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4. Multi-agent Simulation as a Tool for Analysing Emergent Processes in Societies

Alexis Drogoul, Jacques Ferber, Christophe Cambier

Alexis Drogoul and Jacques Ferber:
LAFORIA,
Universite Paris VI,
Tour 46-0, 75252 PARIS
CEDEX O5 FRANCE
Christophe Cambier:
ORSTOM, Centre de Bondy,
72, route d'Aulnay 93143
BONDY CEDEX O5 FRANCE

Abstract

This paper presents a general model of multi-agent simulation which is based on the definition of computational agents that represent individual organisms (or groups of organisms) in a one to one correspondance. Two examples are proposed as an illustration of the multiple domains in which multi-agent simulation may be used. The first is about the simulation of an ant colony and the second simulates the life of populations of fishers along the banks of the river Niger. Computational tools with which they have been implemented are described.

4.1 Introduction

Understanding the process of evolution in population is important in the study of ecological and sociological systems. Simulation is both a design tool and an analytic device which is used to experiment on a model. We are interested in the simulation of the evolution of complex systems where interactions between several individuals which are performed at the "micro" level, is responsible of measurable general situations observed at the "macro" level. When the situation is too complex to be studied analytically it is important to be able to be able to recreate an artificial universe where experiments can be done in a reduced and simulated laboratory where all parameters can be controlled precisely. In this paper we describe a general model of simulation of complex society which is based on the simulation of the behavior of its individuals. We presents examples of applications of this model in two

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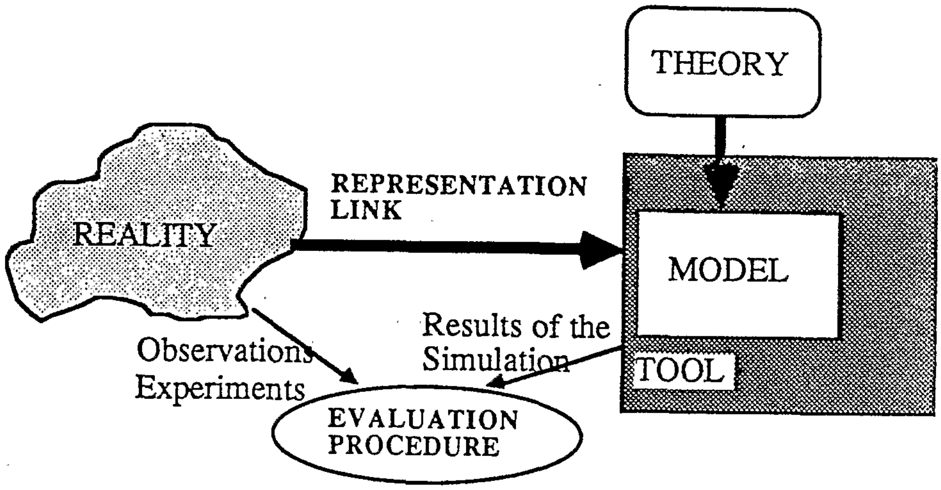

Figure 4.1: The simulation process

domains. The first is part of the Laforia's MANTA (Modeling an ANThill Activity) Project, managed in common with the Laboratory of Ethology of Paris XIII University. Its aim is to model a whole society of primitive ants and to study the emergence of a division of labour within it. The second is part of the ORSTOM's "Niger Central Delta Project" and simulates the life of populations of fishers along the banks of the river Niger.

4.2 Simulation

Simulation consists in artificially reproducing natural phenomena and can be described by the following quintuplet:

<system, model, representation link, tool, evaluation procedure>

where **system** is the natural system to be studied, **model** is an abstract definition of the system according to a theory, **representation link** is an abstract function which maps individuals and/or properties of individuals to elements of the model, tool is a computational device (usually a computer), and **evaluation procedure** a methodology for evaluatings the results and comparing them to the real system. Figure 4.1 illustrates the simulation process.

Traditional techniques of simulation are based on mathematical or stochastic models, usually differential equations which relates various parameters and describe the systems' dynamics. They examine the cause-and-effect relationships during the simulation by relating output variables to input ones. For instance, ecological simulations can relate the population size of a specific species to the growth of different species and the number of predations. The following simple differential equations shows the well known formulas defined by Lotka and Volterra (Volterra 1926) which express the rate of growth of predator and prey populations:

$$dN_1/dt = r_1 N_1 - P N_1 N_2$$

$$dN_2/dt = aPN_1N_2 - d_2N_2$$

where P is the coefficient of predation, N_1 and N_2 are the prey and predator populations, a represents the efficiency with which predators converts food into offspring, r_1 is the birth rate of preys and d_2 is the death rate of predators.

