MANTA: New Experimental Results on the Emergence of (Artificial) Ant Societies

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Abstract. The MANTA project is an application of the EthoModelling Framework (EMF) to the modelling and simulation of the social organization in an ant colony. EMF is based on the principles of multi-agent simulation, which means that each organism of the population is represented as an artificial entity whose behavior is programmed with all the required details. Our aim with MANTA is to test hypotheses about the emergence of social structures from the behaviors and interactions of individuals. This paper presents the results of a set of experiments on the mechanisms of sociogenesis. These experiments have been conducted with the latest version of MANTA, in which ants are provided with a large set of behaviors. These experiments on sociogenesis are the simulations of the foundation processes observed in the natural counterpart of MANTA's ants, called *Ectatomma Ruidum*. In laboratory conditions, the evolutions of all the nests are very close one to another and share the same growth patterns. We show that the evolution of the artificial sociogeneses can advantageously be compared to them. We then adress the question of population control with respect to the environmental constraints through a set of experiments where food is restricted. We analyze the regulation processes that occur at different levels of the colony and show how the society adapts itself to the environment. Finally, we approach the question of hierarchy within a nest by testing different hypotheses on its emergence. These hypotheses rely on three sets of experiments that consist in making polygynous sociogeneses (i.e. sociogeneses with several queens simultaneously present in the nest). We analyze the incidence of each of these situations on the mechanism of sociogenesis.

1. Introduction

The MANTA project, already described in Drogoul et al. (1991a, 1991b) and Ferber and Drogoul (1992), 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 (for a formal definition, see Drogoul and Ferber, 1992), which means that each individual inside a population is represented by an artificial entity whose behaviour is programmed (computationally speaking) with all the required details (for other works on multi-agent simulation see : Doran et al., 1992; Hogeweg and Hesper, 1985; Collins and Jefferson, 1991). Multi-agent simulations mainly help to model situations in which individuals have different complex behaviours and where their interactions involve so much non-linearity that they cannot be easily described within a mathmatical framework. Our aim with MANTA is to test hypotheses about the way social structures, such as a division of labour, emerge as a consequence of the behaviour and interactions of individuals. In other words, we want to evaluate the minimal set of causes 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 have been presented in Drogoul et al. (1991a, 1991b). They 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 simulational experiments on the mechanisms of sociogenesis (Wilson, 1985) and division of labour. 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, for being provided with a larger set of behaviours.

2. The MANTA Agents Model of Behaviour

2.1 The Stimulus/Task Model

In Manta, the behaviour of the agents that compose a colony is programmed using the stimulus/task architecture provided by EMF. This architecture assumes that the whole behaviour of an agent can be described by a set of *independent tasks*, each being made out of a sequence of elementary behaviours called *primitives*. The tasks are exclusive and they are triggered by an external or internal stimulation. This stimulation is represented in the model by a variable strength stimulus (which can be internal or provided by the environment), associated with a preexisting motivation, which is expressed by the tasks' agent. With the basic behaviour reinforcement process[1] provided to the simulated ants, it is also used to accumulate the former experiences of the agent in a given task. A high weight will then indicate a specialization of the agent in this task. The weight is used to compute the *activation level* of a task when it is triggered by a stimulus. Its reinforcement is considered as a long-term positive feed-back. The threshold is viewed as an indicator of the “motivation”[2] of the agent to perform a given task. This motivation is continuously increased as long as the task is not activated, and decreased whenever it becomes active. It respectively results in decreasing the threshold of the neglected tasks and increasing the threshold of the current task during the task selection process. These operations are considered as short-term positive and negative feedbacks. Finally, the activity level is viewed as an indicator of the agent’s motivation to continue the task it is performing. This value is initialized with the activation level of the task and then continuously decreased as long as the task remains active. When it reaches zero, the task is stopped. Hence, a task is considered as activable when its threshold is lower than its weight multiplied by the strength of its triggering stimulus (= its activation level). And it is selected when this activation level surpasses the activity level of the current task. The agent then switches from the previous current task to the new one.

2.2 Communication

As it is defined in the kernel of EMF, agents do not really communicate with one another. They just can drop stimuli in the environment, which may trigger the behaviors of other agents - or may not. Dropping a stimulus results in creating a gradient field around the emitter (by diffusing ths stimulus in concentrated circles around it), and can then be assimilated to a chemical, visual or oral propagation of information. Some of these communication are part of the agents’ behavior (they can choose to deliberately propagate a given stimulus to attract or repulse other agents), and some of them are totally independant from their behavior (from instance, we can assume that, whatever its behavior, an agent will always be visible to other agents, be they friends or enemies, if they can see it). The propagation of stimuli is only stopped by obstacles (walls, etc..).

2.3 Implementation

EMF follows an object-oriented approach, although the agents do not use message passing as a mean of communication. Thus, agents are instances of classes that inherit from EthoBehavior or one of its subclasses, which implement the abstract model of behaviour they are going to use. Each of these classes will represent a given species of agents and will provide them with the knowledge they share together: primitives, tasks, stimuli and other domain-dependent pieces of knowledge. These information can be described in the agent’s class, or inherited from higher classes. That’s why the subclasses of EthoBehavior are divided into two sets: *abstract* classes and *concrete* classes. Abstract classes (like EthoBehavior) cannot be instantiated. They are used to define the primitives and knowledge associated with them. Concrete classes, which can have instances, will inherit these primitives and use them to define the tasks (behaviors) of their agents. An example of such a hierarchy is provided on Figure 1, within the MANTA project, where all the classes whose names end with the *-Behavior* suffix are abstract classes.

