

BIOANT - Biologically Plausible Computer Simulation of an Environment with Ants

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Abstract—The system BIOANT, presented here, is an Artificial Life system that simulates an environment with ants. Each ant moves inside the environment on the basis of a Biologically Plausible Artificial Neural Network, which employs the algorithm GeneRec for supervised learning. In order to obtain an initial configuration, a symbolic algorithm (based on a set of production rules) was created. The environment itself is three-dimensional and consists of the anthill, sugar, water, earth elevations, walls, and predators. The ants interact with the environment using the senses of smell, vision, touch, and hearing, always following the commands of the neural controller. The system aims to contribute to research that deals with development of artificial beings, i.e., Intelligent Agents, Artificial Life, Robotics, and Biologically Plausible Artificial Neural Networks. BIOANT is an implementation of typical behavioral aspects of ants in a computational simulation.

I. INTRODUCTION

The system BIOANT simulates a small ant colony of configurable size (up to 99 ants). The ants search for food in a three-dimensional virtual world and try to defend themselves against predators and other dangers, such as death caused by lack of food or drowning. BIOANT does not intend to focus on a very complex biological system, but to support the idea of Artificial Evolution through a simple insect simulation [1], [3].

II. DESCRIPTION OF THE SYSTEM

There are two modes of operation in BIOANT: the symbolic algorithm, which is step by step based on the current situation (i.e. previous experiences are not taken into account) and the artificial neural network, which controls each ant using action sequences, executed in a logical order.

A. The Environment

The system BIOANT contains a three-dimensional environment with the measures 80 (width), 45 (length), and 5 (height), into which the ants are inserted. The elements of the virtual world are the anthill, high walls, earth elevations, sugar, and water (see figure 1).

At the beginning of the simulation the ants shall move out of the anthill searching for food. They find their way in the environment, pass information on to other ants via trails of pheromone and allomone, and take the food to the anthill where they eat, sleep, and move out again.

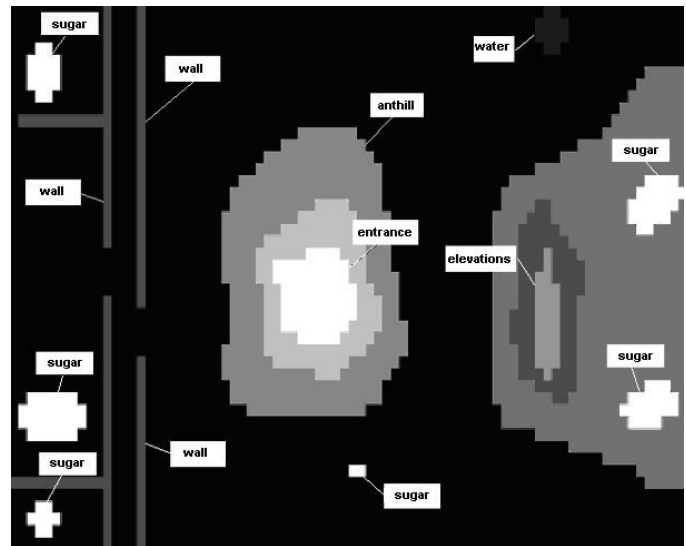


Fig. 1. BIOANT environment seen from above (2D)

B. Predators

There are two simulated predators in the environment: a human being, symbolized by a shoe that can squash ants, and a bird, which observes a small area of the screen and eats an ant or other that comes by.

The user of the system may use the shoe, choosing a place where to step on. There is also the possibility to place several shoes at the same time and remove them all at once, (destroying the ground under them).

The bird is implemented using a square that shall symbolize its vision. This square may be positioned by the user. When the ants come along, the bird tries to catch them and manages to do so with a configured probability of 10% per ant and iteration.

Danger warnings are given by an ant through the emission of allomone, and the others shall react accordingly: running away to other places or returning directly to the anthill.

