A Methodology for Modeling Ecological Systems based on Cellular Automata.

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Abstract: - Ecological systems are generally considered among the most complex ones, because they are characterized by a large number of diverse components, nonlinear interactions, scale multiplicity, and spatial heterogeneity. In this paper a methodology for modeling ecological systems using cellular automata (CAs) is presented. The proposed methodology establishes the ability to capture the essential features-characteristics of the ecological system under consideration, and translate them into a suitable form, in order to obtain an effective CA model. The CA models obtained are of crucial importance in ecological engineering, and they could be used as decision support systems in environmental emergency response. Further, a complete description of the details of this methodology is specified, in order to help other researchers reproduce published simulation experiments. Forest fire spreading and oil slick movement and spreading are considered as possible applications of the proposed methodology. The models obtained can serve as a basis for the development of algorithms to simulate environmental and biological systems based on real data. Moreover, Application Specific Integrated Circuits (ASICs) that would execute and speed up the corresponding algorithms could be designed with the help of VHSIC Hardware Description Language (VHDL).

Key-Words: - Cellular Automata; Modeling; Ecological Systems; Forest fire spreading; Oil slick movement; ASICs.

1 Introduction
Ecological systems are characterized by diversity, heterogeneity and complexity [1]. Complexity often results from the nonlinear interactions among a large number of system components which frequently lead to emergent properties, unexpected dynamics, and characteristics of self-organization [2]-[3]. These systems, in spite of their diversities, share in common several structures and characteristic states which can be modeled and effectively treated [4]. This is made possible thanks to technological progress and to many numerical methods of calculation.

To describe the spatial-temporal evolution in ecological systems as in propagation, diffusion or transport phenomena, these complex systems have most often been modeled by Partial Differential Equations (PDEs) [5], [6]. For the simulation of these phenomena, many mathematical techniques have been proposed, e.g. the finite-elements method. These methods require a good knowledge of the basic model, but since the basic model is not always well defined, other methods must be used allowing, at the same time, modeling and the digital simulation, using other information [7]. This view has been reinforced by the wide-spread use of such methods, opening some new aspects of research, as coupled map lattices, genetic algorithms, agent-based modeling, and cellular automata (CAs), all of which rely heavily on dynamic systems with evolving structures and changing components [8].

This latter class of models was originally developed by Ulam and Von Neumann (under the name of “cellular spaces”) in an ambitious project: to show that complex phenomena can in principle be reduced to the dynamics of many identical very simple primitives, capable of interacting and maintaining their identity [9]. They have widely and effectively been applied in biology [10], and mostly in the study of ecological systems, including population dynamics [11], community ecology [12], forest dynamics [13] and in understanding spatial processes in plant and animal populations [14].

This paper presents a methodology for the usage of CAs in modeling environmental and biological systems. The point of departure of our approach was the need of compromise in ecological modeling between a too heavy and uncritical concentration on detailed information, on one hand, with the threat of drowning in a swamp of information, and, on the other hand, an all too free abstraction that relinquishes the claim of testable predictions and thereby loses its contact with reality [15].
methodology presented leads to the construction of ecological models, which are perceived with the assistance of theory and management, as an aid to orientation in the previously described dilemma. Furthermore, this CA methodology results from the combined consideration of theoretical aspects of ecological modelling and of the authors’ profused personal experiences with CA modelling and simulation in several scientific fields [17]-[23].

In order to accomplish the aforementioned targets, the proposed methodology takes under serious consideration most of the parameters that are essential characteristics for each ecological system and tries to implement the corresponding CA model. Since the complexity of some ecological systems greatly exceeds the limits of the CAs’ original definition [24], a generalization of the CAs’ original nature is quite useful. More details about this generalization of CAs could be found in Section 2. The ability of the methodology was tested in modeling with success in two different ecological systems, namely in forest fire spreading and oil slick movement. The CA models obtained are of crucial importance in ecological engineering and could be used as decision support systems in environmental emergency response. Furthermore, the models produced can serve as a basis for the development of algorithms to simulate environmental and biological systems based on real data.

Eventually, these algorithms are also appropriate for their implementation on parallel computers. The combined use of parallel computing systems and CAs provides high-performance computational simulation environments to be used for solving real world problems in ecology. These environments allow the researcher to define ecological problems in a cellular form and map them on parallel machines [25]. As a result, the models obtained could be speeded up in order to be used as parts of real-time decision support systems with the design of Application Specific Integrated Circuits (ASICs) that would execute the corresponding algorithms.