InterfaceBehavior implements the protocols of the agents' user-interface capacities (graphical trace, inspection, etc.). *LocatedBehavior* provides all its sub-instances with the ability to be in an environment and to act on it (propagating stimuli, for example). *CuringBehavior* implements the primitives needed by agents that will have to cure other agents or receive cares from them. *FeedingBehavior* implements primitives needed by agents that will have to feed themselves, feed another agent or be fed by one. *MaturingBehavior* provides its sub-instances with the capacity of growing old (and consequently, die!) and becoming another agent, if any. The notion of time is implemented in this abstract subclass, as an internal stimulus. The subclasses of these three last classes must define some domain-dependent pieces of knowledge, such as the average expectation of life of their instances, their needs of food and so on. These knowledge will be used to compute implicit stimuli, named after the type of the agent (ant, larva, etc.) prefixed by cure-, hungry- or maturing-, that will always be propagated by these agents *MovingBehavior* gives them the possibility to move in their environment. *SensingBehavior* implements two primitives for following or fleeing a gradient field. *CarryingBehavior* implements the primitives needed for carrying other agents.

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[1] This process is detailed in (Drogoul & al 1991a). It simply consists in incrementing the weight of a task when it has been activated.

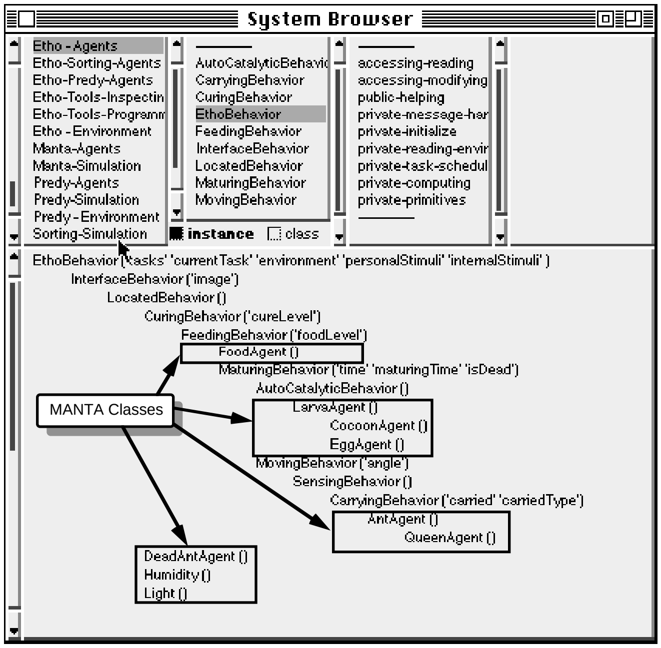


Figure 1 - The hierarchy of classes of the Manta application. The concrete classes are outlined. All the classes inherit from EthoBehavior.

2.4 The MANTA Classes

The concrete subclasses can be divided into three sets. *FoodAgent*, *DeadAntAgent*, *HumidityAgent* and *LightAgent* represent environmental agents, that is, agents that do not perform any other behavior than that of propagating their stimulus (#deadAnt, #food, #light and #humidity). These stimuli can trigger some ants' behaviors (like #food) or be used as guides during others (like #humidity or #light). *EggAgent*, *LarvaAgent* and *CocoonAgent* represent the brood agents, that is, the three stages needed for an egg to become a worker. These agents have to be cured, fed and carried by the ants during their lifetime. These needs are translated in the model by the propagation of some stimuli (inherited from superclasses: #cureEgg, #cureLarva, #cureCocoon, #hungryLarva, #egg, #larva, #cocoon) that will trigger the appropriate tasks within the ants. Finally, *AntAgent* and *QueenAgent* represent the "active" agents of the colony, namely the workers and the queen. These agents are provided with around fifteen tasks, made out of the primitives inherited from their superclasses, that cover all their needs as well as the brood's needs. QueenAgent simply defines a additional task called #layEggs, which actually represents the unique difference between queens and workers in the species we have studied. It is triggered by an internal stimulus whose strength is a periodic function of the time (the task should be triggered every six hours).

Figure 2 - The AntAgents' tasks. On the top-left hand, the icons depicting the primitives. On the bottom-left hand, the drawings representing the simulation's agents. The lines of the main table are to be read this way: ach task is linked to a given stimulus name (column 2), propagated by an emittor (column 1); this stimulus can be

(a type of agent, if there is any) is shown (column 3). Each task then ends by performing one primitive (column 4).

3. Sociogenesis

3.1 Definition and assumptions

In the foundation process (or sociogenesis, a word created by (Wilson, 1985) by analogy with the morphogenesis process) , which is directly related to this work, and that can be observed in many species of ants, the newly-fertilized queen initiates alone a new society. In *Ectatomma ruidum*, a neotropical ant belonging to the phylogenetically primitive sub-family 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' musculature). Furthermore, as we have shown elsewhere (Corbara, 1991), the queen generally continues to forage after the emergence of the very first workers. Sociogenesis is then a remarkable challenge at the queen level. As a matter of fact, the queen has to face alone, during the first stages of the society, a very complex situation, in which it has to take care of the whole brood as well as going and find food. And it is not really surprising to see that, even in laboratory conditions, only 15% of the sociogeneses succeed.

We chose to realize experiments on sociogenesis mainly for three reasons:

(1) The first one is related to the phenomenon of sociogenesis *per se*. Indeed, the first occurence of emergence at the social level is to be found in the generation of the society itself. It would be unnatural to study the transformations of the society organization through the impact of population increase, environmental variations or experimental manipulations without firstly paying attention to the early stages of the society, which obviously condition all its subsequent evolution.

(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 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 the one hand, demographical data, i.e., the number of each kind of brood and nestmates at each stage of the development of the societies; on the other hand, behavioural data, i.e., the individual behavioural profiles of the ants, as well as those of the functional groups they constitute, during the successive periods of the societies development. However, the success of a natural sociogenesis in laboratory conditions can be easily quantified by looking at the evolution of the colony' s demography. The analysis of behavioural data is more complex and, above all, time-consuming. Moreover, very large results concerning the sociogenesis of natural ant colonies and their demographical evolution are already available (Corbara, 1991, Corbara et al., 1991). It is then possible to evaluate the success of an artificial sociogenesis by simply studying the demographical evolution of the concerned colony without paying attention to the artificial ants' behavioural profiles and their subsequent social status. As a matter of example, the demographical evolution of the brood population in a natural colony named ERF2 is shown on Figure 3.