C. Updates of the Environment

The environment is constantly updated:

- As sugar is brought to the anthill, the smell of food

diminishes until its complete end with the depletion of food sources,

- Pheromone trails are derogated after a certain number of steps,
- Alert zones marked by allomone are derogated according to some parameters,
- Noise lasts for a very short period of time if there are not constant emissions, and
- The number of ants decreases with the death of ants in the environment.

D. Reasons of Death

Even though there is no predefined time for an ant's life in the current version, all ants can die inside the environment:

- An ant may drown when getting into water areas. This is a reason of instant death in the system, though it may take more time in nature,
- An ant may be squashed by shoes. In this case the ant is not able to neither defend nor emit an alert on time,
- An ant may be eaten by the bird. In this case it still manages to alert the others via allomone, and
- An ant may die because of lack of food.

E. Sensors

The ants perceive their environment by the following sensors:

- *Smell* (figure 2): the most important sense of the ant, because communication between ants is done via pheromone trails and allomone zones [6]. Apart from these, an ant may distinguish the smells of food and of the anthill. The system treats the current smell (position of the ant), the smell in the front, on the left, on the right, and also the smell felt at the last iteration (history).

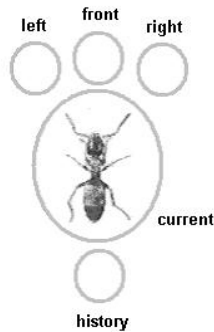


Fig. 2. Sensors implemented in BIOANT: Smell

- *Touch* (figure 3): the ants explore the environment in front of them with their antennae. For the sake of simplicity, in BIOANT the ants actually perceive front objects instantly by touch.
- *Vision* (figures 4 and 5): ants have facet eyes in order to see objects around them. These eyes may be more or less developed - depending on the species [6]. In BIOANT, the ants may see elements at a maximum angle of 135° to the left and 135° to the right (figure 4). Vertically, the ants

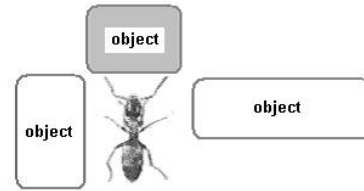


Fig. 3. Sensors implemented in BIOANT: Touch

perceive the virtual world up to an angle of 90° (above) and 22.5° below (figure 5).

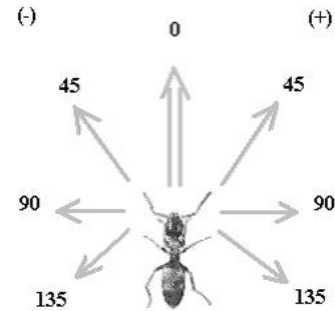


Fig. 4. Sensors implemented in BIOANT: Horizontal vision

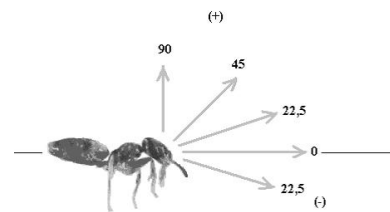


Fig. 5. Sensors implemented in BIOANT: Vertical vision

- *Hearing* (figure 6): ants capture the level of noise in the environment through vibrations felt at their antennae. In this way, hearing is actually a special case of touch for the ants as they do not possess ears. In BIOANT, hearing is used to detect situations of danger (a predator coming) and has no function for communication. The ants may detect noise at a volume of 0 (no noise) to 99 (maximum noise).
- *Stomachs* (figure 7): ants have two types of stomachs: the social stomach, by which the ant may feed other members of the colony, and a common stomach, which is the beginning of the ant's own digestion. In BIOANT, the sensors of the stomachs provide the level of filling in the two cases with values range from 0 (empty) to 99 (full).

