted a set of simulations for each combination of them.

- *Involved populations:* we simulated Iki between two homogeneous groups and between two heterogeneous species.
- *Not–Iki specie state:* we considered a first situation (referred as normal) where an Iki pattern is surrounded by a random distribution of trees of another specie, and a second one where Iki is not surrounded by another specie. In the first case we put in the simulation area a quantity of trees of the not–Iki specie that is approximately double respect to the number of trees involved in the Iki pattern.
- *Iki pattern spatial dimension:* we considered a small (5×5), a medium (5×6) and a large (6×7) neighboring area dimension.
- *Resources distribution on territory:* we considered two territory types, a uniformly favorable terrain and a terrain uniformly worse in the average.

In this experiments, we observed that the type of terrain has a great influence (better results occur when a specie is situated on a favorable terrain). Also in the cases where Iki pattern is destroyed in a given time period, the trees involved in the Iki pattern survive in their position for long (of course, due to the abundance of resources).

B. Experiments on the Occurrence of Ko, Shicho and Tsugi patterns

Simulation in the Ko case (turn over in a shared area) is more difficult because it is not guaranteed the formation of this pattern starting from a given initial situation. We considered the formation of a Ko pattern, when it can be observed a quick change of plant distribution in a local area occurs, while in the rest of the territory the same vegetal patterns do not change for long time.

In the case of Shicho pattern (a group shifts toward more suitable area), we defined a starting suitable situation and than we observed its evolution. We considered the formation of a Shicho pattern when the shift of the influence area of a given group can be observed.

To verify the occurrence of Tsugi pattern (formation of connections) starting from a suitable situation, we considered two groups of different species with their influence on opposite sides of the territory. We put a little group of the second specie in the territory of the first one and we observe whether the two groups of the same specie connect to each other and if this connection allows to save the influence over a given space portion. From the performed experiments, we observed that as one specie tries to connect two groups (reaching the Tsugi pattern) the other one tries to divide adversary groups with an infiltration in the middle. According to our Go game metaphor, a player tries always to divide enemy groups to surround them separately.

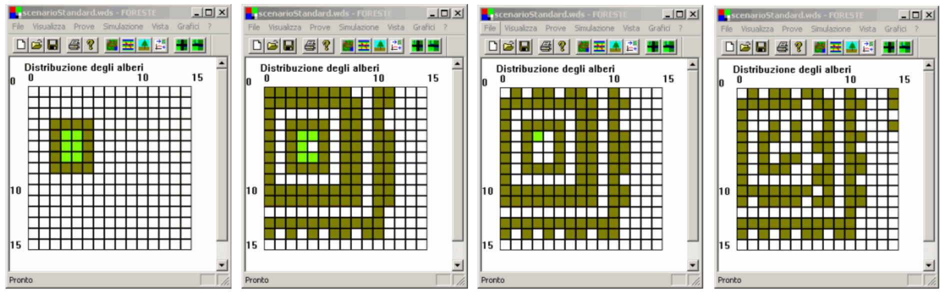

Fig. 7. An example of experimental simulation of Geta pattern: after some simulation time steps the surrounded specie is completely disappeared.

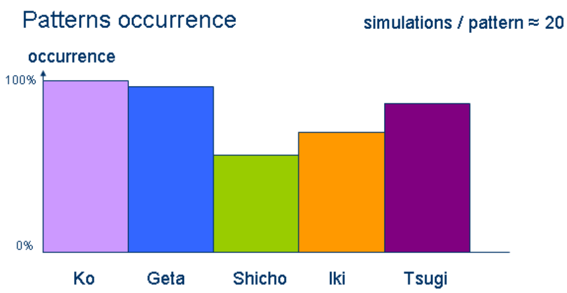

Fig. 8. Results of simulation experiments on pattern expected occurrence.

C. Simulation results

In accordance with experiments done we can conclude the Go–like patterns validity at least in the described domain. All the patterns described occur in a simulation scenario and they have the expected evolution. This first results encouraged us in continuing this research also looking for new other applications of this method. The scheme in Figure 8 shows the ratio of pattern occurrence, that in general very high. The results shown in the ratio are referred approximately to a 20 experiments for each pattern.

IV. Conclusions and future works

Detecting all patterns of emergent phenomena is very difficult for a human operator that analyzes the simulation, in particular for very large scenarios involving a lot of different species. Therefore the main future work that starts from these results is the realization of a detection algorithm capable of recognizing and interpreting the patterns during a simulation. A first prototype of this automatic detection method is already realized and it is based on the groups recognition method as we explained in section III. Our main efforts in the future is going toward the improvement of functionalities for the automatic detection method, and the implementation of a simulator with these automatic tools for pattern detection and analysis.

All these methods and tools will allow us to use the defined patterns for a meaningful interpretation of important phenomena in some simulation scenarios. In particular they can be useful, for example, in the case of artificial repopulation of forest in a given area with the introduction of new species. In this case it is important to understand if the new specie can survive and what are the reactions of the other living species. But while the occurrence of Ko phenomenon means a good equilibrium between species, the frequency of Iki and Tsugi indicates the formation of a strong dominance presence in the area, and Geta and Shicho mean the disadvantage of a specie in comparison with the others. All these considerations can support the decision maker in the illustrated domain problem.

Surely another important future development of the this research can be the study of new patterns for the interpretation of other phenomena in different scenarios obtained, for example, with the introduction of other important elements in the system: the human presence (urbanization or pollution) or other natural interaction phenomena (desertification).

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