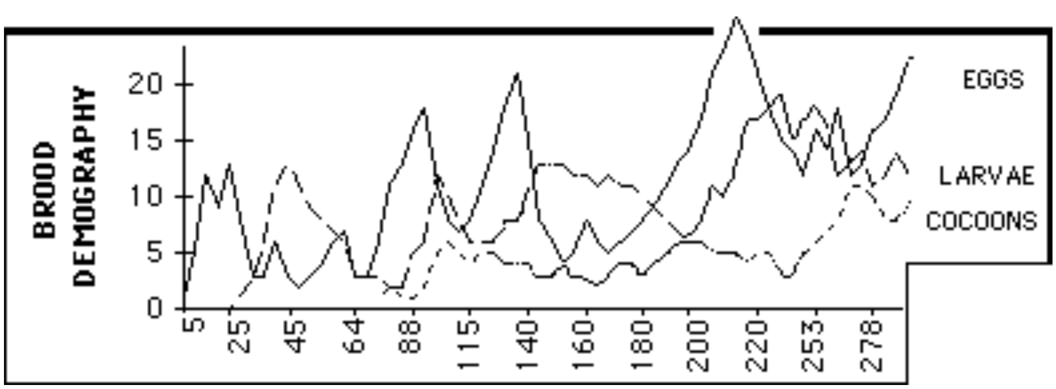


Figure 3 - The evolution of the brood population in a natural colony, characterized by a strong interplay between the eggs and larval population

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

3.2 Artificial Sociogenesis

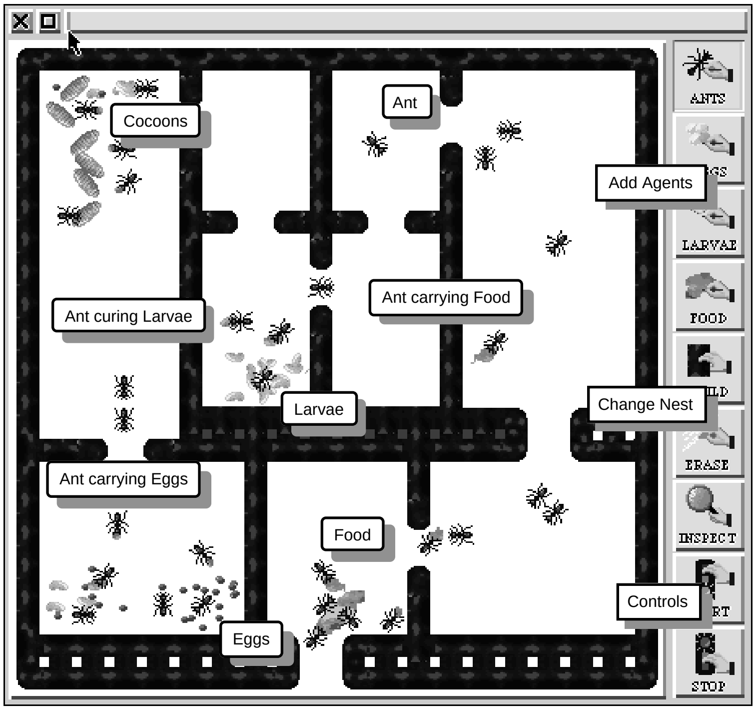


Figure 4 - The simulation nest with its nine rooms.

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 9 adjoining chambers) being the same as on Figure 4. 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 *at 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 twenty workers are born. The first situation signifies the death of the colony and then the failure of the sociogenesis process. The second one is 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 twenty workers constitutes the most difficult period in the sociogenesis process. In Table 1 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.

Results	Composition	Number	Percent
Failures with	Eggs	8	6.06%
	Eggs, Larvae	16	12.12%
	Larvae	27	20.45%
	Eggs, Larvae, Cocoons	24	18.18%
	Larvae, Cocoons	16	12.12%
	Larvae, Workers	10	07.58%
	Eggs, Cocoons	2	1.52%
Failures with Larvae		93	90.29%
Total Number of Failures		103	78.03%
Total Number of Successes		29	21.97%
Total Number of Experiments		132	100.00%

Table 1 - Proportion of failures and successes in the sociogenesis experiments. The 'failures with larvae' item sums all the failures obtained when larvae were part of the population, and provides the proportion of these failures with respect to the total number of failures.

In these experiments, the proportion of failures (78.03%), appears to be close to that observed for natural colonies bred in laboratory conditions (where 86 % never reached the 10 workers stage). Second point, 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 90,29% of the total number of failures. Why is it so? The simplest explanation that can be provided is that larvae must be cared, carried and fed whereas the other agents composing the brood just need to be cared and carried. The presence of larvae then generates, at the population level, a very 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 to be 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 itself. 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 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 the colony #46, which is depicted in Figure 5, where the number of each type of agent is plotted against the time (each unit corresponds to two days of the real time-scale). This colony provides us with a very complete illustration of what has happened in our successful experiments.