F. Symbolic Algorithm

The symbolic algorithm, which was developed before the hybrid algorithm in order to validate the ant behavior in an

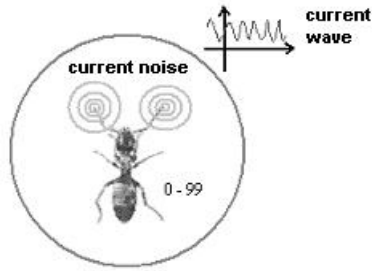


Fig. 6. Sensors implemented in BIOANT: Hearing

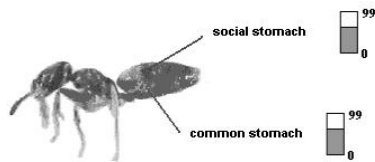


Fig. 7. Sensors implemented in BIOANT: Stomachs

experimental way, employs sensors, low level actuators, and low level interpreters.

It consists of a list of conditions which is applied sorted by priority, i.e., if a higher priority condition has already been satisfied, conditions with less priority are not checked anymore.

The symbolic algorithm uses a set of 18 rules (see figure 8). The rules are established in the form of simple "if-then-else" instructions, where the conditions are the data obtained through the sensors and the conclusions define the low level actuators (basic procedures).

CONDITION	OBJ. FRONT	OBJ. ABOVE	OBJ. BELOW	TOUCH	ALLOMONE	PEROMONE	ANTHILL	FOOD	NOISE	STOMACH	SOCIAL STOM.	ALERT	COORD. Z	RESULT
1				predator										FLEE DANGER
1	very close													FLEE DANGER
2					>0 (+/#)				>= 10					FLEE DANGER
2					0						on			FLEE ALLOMONE_ZONE
3														RETURN_NORMAL
4		ant	0											AVOID_COLLISION
5		water	0								< 99			TAKE FOOD
5		sugar	0								< 99			TAKE FOOD
6					>0 (c)									FLEE_ALERT
7				edge of world										LEAVE_BAD_PATH
7	above													LEAVE_BAD_PATH
8				anthill					<= 10			2		ENTER_ANTHILL
8				anthill					>= 10			2		ENTER_ANTHILL
9				not(water)		in front			> 10	< 10				FOLLOW_ATTRACTION_FRONT
9				not(water)		in front & >0 (+/#)			<= 10					FOLLOW_ATTRACTION_FRONT
9				not(water)		in front & >0 (+/#)			>= 10	< 10				FOLLOW_ATTRACTION_FRONT
9				not(water)		in front			> 10	< 10				FOLLOW_ATTRACTION_FRONT

Fig. 8. Rules 1 to 9 of the symbolic algorithm used in BIOANT

The inputs from the sensors are (see figure 8): object front (is there vision of an object in front of the ant?), object left (is there vision of an object to the left?), object right (is there vision of an object to the right?), object above (is there vision of an object above the ant?), object below (is there vision of an object 22.5° below the ant?), touch (is there any direct contact with an object?), allomone / pheromone / anthill / food (what is the intensity of these smells in the environment?), noise (what is the current volume of noise?), stomach / social stomach (what is the level of filling?), alert (is the ant in alert state?),

and coordinate Z (at what height is the ant? - artificial sensor to enter the anthill).

The following low level actuators (sorted by priority, see figure 8) are available: FLEE_DANGER (flee from imminent danger!), FLEE_ALLOMONE_ZONE (flee from a zone of allomone!), RETURN_NORMAL (the danger terminated, so return to normal operation!), AVOID_COLLISION (avoid collision with another ant!), TAKE FOOD (pick up the food in front and store it in the social stomach!), FLEE_ALERT (flee from the alert zone that is marked by allomone!), LEAVE_BAD_PATH (change direction as the current path is of no advantage!), ENTER_ANTHILL (enter into the anthill right in front!), FOLLOW_ATTRACTION_FRONT (follow smells or visual attraction up in front!), FOLLOW_AMBIGUOUS_ATTRACTION (choose between attractions to the right and to the left with the same intensity!), FOLLOW_ATTRACTION_RIGHT/LEFT (follow smell or visual attraction to the right/to the left!), and FIND_SIGNAL (move randomly in search of a signal in the environment!).

