Simulating the Sociogenesis Process in Ant Colonies with MANTA

B. Corbara (1,2), A. Drogoul (1), D. Fresneau (1) & S. Lalande (1)

(1) Equipe MIRIAD, LAFORIA, URA CNRS 1095 - Université Paris VI
Boîte 169 - 4, Place Jussieu 75252 Paris Cedex 05, France.
corbara@laforia.ibp.fr, drogoul@laforia.ibp.fr
(2) Laboratoire d'Ethologie Expérimentale et Comparée, URA CNRS 667
Université Paris XIII, Av. J.-B.Clément, 93430 Villetaneuse, France.

Abstract

This paper presents the results of multi-agent simulation experiments concerned with the mechanisms of sociogenesis, *i.e.* the generation of a whole society from a single individual, inside an ant colony. Simulation experiments have been conducted by using a new version of MANTA (Drogoul *et al.*, 1992a : ECAL'91), where ant-agens were provided with a more realistic number of behaviours. Preliminary results, in terms of brood and worker demography, are relevant with data observed on natural colonies.

1. Introduction : MANTA and sociogenesis.

The MANTA project, introduced during ECAL'91 (Drogoul *et al.*, 1992a), is an application of the EthoModelling Framework (EMF) to the simulation of the social organization in ant colonies. EMF is based on the principles of multi-agent simulation (MAS; for a formal definition, see : Drogoul and Ferber, 1992; Ferber and Drogoul, 1992), which means that each individual inside a population is represented by an artificial entity whose behaviour is programmed (informatically speaking) with all the required details (for other works on multi-agent type simulation see : Hogeweg and Hesper, 1985; Collins and Jefferson, 1991; Doran *et al.*, 1992). Multi-agent simulations primarily help to model situations in which individuals have different complex behaviours, and can take both quantitative (i.e. in terms of numerical parameters) and qualitative (in terms of individual behaviours) properties of a system into account. Our aim with MANTA is to test hypotheses about the way social structures emerge as a consequence of the behaviour and interactions of individuals. In other words, we want to evaluate the minimal set of conditions that has to be provided at the micro-level to observe definite structures at the macro-level. Some early simulation experiments conducted with a preliminary version of MANTA and presented elsewhere (Drogoul *et al.*, 1992a, 1992b), showed that it is possible to obtain the emergence of a division of labour within a nest of "simple" ants, i.e. provided with only three tasks. Nevertheless, our goal, at that time, was not to simulate the complexity of the social organization as it is observed in real nests but, above all, to demonstrate the relevance of our approach.

This paper presents the preliminary results of a more ambitious set of simulation experiments concerned with the mechanisms of **sociogenesis** (Wilson, 1985), i.e. the generation of a whole society from a single individual. These experiments have been conducted by using a new version of MANTA, in which the ants are more realistically represented than in the previous one, being provided with a larger set of behaviours. We chose to realize experiments on sociogenesis mainly for four reasons:

(1) The first one is related to the phenomenon of sociogenesis *per se*. Indeed, the first occurrence of emergence at the social level is to be found in the generation of the society itself. It would be a little bit unnatural to study the transformations of the society organization through the impact of population increase, environmental variations (ressource availability, climatic changes...) or experimental manipulations without paying

attention to the early stages of the society, which obviously condition all its subsequent ontogeny.

(2) The second reason is relative to the validation of the model. Such a validation requires the comparison of the data obtained from the observation of natural societies with the corresponding simulated ones. Sociogenesis provides us with at least two possible ways to estimate the validity of the model, for the comparison can be done with two different sets of data : on one hand, demographical data, i.e., the number of each kind of brood and nestmates (or the agents that represent the latter) at each stage of the development of the natural (or artificial) societies; on the other hand, behavioural data, i.e., the individual behavioural profiles of the ants (or the agents that represent them), as well as those of the functional groups they constitute, during the successive periods of the natural (or artificial) societies development. The success of a natural sociogenesis in laboratory conditions can be easily quantified (if we exclude material problems) by looking at the growth of the colony' s demography and it is even more easy in the case of simulated societies. The analysis of behavioural data is more complex and, above all, time-consuming. Results concerning the sociogenesis of natural ant colonies are already available (Corbara, 1991; Corbara *et al.*, 1991). As far as simulated societies are concerned, the analysis of behavioural data is actually in progress and thus, in this paper, we will only present results about demography : actually, it is possible to evaluate the success of an artificial sociogenesis by simply studying the demographical changes of the concerned colony, without paying attention to the artificial ants' behavioural profiles and their subsequent social status.