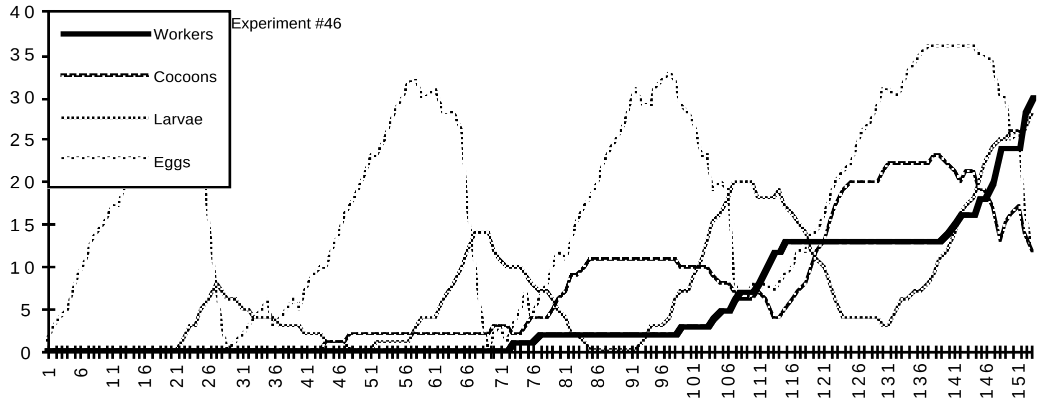
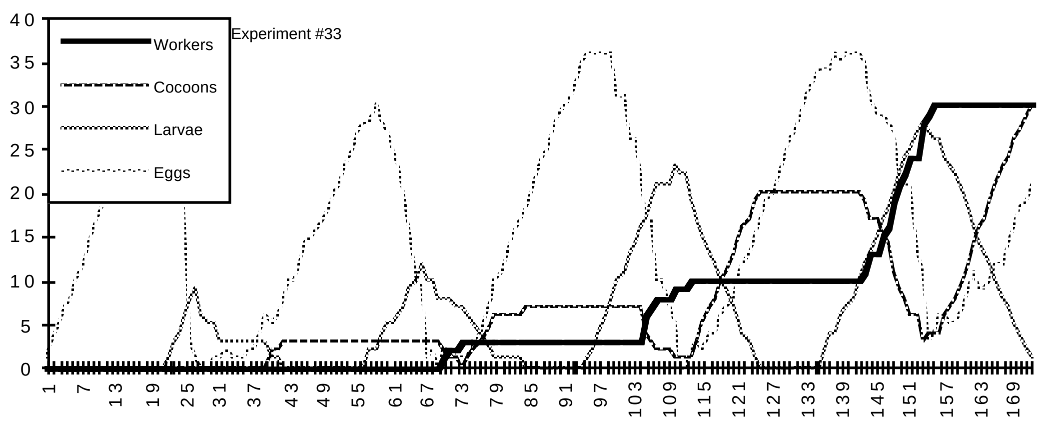
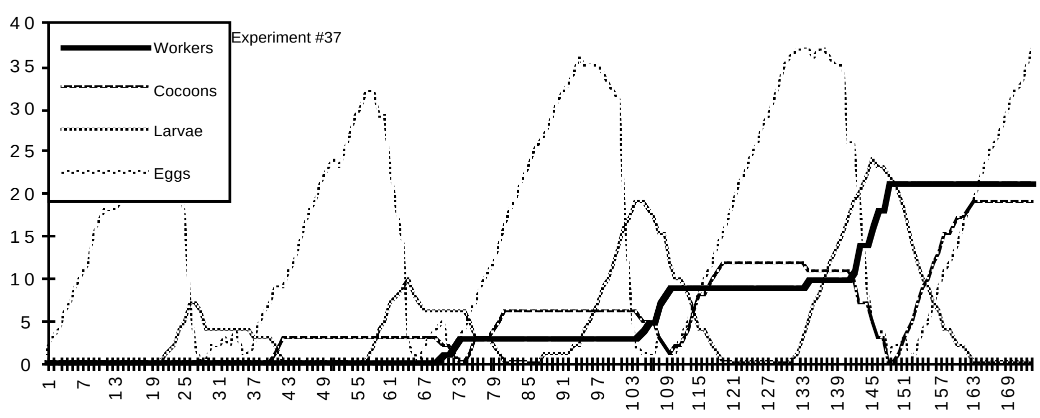


Figure 5- The demographical evolution of colony #46

The curve in very light gray, which represents the population of eggs, is very unequal, although it is possible to detect a regularity in its sudden falls, which occur approximately every fifty days. These falls appear to be synchronized with the peaks of the second curve (in light gray), which represents the larval population. It is apparent 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 particular side effect of a special initial configuration, we have represented, in the next figure, the curves obtained with three other colonies (#33, 37, 44). All these diagrams clearly show that we obtain the same kind of population fluctuations, with small variations, in the different cases.





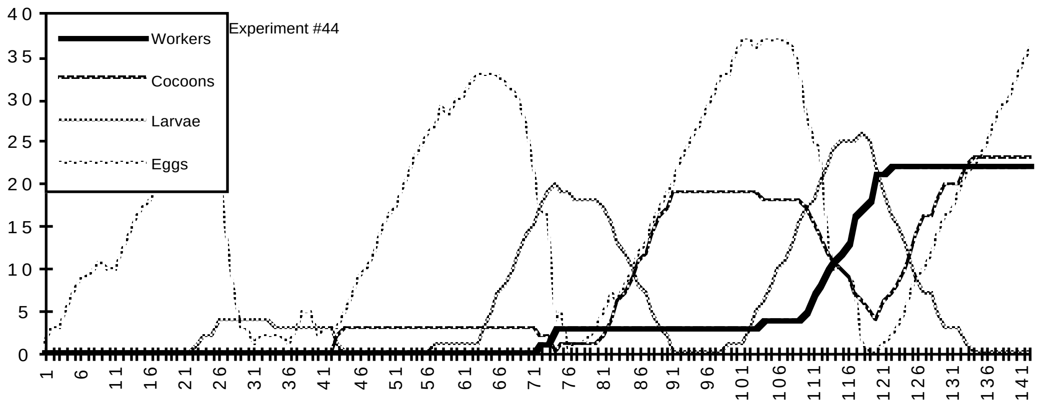


Figure 6- The demographical evolution of the colonies numbered #33, 37, 44

In all these successful experiments, it is easy to detect the gain of stability provided by the workers population increase. Although the frequency of the brood populations variations does not change, the arrival of the workers induces a great change in their amplitudes. This is especially true for the curves representing larvae and cocoons. As the average number of eggs per day laid by the queen does not vary, we can then assume that these eggs are given more chance to become larvae when the society includes workers. The explanation is twofold: (1) on one hand, the foraging activities are likely to involve several ants, thus increasing the amount of food arriving inside the nest. This obviously prevents eggs from being extensively converted into alimentary eggs; (2) on the other hand, the fact that the foraging tasks are performed allows the other ants (including the queen in most cases) to be more attentive to the brood needs. This prevents eggs, larvae and cocoons from dying through lack of cares, as it is often the case in the first stages of the society when the queen must simultaneously forage and take care of the brood.