This paper is organized as follows: All the necessary information concerning the proposed CA methodology is given in Section 2. In Section 3 the applications of the methodology in the cases of forest fire spreading and oil slick movement are presented. The fruitful and interesting possibility of hardware implementation of the models produced is discussed in Section 4. Finally the discussion and conclusions of this work are presented in Section 5.

2 CA Methodology for Modelling Ecological Systems

CAs have enough expressive power to represent phenomena of arbitrary complexity, and at the same time they can be simulated exactly by digital computers because of their intrinsic discreteness; i.e., the topology of the simulated object is reproduced in the simulating device [26]. The mathematical tools mostly used for modeling environmental and biological systems, namely PDEs, contain much more information than it is usually needed, because variables may take an infinite number of values in a continuous space. PDEs are used to compute values of physical quantities at points in continuous time. But the values of physical quantities are usually measured over finite volumes at discrete time steps. CAs are used to compute values of physical quantities over finite volumes (CA cells) at discrete time steps [27]. The CA approach is consistent with the modern notion of unified space-time where space (memory, i.e. CA cell state) and time (processing unit, i.e. CA local rule) are inseparable, i.e. located to a CA cell. Because of the above reasons, models based on CA lead to algorithms which are fast when implemented on serial computers, because they exploit the inherent parallelism of the CA structure.

However, as the complexity of a physical system increases, the number of bits necessary to represent the values of the physical quantities, at each site of the CA lattice may become quite large, especially when these bits are interpreted as the binary representation of an integer, or even, of a floating point number. Then the usual arithmetic operators +, -, * and / can be used to build the CA rule [28]. This generalization of the original nature of CAs, working with real-valued quantities and arithmetic operators is quite useful in ecological modelling, leading to multiparticle automata and lattice Boltzmann models [28]. In this way, even complicated spatial-temporal evolutions resulting in boundary advancement similar to that of Huygens’ waves, i.e. the points of the old boundary are supposed to be Huygens’ sources that emit circular ‘waves’ and the new boundary is the envelope of these waves, could be easily described with the usage of CA models.

In this section, a CA methodology for modeling environmental and biological systems is presented. Briefly, the basic steps of the aforementioned methodology are:

1. Divide the space in which the physical object exists into a 2-D matrix of identical square cells, with side length $a$, and represent it by a CA, by
assuming that each cell of this space is a CA cell.

2. Define the lattice size of the CA array, while the neighbourhood chosen for the 2-D CA is the Moore neighbourhood. The lattice size of the CA is a compromise between accuracy and computation time and memory.

3. Express the state of a CA cell as a real-value number, depending on the location of the CA cell in relation to the propagating or evolvable front [eq. (1)]. The cell state of the CA that propagates or evolves is usually given by:

\[ C_{ij}^{t+1} = \sum_{j=1}^{9} a_{ij} + \sum_{j=1}^{9} b_{ij} \]

where \( C_{ij}^{t+1} \) is the local state of the \((i, j)\) cell, at time \( t \), \( E_{in} \) is the cell area located inside the propagation front and \( E_t \) is the total cell area.

4. If there are other parameters relative to the location of the CA cell in the CA lattice, incorporate them into the local state of the CA cell with the use of flags.

5. Express the CA local rule as a sum of contributions from all neighbouring cells [eq. (2)]. The CA local rule that produces the propagation or evolution fronts is the following: the basic steps of the proposed CA methodology implemented on modelling forest fire spreading are given as follows:

STEP 1: The forest is divided into a matrix of identical square cells, with side length \( a \), and is represented by a CA, where each cell of the forest is considered as a CA cell.

STEP 2: The neighbourhood of the \((i,j)\) CA cell is chosen to be Moore neighbourhood.

STEP 3: The local state of each CA cell at time \( t \) is defined as the ratio of the burned out cell area to the total cell area:

\[ S_{ij}^{t+1} = \frac{A_b}{A_t} \]

where \( A_b \) and \( A_t \) are the total cell area, respectively. The state of an unburned cell is zero, whereas the state of a fully burned out cell is 1. \( S_{ij} \) may take any value in between.

3. Applications of the proposed CA Methodology

3.1 Forest Fire Spreading

Fires are an integral part of almost all natural area ecosystems, and over the course of many centuries have exerted an exceptionally important influence on the condition and structure of forests in many regions of the planet. The environmental effects of forest fires are enormous and, therefore, there is a constant demand for effective fire fighting and management [29]. The difficulties in modelling and simulation of forest fires are severe, because the problem of predicting forest fire is a highly non-linear problem and the shape of the forest and the different areas in it impose complicated boundary conditions. The most important factors affecting the forest fire spreading are: the weather conditions, and especially the wind direction and speed, the complex topography of the landscape and the existence of areas with different rates of fire spread.