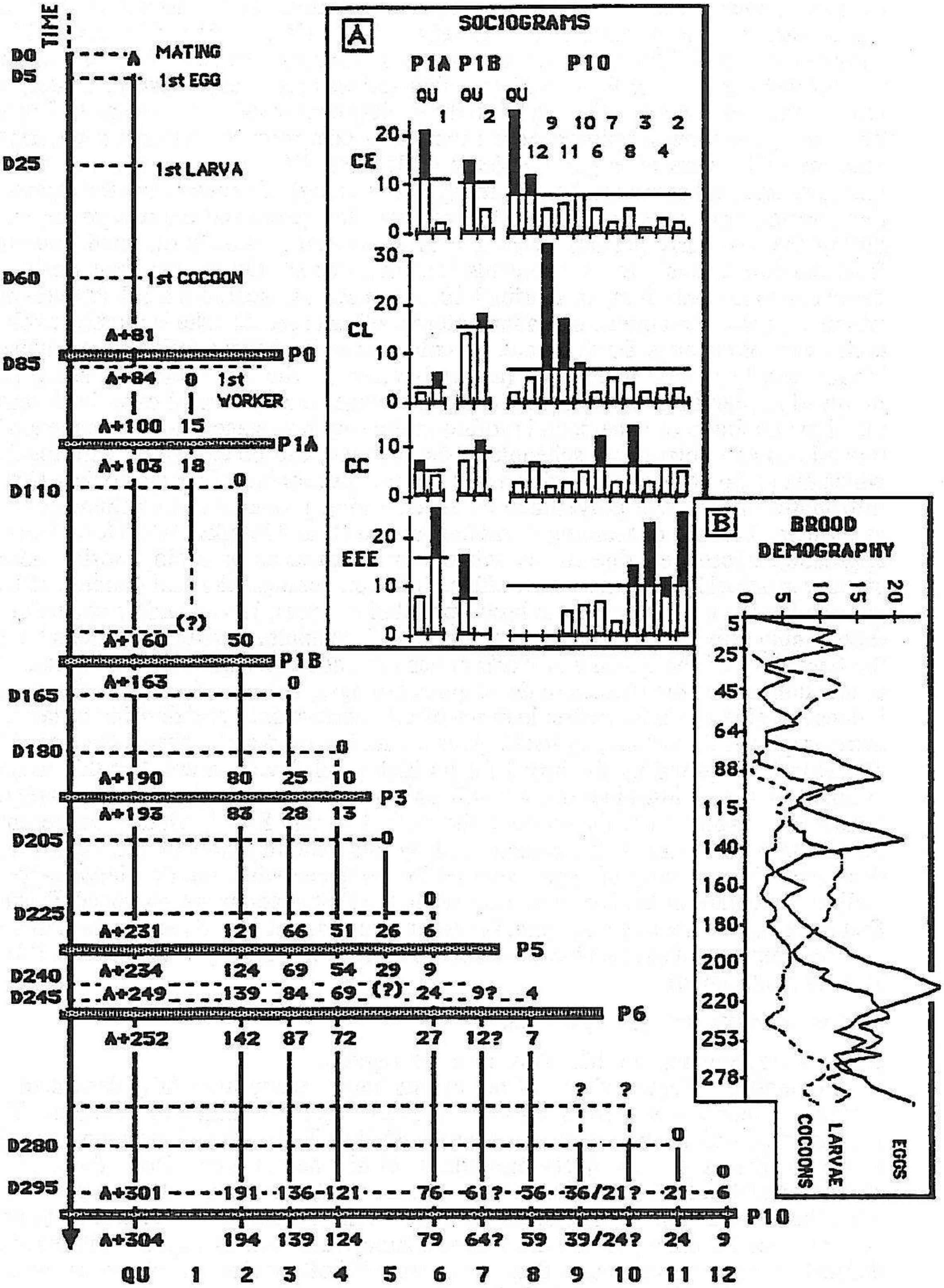
(3) The third reason is that performing an artificial sociogenesis provides us with a totally "artificially built" colony, whose structure has been generated by means of a self-organizing process, and not translated from its natural counterpart. In this way, we hope to reduce to a minimum the bias usually introduced by such a translation.

(4) The last point is that sociogenesis, viewed in a distributed artificial intelligence (DAI) perspective, is a remarkable challenge at the individual level. In our system, the agent simulating the queen, as an agent first intended to behave in coordination with other agents, has to face alone an uncommon situation during the first stages of the society development : it has to reproduce the behaviour of the natural queen that takes care of the whole brood and goes out of the nest to provide food. Consequently, from a micro point of view, we can test the way a single agent, provided with our (multi-agent) model of behaviour, undergoes such a situation. Thereafter, the arrival of the first workers will allow us to check if something is gained at the macro level, in terms of stability, efficiency, etc...

2. Sociogenesis in natural ant societies.

In social Hymenoptera (i.e. : wasps, ants and bees), new colonies are created in two ways : fission and foundation. A well-known case of fission is represented by the honeybee's swarming where the old queen leaves the hive with one half of the workers. In the foundation process, which is directly related to this work, and that can be observed in many species of ants, the newly inseminated queen initiates alone a new society. In *Ectatomma ruidum*, a neotropical ant belonging to the subfamily of the Ponerinae and whose societies are the natural counterparts of MANTA's simulated ones, the foundation is said to be semi-claustral. In such a case, the foundress leaves her nest to provide the food that is necessary for herself and, above all, for the larvae (in a claustral foundation the queen provides food to the larvae by using her own internal reserves derived from the degeneration of her wings'muscles). Furthermore, as we have shown elsewhere (Corbara, 1991), the queen generally continues to forage after the emergence of the very first workers. Insect societies constitute a good example of natural social self-organizing system (Corbara *et al.*, 1988; Theraulaz *et al.*, 1990). During the first steps of the sociogenesis process, the colony generally grows one individual after an other and it is possible to study in detail the progressive modifications of its organization. It is all the more true for *Ectatomma ruidum*. since the demographical increase is slow. In this species, in order to get data on 10 societies reaching the 10 workers' stage, we have been obliged to study the demography of 72 societies : 86 % of the latter died in the process. Figure 1 describes the demographical evolution of one of these societies (named ERF2)

Figure 1. Sociogenesis of colony ERF2.