Input and output parameters are defined at the same level, i.e. they do not relate global parameters to local ones. For instance, from differential equations, it is not possible to relate a global parameter such as the population size to local parameters such as the decision processes of the individuals. Individual behaviors, i.e. decisions made at the individual or group level, cannot be incorporated into these simulations.

There are other difficulties with numerical modeling. The most important comes from the fact that numerical modeling do not represent actions, i.e. activities which results in a modification of the world. Actions are only seen by their achievement, in terms of their probability to happen.

For instance in numerical modeling, a feeding and hunting process can be described by an equation which relates the number of preys to the probability for a predator to find a prey, and the number of predators. This kind of equations do not show the different kind of strategies by which a predator can find and hunt a prey. Its does not describe the behavior of the predator but only relations between the number of predators and number of preys in a delimited area.

Lastly, numerical simulations cannot cope with qualitative data such as the relation between a stimulus and the behavior of an individual. These relations, which are typical of ethological models, are beyond the scope of analytical equations and numerical simulations. They require new computing models and tools that can capture the local interactions from which a global behavior of the population emerges.

4.3 Multi-agent simulation

The life of an individual can be characterized by its behavior, where the term behavior means the set of actions an agent perform in response to its environmental conditions, its internal states and its drives.

The multi-agent simulation model is based on the idea that programs do exhibit behaviors that can be entirely described by their internal mechanisms, the program instructions. By relating an individual to a program, it is possible to simulate an artificial world populated of interacting processes. This is what is called multi-agent systems in the field of computing sciences. Simulation can be achieved by transposing the population of a real biosystem to its artificial counterpart. Each individual organism of the population is separately represented as a computing process, an agent. The behavior of an agent during all its stages of life (e.g. birth, feeding, mating, reproduction and death) is programmed with all the desired details.

Multi-agent simulations are primarily used to represent complex situations in which individuals have complex and different behaviors, and to analyse the global situations as emergent structures of the processes interactions. The purpose of such simulations is to take into account both quantitative (e.g. numerical parameters) and qualitative (e.g. individual behaviors) properties of a system in the model, as opposed to traditional simulation in which the representation link only relates properties to quantitative parameters. Multi-agent simulation is also called *microanalytic* simulation meaning that each individuals behavior and environmental conditions are effectively represented (Collins and Jefferson 1991).

Such simulations are based on the construction of microworlds where particular hypotheses can be explored, by controlling and repeating experiments in the similar way as real experiments are performed in a real laboratory.