The problem of predicting forest fire spreading can be stated as follows: Given a scalar velocity field \( R(x,y) \) representing the distribution of the rates of fire spread at every point in a forest, the forest fire front at time \( t_1 \), the wind direction and speed, and the height and shape of the land, determine the fire front at any time \( t_2 > t_1 \) [29].

The basic steps of the proposed CA methodology implemented on modelling forest fire spreading are given as follows:

\[ S_{ij}^{t+1} = \frac{A_b}{A_t} \]
**STEP 4:** At each cell of the CA is allocated a rate of fire spread \( R \), which is the value of \( R(x,y) \) at the central point of the cell. The rate of fire spread distribution is given by some other model [39]. \( R_{ij} \) is the rate of fire spread allocated to the \((i,j)\) cell, and it determines the time needed for this cell to be fully burned out.

**STEP 5:** The state of a cell at time step \( t+1 \) is affected by the states of all eight cells in its neighbourhood at time step \( t \) and by its own state at time step \( t \):

\[
S^{t+1}_{i,j} = F \left( S^t_{i-1,j-1}, S^t_{i-1,j}, S^t_{i-1,j+1}, S^t_{i,j-1}, S^t_{i,j+1}, S^t_{i+1,j-1}, S^t_{i+1,j}, S^t_{i+1,j+1} \right)
\]

This function is the CA local rule. \( S^t_{ij} \) and \( S^{t+1}_{ij} \) are the states of the \((i,j)\) cell at time steps \( t \) and \( t+1 \), respectively.

**STEP 6:** Forest fire spreading is also affected by height differences between various points of the forest and by wind speed and direction. It is well known that fires show a higher rate of spread when they climb up an upward slope, and a smaller rate of spread when they descend a downward slope. The effect is given by \( H_{kl} \) which is a constant that depends on the height difference between the central points of cells \((k,l)\) and \((i,j)\). If \( h_{ij} \) is the height of the central point of the \((i,j)\) cell, and \( h_{kl} \) is the height of the central point of the \((k,l)\) cell, then:

\[
H_{kl} = F(h_{ij} - h_{kl})
\]

The CA local rule that incorporates both the wind and height differences is given by [30]:

\[
S^{t+1}_{i,j} = S^t_{i,j} + \left( nH_{i-1,j}S^t_{i-1,j-1} + wH_{i,j-1}S^t_{i+1,j-1} \right) + eH_{i,j+1}S^t_{i+1,j+1} + sH_{i+1,j}S^t_{i+1,j+1} + \left( nh_{i-1,j}S^t_{i-1,j-1} - nh_{i-1,j}S^t_{i+1,j-1} \right) + eH_{i,j+1}S^t_{i+1,j+1} + sH_{i+1,j}S^t_{i+1,j+1} + \left( nh_{i-1,j}S^t_{i-1,j-1} - nh_{i-1,j}S^t_{i+1,j-1} \right) + eH_{i,j+1}S^t_{i+1,j+1} + sH_{i+1,j}S^t_{i+1,j+1}
\]

where \( w, e, n, s, sw, nw, se, \) and \( ne \) are weights which are assigned to the states of the neighbouring cells in the CA local rule in order to incorporate the wind into the model.

**STEP 7:** No need for "if, then, else" statements for the expression of the CA rule is mentioned. The CA model for forest fire spreading has finally been produced, based on the aforementioned methodology. Fig. 1(a) shows successive fire fronts in a flat homogeneous forest when wind is blowing from west towards east (from left towards right). The units in all axes are arbitrary. In all cases it is assumed that the fire starts at the center of the forest. Fig. 1(b) shows successive fire fronts in a flat inhomogeneous forest when no wind is blowing. There are two areas with different vegetation and, consequently, different rates of fire spread \( R_1 \) and \( R_2 \), with \( R_1 > R_2 \). Fig. 1(c) shows a homogeneous forest in which there exists a hill, or a mountain. No wind blows. The successive fire fronts in this forest are shown in Fig. 1(d). The lines of equal height (i.e. the contour map) are shown using dashed lines.