that succeeded. On this Figure, each ant, identified by means of a number corresponding to its order of emergence (from the cocoon) in the society is represented from left to right on the lower edge. We also give the dates of the arrival of the first egg, the first larva, the first cocoon, as well as the dates of emergence (and eventually death) of every worker. As we have reported above, the demographical growth is very slow : the one worker's stage (ST1) is reached three months after the date of the queen's mating. ST10 is reached 295 days after that former date. All the periods of study lasted for three days and are represented on the Figure by means of horizontal grey stripes. On the same Figure, Frame A shows three examples of sociograms that describe the social organization of ERF2 during three periods : successively, P1A, P1B and P10. P1A and P1B both correspond to ST1. During P1A, the society was composed of two adults, the queen and worker number 1. After P1A, worker 1 died and was replaced, a few days later, by the newly-emerged worker 2. During ST10 the society comprised the queen and 10 workers. The sociograms are simplified ones : they only take four behavioural categories into account : CE (care of eggs), CL (care of larvae), CC (care of cocoons) and EOA (external-oriented activities, i.e., guarding and foraging). To summarize the meanings of these sociograms, note the variable behaviour of the queen and the two young workers during the two early periods. During P1A the queen is mostly oriented towards the "internal duties" and worker 1 towards "external duties". On the contrary, during P1B, the queen is the only forager. During P10, the queen has acquired a behavioural profile which is typical for a queen in mature colonies of that species : she is mostly involved in taking care of the eggs. Furthermore, the colony already shows a well-defined division of labour clearly related to the age (age polyethism) : the older workers being mostly involved in guarding and foraging, and the younger ones in brood care. Both features, the high variability of behavioural profiles in the very first stages, as well as the tendency towards an age polyethism schedule in the last one, can be explained with local rules which are at the basis of the sociogenesis and the functioning of the ant society (for more information about age polyethism as an emerging property see Corbara (1991) for experimental results concerning *E. ruidum,* and Tofts and Franks (1992) for a theoretical approach). Moreover, due to the self-organized process of sociogenesis, there is a circular relationship of causes and effects between demography and division of labour. On one hand, an increase of the brood population (eggs, larvae and/or cocoons) has a determining effect on the behavioural profiles of the adult nestmates. On the other hand, the behaviour of the queen and workers has dramatic consequences on the rate of egg production and on the success of development of eggs, larvae and cocoons. Then, even if it does not give any information in terms of task performance and division of labour, the demography of the colony, by itself, gives the indication that the agents have carried out all the tasks required by the brood for its biological development. For this reason, as announced in the Introduction, we will only present results about demography. The quantitative evolution of the brood in the natural society ERF2, which is represented in the frame B of Figure 1, is characterized by this general tendency : there is a typical decrease in the quantity of eggs produced by the queen when the first larvae appear, as well as a decrease of the larvae number when the first cocoons are produced. During the first stages of the society ontogeny, the older categories of brood seem to be cared for in priority. Comparable results have been obtained with two other young societies (Corbara, 1991 and submitted).

3. Simulation of sociogenesis.

3. 1. A description of MANTA and its agents.

Although the characteristics of our agents have already been fully described in our previous papers, this section provides a brief digest of their key features. EMF is implemented with a language of actors under SMALLTALK-80, where agents are viewed as actor-objects (i.e., objects embodied within actors that allow them to work asynchronously). EMF provides the programmer with a domain-independent kernel that rules the internal functioning of the agents and the interactions between them and the environment. Its main part is a class named EthoBehaviour. The model entities are then defined as instances of classes that inherit from EthoBehaviour. Each class represents a type of agent, each instance an individual in this type.

The environment is defined as a set of squares of the same size, called *places*, which know the agents that are located on them and their neighbouring places. Places can be obstacles; in that case, they cannot accept agents and do not propagate any stimulus. In EMF, agents propagate in the environment some "pheromone-like" signals, called stimuli, that are their own signature. A stimulus is a doublet *<name, strength>*, *name* being the identifier of the stimulus and *strength* the value that is propagated by the place. Stimuli are used as triggers for the behaviours of the other agents.

An agent is seen as consisting of a set of behaviours that we call *tasks* among which only one can be active at a time. The selection and the suspension of a task are entirely stimuli-oriented, which means that its behaviour is seen as a stereotyped response to a stimulus, and that the selection and duration of the response is entirely governed by the intensity of this stimulus. The term task refers to a set of behavioural sequences as opposed to the low-level actions (moving, and so on), that we call *primitives*. Therefore, the whole behaviour of an agent will be defined by a set of tasks, each of them being related to a particular stimulus name and encapsulating a sequence of primitives. Each task must then be provided with:

- a *name*, usually the name of the stimulus that triggers it.
- a *weight*, which specifies the importance of the task for the agent.
- a *threshold*, under which the task will not be triggered by a stimulus.
- a *level of activity* computed when the task becomes active.
- two sequences of *primitives*, respectively executed when the task becomes active and inactive.

An agent always knows the *current task* in which it is involved. When this task executes one of its *primitives*, the agent performs the *task selection process*, to determine if a 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 and eliminates those that do not match with a task.

(2) Selection: the agent computes each activation level by multiplying the strength of the stimulus and the weight of the related task. Tasks the activation level of which surpasses the threshold and the activity level of the current task are selected.

(3) Activation: If some tasks can be activated, the agent chooses the one with the greatest activation level. It then stops the current task and activates the new one. When no tasks can be selected, the current task simply goes on and its activity level is decremented. When a task is selected, it becomes the current task of the agent and its activity level is initialized to the value of its activation level. The agent then performs its *activation behaviour*. When a task is stopped, the agent performs its *deactivation behaviour* and zeroes its activity level.

