Formalization of a Spatialized Multiagent Model using Coloured Petri Nets for the Study of an Hunting Management System

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Abstract. This paper presents an experience of a multiagent model formalization using coloured Petri nets, applied to the study of an hunting management system. The multiagent model of the hunting activity is presented, with simulation results. Then we describe Petri nets model assumptions and we give details about system modules. We analyze the model and we compare formal properties to multiagent simulation results. Pertinence of the approach is briefly discussed

1 Introduction

Multiagent approach provides a new way to model phenomena in which interactions between various entities are too complex to be apprehended by the traditional tools of mathematical modelling. Thus this approach is increasingly used in problems of environment management, and particularly in modelling of natural and renewable resources management [1], [2], [3]. The expression power of multiagent models allows us to represent interactions between autonomous entities, which have an individual behavior and are able to evolve in an environment [8]. But when it is necessary to analyze the system and identify global and general properties, the multiagent approach appears to have limits. The use of formal methods of specification seems to be the way indicated to analyze these virtual worlds which can not be studied only by simulation.

We present in this paper an experiment of the use of a formal approach to apprehend a multiagent system. Singh [13] underlines that althought several powerful formalisms exist, finding the right formalism is a nontrivial challenge. From a multiagent model of the hunting activity based on data collected in an

Eastern Cameroon village, we have built an equivalent Petri net model. Petri nets are choisen as a middle way between two extremes: differential equations which are not adapted to model individual behaviours and multiagent approach which has inadequacies when trying any formalization. After some simplifications, we use a model checker to exhibit formal properties of the system. Some previous related works have already attemped to use Petri nets to formalize multiagent models [4], [5] but these works usually focus on the behaviour aspect of those agents. Since in the field of natural and renewable resources modelling the space is often very important, we have built a Petri net model which integrates spatial distribution of the agents and their moves in this space. Gronewold [6] gives an example how the modelling technique of Petri nets can be adopted to the individual oriented modelling of ecological systems. But they are inadequacies in that work, according to the possibility to demonstrate general properties of the model.

We will begin with a brief presentation of the multiagent model, after which we will give the coloured Petri net we have built there from and the analysis we have carried on this model using available tools. We will discuss the pertinence of the approach and we will end by drawing some conclusion on the use of formal methods according to our experiment.

2 The multiagent model of hunting activity

During these last years, different organizations concerned with wildlife are unanimous that African fauna is increasingly being destroyed by anarchical hunting pratices. Many solutions (protected areas, taxes) have been tested, without producing the expected effects. The purpose of the use of multiagent approach to model hunting activity was to evaluate the viability of local strategies of wildlife preservation. The multiagent model we have built [9] represents hunting of the blue duiker in the forest around the village. An artificial landscape, mapping on the forest landscape has been defined as a grid of cells. Each cell has attributes corresponding to the state of the space portion it represents : road, water, trap...

A duiker agent has been created. Its attributes are the age, the sex, the duration of gestation and the partner. Using data on the life history of the blue duiker obtained from the work of Dubost [7], we have implemented growth, mortality and reproduction functions.

Then we have simulated the natural evolution of the population without any human activity. The results for population density suggest that the multiagent model converges with damping oscillations to a steady state of approximately 90 animals per km2. That density appears realistic because it is the one observed in the non hunted forest of the region. A second set of simulations uses the hunting data collected on the field.

Many scenarios have been implemented to test the influence of different hunting strategies: continuously repeating 1995 hunting data; removing traps from the spatial grid every 26 weeks and locating again at the same place or randomly re-locating within the same hunting location...

These experiments point out the crucial influence of the spatial dimension. We used CORMAS platform, (Common-pool resources and multiagent systems), a generic simulation environment based on Smalltalk which allows to build spatially-explicit individual-based models in a flexible way [11], developped in the GREEN research team of CIRAD [1].