![Fig. 1(a) Successive fire fronts in a flat homogeneous forest when wind is blowing from west towards east (from left towards right).](image1)

![Fig. 1(b) Successive fire fronts in a flat inhomogeneous forest in which there are two areas](image2)

![Fig. 1(c) Homogeneous forest in which there exists a hill, or a mountain.](image3)
Fig. 1(d) Successive fire fronts in forest of Fig. 1(c). (The units in all the above axes are arbitrary).

3.2 Oil Slick Movement and Spreading

Extensive oil drilling and transportation activities increase the possibility of oil spills and the consequent threat of oil pollution to the regional environment. Oil spills are hazards for marine and freshwater environments and oil spill/slick detection, monitoring, and management has received considerable attention over the past few years [31]. The problem of predicting the oil slick movement and spreading is a highly non-linear problem and the shape of coasts and islands impose complicated boundary conditions [32]. The most important factors affecting oil slick movement and spreading are: wind direction and speed, as well as water surface currents’ direction and speed.

The problem of predicting the oil slick movement and spreading is stated as follows: Given the oil mass distribution at time $t=0$ (i.e. $M_{i,j}^t$), the geography, the wind and water current speed and direction, determine the oil mass distribution at all future times $t>0$ (i.e. $M_{i,j}^t$) [33].

The basic steps of the proposed CA methodology implemented on modelling oil slick movement and spreading are given as follows:

**STEP 1:** The surface of the area where the spill occurred is divided into a matrix of identical square cells, with side length $a$, and it is represented by a CA by assuming that each square cell of the surface is a CA cell. This area includes water (sea, lake, river) areas and land (coasts, islands) areas.

**STEP 2:** The neighbourhood of the $(i,j)$ CA cell is chosen to be Moore neighbourhood.

**STEP 3:** The oil mass of CA $(i,j)$ cell at time $t$ is defined as $M_{i,j}^t$. In general, the oil masses are not equal to each other and therefore oil is transported from cells where oil mass is large to cells where oil mass is small. The driving force for oil transport between two cells is the difference of oil mass. Consider the $(i,j)$ cell and one of its neighbours, the $(i-1,j)$ cell. If at time $t$ $M_{i,j}^t > M_{i-1,j}^t$, then at time $t+1$ oil will be transported from the $(i,j)$ cell to the $(i-1,j)$ cell, whereas, if $M_{i,j}^t < M_{i-1,j}^t$, then at time $t+1$ oil will be transported from the $(i-1,j)$ cell to the $(i,j)$ cell. As a first order approximation the transported oil mass is supposed to be proportional to the oil mass difference between the two cells.

**STEP 4:** In order to include the previously mentioned important factors affecting the oil slick movement and spreading, the state of the $(i,j)$ cell at time $t$, $C_{i,j}^t$, is finally given by:

$$C_{i,j}^t = \{ LF, M_{i,j}^t, CD_{i,j}^t, CV_{i,j}^t, WD_{i,j}^t, WV_{i,j}^t \} \quad (7)$$

where $LF$ is a one bit flag which indicates land or water areas. If the $(i,j)$ cell is a land area then $LF=1$, whereas, if the $(i,j)$ cell is a water area $LF=0$. $M_{i,j}^t$ is the oil mass at time $t$ in the area corresponding to the $(i,j)$ cell. $CD_{i,j}^t$ and $CV_{i,j}^t$ are the water current and wind speeds at time $t$ in the area corresponding to the $(i,j)$ cell respectively. $CD_{i,j}^t$ and $WD_{i,j}^t$ are flags that indicate the direction of the current and wind speeds at time $t$ in the area corresponding to the $(i,j)$ cell respectively. The number of bits in these flags is proportional to the number of directions, i.e. if the number of bits is two, then the flags can indicate only four directions (for example 01 corresponds to east direction). If the number of bits is three, then the flags can indicate eight directions (for example 101 corresponds to south-west direction). It should be mentioned that the values of the aforementioned parameters are not calculated in this model, but assumed to be given by some other simulation (weather or surface current simulation) or system.