Agents must be provided with a task called *default*. This task is always viewed as activated, with an activation level equal to 1. It is then chosen when no tasks can be elected and when the activity level of the current task becomes nil. This task specifies the default behaviour of the agent when its environment is not particularly "attractive". Natural creatures, although they are often provided with preprogrammed behaviours, exhibit flexible mechanisms of behaviour selection and can often take former experiences of interaction with their environment into account in their next behaviour. Numerous types of flexibility mechanisms have been studied in animals (Beer and Chiel, 1990); we only have implemented in EMF a simple one : *behaviour reinforcement*. Behaviour reinforcement has been observed in many animal species and particularly well studied in social insects as a mechanism of social organization (Deneubourg *et al.*, 1987; Theraulaz *et al.*, 1991). In our perspective, it may be defined by the sentence: *"The greater number of time an agent performs a task, the better it is able to perform it again"*. The *reinforcement process* takes place after the current task has been deselected and increases its weight proportionally to its duration.

3.2. The agents and their behaviour.

Environmental agent : each environmental agent represents an environmental factor, such as light or humidity, that can be placed anywhere and propagate its particular stimuli. For example, light agents are used to create the difference between the outside and the inside of a nest. Light agents are also intended to simulate the change between day and night (by modifying the strengths of their stimuli). These agents propagate stimuli respectively named #light and #humidity. Another class of agents that can be included in this category is FoodAgent, which intends to model any kind of food that can be either eaten by the ants or by the larvae. Eggs and larvae (see the Brood Agents category) can become food agents. Food agents propagate a stimulus called #food, the strength of which depends on their nutritive value.

Spy agents : spy agents are intended to borrow information from the simulation and translate them into statistical, numerical or textual data. These agents can be added or removed at any time during the progress of a simulation. They can manage special windows displaying text or graphs, save their data on files or perform complex data analysis. Spy agents do not propagate any stimulus.

Brood agents : the brood is composed of the eggs, the larvae and the cocoons which are the three stages leading to adults. If we refer to ethological and biological data (Corbara, 1991), the brood agents will just have to be fed (only in the case of larvae), tended and carried by other agents. The propagated stimuli are respectively named #egg, #larva and #cocoon. Due to their inheritance of classes that implement implicit stimuli (see Drogoul and Ferber, 1992), they also propagate stimuli named #careEgg, #careLarva, #careCocoon, #maturingLarva and #hungryLarva. The strengths of these stimuli are related to some state variables of the agent (foodLevel, careLevel, for example). The #maturingEgg, #maturingLarva and #maturingCocoon stimuli, the strength of which depends on the age of the agent, are used to trigger the tasks that allow an egg, a larva or a cocoon to become respectively a larva, a cocoon or an adult, assuming that it does not miss tending. Otherwise, this task leads EggAgents and LarvaAgents to become FoodAgents, and CocoonAgents to die.

Ant agents and queen agents : these are the most complex agents in the simulation. As a matter of fact, we have provided them with almost all the behavioural categories described in Corbara (1991) and depicted in Table 1. The stimuli that could be present in the environment are shown in the left-hand column, while the tasks directly related to them are in the right-hand one. The stimuli that are only considered as internal and not propagated in the environment are italicized. They can just trigger the tasks of the emitter.

The ant (= worker) and queen agents are provided with a lot of primitives (almost twenty), including all the moving, feeding, caring and sensing primitives. The two classes AntAgent and QueenAgent share the same basic properties (QueenAgent being a subclass of AntAgent), but queens can lay eggs. In the model, it simply results in providing queens with a new task, called layEggs, which consists in creating and putting down an instance of EggAgent. Its trigger is an internal stimulus only possessed by the queen, the strength of which depends on the time (according to biological data, a Ponerine queen can lay between two and three eggs a day, which roughly means one egg every ten hours on the average).

Before presenting the experimental results obtained with these agents, we would like to give some explanations about the way tasks are conceived. Although there are no strict rules for building the sequences of primitives that make up a task, most of them follow these guidelines: (1) Be as short as possible. Otherwise, try to split the task into two smaller ones. For instance, tasks in MANTA never surpass four primitives. (2) Try to implement a "consumption" behaviour. That is, a behaviour that eventually lowers the stimulus that triggers the task. For example, feeding the larvae when they are hungry reduces the intensity of the hungryLarvae stimulus. (3) Avoid conditional primitives as much as possible, that is, primitives that test a condition, unless it is absolutely necessary. The behaviour selection process should be a sufficient filter, and the strengths of the stimuli can be computed using a combination of state variables. For example, the layEggs task does not test if it is time for the queen to lay eggs. It just assumes that its selection has taken the time parameter into account. In that way, a typical task (for instance the carryLarva task) can be formulated with only three primitives : follow the gradient emitted by the larva, pick up the larva that needs to be carried, follow the gradient emitted by other larvae if there is one, put down the carried larva. Using the

Stimulus	Propagated By	Related Task
careAnt	AntAgent, QueenAgent	Take Care of Ants
careEgg	EggAgent	Take Care of Eggs
careLarva	LarvaAgent	Take Care of Larvae
maturingLarva	LarvaAgent	Take Care of Larvae
careCocoon	CocoonAgent	Take Care of Cocoons
maturingCocoon	CocoonAgent	Take Care of Cocoons
hungryAnt	AntAgent, QueenAgent	Feed Ant
hungryLarva	LarvaAgent	Feed Larva
maturingAnt	AntAgent, QueenAgent	Die
ant	AntAgent	No Task
egg	EggAgent	Carry and Aggregate Eggs
larva	LarvaAgent	Carry and Aggregate Larvae
cocoon	CocoonAgent	Carry and Aggregate Cocoon
food	FoodAgent	Carry Food
light	LightAgent	Flee Light
humidity	HumidityAgent	No Task

Table 1 - Links between the stimuli and the tasks of the ants

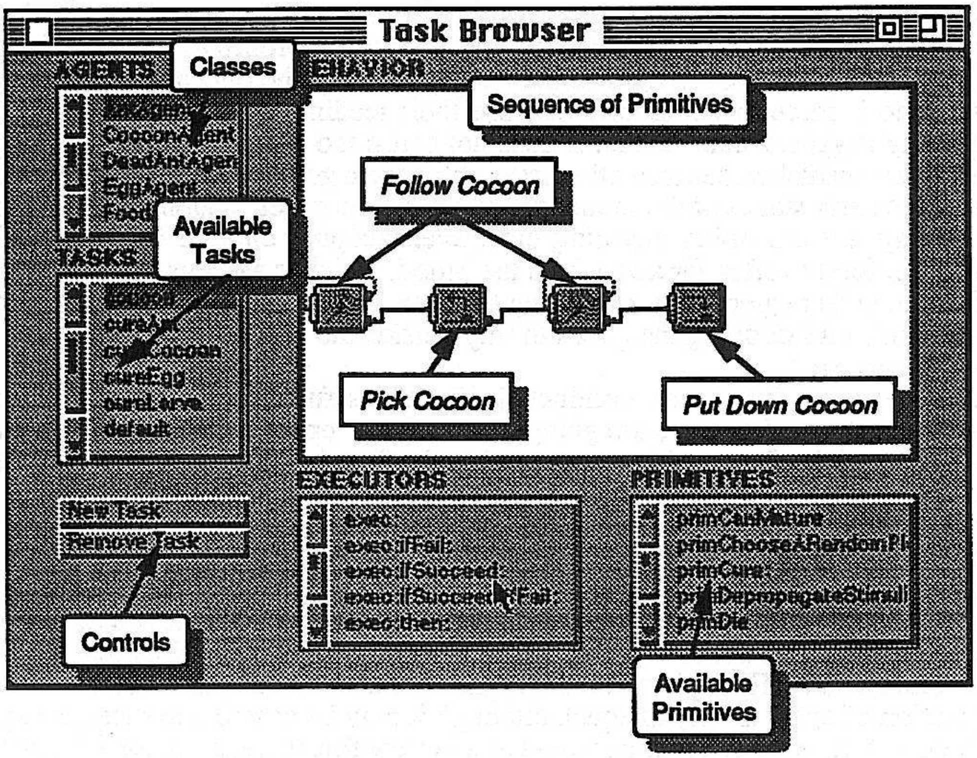


Figure 2 : The task Browser

visual programming tool called Task Browser, we can then write the task very simply (see Figure 2).

3.3. Experiments on artificial sociogenesis with MANTA.

The simulation experiments have been conducted with a model that reproduces the laboratory conditions in which natural sociogeneses have been studied, the shape of the laboratory plaster nest (made of adjoining chambers) being the same as on Figure 3. Some humidity agents are placed on the left-hand wall, and a light agent on a place outside the nest. A variable amount of food, that depends on the number of ants constituting the colony, is provided every day (of the simulation timescale) at the entrance of the nest, as in the case of true ants that were fed *ad libitum*. All the experiments have been tested with the same parameters (tasks' initial weights, biological parameters, etc.), which means that the only source of unpredictability is to be found in the default random walk of the ants. An experiment begins by putting a queen agent, alone in an empty nest and let it evolve. The experiment is stopped whenever one of the two following situations is reached: (1) the queen dies (by starving); (2) more than six workers are born. The first situation signifies the death of the colony and then the failure of the sociogenesis process. The second one has been chosen as a good estimation of the sociogenesis success, with respect to what happens in natural colonies. As a matter of fact, a natural colony that reaches this stage ordinarily keeps on growing, which means that reaching around six workers constitutes the most difficult period in the sociogenesis process. In Table 2 are reported the results in terms of success and failure. Failure cases are clustered in seven categories, which correspond to the composition of the population when the queen dies. In these experiments, the proportion of failures (71%), appears to be close to that observed for natural colonies bred in laboratory conditions (where 86% never reached the 6 workers stage). The situations in which the foundation of the colony is likely to fail can be obviously characterized by the fact that larvae are part of the population. As a matter of fact, cases of failure in the presence of larvae represent 89% of the total number of failures. Why is it so? The simplest explanation that can be provided is that larvae must be cared for, carried and fed whereas the other agents composing the brood just need to be cared for and carried. The presence of larvae then generates, at the population level, a important need in food, propagated by means of the appropriate stimuli. Therefore, the agents that can bring back food to the colony (namely the queen and the workers) will have to do it more often, simply because their feeding behaviour will be much more frequently triggered than before. It does not cause too much problems as long as many workers are available, because other tasks still have a good probability of being executed. But, in the early stages of the foundation in which the queen is alone, it quickly results in preventing it from doing anything else, even keeping enough food to feed herself. Moreover, food is often far away from the brood, which is aggregated near humid places and can then be neglected during a long time, and, more simply, because food can begin to run short, thus obliging the queen to stay outside the nest (or near its entry) until more food is supplied.