We used multiagent approach as an alternatve to traditional mathematical tools: differential equations have been for a long time the adequate way to handle population dynamics. Multiagent systems offer efficient concepts to design, implement and simulate individual-based models. Nevertheless, simulations only provide short (finite) time information. In the field of natural resources management, it is of interest to know long term effects of managing decisions. The use of a formal approach may help to evaluate tendancies shown by simulation. Petri nets appear as the adequate approach which preserve formal analysis and individual-based modelling capabilities. More, efficient tools are available to design and analyze Petri net models.

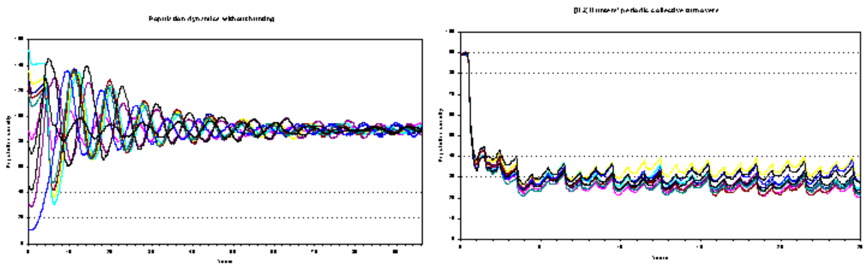

Fig. 1. Multiagent simulation results: the population size variation during time for two scenarios.

3 The coloured Petri net model

Petri nets are a graphical and mathematical modelling tool applicable to many systems which the behavior can be described in terms of system states and their changes. Formally, a Petri net is a 5-tuple $PN = (P, T, F, W, M_0)$ where:

- $P = \{p_1, p_2, ..., p_m\}$ is a finite set of places,
- $T = \{t_1, t_2, ..., t_n\}$ is a finite set of transitions,
- $F \subseteq (P \times T) \cup (T \times P)$ is a set of arcs,
- $W : F \rightarrow \{1, 2, 3, ...\}$ is a weight function,
- $M_0 : P \rightarrow \{0, 1, 2, 3, ...\}$ is the initial marking,
- $P \cap T = \phi$ and $P \cup T \neq \phi$.

[1] http://www.cirad.fr/presentation/programmes/espace/cormas/

A transition t is said to be enabled if each input place p of t is larked with at least $w(p,t)$ where $w(p,t)$ is the weight of the arc from p to t. A firing of an enabled transition t removes $w(p,t)$ tokens from each input place p of t, and adds $w(t,p)$ tokens to each output place p of t, where $w(t,p)$ is the weight of the arc from t to p. In graphical representation, places are drawn as circles, transitions as bars or boxes. Arcs are labeled with their weights (positive integers), where a $k-$weighted arc can be interpreted as the set of k parallel arcs. Labels for unity weight are usually omitted.

Coloured Petri nets allow the use of tokens that carry data value and can hence be distinguished one from the other. Arbitrary complex data types can be used as coloured sets, like a list of many thousand records, involving fields of many different types [12]. To be able to occur, a transition must have sufficient tokens in its input places, and this tokens must match the arc expression. We used CPN-AMI[2] which is a Petri Net based environment. It offers a set of services to ease the work of designers who specify systems and take benefits of the Petri net theory. It relies on the Macao graph Editor which also behaves as the User Interface of CPN-AMI [10].

3.1 Assumptions of the model

The model is built by assembling modules which correspond each to an hypothesis. The main hypothesis are :

- H1: The moving hypothesis:

(a) The animals move randomly in the 4 directions (north, south, east and west); (b) The animals which move on an hunted cell are taken in the trap, according to a catch probability; (c) The animals taken in a trap are removed from the system (dead); (d) The maximum number of animals in a cell is defined; (e) The moves of the animals relate to all the population for each time step.

- H2: The population of animals increases by a fixed percentage
- H3: The growth hypothesis:

(a) The animals grow; (b) When an animal reach the fixed maximum age, it is removed from the system.

- H4: The schedule of the various actions is well defined.

Those assumptions have been grouped (as shown by their number) and a net module was built for each group. Modules share common places which will be used to connect each other. Each module contains two special non coloured and 1-bounded places: $Start\_Hx$ and End_Hx which are marked respectively at the beginnning and at the end of the "execution" of the module. The main places of the system are defined as follow:

[2] http://www.lip6.fr/cpn-ami

- A place named *Population* contains tokens $< Id, Age, X, Y, State >$. Each token represents an animal. *Age* is its age expressed in half-years, X and Y are the coordinates of its spatial position, Id its number and *State* represents the state of the animal.
- A place named *Space* contains tokens $< X, Y, Attr >$ corresponding each to a cell of the grid space similar to the space in the multiagent model. X and Y are the same as in the place named *Population*. *Attr* represents the state of the cell and express the fact that the cell is hunted or not, if it's water or road, or simply an empty cell.
- Some other places can be mentionned here: the place *Size* which contains a coloured token $< IdT >$ representing the population size; the place *SpaceEmpty* which contains tokens $< X, Y >$ for all the available positions in the space; the place *SpaceOcc* for all the occupied positions.

Below we have described two modules: the moving module corresponding to the first group of assumptions $H1$ which carry the spatial aspect of the model and the increasing population module corresponding to assumption $H2$.

3.2 The moving module

The module (figure 2) represents the moves of the whole population during a time step of the evolution of the system. Each animal can move to one of its four neighbour cells or stay on its cell.

When a token is put on place $Start\_H1$, transition *copy* becomes enable and the population size $< IdT >$ is copied from place *Size* to place *SizeBis*, the place *step_1* recieved a non coloured token. The token of the place *SizeBis* will be decreased during the moving process and will match the *Id* attribute of the token $< Id, Age, X, Y, State >$ currently moving. One of the transitions $Left, Right, Up$ or *Down* is firing according to the current moving direction. Otherwise, when there's no available position in the destination cell, the token stays in its initial position. After the moving step, the value of the token p and the state of the new position determine if the animal will be caught or not.

3.3 Increasing population module

This module (figure 3) increases the population size by creating a sub population which is added to the initial population. We have implemented in this module a divide mechanism which allows to increase the population according to the fixed increasing percentage defined by the model assumptions. The module starts by the marking of the place $Start\_H2$ and ends when there is a token in the place End_H2. It shares places *SpaceOcc*, *Size*, *SizeBis* and *Population* with the moving module.

3.4 The complete modele

We have defined a scheduling module which connects End_H_i to $Start\_H_{i+1}$, and the last module to the first for repeating seasons. A control mechanism was

