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Developments In Ecological Modeling Based On Cellular Automata

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Abstract

The models with focus on spatial clumping generally fail to consider the effects of local interactions and spatial contrasting. These factors are sometimes conclusive to the developments of ecosystems. Cellular Automata are individual potent systems in which many simple components act together locally to bring complex patterns, which may explain "self-organizing" behavior. Since cellular automaton has ability to consider local influences and spatial disparateness, it has been applied to various fields. This paper attempts to highlight important aspects of Cellular Automata and is centered on the development and application of the approach to ecological modeling. The results indicate that spatially distinct models such as cellular automata have a special capacity to connect the local operations and universal figures hence resulting in complex patterns.

Keywords: Cellular automata, ecological modeling, spatially contrasting

1. Introduction

The main aim of ecological modeling is efficient plan of the dynamics for better judgment about species extinction or about spreading and interactions of variant species under various environmental conditions. This involves high complexity of the spatial and temporal relationships. Traditional population dynamics models are mostly accumulated and model the system by means of ordinary or partial differential equations (May 1975). One of the simplest models is provided by the predator-prey equations of Lotka- Volterra (LV). However, these models may fail to produce realistic results when individual characteristics and local interactions play a convincing role in determining the relationships between populations and between species and its neighborhood (Mynett & Chen 2004).

.The local correlations are somehow lost in conventional models. An alternative technique is to use spatially distinct models such as cellular automata (CA) which have ability to connect local and universal processes. The agents including population density, host reactivity and immunity, transmissibility can be well taken care by CA models.

2. Spatial Models: Cellular Automata

Cellular automata (henceforth: CA) are typically spatially and temporally *discrete*: they are composed of a finite or denumerable set of homogeneous, simple units, the *atoms* or *cells*. All the cells form a regular spatial lattice. At each time unit the cells exemplify one of a finite set of states. They emerge in similar at discrete time steps, following state update functions or dynamical transition rules: the update of a cell state obtains by taking into consideration its own state and the states of cells in its local neighborhood (there are, therefore, no reactions at a distance) (Berto & Tagliabue 2012).Cellular automata often show 'self organizational' behavior. Even starting from complete disorderliness, cells act together and organize themselves into complicated patterns. These identical cells, although individually simple, are together capable of showing complex behavior.

CA was originally proposed by Ulam and Von Neumann (John Von Neumann 1966) to provide a formal base for inspecting the behavior of complex, extended systems. A broader study of CA has been performed by S. Wolfram starting in the 1980s (Wolfram 1984).

CA comes in various shapes and dimensions. The arrays usually form a 1-dimensional string of cells, a 2-dimensional grid, or a 3-dimensional solid. One of the most fundamental properties of a cellular automaton is the type of 'grid' on which it is worked on. The simplest type of cellular automaton is a binary, nearest-neighbor, one-dimensional automaton. Such automata are referred as "elementary cellular automata". A one-dimensional cellular automaton consists of two things: a row of "cells" and a set of "rules". Two dimensional cellular automata are more useful in understanding the subject matter. They are extremely valuable in modeling and analyzing systems in many fields of study. In two dimensions, square, triangular and hexagonal grids may be considered and cellular automata can be easily implemented using these two dimensional grid of points. The grid is displayed on a computer screen, each point of the grid being either on or off. Each point is examined and its current visual state is changed. The new state is dependent upon its current state and the state of its neighbors. The number of distinct states a cellular automaton may have must also be specified. This number is typically an integer, with binary being the simplest choice. For a binary automaton, color 0 is commonly called "white," and color 1 is commonly called "black". However, cellular automata having a continuous range of possible values may also be considered.

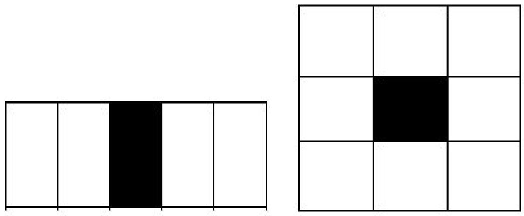

Figure1: CA (left) 1-D, (right) 2-D

3. Type of Neighborhoods

Apart from grid, the neighborhood over which cells interact with each other also plays a significant role. The simplest choice is "nearest neighbors," in which only cells directly adjacent to a given cell may be affected at each time step. Two common neighborhoods in the case of a two-dimensional cellular automaton on a square grid are the so-called Moore neighborhood (a square neighborhood) and the von Neumann (a diamond-shaped neighborhood) (Weisstein, Eric W.)

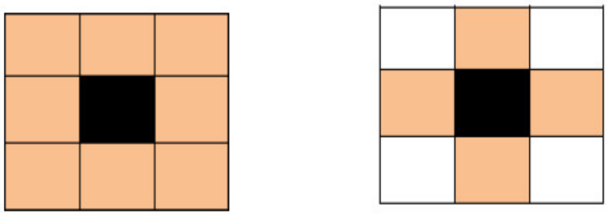

Figure 2: Neighborhood (left) Moore, (right) Von Neumann

To summarize, a CA system can be characterized by (Chen *et al.* 2009):

1. Parallelism, which means all cell states are updated simultaneously;

2. Homogeneity, which states that all cells follow the same evolutionary rules;

3. Locality, which implies a cell can only gather information from its nearest neighbors and can only affect its direct neighbor;

In general modeling of CA involves the following steps:

- set parameters
- set initial conditions
- set update rule
- set graphics

4. Recent Developments

Cellular automata were originally inspired and motivated by biological concepts, and have also been used to study of biological processes. By 1951, molecular biologists had identified the structure of DNA and its reproduction phenomena. It is remarkable to find that Von Neumann's idea of self-reproduction is self-organization, viz. the capability of a biological system to contain a detailed description of itself and use that information to create new copies. The idea of cellular automata was also introduced to study the development of HIV infections (Mielke *et al.*1998).

From the 1990s, following ecologist's awareness of the significant roles of local influences and spatial disparateness within ecosystems, the development and application of cellular automata were greatly stimulated in environmental and ecological fields. It was adopted in modeling of environmental model for forecasting the effects of climate change (Engelen *et al.* 1995). In addition, the traditional cellular automata have been extended to include external factors, where the evolution not only depends on state of a cell and its nearest neighbor, but also on external driving factors (White & Engelen 1997; Wootton, J. Timothy. 2001).

A rule based hypothetical prey–predator model *EcoCA* was developed in 2003 and first calibrated against the classical Lotka–Volterra (LV) model. The model was then used to investigate effects of cell size and cellular configurations. It was observed that the resulting spatial patterns were dependent on the choice of cell size, change of cellular configurations affect both spatial patterns and system stability. On the basis of these findings, it was proposed to use the principal spatial scale of the studied ecosystem as CA model cell size and to apply the Moore type cell configuration (Chen & Mynett 2003). EcoCA is hypothetical cellular automata based computer model that was developed to approximate a simple prey-predator system (Mynett & Chen 2004). It is a two dimensional CA model which has three possible cell states: empty, prey and predator. The neighborhoods are completed with cells taking the state of empty, hence fixing the boundary conditions. At each time step only one of the three states can exist in one cell. The evolutions for each cell (i,j) are based on cell current state, $S_{i,j}^{t}$ the number of itsneighbouring cells occupied by prey,N_{py}^{t} and the number of its neighboring cells that are occupied by predator,N_{pd}^{t}, as given by

$$p = f\left(S_{i,j}^{t}, N_{py}^{t}, N_{pd}^{t}\right)$$

where f are evolution rules defining the transition probability $p$that a cell will becomeeither prey or predator dominated or empty at the next time step. These evolution rules take into account reproduction, mortality, predation, loneliness and over crowdedness (Mynett & Chen 2004)

In 2006 the *EcoCA* model was used to study the stabilities of variant harvesting strategies of the predator-prey system. It was concluded that the joint harvesting of prey and predator with an acceptable constant effort can improve system stability and increase the total yields. In addition, it was once again confirmed that space places a significant role in the stability properties of the predation and harvesting system, which indicates the importance to use spatially explicit model in conservation of ecology (Chen *et al. 2006).* Keeping in view the involvement of time and space in ecosystem, spatio-temporal ecological models have been introduced, which indicates the significance of using a spatially explicit model in conservation of ecology (Chen *et al. 2011).*

5. Conclusion

This review has only begun to discuss Cellular Automata- its emergence and usefulness, as a tool to model ecological system. Owing to the capability to model local influences and spatial disparateness, cellular automata have been applied to various broad fields. The results indicate that spatially distinct models such as cellular automata have a substantial capacity to connect the local operations and universal figures.

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