However, we have also conducted 19 successful experiments. And, given the constraints stated above, we are going to see which "emergent strategy" is employed by the queen and the first workers to succeed in the foundation of the colony. By "emergent strategy" we mean a global long-term behaviour that *looks like* a strategy from the point of view of the observer, but which has not been coded into the behaviours of the agents. We will first begin by looking at the demographical evolution of a colony called C9, which is depicted in Figure 4, where the number of each type of agent is plotted against the time (in days). C9 provides us with a typical example of the growth of the population in our simulated colonies and can advantageously be compared to that of the natural sociogenesis of ERF2 depicted on the Figure 1. The curve in white, which represents the population of eggs, is very unequal, although it may be possible to detect a regularity in its sudden falls, which occur approximately every fourty days. These falls appear to be synchronized with the peaks of the second curve (in very light gray), which represents the larval population. It is apparent, when looking at the curves, that there is an interplay between the populations of eggs and larvae at the colony level. What is interesting, however, is that this interplay has not been coded in the system. As it could be seen as a

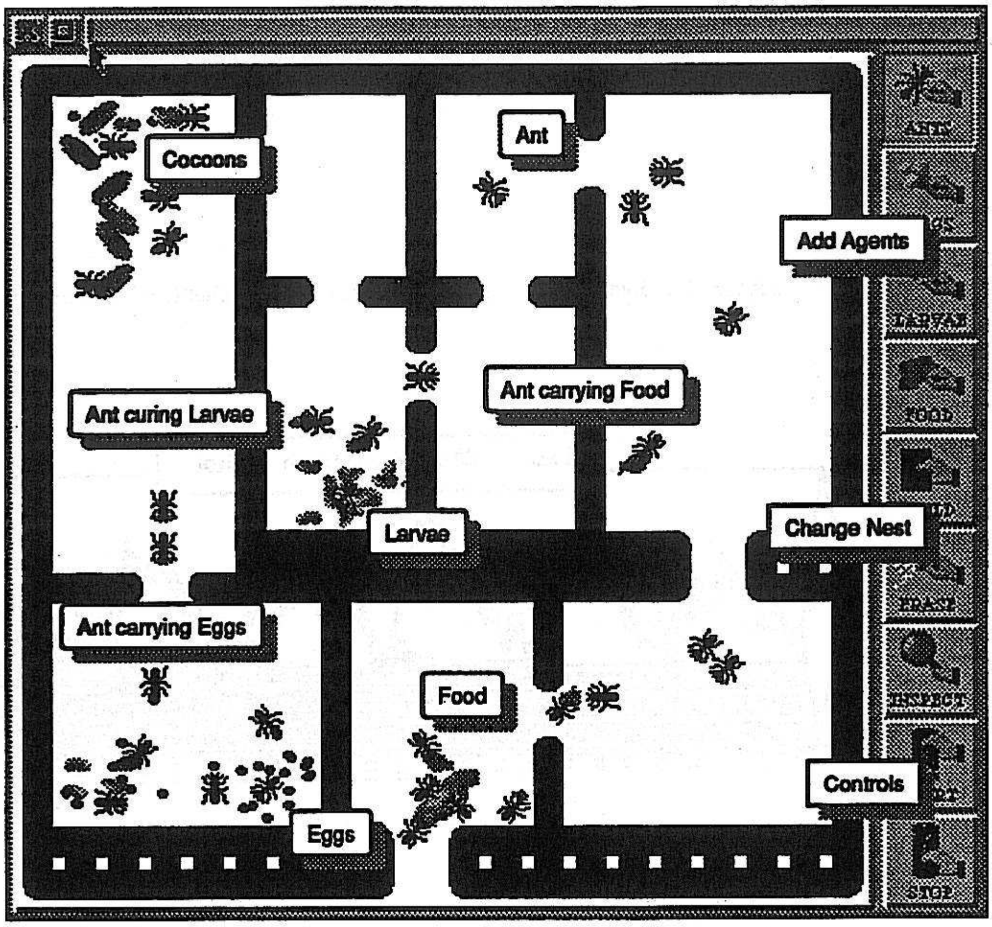


Fig. 3 - The main window of the simulation, reproducing an ant colony in its artificial laboratory nest.

Results	Composition	Number	%
Failures with	Eggs	4	6.15
	Eggs, Larvae	10	15.38
	Larvae	19	29.30
	Eggs, Larvae, Cocoons	3	4.62
	Larvae, Cocoons	7	10.77
	Eggs, Cocoons	1	1.40
	Larvae, Workers	2	3.08
Total Number of Failures		46	70.77
Total Number of Successes		19	29.23
Total Number of Experiments		65	100.00

Table 2 - Successes and failures of the simulated sociogeneses

Figure 4 : Evolution of the demography in the simulated colony C9.

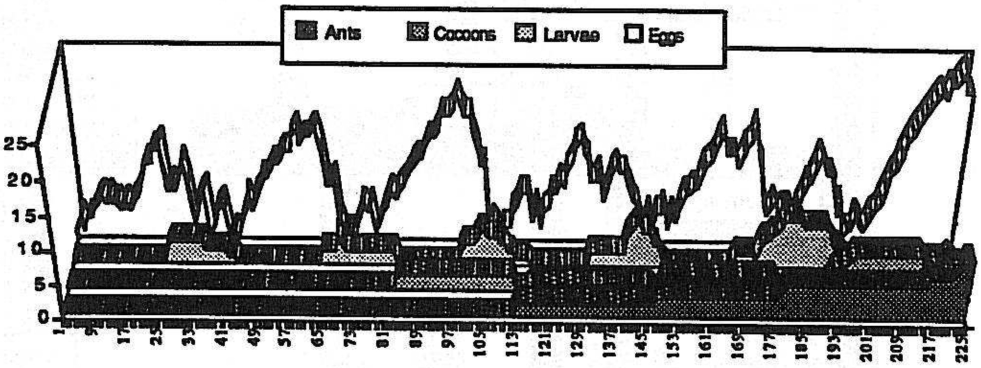
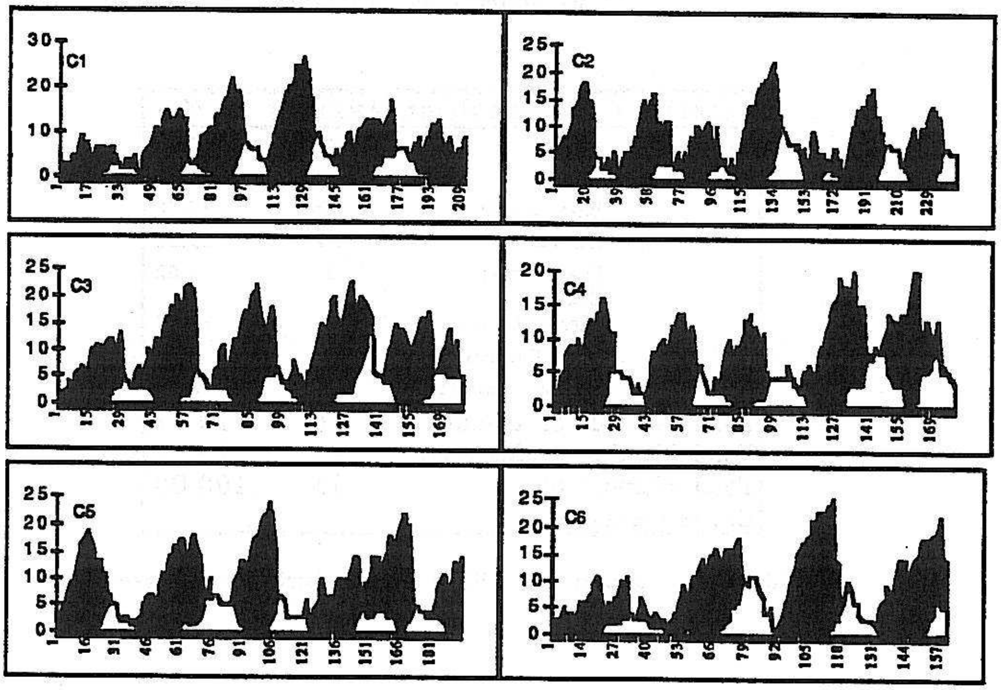


Figure 5 : Evolution of the demography in colonies C1 to C6.



particular side effect of a special initial configuration, we have represented, in the six panels of Figure 5, the same curves obtained with six other colonies (from C1 to C6). All the diagrams of Figure 5 clearly show that we obtain the same kind of population fluctuations, with small variations, in the different cases. These fluctuations appear to be closely related to those observed in real colonies (see Figure 1, Frame B). As we did not put any global data in the simulations, we can obviously assume that these macro-properties are produced by the behaviours and interactions of the agents at the micro-level. And it is interesting to see that only a few rules at the individual level can generate such patterns at the collective level. From a behavioural point of view, the comments that can be made about these curves are close to those already made for the failure cases, except that the queen succeeds in tending, carrying and feeding all the brood agents.

4. Conclusion and perspectives.

Our first results show that the model reproduces an evolution which is largely comparable to the natural colonies' one. In particular, the rate of successes and failures of the sociogeneses are comparable, which was not an expected result. We suspect that our simulated nest, provided with a linear succession of 9 chambers, is certainly responsible for the difficulties encountered by the queen and the very first callow workers (note that *Ectatomma ruidum* is a terricolous-nesting species and that its nests are very often deeply built). It would be interesting to run experimentations with a one-chamber nest, or by providing food directly inside the nest. Nevertheless, in laboratory and field conditions, the same kind of problems occur and in the ideal conditions of the laboratory, where food is provided and predators are absent, failures represent more than 80% of the cases. As far as the demographical data is concerned, results given by the simulated societies are largely comparable to those observed in *Ectatomma ruidum* (as well as in the other Ponerinae *Neoponera apicalis* : Fresneau, pers. comm.) natural ones.

Perspectives.

As we wrote above, our future investigations with MANTA will be concerned with social organization. The main question about our expectations now is: will the model generate a clear division of labour (it is possible to imagine a system in which there is no division of labour, no tendency towards specialisation, but it is interesting to see that, as far as we know, this does not exist in nature) and will the latter be consistent with the age polyethism schedule ? In addition to sociogenesis *per se*, our perspectives with MANTA are mainly twofold. First, we plan to use MANTA as a "colony provider" to conduct, with the simulated colonies, the same kind of experiments and observations that have been realized in the case of natural colonies. They are, for instance :

- sociotomies as in the works of Lachaud and Fresneau (1987) on *Neoponera apicalis* : a sociotomy consists in splitting a colony into two or more sub-colonies made of different functional groups in order to observe how do these subcolonies (if they do) produce again the specialists that are lacking;
- a study of the relationships between social structure and spatial organization in the nest (see Fresneau *et al.*, 1989; Corbara and Fresneau, submitted);
- a study of the social organization in "simulated mixed colonies" on the model of heterospecifical mixed colonies as studied in Corbara and Errard (1991).