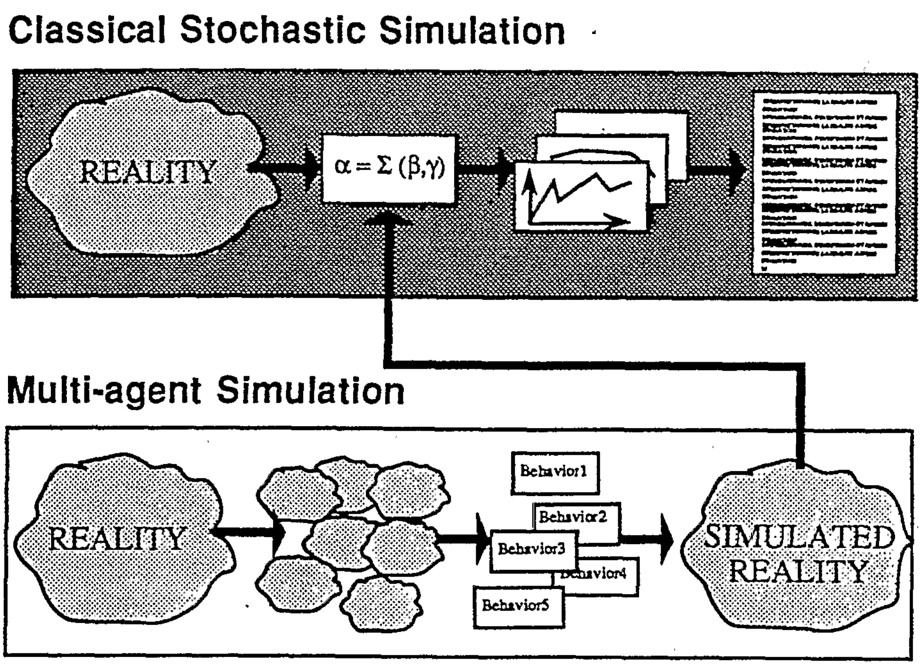

Figure 4.2: Multi-Agent Simulation vs. Stochastic Simulation

In a multi-agent simulation, each biological and sociological individual (or a group of individual) is analogically represented as a computational agent, i.e. an autonomous computational process capable of performing local actions in response to various stimuli and/or communications with other agents. Therefore, there is a one to one correspondance between individuals (or groups) and agents.

In a multi-agent simulation, the model is not a set of equations as in mathematical models, but a set of entities which can be described by the quadruplet:

<agents, objects, environment, communications>

where **agents** is the set of all the simulated individuals, **objects** the set of all represented passive entities that do not react to stimuli (e.g. furniture, etc...), **environment** is the topological space where agents and objects are located, where they can move and act upon, and where signals (e.g. sounds, smells, etc...) propagate, **communications** the set of all communications categories, such as voice, written materials, media, scent, signs, etc...

Agents are defined by their ability to perceive specific kind of communications, by their skills, i.e. their ability in performing various actions, their deliberation model if any, and their control structures, i.e. their ability to relate perception to action.

Multi-agents and mathematical models are not contradictory, but they are intended to be used at different levels. Multi-agent models are used at a local level as analogical mappings of a real system. From this description, one can derive global parameters which can be studied and be incorporated into a mathematical model, as suggested by the Figure 4.2, which illustrates the differences between the two approaches.

In multi-agent simulations, numerical data and statistics are not eliminated, but they are used as as evaluation procedures to compare the results coming from the simulation tool to the observation data coming from the "real" world. Thus mathematical models are used at the macro-level whereas multi-agent simulation models are used to cross the micro- macro bridge by letting global configuration emerge from the local agent interactions.

4.4 Examples

As to illustrate the wide range of domains in which multi-agents simulation can be used, we present in the next sections two examples taken from two different projects in progress. The first is strongly oriented towards ethology, while the second results from a multidisciplinary research managed in common by ecologists, economists, demographers, anthropologists and biologists. The first models a small population of individuals that do not really make any decision and rather react according to their local environment. The second involves lots of different agents with some of them being able of complex cognitive processes. But, in both cases, the whole simulation relies on the same basic concepts, namely those that have been described in the previous section.

4.4.1 The MANTA Project

The purpose of this project, whose name stands for "Modelling an ANThill Activity", is to study the emergence of a division of labour within a society of primitive ants. It has been developped as an application of the EthoModelling Framework, a multi-agent modelling system whose features are briefly described in the next section. More details about its implementation and its use in the *artificial life* area can be found in (Drogoul and al. 1991).

The EMF Model

EMF provides the user with a domain-independent kernel that allows him to easily design simulations including different species of individuals and an environment. In this model, the species are called *classes*, the individuals *agents*. *Classes* are defined by inheritance of the kernel class *EthoAgent* and define the default behaviors and knowledge of their *agents*. The creation process of an *agent* from its *class* is called *instanciation*. *EthoAgent* rules the default internal functioning of the agents and the interactions between them and their environment. As each class represents a particular species of agents (with its own features), and each instance an individual in this species, it is possible to define:

- New species of agents by creating new classes that inherit from *EthoAgent*.
- Sub-species by inheritance, modification of the behaviors or addition of new ones.
- An individual differentiation among the agents by allowing a specific *instanciation*.

Environment and Communication

The environment is defined as a large set of entities that are called *places*. The *places* are squares of the same size. *Places* are divided into two categories: free *places* and *obstacles*. The main difference between them is that *obstacles* cannot accept *agents* and do not propagate *stimuli*.

The *agents* communicate by propagating their signature(s) in the environment. *EthoAgent* provides each agent with *personal stimuli*, a set of "pheromone- like" signals identifying it. When an agent changes its state in the environment, the *place* on which it lies collects these *stimuli* and propagates them to the adjacent places. A *stimulus* is a doublet <*name*,*strength*> where *name* is its identifier and *strength* the value which will be propagated by the place.

Agents Structure

The knowledge of an agent are reduced to a set of places among which it can collect stimuli. Coding the behaviors triggered by these stimuli requires two different kinds of features:

- The *primitives*, low-level behaviors mainly related to physiological possibilities. We assume that they cannot be decomposed into behaviors of lower level. Agents of the same species share the same *primitives*. The *primitives* are not related to any *stimulus* and then cannot be directly used by the agent. They have to be encapsulated in *tasks*.

- The *tasks*, high-level behaviors that coordinate the call of some primitives in response to a *stimulus*. Agents of the same species do not necessarily own the same *tasks*. From an ethological point of view, *tasks* are close to *fixed-action patterns*. Each task is defined by a name—which identifies both the task itself and the name of the *stimulus* that could trigger it, a weight—which specifies its relative importance inside the agent, a threshold and an activity level—when it becomes active.

When a task calls a *primitive*, the agent performs the *task selection process*, in order to determine if another task is not more appropriated to its environment than the current one. This process is made up of three steps:

1. **Sensing**: the agent collects the *stimuli* in its *environment* and eliminates those that do not match with a task name.

2. **Selection**: the agent computes the *activation level* of each task by multiplying the *strength* of the stimulus and the *weight* of the related task. The tasks whose *activation level* surpasses their *threshold* and the *activity level* of the *current task* are selected to be potentially activatable tasks.

3. **Activation**: If some tasks can be activated, the agent chooses the one whose *activation level* is the greatest. Then it deactivates the *current task* and activates the selected one. When no tasks have been selected, the *current task* simply goes on (its *activity level*being decremented by the agent).

Because "real" creatures exhibit flexible mechanisms of behavior selection and can take former experiences of interactions with their environment into account when choosing their future behavior, *EthoAgent* has been provided with a simple mechanism of *behavior reinforcement*and a partial *motivation-oriented behavior selection.*

Behavior reinforcement is defined by the sentence: "*The more an agent performs a task, the more it will be able to perform it again*". The *reinforcement process* takes place just after the *current task* has been deselected and increases its *weight* relatively to its duration.

The *threshold* associated with each task is viewed as an indicator on the motivation to do it. A low *threshold* allows any *stimulus* to trigger the task, when a high one inhibits its selection. We assume that: "*The motivation to do a task decreases when this task is being performed and otherwise increases*". Expressed in our agents, it results in incrementing the *threshold* of the *current task* when it is deselected and decrementing the *thresholds*of all potentially activable tasks each time a task is selected.

The MANTA (Model of an ANThill Activity) Application

The species modeled in the MANTA project, *Ectatomma ruidum*, has a geographical distribution extending from southern Mexico to northern Brazil. The colonies contain a small number of ants (less than 300). This species is usually monogynous and a clear dimorphism distinguishes the queen from the workers. There are no physiological distinctions between the workers. The social organization of this species has been fully studied in (Corbara and al. 1986; Lachaud and Fresneau 1987; Corbara and al. 1989) from the foundation of a society to its maturity, through:

1. An individual analysis of the behavior of each member of a society.
2. The establishment of an inventory of behavioral acts, combined into behavioral categories.
3. The determination of "functional groups" by comparing and aggregating the behavioral profiles of the ants.

From the point of view of our study, *Ectatomma ruidum* has two major properties:

- All the ants seem able to perform a wide range of tasks - see the readjustments of individual behaviors following an experimental sociotomy in (Lachaud and Fresneau 1987) - but show a *differential reactivity* to *stimuli* depending on their behavioral profile. We hypothesize that it is directly related to a notion close to *behavior reinforcement.*
- The stability of repartition into functional groups - though a variability within these groups has been shown in (Corbara and al. 1989) - among numerous colonies allows the comparison between the social organization obtained in the model and that observed in the reality. Furthermore, as explained in the **Multi-Agent Simulation** section, this comparison is facilitated by the possibility of using the same tools in both cases.

The MANTA Features

The environment of the simulation, depicted in Figure 4.3, reproduces a laboratory nest, with a large place not shown here representing the "outside" in which food can be placed.

MANTA firstly defines some *environmental agents*, that are only used for propagating *environmental informations.* The classes that have been defined are LightAgent and HumidityAgent, which propagate *stimuli* named #light and #humidity.

The ants involved in the model are instances of two classes: *EctatommaAnt* and *EctatommaQueen* (which inherits from *EctatommaAnt*). An instance of these classes can respond to five stimuli - #egg, #larva, #cocoon, #food, #ant. The *weights* and *thresholds* of the related *tasks* are arbitrarly fixed (but can be easily modified).

These tasks can manage eight primitives. For instance, *doEgg*, called when an ant senses some eggs, makes the agent follow the maximum gradient path in order to find the source of the stimulus #egg (*positiveTaxis*), then carry the agent that propagates this stimulus (*carryAgent*). If there is one, the ant searches for a place containing other eggs, less humid than its place (*positiveTaxis* and *negativeTaxis*). When it finds one, it simply drops the carried agent (*dropAgent*). If the ant cannot carry the propagator of the *stimulus* (it has disappeared or there is noise), it stops its *current task.* The complementary method, *stopEgg*, calls the primitive *dropAgent.*

Three classes of brood agents have also been created: *EctatommaEgg*, *EctatommaLarva*, *EctatommaCocoon.* Each of them defines a particular *stimulus* -#egg, #larva, #cocoon. At

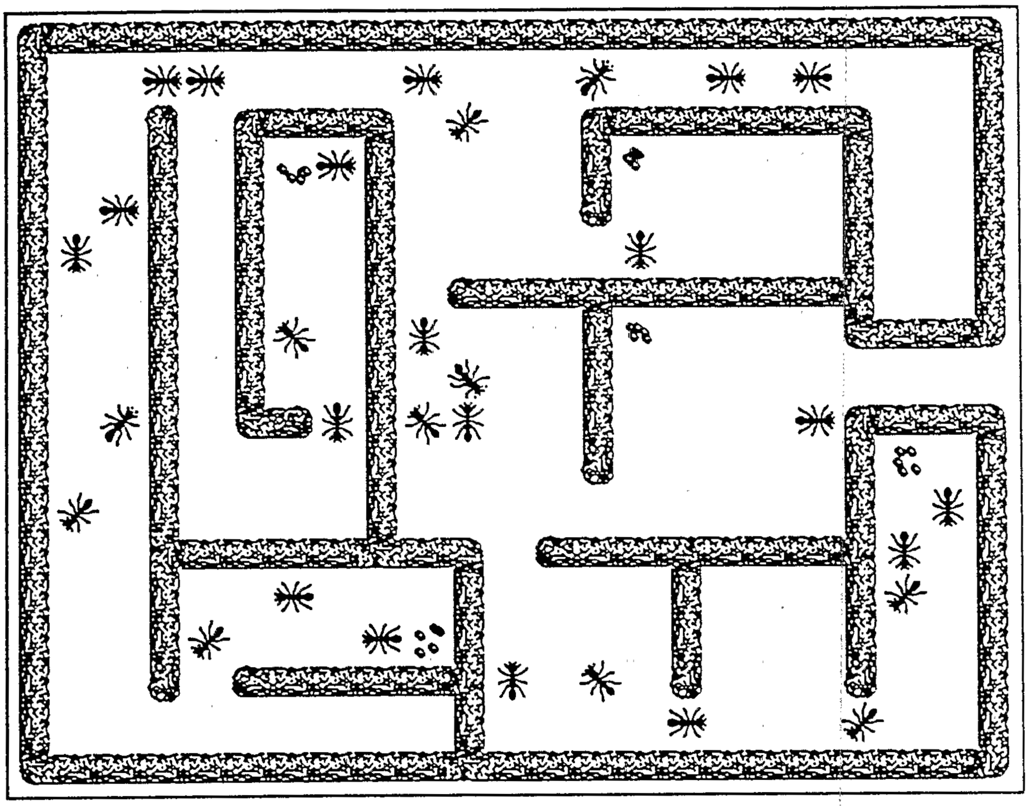

Figure 4.3: The artificial ant nest

this time, their instances are simply provided with the default behavioral method *doNothing* which increases the *strength* of their *stimulus* and calls the primitive *repropagateStimulus*. This primitive automatically lowers the *stimulus* to zero when the agent is being carried by an ant.

An Example of Experimentation

As a simple example, we are going to study some ants provided with three tasks (#egg, #larva, #food). These tasks are similar to *doEgg*, described in the previous section. The case study is composed of 30 identical ants (the initial weights and thresholds of their tasks are the same), 50 larvae, 50 eggs and 50 pieces of food randomly disseminated in the nest. The amounts of time spent on each task by each ant are cumulated throughout the simulation. The simulation ends when the eggs, larvae and pieces of food are totally sorted into three separate clusters.

Although this example does not intend to simulate a real nest, because the ants are not provided with all their behaviors, two lessons can be drawn from it:

1. The average repartition of the global working time between the three tasks equals the initial repartition between eggs, larvae and pieces of food (33been verified in other examples (Drogoul and al. 1991).

2. A division of labour appears within the nest, characterized by five functional groups (see Figure 4.4, which details the obtained sociogram of the population):

   - **Eggs nurses** (Group 1, 8 ants): distinguished by a high level of care of eggs and a low level of inactivity.
   - **Unspecialized** (Group 2, 8 ants): distinguished by a high level of inactivity. The ants nevertheless contribute to the other activities in the nest.
   - **Feeders** (Group 3, 7 ants): distinguished by a high level of feeding activities. The members of this group also show an important level of inactivity.
   - **Larvae-Inactive** (Group 4, 3 ants): distinguished by a high level of care of larvae, a high level of inactivity and a very low level of care of the eggs.
   - **Larvae nurses** (Group 5, 4 ants): distinguished by a high level of care of larvae and a low level in the other activities.

This division of labour appears to be more simple than those observed in the reality. As said above, the reason is that we provided the ants with a relatively small set of behavioral capacities. However, this structuration appears to be very stable throughout the many simulations we have made, which confirms in a way the validity of our approach. So we can reasonably hope to model anthills much closer to reality in the near future.

4.4.2 The Central Delta of Niger

The agents involved in the previous example have been implemented by simply following the behaviours rules observed and described by ethologists. But, sometimes, it appears that a situation cannot be described using a sole point of view. The next example shows how a multi-agent system can be used to model a complex reality, namely the evolution and adaptation of populations of fishermen along the banks of the Central Delta of river Niger. The originality of this simulation is that both classical and multi-agent models cohabit within it, thus allowing to compare their respective performances. This example constitutes

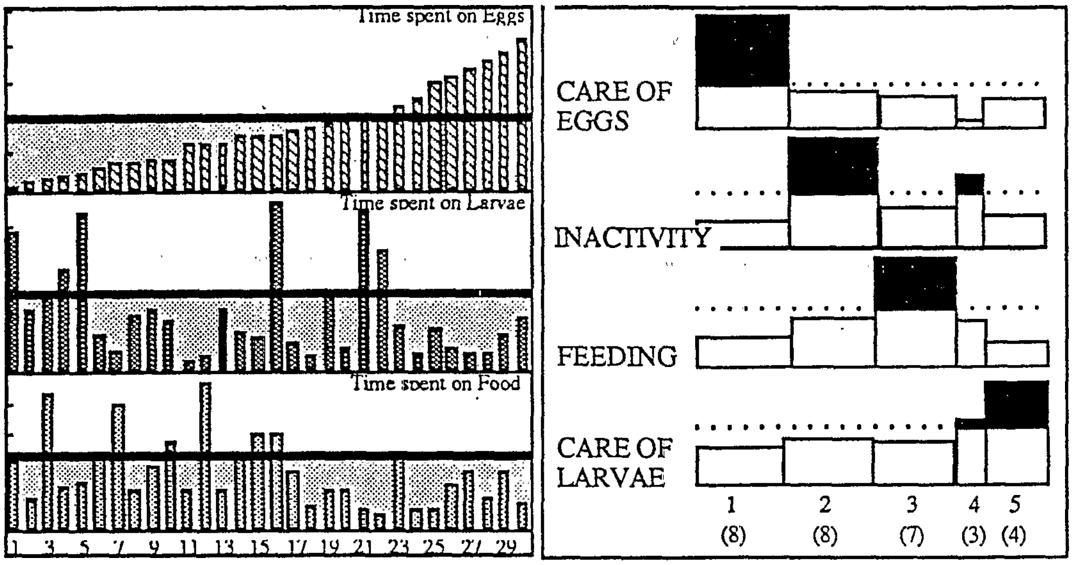

Figure 4.4: The division of labour of a simulated population

a short summary of the communication of (Bousquet and al. 1992), in which a more detailed presentation of the whole system can be found.

The Case Study

The central delta of Niger situated in Mali covers several thousands of square kilometres in the Sahelian zone. The river whose water level varies considerably in the course of the year flows into a very flat zone. At the flood period, water is rising in the flooded plains, the channels ; at the recession period, ponds remain until the nearly complete drying. This hydrological situation gives rise to a highly productive ecosystem for the fish populations which ascend streams to reproduce in the easily flooded plains during the flood and descend from streams during the recession. This zone which yields nearly 100 000 t of fish/year has been severely affected by various phenomena such as the great Sahelian drought which led to the decrease of fish catches. A multidisciplinary ORSTOM and IER (Institute of Rural Economy, Mali) research team tries to identify the causes of this crisis. This team includes demographers, anthropologists, micro and macro- economists, biologists, fishing biologists and ecologists. The basic aim of the model presented is to simulate different households of fishermen that are subjected to a fluctuating hydrological and ecological environment, while taking all the theories, points of view and models involved by such a multidisciplinarity inot account.

The simulator is divided into two great models : the ecological dynamics and the fishing dynamics. We give a simple description of the ecological dynamics and we will lay more emphasis on the simulation of the activities carried out by the fishermen's groups.

Hydro-ecological modelling

In the delta, four great types of different biotopes can be distinguished : the river which is supplied with water all the year round, channels or arms which are supplied with water at the time of the flood and flooded plains which are supplied with water at the top of the flood. During the recession period, plains and channels are no longer supplied with water and there are ponds which dry up little by little. These four great types of biotopes to which we will add the fields for agriculture represent the area common to fish and fishermen, the sites where they interact. We simulated the dynamics of fish populations within this area composed of biotope objects by defining agents of fish groups which reproduce, grow bigger, die, migrate and enter into competition through biotopes as related to their hydrological evolution. This dynamical simulation by representing the variability linked to resource is used as a basis for the simulation on the fishermen's decisions and at the same time as a basis of comparison for the different strategies of production which will be tested. We will observe how these different activities change the characteristics of the fish populations (evolution of the biomass, weight and age structure etc.).

Modelling of the fishermen's decision making

Households are considered as agents that are provided with different attributes which correspond to their ethnic group, to the numbers of individuals they contain, etc. The simulator allows to create fishermen's populations according to the distributions observed in the field. Once these households have been entered into the simulation, they make decisions about their activities and act accordingly. The decision making model we have formalized is divided into four phases: **building up – perception – decision(selection) – action.**

- The **building** phase is used to record all the activities likely to be carried out in the present environmental conditions. According to the works conducted by the different researchers of the team, the whole possible fishing activities are composed of the whole biotope-equipment couples (pond-cast net, river-cast net, river-gill net, etc.) that are also called "technotopes". Each fisherman defines for each of the possible activities an object called agenda on which he will store information in the course of the following phase, namely the perception phase. Therefore, there are as many agenda objects as there are possible activities.

- The **perception phase** consists in getting information on each of the potential activities. The environmental conditions of the fisherman are interpreted by the different researchers who give information which are stored on the agenda objects. This information must be transcribed into a common syntax in order to be compared. We selected two types of representations in order to translate the information which result from the fisherman's environment through the researcher's knowledge. The first transcription is quantitative and the second one is qualitative.

- Quantitatively speaking, the **decision-making** of the fisherman is the result of a "financial" transcription of the information into profit or cost. For instance, consider the following statement: *Given x Household Given y Flood If y height = high Then x fishing River : 1000*, which provides the household with the information that it is going to be rewarded if it goes fishing in the river when the height of the flood is high. The decision-making is also influenced by the former experiences of the individual (for example, a fisherman knows that a fish catch will be included into a distribution of all its previous caught in this site with this equipment and can interpret this distribution using different attitudes: risky, thinking that catches will be maximum, discreet, thinking they will be minimum and moderate).

  But, among the knowledge provided by the researchers of the team, some informations cannot be transcribed using quantitative parameters. Therefore, we also foresaw a more qualitative representation derived from the poll theory. The X information shows that the Y activity is favourable, unfavourable, impossible, compulsory. The **decision** consists in making a choice among the various possibilities offered. For this purpose, different models are available. Some of them impose the decision without any other choice. Others, like that of the economical decision, allow the comparison of all the potential activities. Again, several processes are possible : selection of the most profitable activity, selection of the activity which got the most favourable opinions, the least unfavourable opinions, etc.

- After having determined its activity, the household **acts** on its environment by going to fish. In relation to this activity, it selects an equipment and goes to a site, the biotope. There, his fish capture depends on the amount of fish observed in the biotope, which can be characterized by a certain variability. The fisherman does not catch exactly the same amount of fish in the same biotope with the same equipment. He stores this fishing and adds it to his experience. The belief attribute records all the fishings practised by the fishermen's household for different sites, equipment and seasons. Thus, he acquires an experience which can be a source of new interrogation on his decision. The construction- perception-decision-action cycle is completed.

Simulations

Our first simulation copes with the evolution of the resource without any catch of fish. An artificial world has been created, composed of four biotopes: river, channel, flooded plain and pond. The hydrological cycle is as follows : at the beginning of the flood, water rises from the river to the channel and from the channel to the easily flooded plain. The three biotopes are connected, which allows fish to migrate from the river to the plain. At the recession period, water withdraws progressively from the plain and the channel and fish gather in the river. The pond is a specific biotope for it is isolated from the others. Schematically, the resulting resource cycle is as follows. At the flood period, fish reproduce, ascend the channels or the plains, find conditions which are very favourable to growth and at the recession period, they descend the river where fish are too numerous. This overcrowding slows down their growth. The dynamical modelling of the resource allows to supply the fishing model with a basis for the fishermen's captures.

In all the following examples, we will present results for 2 years long simulations in which the fishermen's population includes 50 fishermen, 5050whose mean is 7 and standard deviation is 2.Several different models of decision making have then been tested, in order to show the possibilities of the simulator:

- The first simulation was based on a model of economical rationality without considering the fishing variability. Any fisherman who goes to the same site with the same equipment catches the same amount of fishes. At each time, the fisherman's household selects the most profitable activity which will yield the biggest profit. The results show that all the fishermen make the same choice at the same moment. The only period when the fishermen occupy simultaneously several different areas is the low water period for catches are similar in the pond and in the river. Rapid changes in the space occupation are observed : all the fishermen change their activity together at the same moment. Due to this type of result, this model of economical rationality which did not include the variability of the ecological environment and of the human behaviour was dismissed.

- The second simulation included the catch variability. In each biotope, a fishing is selected randomly in a normal law with a mu mean and a sigma standard deviation according to the equipment and the existing amount of fish. Again, a big homogeinity was observed in the results. The fishermen tend to do all the same thing at the same moment. Although the activities begin to diversify and the changes in phase are less immediate than the previous simulation, the conclusions that can be drawn from it are nearly identical.

- The third simulation supplied the previous fishermen's households with different behaviours towards the risk. We simulated a population including : 1/3 of the households which select an activity by averaging their experiences, 1/3 of the households which select an activity by taking the risk to consider their highest achievement in the course of the two previous weeks, 1/3 of the households which select an activity by considering their lowest achievement in the course of the two previous weeks. A even more important diversity is then observed in the space occupation. Fishermen select different activities and the changes in the space occupation are more spread over time. Therefore, the simulation shows, in our theoretical world, that different behaviours towards the risk may change the model of space occupation.

In the previous simulations, the households were involved into an environment which is only ecological. The interactions between households were very indirect and solely based on the modification of the environment. A lot of other experiences have therefore been conducted in order to determine the importance of social interactions, information sharing, negotiation between households on the societies of fishermen. We will not describe them here for they are fully depicted in (Bousquet and al. 1992).

4.5 Conclusion

In this paper, we have presented a general model of multi-agent simulation and compared its paradigms to those of classical simulation. We have also introduced a generic formalism that allows to describe the multi-agents systems of simulation. This theoretical section has been followed by two examples of such systems. The first is taken from the MANTA project that aims at modelling an entire ant society. We only presented the part of that work related to the simulation of a division of labour genesis. The second is taken from the Central Delta of Niger Project, also presented in the paper of (Bousquet and al. 1992), which aims at modelling the societies of fishermen that live on the banks of the river Niger.

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