This set of experiments allows us to underline two points:

- First, the dynamics of the sociogenesis process in natural colonies can be simulated by the interactions of artificial agents provided with a small behavioral repertoire and a simple mechanism of behaviour reinforcement. It does not mean that ants really behave this way. It just means that a stimulus/task model of behaviour at the individual level, even if it does not account for the plasticity of real ants, is able to generate a complex pattern at the colony level, which does account fairly well for the development of ant colonies.
- Secondly, the whole demographical evolution of the society is generated without any centralized control. The kind of "birth regulation" that emerges here is entirely due to local behaviours and interactions between ants, or between ants and the brood and is conditioned by the constraints of the environment, as we will see below.

4. Regulation of the Colonies' Demography

In the previous experiments, the quantity of food provided to the colonies was automatically incremented by a fixed amount at each birth of a worker. This is what is normally done in laboratory conditions. In that way, the colony has theoretically enough food to feed all its workers. However, it does not really take place this way in natural conditions. The amount of food (constituted either by preys or vegetables) is much more variable and bound by events that can not be controlled neither by the colony (climatic changes, etc.) nor the experimentator. However, these somewhat normal conditions demonstrate the adaptivity of ant societies in that they automatically regulate their demographical evolution in order to adjust their population to their environment.

In order to see if the MANTA model could simulate this capacity of "self-control", we have conducted a set of sociogenesis experiments in which the quantity of food provided to the colony is limited to a fixed number of workers. In that way, the system still increments the daily food amount at each birth of ants, but only until the limit is reached. This amount is also decremented in case of deaths. All the experiments were conducted with a maximum fixed to 10 workers.

The results reveal one strong tendency, illustrated by the diagram on Figure 6 which depicts the demographical evolution of colony #P3_2. It could be interpreted as an inclination toward "wisdom" and is shared by approximatively 90% of the successful experiments we have obtained. In this case, the colony size increases up to 10 (or more) workers, and then decreases down to five or six workers, where it stabilizes. The experiments that have been stopped (like #P3_2) after one year of the simulation timescale gives this impression of stability at approximatively half the theoretical possibilities of the colony.

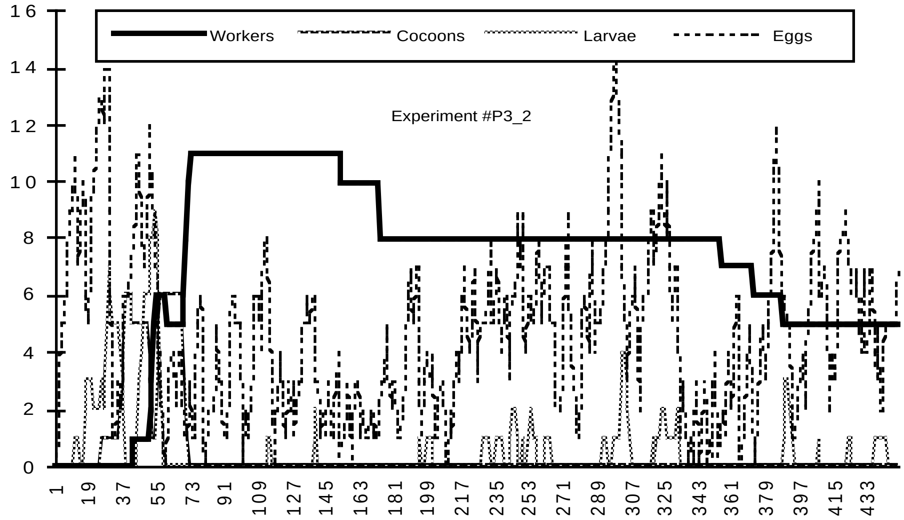


Figure 7 - The demographical evolution of society #P3_2, where the distribution of food is restricted to 10 workers (number of each type of agents against the simulation time in days).

However, when pursuing the experiments, it appears that it is more oriented toward a dynamic equilibrium. This fact is illustrated by the demographical evolution of colony #P11_2, which clearly shows two "endeavours" performed by the colony to increase its population, immediately followed by a temporary stabilization around seven workers.

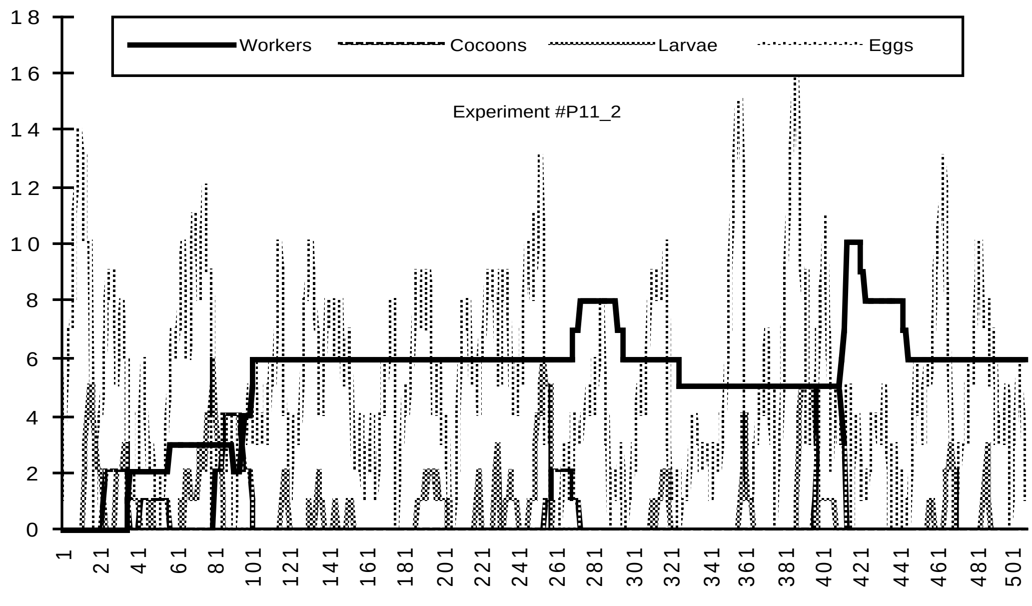


Figure 8 - The demographical evolution of society #P11_2, where the distribution of food is restricted to 10 workers (number of each type of agents against the simulation time in days).

It has to be noted that the stabilization or equilibrium obtained at the workers' level is the result of very important dynamics at the brood level. The eggs, larval and cocoon populations size vary quite substantially from one day to another. The behavioral explanation that can be given is as follows:

- When the number of workers is under the limit fixed in the experiment, the evolution of the population remains quite the same as that observed in the previous experiments on sociogenesis. There are, in fact, no objective reasons for it to be different.
- When this number overpasses the limit, the same phenomenon as that observed in the interplay

several eggs are killed and converted into alimentary eggs. This automatically reduces the chance for this generation of eggs to become larvae. As alimentary eggs do not provide enough food to maintain this number of workers, some of them die (by starving). This lowers the demand in food and stabilizes the process. But, during this stage, brutal cuts in the generations of eggs have been performed (this is particularly manifest on Figure 7), which constrain the society to wait during the full cycle of maturation before obtaining newly born workers. This explains the stability (which lasts three months) between the two picks on Figure 8. And the whole process then starts over again.

Despite the fact that these results are difficult to identify with natural experimentations results (where this kind of experiments have not been conducted, as far as we know, on the species we study), the simulations presented here represent a very important step in the validation of the model. The simulation of sociogenesis has allowed us to obtain societies that grow up quite the same way as the natural ones. We now have societies of artificial ants that can adapt their sizes to their environment's changes in a dynamical way. Although this has to be confirmed by means of natural experimentations, we are quite sure to be very close to reality.

5. From Dominance Relationships to Hierarchy (preliminary results)

A large majority of the ants species show a social structure governed by two distributed means: a division of labour created through an individual specialization and a hierarchical organization (which can be linear or not) generated by dominance interactions between the individuals. This hierarchy[3] can involve all the ants of the colony, or simply be limited, in polygynous societies, to the reproductive females, namely the queens. In this case, one queen emerges during the foudation as the leader and habitually prevents the other ones from laying eggs, thus converting them into simple workers. It allows the society to get ahead on the schedule of the sociogenesis process, thus limiting the cases of failures.

Ectatomma Ruidum is a monogynous species and no phenomenon of hierarchy have ever been reported in it. However, we were interested in searching for the conditions in which a hierarchy could appear between queens in a decentralized way, and what could gain our artificial queens from being hierarchically organized. In the following sections this gain will be evaluated with respect to the success of the sociogenesis process.

In conducting such experiments, we temporarily abandon *ethological simulation* to make some*artificial ethology* (Collins & Jefferson 1991). It results in looking at the system with the eyes of the ethologist, as if it is a really living system. We believe in this approach because we think that it may become a powerful tool for the ethologists, a kind of "idea-generator" for further natural experiments. As a matter of example, the experiments described in the next section are going to have natural counterparts soon[4]. On this aspect of multi-agent simulation, we believe that "*what is important is not so much the answers that are given, but rather the questions that are asked*"[5]

5.1 Polygynous Sociogeneses

The first set of experiments consists in beginning a foundation with four queens identical to those used previously. With this experiment, we just wanted to evaluate the impact of this manipulation on the sociogenesis process. Each individual (brood agents and workers) is labelled throughout its evolution with a lineage number (from 1 to 4), which represents the queen it is descended from. The results are quite suprising.

First, there is an important decrease of the proportion of successes (down to 6,6%), which can be explained by the "group effect" of the brood. As a matter of fact, the four queens continuously lay eggs during the sociogenesis. They then have to face a brood much more important than those that characterize in the previous sociogeneses the situation with a queen and the three first workers.

Secondly, the successful experiments show an evolution that is exactly comparable to that of a monogynous sociogenesis (the number of eggs is roughly multiplied by 4, see Figure 10, but the multiplying factor is around 1.5 for the other categories of the brood and for the workers). This is due to a very huge amount of cannibalism (conversion of eggs into alimentary eggs).

Thirdly, as depicted on Figure 9, the demographical evolution of each lineage appears to be strictly analogous to the others, as if four small sociogeneses had been conducted in parallel.

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[3] For lack of a better term, we shall use hierarchy.

[4] A hundred experimentations have begun on polygynous sociogenesis within a monogynous species at the Ethology Laboratory of Paris XIII.

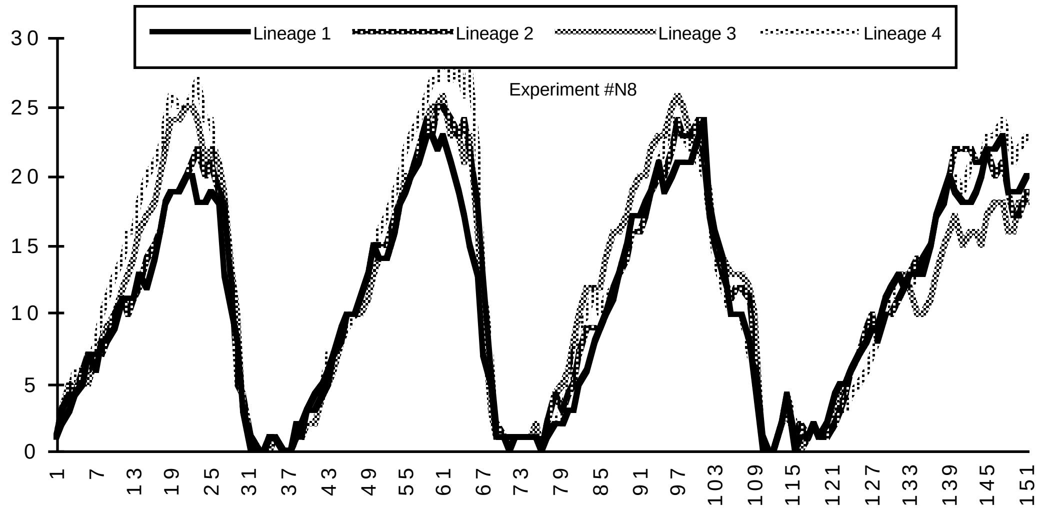

Figure 9 - The demographical evolution of the four lineages of eggs plotted against the time (in days)

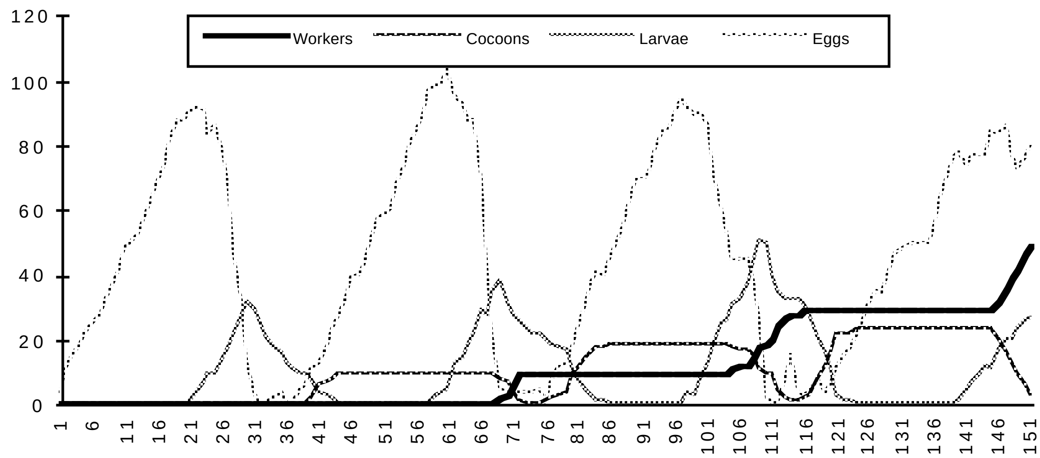

Figure 10 - The demographical evolution of the whole population in colony #N8. Note that, although the number of eggs is high, the size of the other populations are comparable to those of the monogynous sociogeneses.

In brief, a polygynous sociogenesis is not really advantageous for our artificial entities. They have more chance to fail (93,4%!) and the results are not very impressive from a quantitative point of view. What we show, here, is that having four queens together in the same nest is not similar as having one queen plus three workers in this nest. And what a hierarchy usually provides is precisely the possibility to dynamically switch from the former to the latter. However, in a way, this should not be so surprising. Our artificial queens have been provided with a behavioural repertoire compiled from the observation of the queens' behaviours in a monogynous species. Even if the real queens can exhibit enough plasticity to react in a proper manner to a polygynous situation (and that is what we are going to test by making natural experiments, see note 4 page 17), these behaviours have not yet been studied. Hence, our simulated queens are not likely to adopt a behaviour adapted to this somewhat artificial situation.

5.1 Polygynous Sociogeneses with a Repulsive Behaviour

We can however draw hypotheses on the behaviours that are necessary for making polygynous sociogeneses as efficient as those observed in other species. The first hypothesis comes from (Theraulaz & al. 1990), who explains that, in the case of the bumble-bees, there is a link between the rank of an individual in the society and its mobility inside the nest. In other words, a dominated bee will be less mobile than the bees that dominate it. The second hypothesis comes from the observation of the spatial repartition of the ants within the nest. When laying eggs, queens try to put them as close as possible to the most humid places in the nest. Due to the position of humidity, it results in the model in aggregating the eggs in the top-left room. Eggs placed outside this area die quicker than the others. The idea we had was then to combine these two hypotheses by providing the queens with a new behaviour, directly triggered by a stimulus they propagate, which makes them flee the gradient associated with this stimulus. In other words, queens will now repulse each other. Our assumption was that a queen already engaged in a behaviour like laying eggs would repulse the other queens outside the room of the brood, thus resulting in a differential repartition of the brood inside the nest. Being rejected outside this room, the queens would then lay eggs in other places, with less chance for them to grow old[6]. This would in turn result in differential evolutions of the lineage and reduce the demands of the brood, thus converting these queens into workers-like.

Despite the wonderful appearance of this reasoning, our expectations were not really fulfilled. Or, more precisely, not fulfilled the way we thought. Quantitatively, all the experiments made with these new queens largely overpass the results obtained previously with both monogynous and polygynous sociogeneses (see Table 2). The proportion of failures is now 15,15%, instead of 76 or 94%!

Results	**Composition**	**Number**	**Percent**
Total Number of Failures		5	15,15%
Total Number of Successes		28	84,85%
Sucesses with	one queen	20	71,43%
	two queens	3	10,71%
	three queens	3	10,71%
	four queens	2	7,14%
Total Number of Experiments		33	100,00%

Table 2 - The proportion of failures and successes of polygynous sociogeneses began with four queens. The percentages indicated for the item 'Successes with...' are computed on the number of successes.

However, the qualitative results are not what was expected. More than 71% of the successful experiments end up with only one queen, the three others being dead. And, if we look more closely at these societies, we discover that the death of the three queens essentially occurs in the first stages of the society (see Figure 11 for example).

[6] It has to be noted that we do not pay attention to the phenomenon of inhibition that has been reported to occur in many species of ants. This phenomenon makes a queen inhibit the reproductive capacities of the other potential reproductive females by propagating a special pherormone. We shall probably consider it in our future experiments on hierarchical organization. The problem is that we would have to modify the model of behaviour of the agents in

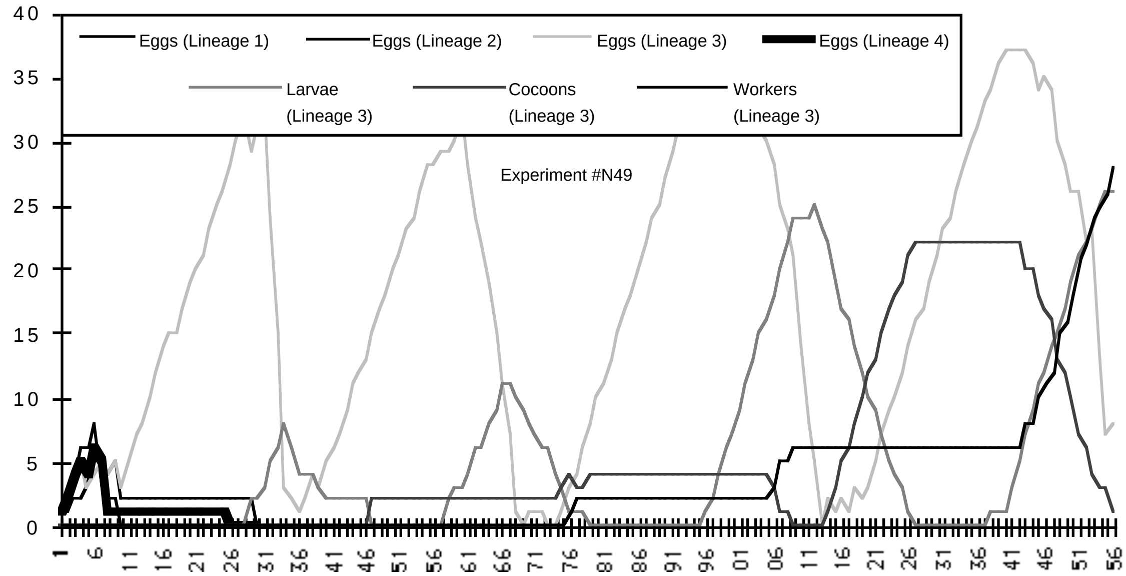

Figure 11 - The demographical evolution of the polygynous sociogenesis #N49. The sizes of the population are plotted against the days (/2). Note the quick death of the queens 1,2 and 4, after just one month of life.

By looking closely the simulations running, we have observed the three following phenomenas:

- In the societies that end up with more than one queen, there are little spatial differentiations among the queens. As a matter of fact, a queen occupying the room of the brood for laying eggs or taking care of them does not always stay there. This is essentially because of the larval demand in food, to which it is more exposed (being closer to them) than the other queens, and which obliges it to go outside the room. During this time, the other queens can then lay eggs or carry their eggs into the brood's room. However the repulsive behaviour seems to have a powerful impact (although it is not the one we were expecting) on the success of the sociogenesis. It seems to allow the queens to perform a task completely without being continuously disturbed by the other ones.
- In the societies that end up with only one queen, the explanation of their success is more difficult. As a matter of fact, most of them really look like the monogynous sociogeneses. We have however observed that: (1) the most difficult stage of the foundation process is to be found when the first larvae appear; (2) in most of the cases (around 80%), the three queens die during this stage; (3) most of them (around 70%) die because they spend their time in taking care of the newly born larvae. We can then conclude that: (1) the sucesses of the foundations are due to the help provided by these three queens to the last one in taking care of the larvae; once this stage has been terminated, i.e. when the first cocoons appear, the last queen is quite definitely certain to succeed (see the low proportion of failures during this stage in Table 1); (2) the eggs layed by the three queens are always converted into alimentary eggs, which means that they constitute an supplementary amount of food with respect to that available in a monogynous foundation.
- We conducted ten experiments where we provided the queens with the ability to reinforce their repulsive behavior (by increasing its weight). Our aim was to obtain a differential reactivity to this stimulus, which could be converted quite easily into a hierarchical pattern[7]. Although we did not gain a clear differentation in this behaviour, the results we have obtained are quite surprising: (1) all the experiments succeeded and, most of all, (2) six of the ten experimentations ended up with four queens, in which several lineages were clearly dominated in size by the others. These results are to be confirmed by further experimentations, so we shall not develop them here. But this approach certainly constitues the key to obtaining emergent hierarchical structures, whose usefulness in the development of the society is quite clear (quantitatively speaking).

Conclusion

[7] As a matter of fact, a queen with a high weight would have been repulsed more frequently than one with a low

All the results presented here were preliminary results (except those on monogynous sociogeneses) and we still conduct other experimentations with alternative hypotheses in order to understand the mechanisms underlying the generation of social structure within ant societies.

The results that we are waiting for are those on the divisions of labour that occur within the colonies. They are still being analysed and examined, but because they represent a huge amount of work, they certainly will not be available after quite a long time. We need them to begin experiments on sociotomies (Lachaud and Fresneau 1987), which consist in splitting a colony into two or more sub-colonies made of different functional groups in order to observe how these sub-colonies produce the specialists that are lacking. We also want to make studies on the relationships between social structure and spatial organization in the nest (see Fresneau et al., 1989).

We will conclude by a word on the simulation we have conducted on the generation of hierarchical structures. Apart from the interest of such a simulation in itself, the underlying problem it emphazises is the apparently out-of-nature relation linking competition and cooperation. As it is programmed, the behaviour of the queens makes them compete with each other without specifying any kind of collaboration. However, the results obtained with the polygynous sociogeneses (and especially those concerning the colonies that terminate with one queen) can be easily interpreted in terms of cooperation between the queens. In most cases, it is even possible to describe the evolution of these colonies by using notions such as "altruism" or "social sacrifice" which are currently employed by sociobiologists to describe similar phenomenas among eusocial insects. What we simply want to underline is that the notion of cooperation is a very fuzzy one and that many processes or behaviors viewed as cooperative can be obtained by the competitive interplay between the individuals and the constraints generated by their environment.

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The following outline is provided as an overview of and topical guide to artificial intelligence: Artificial intelligence (AI) â€“ intelligence exhibited by machines or software. It is also the name of the scientific field which studies how to create computers and computer software that are capable of intelligent behaviour. A form of intelligence. Synthetic intelligence â€“ intelligence of a man-made yet real quality: actual, not fake, not simulated. A type of technology. A type of computer technology. Artificial society is the specific agent based computational model for computer simulation in social analysis. It is mostly connected to the theme in complex system, emergence, Monte Carlo method, computational sociology, multi-agent system, and evolutionary programming. The concept itself is simple enough. Actually reaching this conceptual point took a while. Complex mathematical models have been, and are, common; deceivingly simple models only have their roots in the late forties, and took the