Secondly, we plan to use the MANTA model as a basis to study an other aspect of social organization in ant societies : the hierarchical relationships between reproductive females. In this case, the ant agents that will be used will probably be different from the actual agents of MANTA and probably not strictly reactive ones. Apart from the interest of such a simulation in itself, the underlying problem it emphazises will be the (apparently contradictory) relation linking competition and cooperation. This relation being also emphasized in an other field of DAI as promising as the simulation studies : "Eco Problem Solving" (see : Ferber and Jacopin, 1991; Ferber and Drogoul, 1992).

Acknowledgements : We are very grateful to Michel Denis, (IPT-Université Paris XIII) for allowing us to use 15 IBM micro-computers which have been, during a few week-ends, the hosts of our simulated ant colonies.

References :

Beer, R.D. and Chiel, H.J. 1990. The neural basis of behavioral choice in an artificial insect. In : From Animals to Animats. Meyer, J.-A. and Wilson, S. (eds). MIT Press/Bradford Books, Cambridge, 247-254.

Collins, R.J. and Jefferson, D.R. 1991. Ant farm : towards simulated evolution. In : Artificial Life II. C. Langton (ed.), Addison-Wesley, 579-586.

Corbara, B. 1991. L'organisation sociale et sa genèse chez la fourmi *Ectatomma ruidum* Roger (Formicidae, Ponerinae). Thèse de Doctorat de l'Université Paris XIII (PhD Thesis), 125 pp. (Microfiche ANRT/Grenoble : 91/PA13/1007).

Corbara, B. and Errard, C. 1991. The organization of artificial heterospecific ant colonies. The case of *Manica rubida/Formica selysi* (Myrmicinae/Formicinae) associations : mixed colony or parallel colonies ? *Behav. Proc.* **23**, 75-87.

Corbara, B. and Fresneau, D., *submitted*. Spatial organization in the nest in relation with division of labour in two Ponerine ants (Formicidae : Ponerinae).

Corbara, B., Fresneau, D. and Lachaud, J.-P. 1988. La flexibilité de l'emploi chez les fourmis. *La Recherche* **195**, 116-117.

Corbara, B., Fresneau, D., Lachaud, J.-P. and Leclerc, Y. 1991. Evolution de la division du travail dans les jeunes sociétés de *Neoponera apicalis* et d'*Ectatomma ruidum* (Formicidae, Ponerinae). *Actes Coll. Ins. Soc.* **7**, 189-194.

Corbara, B., *submitted* . The ontogeny of division of labour in young colonies of the ant *Ectatomma ruidum* (Formicidae : Ponerinae) : Emergence of age polyethism.

Deneubourg, J.-L., Goss, S., Pasteels, J.M., Fresneau, D. and Lachaud, J.-P. 1987. Self-organization mechanisms in ants societies (II) : Learning in foraging and division of labor. In : From individual to collective behavior in social insects. Pasteels, J.M. and Deneubourg, J.-L. (eds), *Experientia Supp.* **54**, 177-196.

Doran, J., Palmer, M. and Gilbert, N. 1992. The EOS Project : Modelling upper Paleolithic social change. In : Simulating Societies. Gilbert, N. (ed.), Surrey Conferences on Sociological Theory and Method, Guilford (U.K.), 31-47.

Drogoul, A., Corbara, B. and Fresneau, D. 1992a. Applying Ethomodelling to social organization in ants. In : Biology and Evolution of Social Insects. Billen, J.(ed.), Leuven University Press, 375-383.

Drogoul, A. and Ferber, J. 1992. Multi-agent simulation as a tool for modeling societies : application to social differentiation in ant colonies. In : MAAMAW' 92, Castelfranchi, C. and Werner, E. (eds), North-Holland.

Drogoul, A., Ferber, J., Corbara, B. and Fresneau, D. 1992b. A behavioural simulation model for the study of emergent social structures. In : Toward a practice of autonomous systems. Varela, F.J and Bourgine, P. (eds), MIT Press, 161-170.

Ferber, J. and Drogoul, A. 1992. Using reactive multi-agent systems in simulation and problem solving. In : Distributed artificial intelligence : theory and praxis. Avouris N.M. and Gasser L. (eds). ECSC-EEC-EAEC, Brussels and Luxembourg, 53-80.

Ferber, J. and Jacopin, E. 1991. The framework of Eco Problem Solving. In : Decentralized Artificial Intelligence, Vol. II. Demazeau Y. and Müller J.-P. (eds), North Holland.

Fresneau, D., Corbara, B. and Lachaud, J.-P. 1989. Organisation sociale et structuration spatiale autour du couvain chez *Pachycondyla apicalis* (Formicidae, Ponerinae). *Actes Coll. Ins. Soc.* **5**, 83-92.

Hogeweg, P. and Hesper, B. 1985. Socioinformatic processes : MIRROR modelling methodology. *J. Theor. Biol.* **113**, 311-330.

Lachaud, J.-P. and Fresneau, D. 1987. Social regulation in ponerine ants. In : From individual to collective behavior in social insects. Pasteels, J.M. and Deneubourg, J.L. (eds), *Experientia Supp.* **54**, 197-217.

Theraulaz, G., Goss, G., Gervet, J. and Deneubourg, J.-L. 1990. Task differenciation in *Polistes* wasp colonies : a model for self-organizing groups of robots. In : Simulation of adaptive behaviour : from animals to animats. Meyer, J.-A. and Wilson, S.W. (eds), MIT Press/Bradford Books, Cambridge, 346-355.

Tofts, C. and Franks, N.R. 1992. Doing the right thing : ants, honeybees and naked mole-rats. *Trends Ecol. Evol.* **7**, 346-349.

Wilson, E.O., 1985. The sociogenesis of insect societies. *Science* **228**, 1489-1495.