G. The Artificial Neural Network

As a second step a hybrid algorithm was created (figure 9). This architecture employs a standard recurrent network as control instance which makes use of high level interpreters and actuators to simplify processing.

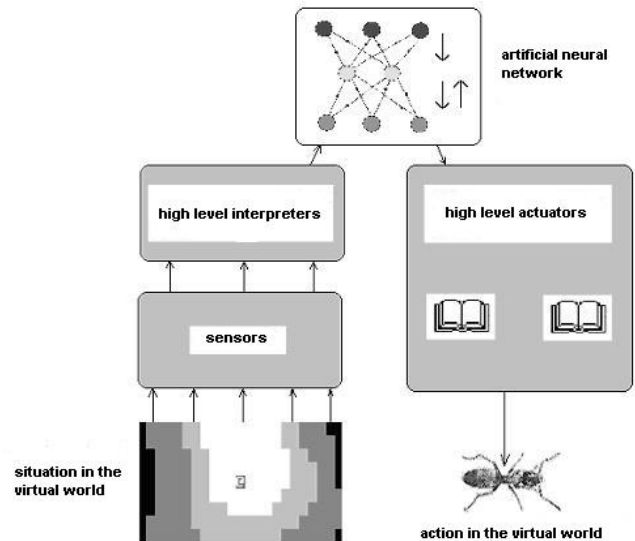


Fig. 9. Scheme of the hybrid algorithm in BIOANT

The neural network was developed to work with the GeneRec algorithm [9]. This algorithm is considered biologically more plausible since it supports bidirectional propagation, among other items. Yet, GeneRec is a supervised algorithm with which input-output sequences may be learned [9], [11]. Additionally, the recurrent architecture is especially adequate to learn multistep procedures.

The sequences learned by the algorithm are listed in figure 10. The interpreters provide the values 1 (true) and 0 (false). High level interpreters are (see columns of figure 10):

danger present (is there danger currently present?), visual object present (does the ant see any object around it?), touching food (is the ant touching any food?), anthill entry in front (is the anthill entry right in front of the ant?), smell allomone / pheromone / anthill / food present (is there any smell of allomone / pheromone / the anthill or food in the air?), hunger present (is the ant hungry?), cargo present (is the ant carrying food?), and ready to leave anthill (is the ant ready to leave the anthill?).

sequence	step	danger present	visual object present	touching food	anthill entry in front	smell allomone present	smell pheromone present	smell anthill present	smell food present	hunger present	cargo present	ready to leave anthill	RESULT
1	1	0	0	0	0	0	0	0	0	0	0	1	leave anthill!
1	2	0	1	/	/	0	/	/	/	/	/	/	explore environment!
1	3	0	/	/	/	0	1	/	0	0	/	/	follow smell of pheromone!
1	4	0	/	/	/	/	/	/	1	0	/	/	follow smell of food!
1	5	0	/	1	/	/	/	/	/	0	/	/	take food!
1	6	/	/	/	/	/	/	/	/	/	1	/	find anthill smell!
1	7	/	/	/	/	/	/	1	/	/	/	/	follow smell of anthill!
1	8	/	/	/	1	/	/	/	/	/	/	/	enter anthill!
2	1	0	0	0	0	0	0	0	0	0	0	1	leave anthill!
2	2	0	1	/	/	0	/	/	/	/	/	/	explore environment!
2	3	0	/	/	/	0	/	1	0	/	/	/	follow smell of food!
2	4	0	/	1	/	/	/	/	/	0	/	/	take food!
2	5	/	/	/	/	/	/	/	/	/	1	/	find anthill smell!
2	6	/	/	/	/	/	/	1	/	/	/	/	follow smell of anthill!
2	7	/	/	/	1	/	/	/	/	/	/	/	enter anthill!
3	1	1	0	0	0	0	0	0	0	0	0	/	alert danger!
3	2	/	/	/	/	1	/	/	/	/	/	/	flee danger!
3	3	/	/	/	/	/	/	1	/	/	/	/	follow smell of anthill!
3	4	/	/	/	1	/	/	/	/	/	/	/	enter anthill!
4	1	0	0	0	0	0	0	0	0	1	0	/	find anthill smell!
4	2	/	/	/	/	/	/	1	/	/	/	/	follow smell of anthill!
4	3	/	/	/	1	/	/	/	/	/	/	/	enter anthill!
5	1	0	0	0	0	1	0	0	0	0	0	/	flee danger!
5	2	/	/	/	/	/	/	1	/	/	/	/	follow smell of anthill!
5	3	/	/	/	1	/	/	/	/	/	/	/	enter anthill!

Fig. 10. Sequences of the hybrid algorithm

High level actuators (lines of figure 10) are: leave anthill! (the ant shall leave the anthill), explore environment! (the ant shall explore the environment searching for food), follow smell of pheromone / food / anthill! (the ant shall follow the smells of pheromone / food or the anthill), take food! (the ant shall pick up the food in front and put it in the social stomach), find anthill smell! (the ant shall try to find the smell of the anthill in the environment), enter anthill! (the ant will enter the anthill), alert danger! (emit an alert of danger to the other ants), and flee danger! (the ant shall flee from danger).

The sequences (see figure 10) treat the following tasks: (1) find food following a pheromone trail, (2) find food without a pheromone trail, (3) alert and flee of danger, (4) find the anthill, and (5) avoid dangers.

III. RESULTS

In this section, some of the results obtained with BIOANT are presented.

A. Learning

With only 40 iterations a set of standard sequences is almost 100% learned (figure 11). This way, learning may be considered appropriate.

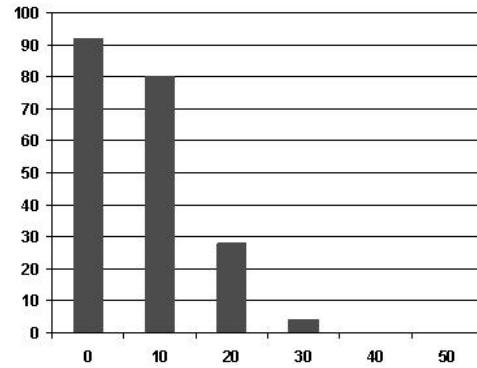


Fig. 11. Learning results: Iterations (x-axis) and percentage of errors (y-axis)

Adequate learning rates start with a minimum of 0.5. In BIOANT, a rate of 0.7 was chosen due to a minimum of necessary steps at that rate (see figure 12).

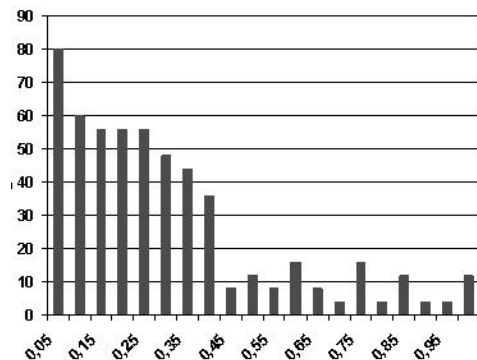


Fig. 12. Learning rate (x-axis) and error percentage (y-axis) after 30 iterations

Examining figure 13, it is possible to find out that a 12-neuron hidden layer is the best choice. Although other possibilities may exist, the choice of 12 neurons, in this case, concerns cost-benefit calculations.

B. Comparison of the Solutions

Several tests were made with the two approaches (symbolic and hybrid) and the results varied a lot due to the dynamic environment. However, the following characteristics may be observed:

- The hybrid algorithm shows good performance, normally managing to deplete the food sources in the environment before the symbolic algorithm (see figure 14).
- The hybrid algorithm has shown more flexibility in different situations than the symbolic algorithm, which is a characteristic attributed to the neural net.

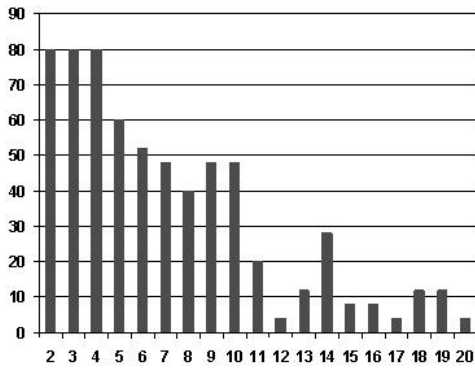


Fig. 13. Architecture of the hidden layer: number of neurons (x-axis) and error percentage (y-axis) after 30 iterations

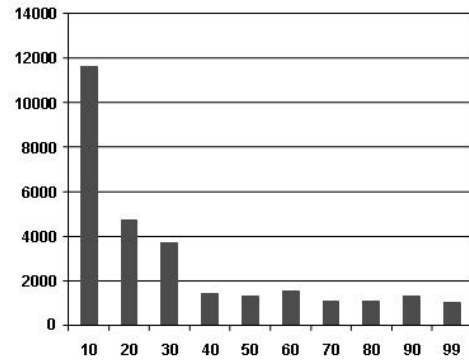


Fig. 15. Number of ants (x-axis) and iterations until the end of the food (y-axis)

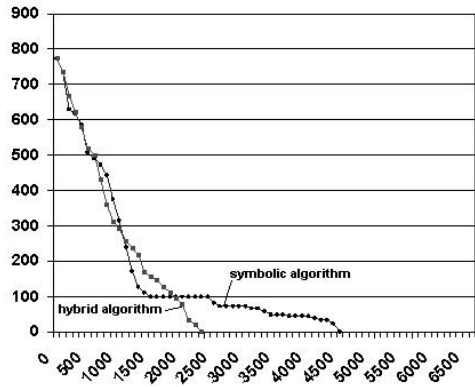


Fig. 14. Typical comparison between symbolic and hybrid algorithms in an environment without a predator (x-axis: amount of sugar in the environment, y-axis: iterations)

C. Organization

Ant colonies use to be composed of millions of individuals [7]. It is possible, in BIOANT, to configure a colony from 1 up to 99 members. Despite the fact that even one ant will know what to do in the environment, this process does not make much sense, firstly because transport to the anthill will take much more time and secondly because the situation is not biologically plausible due to the social behavior of the ants.

Thus, situations with a minimum of 10 ants were examined to determine an ideal number of ants for the proposed task. It can be observed that 40 ants manage to carry all the food to the anthill needing almost the same time as 99 ants (figure 15). Again, taking cost-benefit calculations into account this configuration was considered the ideal for the colony emulated in BIOANT.

D. Communication Among Ants

Smell is the most important sense of ants, so it is used to establish a form of communication [7], [8]. Therefore, the influence of the parameterization of smells on the final result (end of the sugar) was studied.

The reach of the pheromone smell is important for the simulation process. It is advantageous to present large pheromone trails (around 11 fields), however, if the trails get too large

(around 14 fields), the ants may become confused, possibly due to concurrent smells of two or several trails and, consequently, the number of necessary steps until the end of the food increases (figure 16).

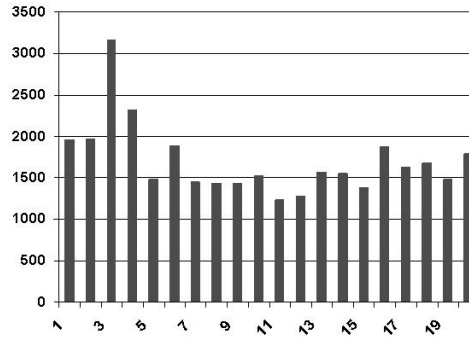


Fig. 16. Pheromone reach in fields (x-axis) and the number of iterations until the end of the food (y-axis)

The derogation of pheromone is important for dynamic processing. Old trails shall not be followed as the food source at the end of them is probably already depleted. On the other hand, trails must not derogate too fast in order to ensure a good recruiting and guidance of ants. Tests showed that the point of balance is one step of derogation per 140 iterations (figure 17).

E. Biological Plausibility of the System

BIOANT may be considered a biologically more plausible Artificial Life system because of the following reasons:

- It uses a connectionist architecture which fulfills 4 of the 6 criteria proposed by [10] for a Biologically Plausible Artificial Neural Network: biological realism, distributed representation, bidirectional activation propagation and error-driven learning. The remaining unattended principles of inhibitory competition and Hebbian Learning may be implemented in future versions,
- Typical behavioral aspects of ants were successfully implemented, and
- Physical elements of ants were simulated (sensors and actuators).

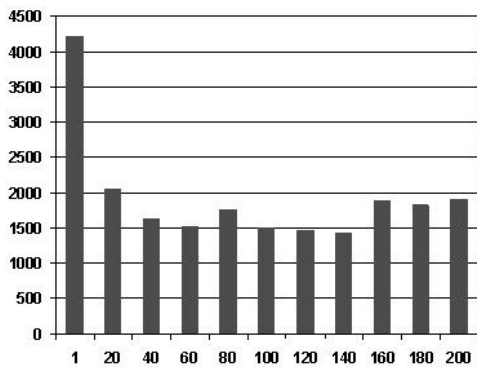


Fig. 17. Pheromone derogation (x-axis) in necessary iteration steps per one derogation step and required iterations until the end of sugar (y-axis)

IV. ARTIFICIAL EVOLUTION

BIOANT intends to contribute to Artificial Evolution research, i.e., the principle of evolution applied to Artificial Life systems. Natural evolution took billions of years in history and today it worries researchers who try to discover more complex principles [1], [3]. This way (even if modern times are times of hurry and stress), scientists shall not lose the feeling for the fact that knowledge needs to grow, paradigms must be broken, and all this takes time.

The present system aims to be inserted in Artificial Evolution, starting - just like in natural evolution - with a simpler situation. It is certainly interesting to start Artificial Life projects this way, because even less information exists on more complex beings. Everything around the system must mature (not only the programming techniques) and the fact that nature took so long to arrive at the current state may be a firm alert that there is much research to be done, small and firm steps to be taken and that there is no room for hurrying, arrogance, or politics [1], [3].

V. FUTURE DEVELOPMENTS

There are many possibilities for future developments. The general objective is to create a simulation that is even closer to the real situation:

- Development of a completely connectionist approach: as a preliminary step, a system might be created which does not use symbolic routines anymore and produces the same outcomes via connectionist controllers,
- Development of a system that is more open: although an ant does not learn exactly with the environment and evolution is quite slow, a system that is more open and allows continuous evolution may be created with the aim to produce a "super-ant" (without having defined beforehand what exactly that would mean). This kind of project may contribute fundamentally to biological research, explaining how prepared a species of ants may be for the future (see [5]), and
- Creation of a robot based on the results of the simulation: this may be especially interesting as it may contribute

to the existing commercial applications of Artificial Life systems (e.g. in Shopfloor systems as in [4], [2]).

VI. CONCLUSION

The system BIOANT simulates a small ant colony using a hybrid and a symbolic control algorithm. It was shown that the connectionist controller has several advantages over the symbolic algorithm and that it is adequate for use in this situation.

It is the objective of the proposed system to contribute to the following areas of research: Artificial Neural Networks, Artificial Life, Intelligent Agents, and Robotics.

The present system aims to be part of Artificial Evolution research, starting - just as in natural evolution - with a simpler form of life [1], [3].

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