

Simulating Multiple Emergent Phenomena - Exemplified in an Ant Colony

Franziska Kluegl and Frank Puppe

Dep. for Artificial Intelligence, University of Wuerzburg
Am Hubland, 97074 Wuerzburg

{kluegl, puppe}@informatik.uni-wuerzburg.de

Ulrich Raub and Juergen Tautz

Dep. for Behavioral Physiology and Sociobiology,
University of Wuerzburg
Am Hubland, 97074 Wuerzburg

{raub, tautz}@biozentrum.uni-wuerzburg.de

Abstract

Modeling the activity of an ant community based on the individual behavior of a single ant is a very modern approach, but until now the modeling has often been restricted to single phenomenon, e.g. foraging or recruiting. But these activities can not be seen independently from other necessary abilities. For example foraging, breeding, building a nest or defending a territory from enemies are all dependent on each other. In this paper we want to present a model of an ant community that unifies different activities during a complete life cycle of a colony. We present experiments with a simulated ant colony that exhibits concurrently

- foraging and recruiting
- storing energy and distributing it inside of the anthill
- breeding and individual development
- mass recruitment for defending the colony's territory

For modeling the behavior of an ant we use the SeSAM-architecture. This is a discrete, rule-based multi-agent simulation system that allows easy graphical modeling. Because of its simple structure and powerful graphical editors the large, unifying ant-model is easily accessible.

1. Introduction

How can complex and seemingly organized behavior of a group of agents result from simple behavioral rules of the individual agents without central control? Answers to this question may not only help in better understanding social animal or human behavior, but also in computational approaches for reducing complexity. For studying such emergent phenomena, a sophisticated multi-agent simulation shell is necessary, which allows straightforward modeling of the behavior of single agents and the environment as well as offers sophisticated tools for recording the behavior of the group. A typical example is the organization of an ant colony with emergent phenomena like effective foraging or recruiting. Currently, most approaches have studied such phenomena in isolation and shown, that they can be reached with simple individual rules. The next step is to study them in combination. Is it necessary to completely redesign the local behavior of the agents or reassemble the single emergent phenomena more like modules in software

engineering with nice integration opportunities? In the following we report about the experiences of modeling a broad range of behaviors of an ant colony with SeSAM (**Shell for Simulated Agent Systems**). This system provides a generic environment for modeling agent-based systems and experimenting with these models. We specially focused on providing a framework for the easy construction of complex models. Besides several graphical tools for animating and evaluating the simulation experiments, the modeller may use a rule-based activity selection paradigm that is also supported by a graphical modeling tool (for further information see Kluegl, 1998).

There are four categories for modeling the behavior of single agents related to the stimulus-response paradigm which is easily translated using rule-based mechanisms. They vary in different degrees of flexibility:

1. Strict caste-controlled agents: they perform only activities associated with their role
2. Less strict caste-controlled agents: they perform activities associated with their role, but can execute other activities on very strong stimuli.
3. Unspecialized, activity-bounded agents: they perform activities which may last over some time, but can be interrupted on certain stimuli.
4. Unspecialized agents: Their actions are determined from one basic time-step to another dependent only on external stimuli and internal state.

All four of these paradigms can be found in the simple behavioral rules that form the basis for the development of several individual based stochastic models, specially modeling task allocation. See for example (Pacala et. al., 1996), who use the following simplified rule to develop stochastic processes for task allocation: Ants that don't encounter a task-specific resource during a certain time interval, switch their task or become inactive. The problem with all these analytic simulation models is that they cannot formulate the complex situation the ant is confronted with. Neither spatial structures, nor complex, interacting stimuli or activities can be considered without an essential reduction to very simplified assumptions.

For our aim of modeling different interacting phenomena the approach of multi-agent simulation seems more promising. The behavior of an ant is modeled explicitly using the rule-based paradigms above. The first (strict caste-like system) is - as it excludes task switching - not very useful for modeling. The second paradigm provides the standard action selection paradigm used in SeSAM. For flexibility there is also the possibility to introduce stimuli which can interrupt all activities. Therefore a modeller is provided with an additional (3)-like paradigm. This third paradigm corresponds to some of the „classical“ task competition approaches (e.g. Maes, 1991). For the selection of the next action, possible tasks, including the specially treated current activity are rated and the best one is chosen to determine the next action of the agent. Dependencies between the different tasks are taken into account, therefore the modeling of many different behaviors becomes rather costly. The last category where the selection of the next action is only based on the currently perceived stimuli is for example used in the MANTA model (Drogoul and Ferber, 1994).

In the next section, we generally describe the natural behavior of ant colonies. Thereafter models of the behavior of individual ants sufficient for single emergent phenomena like foraging, recruiting, storing and distributing energy, breeding, and defending territory are given, followed by a report on our experiments with combining them. The last section discusses the results and describes open questions.

2. Ant behavior

The natural behavior of ants is enormous variable and perfectly fitted to the environment the colony lives in. The ecological range of the nearly 9000 described ant species is from the arctic circle to the rain forests of south America (for review see Hölldobler & Wilson 1990). The very common feature of ant societies is „eusociality“. This term describes three behavioral characteristics, that are the main reasons for the success of the ants: 1. Reproductive division of labor with one or more queens responsible for the reproduction and non-reproductive workers helping the queens 2. Cooperation of the workers in caring for the young and 3. the overlap of two or more generations living in one colony capable to contribute to the colony labor.

Next to eusociality, the potential of most of the members of a colony to switch from one task to another guarantees the functioning of a colony. Doing so, the colony has the ability to divide their capacities among the routine tasks or, if necessary adjust it to the actual situation. One example is the use of foragers to look for food supply outside the nest. Usually food items are distributed in an unpredictable way in the environment. So it is very important to concentrate the workers available for searching and exploiting a food source in a efficient way. This problem is solved by employing subgroups of ants, called foragers, to go out to look for these items. Successful foragers run back to the nest and recruit unemployed workers to exploit this food source in a fast and effective way.

3. Simulated ant behavior

In ant colonies several self-organizing behaviors can be observed, each is in itself an interesting phenomenon. Therefore several separated approaches to simulate it were already undertaken. The following aspects are part of our model (Kluegl et al. 1996), (Raub and Kluegl, 1997).

3.1. Foraging and Recruiting

The emerging cooperation of ants in order to exploit a food source is one of the most famous and probably most often modeled and simulated self organizing pattern. It even supplies a model for emergent cooperation (Steels, 1990). Dispersed food resources are exploited very effectively using a chemical trail for information about the position and the quality of the source.

We constructed a simple model for the behavior of a forager: depending on its individual energy level the worker leaves the nest searching for food. When it perceives a pheromone trail, the modeled worker chooses to follow it with a high probability. When discovering a food particle, it transports it back to the nest thereby refreshing the trail. For modeling the „exact“ pattern of behavior, some questions arise: For example, when a worker perceives more than one trail, which one does it follow? In our model the ant chooses always the strongest, but with a small probability it does not follow a perceived trail at all, but starts searching for new food sources. Figure 1 shows a typical situation during a simulation experiment.

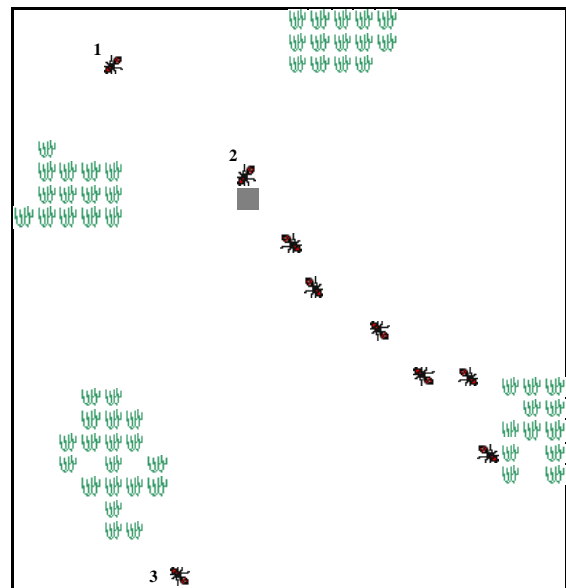


Figure 1: Situation during an animated simulation experiment: Foraging ants are exploiting a food source, whereas the numbered ant search for new patches.

There are many reports about models examining the distribution of foraging ants between several food sources, often

developed from experiments with real ants. The asymmetric, most effective foraging between two food sources could be reproduced using logistic equations (Pasteels et al., 1987) or stochastic processes (Fletcher et al., 1995). They also consider the question, whether ants could lose the trail and state that there may be a relation between the length and the concentration of the pheromone and the probability to leave it. In our model an agent only leaves a selected trail, when it arrives at the end and no food is perceived. Then it starts searching. (Millonas, 1994) focuses still more on the way ants follow trails. He uses microscopic dynamics described by an pheromone energy function to describe how ants follow trails.

3.2. Development inside of the nest

The activity inside of an ant hill is strongly depending on the queen. She produces eggs that become new workers via several stages of development.

In our model the queen produces eggs and feeds them with her own energy until the first workers hatch and take over this job. The time she needs for producing an egg increases with falling energy. When she has used up her energy she has to be fed by other agents, otherwise she stops production and finally starves. We subsumed all stages of development into one of the following agent types: „brood“ and „sexual brood“. When the colony reaches a certain size, the queen starts producing sexual brood, that become new queens representing the next generation of ant colonies. Thus the number of produced sexual animals determines the overall success of an ant colony.

A critical question in modeling the behaviors of ants concerning the growth of a colony is the mechanism how the queen decides, when to produce what kind of brood. In our model we designed simple rules like: If the queen perceives more than 30 brood agents with enough energy inside a restricted radius, it starts producing sexual brood entities.

In the MANTA project (Drogoul and Ferber, 1994) the activities inside of an anthill are modeled based on agents that purely react on stimuli that spread on the spatial structure of the nest. They incorporate the different stages of development requiring different caring activities, but do not consider other than brood that becomes workers.

Additional to the explicit feeding of the queen and the brood there is another mechanism to share energy between the workers committed to tasks beyond foraging (and thus information about the complete energy supply in the nest). We combined two mechanisms as can be found in real ants (Hölldobler and Wilson, 1990). One is a central storage in form of ants (e.g. the „honeypot ants“ of the American desert ant *Myrmecocystus mimicus*) representing a reserve for the dry season. A second mechanism is a decentralized distribution. Every time one ant meets another, the one with more energy gives some amount of energy to the other („trophallaxis“).

As the colony grows, the nest itself will become too small thus the nest size has to be adjusted dynamically. Although in our model the number of ants on the same grid is not yet

restricted, we modeled nest building, as the size of the nest generally determines the amount of social contact inside of the anthill. In the modeled colony the motivation of a nestworker to dig out a part of the nest is coupled with the amount of social contact during a certain time (see figure 2 for an example of nest enlargement during a simulation experiment). A piece of soil is deposited outside the nest. With the simple rule „if another piece of soil is perceived, add it to it“ it was possible to establish a waste deposit site.

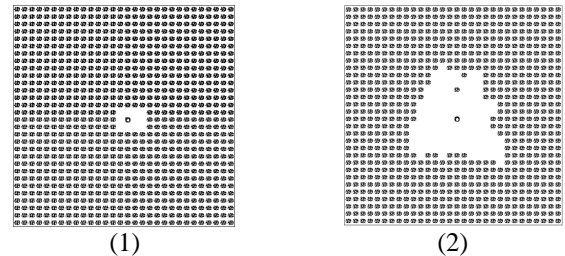


Figure 2: Structure of the nest at the start of the simulation (1) and after 2000 time-steps (2). The circle in the middle of the maps depicts the connection to the outside world.

A simple form of nest building behavior was also reproduced by (Deneubourg, et al., 1991). They compared the construction of nest-structures by social insects (termite or wasp colonies) using different, very simple, fixed behavioral patterns for agents filling the cells they occupy and moving to neighboring cells.

3.3. Mass recruitment for defending the territory

One of the biggest competitors of an ant colony is another colony, therefore a mechanism for interacting with ants from other colonies is necessary.

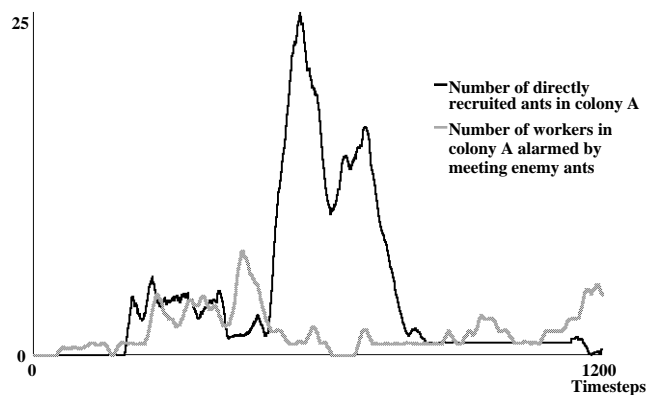


Figure 3: Recruitment of workers in reaction to contact with ants from another colony

We modeled the interaction pattern that is exhibited by ants of the species *Myrmecocystus mimicus*, that assess in „tournaments“ the strength of the other colony. We incorporated one of the explaining hypotheses for their emergence (Hölldobler 1983) in our model: Having contact to a foreign ant, the ant checks the number of foreign animals

in an area by running in circles for a short time. If a certain number of foreign ants is counted the ants runs back and recruits other nestmates to this area. If additional ants encounter foreign ants there will be an exponential increase of alerted ants. By this it is guaranteed that a single ant is not sufficient to alert the whole colony. This is exemplified in figure 3.

4. Issues in combinability

An ant colony in reality must perform all the above described behavioral processes concurrently, as they are strongly associated. For example foraging is useless, when there is no effective mechanism for distributing energy to ants busy with other tasks. An attempt to recruit ants for a tournament is futile, when all workers are foraging and no waiting reserve can be found in the nest. Only a effective foraging mechanism supplies sufficient energy for feeding the brood. Many more of these interconnected tasks can be found.

In principle the integration of several separate phenomena raises problems of two categories: A complete model must be carefully calibrated to exhibit a functioning task allocation and on the other side energy consumption and gain must be balanced. Thus combining several processes is not trivial: Both time and energy balance is disturbed when adding a further process, as ants that are committed to the new task can not perform others, but nevertheless consume energy.

Our rules for switching from one task to another mostly represent priorities between the different behaviors. The most critical issues can be associated with the workers: They can stop being inactive (resting) and start foraging at any time with a rather low probability, which is increasing when their energy falls beneath a certain value and any honey-pot ant cannot provide enough new energy. An ant always performs trophallaxis-behavior when it has contact to another of its own colony, and continues its former work after that. When a worker encounters a foreign ant, it starts immediately with the alarmed counting behavior, independent from what it has done before.

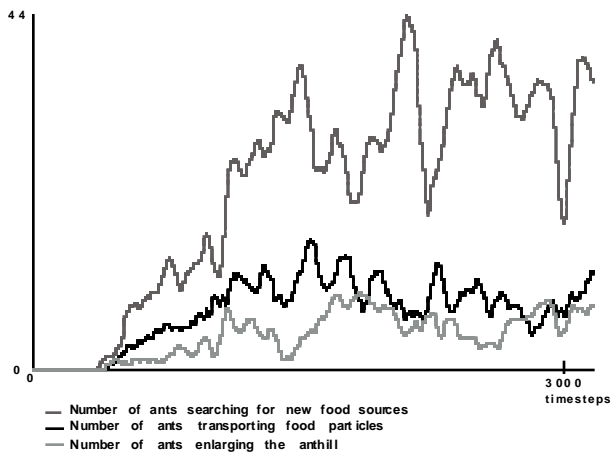


Figure 4: Number of workers committed to different tasks.

The figures 4 and 5 show clarifying example results of simulation experiments for the functioning of the combination of the behaviors. In figure 4 the number of workers committed to different tasks, like the different phases of foraging or enlarging the nest, are presented. After about 1000 time-steps constantly more than 200 workers are available, between 30 and 50 of them are busy with caring for brood and queen. In figure 5 the distribution of different behavioral roles during a simulation experiment is presented. At the beginning of the colonies life - starting with just one queen, only brood exists. The queen feeds the brood, until its own energy level decreases - some brood starves. After nestworker have developed, they start feeding the hungry brood... When a certain amount of brood can be maintained, the colony starts crowing...



Figure 5: Number of ants belonging to certain developmental states or behavioral roles.

Thus we generated in principle an explicit, rather sophisticated task allocation model. In the real world social insects distribute workers on tasks quite optimally, but how this is accomplished based on pure self-organization is not completely known. Reproducing it is therefore a very attractive research area. In contrast to the work of for example (Pacala et al. 1996), we modeled the stimuli that lead to task switching explicitly, not translating them into abstract probabilities and transition rates. The behavior and situation of a single ant can be pursued and recognized directly in the model, and is not hidden in decision matrices for a small number of different tasks (Gordon et al. 1992). We can directly model spatial properties, feed back loops, etc. without simplifying in order to cope with large equation systems (Lachmann and Selly, 1995). Using multi-agent simulation we can directly translate the results of observing the individual ants into the model and thus produce plausible over all behavior of an ant colony without restrictions that must be taken into account when modeling mathematically.

5. Conclusion and further work

Examining different phenomena and integrating them into one unified model, we gain results that mirror better the fragile balance between different aspects of a colonies life

than previous simulations. There are no structural problems combining different emerging phenomena, but the critical issue is finding out the overall optima of the combined behavior. Although we have managed to build a model that leads to plausible behavior of the colony, we have to do controlled experiments to find out whether the model is both realistic compared to external field data and optimal with respect to internal parameter adjustments. Evaluating the experiments based on animation, statistics and the genetical fitness measure of produced sexual animals, we can gain more evidence about the quality of our model. Currently the model can already be used as a basis for testing specialized hypotheses about e.g. different counting mechanisms during a tournament.

The most important result of our attempt to integrate several phenomena in one model consists of the questions arisen during the model construction: What mechanism are responsible for the optimal distribution of ants in nest-workers, forager exploiting known resources or looking for new resources, lazy colonist numbers, etc.? How can an ant gain reliable information about important aspects of the colony state (e.g. the details of the counting mechanism in tournaments, see section 3.3)? And, after all, how does the queen decide, how many eggs she should produce.

References

- Deneubourg, J.-L., Theraulaz, G. and Becker, R. 1991. Swarm-Made Architectures. In: Towards a practice of autonomous agents (= Proceedings of the first European Conference on Artificial Life), 123-133
- Drogoul, A. and J. Ferber. 1994. Multi-Agent Simulation as a Tool for Modeling Societies: Application to Social Differentiation in Ant Colonies. In Castelfranchi, C and Werner, E (eds.) Artificial Social Systems (= Proceedings of the MAAMAW'92). Springer, 3-23.
- Fletcher, R. P., Cannings, C. and Blackwell, P. G. 1995. Modeling Foraging Behavior of Ant Colonies In: Advances in Artificial Life, Proceedings of the Third European Conference on Artificial Life. F. Morán, A. Moreno, J. J. Merelo and P. Chacón (eds.). Springer. 772-783
- Gordon, D. M., Goodwin, B. C and L. E. H. Trainor: 1992. A Parallel Distributed Model of the Behavior of Ant Colonies. *Journal of Theoretical Biology*, 156:293-307.
- Hölldobler, B. and E. O. Wilson. 1990. *The ants*. Heidelberg: Springer.
- Hölldobler, B. 1983. Chemical Manipulation, Enemy Specification and Intercolony Communication in Ant Communities. In: Neuroethology and Behavioral Physiology. Huber, F. and Markl, H. (eds.), Springer, Berlin
- Kluegl, F. 1998. The multi-agent simulation environment SeSAm. Forthcoming
- Kluegl, F., Puppe, F., Raub U. and Tautz, J. 1996. A Simulation System for the representation of emergent behavior. In: Proceedings of the Conference Simulation and Animation 1996 (ASIM, ed.), Magdeburg (in German)
- Lachmann, M. and Selly, G. 1995. The Computationally Complete Ant Colony: Global Coordination in a System with no hierarchy. In: Advances in Artificial Life, Proceedings of the Third European Conference on Artificial Life. F. Morán, A. Moreno, J. J. Merelo and P. Chacón (eds.). Springer. 785-800
- Maes, P. 1991. A Bottom-up Mechanism for Behavior Selection in an artificial Creature In: From Animals to Animats (= Proceedings of the First International Conference on Simulation of Adaptive Behavior). J. A Meyer and S. W Wilson (eds.). MIT Press, 238-246
- Millonas, M. 1994. Swarms, Phase Transitions, and Collective Intelligence. In: Artificial Life III C. Langton (ed.), Addison-Wesley, 417-445
- Pacala S. W., Gordon, D. M. and Godfray, H. D. J. 1996. Effects of social group size on information transfer and task allocation. In: *Evolutionary Ecology*. 10. 127-165
- Pasteels, J. M., Deneubourg, J.-L. and Goss, S. 1987. Self-organization mechanisms in ant societies (I) Trail recruitment to newly discovered food sources. In: *From Individual to Collective Behavior in Social Insects*, Pasteels, J. B. and Deneubourg, J.-L. (eds.). 155-176
- Raub, U. and F. Kluegl. 1997. A new technique to simulate ant-colonies. In: *Social Insects*, Proceedings of IUSSI-Conference, K. Crailsheim and A. Stubentheiner (eds.) Graz, Eigenverlag
- Steels, L. 1990. Cooperation between Distributed Agents through Self-organization. In: *Decentralized A. I.* Demazeau, Y. and J.-P. Mueller (eds.), North Holland, 175-196