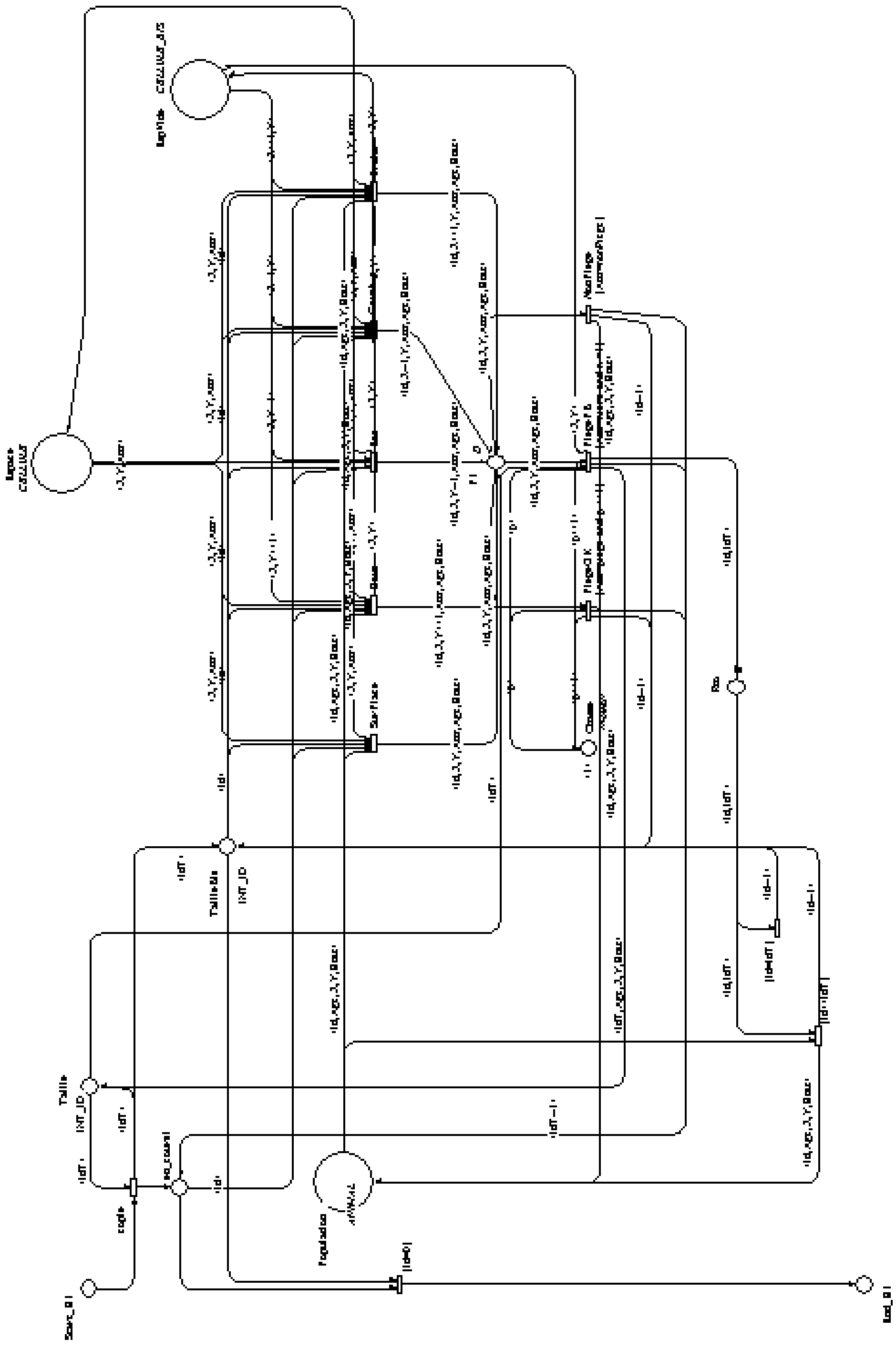

Fig. 2. The moving module

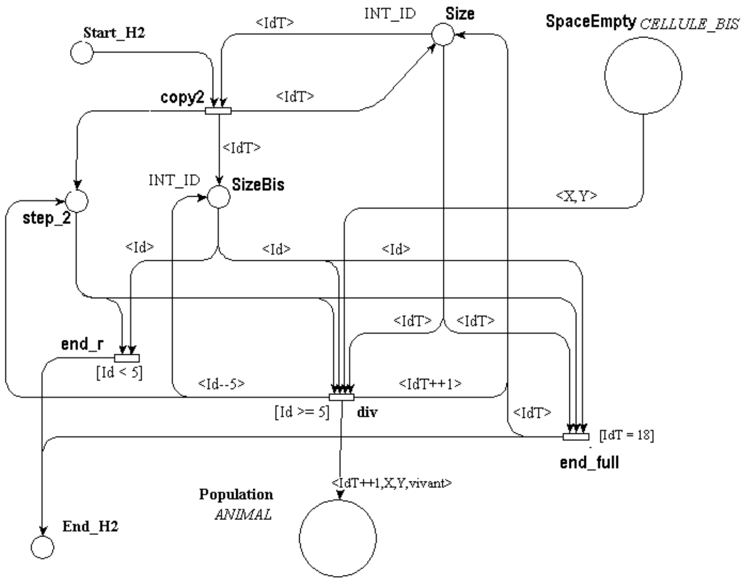

Fig. 3. Increasing population module

added to stop the system when the population size reaches zero value. The whole system was obtainaed in connecting modules by means of "channel places". It gave a Petri net with 20 places and 22 transitions.