**STEP 5:** When oil transport to or from all eight neighbouring cells is taken into account, the oil mass in the $(i,j)$ cell at time $t+1$ is given by:

$$M_{i,j}^{t+1} = M_{i,j}^t + m \left[ \left( M_{i-1,j}^{t+1} - M_{i,j}^t \right) \left( M_{i+1,j}^{t+1} - M_{i,j}^t \right) \right] + d \left[ \left( M_{i,j-1}^{t+1} - M_{i,j}^t \right) \left( M_{i,j+1}^{t+1} - M_{i,j}^t \right) \right] + \left[ \left( M_{i+1,j-1}^{t+1} - M_{i,j}^t \right) \left( M_{i,j+1}^{t+1} - M_{i,j}^t \right) \right]$$

where $m$ and $d$ are constants that absorb the difference between oil transport between adjacent cells, in case of $m$, and oil transport between adjacent cells and oil transport between diagonal cells, in case of $d$, respectively. Obviously, oil transport between diagonal cells is less than oil transport between adjacent cells. Eq. (8) preserves the total oil mass because the oil mass transported into the $(i,j)$ cell from some other cell, the $(i+1,j)$ cell, is equal to the oil mass transported out of the $(i+1,j)$ cell. If one of the neighbouring cells is a land area (i.e. $LF=1$) then it is assumed that no oil transport is possible to or from that cell and the
corresponding term in eq. (8) is not taken into account.

**STEP 6:** In an oil slick, oil mass is continuously reduced because of oil evaporation. In order to include oil evaporation, on the CA local rule another term has been added to eq. (8):

$$M^{i,j+1} = M^{i,j} + mn \left[ \left( M_{i-1,j}^{i+1,j} - M^{i,j} \right) + \left( M_{i+1,j}^{i+1,j} - M^{i,j} \right) \right]$$

$$+ md \left[ \left( M_{i-1,j-1}^{i+1,j-1} - M^{i,j} \right) + \left( M_{i+1,j+1}^{i+1,j+1} - M^{i,j} \right) \right] - \rho m T'$$

The term ($\rho m T'$) is a first order approximation to oil evaporation rate, i.e. the oil mass evaporated during a time step depending mainly on temperature. Constant $\rho$ is a user defined constant with units [kg (sec oK)$^{-1}$], $T_m$ is the time corresponding to a model time step and $T'$ is the temperature of the environment at time step $t$ ($t$ in $T'$ is an index and not an exponent).

Water currents and wind-driven currents greatly affect oil transport from one cell to another. In order to include the effect of currents in oil transport, eq. (9) is written as follows:

$$M^{i,j+1} = M^{i,j} + mn \left[ \left( 1 + N_{i,j} M_{i-1,j} - M^{i,j} \right) + \left( 1 + S_{i,j} M_{i+1,j} - M^{i,j} \right) \right]$$

$$+ md \left[ \left( 1 + NE_{i,j} M_{i-1,j-1} - M^{i,j} \right) + \left( 1 + SW_{i,j} M_{i+1,j+1} - M^{i,j} \right) \right]$$

$$- \rho m T'$$

Constants $N_{i,j}$, $E_{i,j}$, $S_{i,j}$, $W_{i,j}$, $NE_{i,j}$, $NW_{i,j}$, $SW_{i,j}$, and $SE_{i,j}$ correspond to north, east, south, west, north-east, north-west, south-east and south-west directions and are called direction constants. Each direction constant models the effect of both water currents and wind-driven currents. The signs of the wind and water current direction constants are determined by the values of $WD_{i,j}$ and $CD_{i,j}$ which indicate the wind and current direction at time step $t$, respectively.

**STEP 7:** No need for "if, then, else" statements for the expression of the CA rule is mentioned.

The CA model for oil slick movement and spreading describing the effects of land areas, oil evaporation, and wind-driven and water currents has finally been produced, based on the aforementioned methodology. It should be stated here that some other factors such as water depth, coastal waves, shoreline deposition and oil dissolution in water should have been taken under consideration in order to complete the proposed model. In Fig. 2 a hypothetical circular oil slick, with total oil mass 50 000 kg, in a 10 km X 10 km square area is considered at time $t=t_1$. Suppose that the oil mass distribution in this circular oil slick follows a Gaussian distribution, i.e. oil mass is maximum at the center of the slick and decreases with the circle radius following the Gaussian function and also that oil evaporation is essentially zero. The values of $m$ and $d$ are set to 0.0014 and 0.18, respectively. In this area an arbitrarily shaped island is found. Suppose that no water currents exist and no winds blow. Fig. 2 shows simulation results at two future times $t_2$ and $t_3$ ($t_3>t_2>t_1$). No water currents exist and no winds blow.
The same slick in the same area as in Fig. 2, but with a water current with direction from south to north are depicted in Fig. 3 at time $t = t_1$. Suppose that no winds blow. The direction of the arrows in Fig. 3 shows the direction of the water current and the size of the arrows indicates the water current speed. The width of the water current strip is 1.5 km. The current speed at the center of the strip was taken to be equal to 20% of the maximum possible water current speed, whereas the speed at the edges of the strip was taken to be equal to 10%. The current speed was supposed to vary linearly from the center to the edges of the strip.