4 Analysis of the coloured Petri net model

We use simulations to validate each module of the model during the construction phase, by making sure if it had the expected behaviour on small initial marking. When the net is debugged, it can be analysed using structural properties analysis or model checking. The first way permits us to verify the coherence of the model. By computing invariants of places, we assume that the different control mechanisms we used in the model are well implemented.

configurations	permanent hunting seasons						alternating hunting and no hunting seasons (2)		
	maintaining trap positions (1a)			alternating trap positions (1b)					
	nodes	arcs	terminal nodes	nodes	arcs	terminal nodes	nodes	arcs	terminal nodes
	389584	412081	2	776396	820866	12	565206	583922	**0**
	443260	469479	6	884760	936715	**0**	724103	748391	**0**

Table 1. Statistics about the complete reachability graph of the Petri net model

The main phase of the analysis of the model is the study of its reachability graph. It is a directed graph with a node for each reachable system state and an arc for each possible transition from one system state to another. We used the PROD analysis tool which was integrated in CPN-AMI platform. Since the graph size is large, we experimented the model checker on smallest values of initial marking. We defined as initial marking a 2×2 space where each cell can contain at most two animals and where two of the four cells are hunted. With an initial population of 4 animals, we obtained a complete reachability graph with characteristics shown in the table 1.

We observed that the liveness of the system can be verified when the reachability graph doesn't have any terminal node. It's always the case when we alternated hunting and non hunting seasons (2). For the scenario (1b), we obtain a significant difference betwen the two configurations. It appears as a consequence of the neighbourhood mode we implemented. When traps are always maintained on their position (1a), it is possible to reach a terminal node. These results show that there is an important correlation between spatial and temporal dynamics of the system.

5 Discussion

As explained by Singh & al. [13], in general, formalizations of agents systems have been used for two quite distinct purposes: as internal specification languages to be used by the agent in their reasoning or action and as external metalanguages to be used by the designers to specify, design and verify certain behavioral properties of agents situated in a dynamic environment. Our work can be classified under the second purpose. We are going to discuss here two aspects of the experiment: modelling and verification of properties.

The use of Coloured Petri nets to represent spatial behaviors induces to develop specific mechanisms to model certain dynamics:

- the choice of a moving direction;
- what happens if there is no empty position to reach;
- how to assume coherence within the different places of the model (*SpaceOcc* and *SpaceEmpty*, *Population* and *Size*).

The representation of random events too is not a trivial exercise. These difficulties are enough to divert the modeller's attention from the real problem. Furthermore, modelling a complex problem such as wildlife management using Petri nets enables us to get benefit from the formal semantic of the approach, and then avoid any ambiguity in the interpretation of the system description. System modularity allows maintenance facilities and avoid spaghetti effects which would appear if trying to design directly the complete net.

Model checking is a useful method for verifying properties of finite states systems. After formalizing a multiagent model, there is a real methodological challenge to achieve the verification part of the study, because of the system complexity. In our case, we are trying to know if they are (or are not) system states for which the population size has a nil value. We didn't obtain any significant difference when checking the model with that specific property or building the whole reachability graph. This is why we analyzed statistics about the complete reachability graph. It is clear that, due to the state-explosion problem, it would not be possible to analyze the model with realistic values. The model checker exhibits very interesting qualitative results, according to the field study. Formal analysis show the crucial influence of spatial dynamics (neighborhood's type, moving directions, trap's configuration) when studying the liveness of the system. These results have been pointed out by multiagent simulations.

6 Conclusion

The aim of this study was to validate simulation results we obtained from a multiagent model of hunting activity, using formal methods. We have built a coloured Petri net model with some assumptions taken from the multiagent model, and we analysed the reachability graph for some particular initial conditions which allow to prove the liveness of the system. In terms of management of natural resources, the liveness of our Petri net model is equivalent to the viability of the resources. We focussed our study on the qualitative aspect of the system and we showed correlations between the viability of the system, the spatial behaviour of animals and hunters spatio-temporal strategies. The use of coloured Petri nets, because of its call for precision, allows us to apprehend a very large specification. It gives us a good small-scale model to formally test the viability of some management strategies of the hunting activity and to validate simulation results of the multiagent model.

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