![Fig. 3](image-url)

Fig. 3 shows simulation results at two future times $t_2$ and $t_3$ ($t_3 > t_2 > t_1$). The presence of the current increases the oil transport from south to north and causes a secondary oil transport from west to east.

4 Hardware implementation of the CA models

In all cases, the design of Application Specific Integrated Circuits (ASICs) that would execute the corresponding algorithms could speed up the models obtained so as to be used as parts of real-time decision support systems with. CAs have been extensively used as a VLSI architecture [16], [17], [19], [34]-[37]. The CA VLSI architecture offers a number of advantages and beneficial features such as simplicity, regularity, and locality of interconnections.

The main difference between CAs as models for ecological systems and CAs as a VLSI architecture lies in the CA state space. The state space of CAs which model ecological systems is usually continuous, whereas the state space of CAs which are used as a VLSI architecture is discrete. It is, therefore, clear that the discretization of the CA state space is the first step towards the design of the corresponding dedicated processors, which will execute CA algorithms that model ecological systems. As it has been mentioned, the CA local rule obtained by the presented methodology [eq. (2)] includes multiplications and divisions, and its hardware implementation will result in an integrated circuit with a large silicon area, which would not only be expensive to fabricate, but its power consumption would require a rather large battery to be carried along in the field, in case of modeling online real phenomena, i.e. a real fire in progress.

For the above reasons the use of alternative techniques in order to design dedicated hardware for modeling ecological systems is essential.

In order to design the dedicated hardware the following problem should be solved: Given a CA with continuous state space obtained form the aforementioned CA methodology, use a Genetic Algorithm (GA) in order to find a CA with discrete state space, having the smallest possible lattice size and the smallest possible number of discrete states, the results of which are as close as possible to the results of the CA with continuous state space. The two CAs may not have the same lattice sizes. Generally the CA with discrete state space is expected to have larger lattice size than the CA with continuous state space. The role of the GA in this case is similar to the role of the analog to digital (A/D) converter which converts real-world analog
signals to digital signals that can be processed by computers and digital systems. The CA with discrete state space with the local rule found by the GA should be implemented in hardware. Furthermore, according to Sipper et al. [34], since only the final solution found by evolution is implemented in hardware, the dedicated hardware is characterized as off-line evolvable hardware.

The implementation of the algorithms could be achieved after the manual translation of the parts of the algorithms, to become hardware, into a synthesizable subset of a hardware description language (HDL), such as Verilog or VHDL. VHDL is one of the most important and widely used hardware description languages of the present time, and the applications written in VHDL are increasing in size and complexity, prompting the use of parallel algorithms to achieve an acceptable simulation performance. The use of VHDL language could be an exceptional implementation medium in order to produce easily with less dysfunction the dedicated processor, which corresponds to the ecological system, directly from the CA algorithm [37]. The VHDL code, thus obtained, can be introduced as input to a commercial VLSI CAD system, which will automatically produce the layout of the corresponding dedicated processor. This hardware is actually the VLSI implementation of the CA with discrete state space.

5 Conclusions

A methodology for the use of CAs in modeling ecological systems was presented in this paper. The proposed methodology establishes the ability to capture the essential features-characteristics of the ecological system under consideration, and translate them into a suitable form, in order to obtain an effective CA model. The ability of the CA methodology was tested in modeling with success in two different ecological systems, namely in forest fire spreading and oil slick movement. In all cases, we have used two-dimensional CAs with a Moore neighbourhood, and we have divided the space in which the physical object exists into a 2-D matrix of identical square cells, with side length \( a \), and represented it by a CA, by assuming that each cell of this space is a CA cell. The models obtained can serve as a basis for the development of algorithms to simulate environmental and biological systems based on real data.

Furthermore, the CA models obtained are of crucial importance in ecological engineering, and they could be used as decision support systems in environmental emergency response. The fruitfull and interesting possibility of hardware implementation of the models obtained, in order to speed up the corresponding algorithms, was also discussed. The usage of a GA which operates on a (number of CA states X CA lattice size) grid to find a CA with discrete state space the results of which are as close as possible to the results of the CA with continuous state space may contribute in this effort. VHDL language was assumed to be the implementation medium for the production of the ASIC that would execute the corresponding CA algorithm with discrete state.

References:


