Territory Formation in Mobile Robots

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Abstract

Animals navigate through their environment using diverse strategies. These navigation strategies might be highly dependent on the animal's ecological niche. Though a lot of work is focused on biological navigation mechanisms, the cognitive ecology of spatial memory is poorly understood. The performances of different navigation mechanisms in the context of a biologically relevant behavior can be assessed by using mobile robots. For this task, territorial behavior was built on Khepera miniature robots. Territoriality is strongly dependent on spatial learning and thus provides a powerful context for testing of sensory and computational complexity needed by animals solving special tasks. Simultaneously, the principles underlying the establishment of territories in a previously uninhabited area and how it is dependent on environmental parameters can be investigated. In the present paper, territoriality in robots is introduced. The robots navigate by relying on poor sensor input and a representation of the environment of a low complexity. Qualitative results show that territories form. Subsequently, the consequences of the introduction of a newcomer in already established territories are presented.

Introduction

If animals navigate through their environment, they generally rely on various orientation mechanisms. By navigating they have to solve problems according to their ecological niche. It can be expected that the navigational mechanisms found in animals are strongly dependent on this niche or — the other way around — that a certain mechanism might be favorable for one species but useless for another. Hence, the performances of navigational strategies have to be determined dependent on their context.

Many attempts have been made to adapt biologically inspired navigation strategies in robotics (for review see Franz & Mallot 2000). In these applications the general functionality and use of certain mechanisms for navigation were shown. However, if the cognitive ecology of spatial memory should be assessed by using mobile robots, the navigational strategies have to be integrated in a behavior. The goal is to find out how valuable different mechanisms are for spatial behaviors since animals usually rely on combinations of multiple mechanisms. Thereby, the least sensory and computational complexity needed for the behavior can be investigated and the performance of individuals with different strategies can be compared.

Territoriality is a behavior which is based on a representation of the animal's environment and thus provides a biological relevant context for the use of navigational strategies. The territorial behavior of Khepera robots presented in this work is based on a model for territory establishment proposed by Stamps and Krishnan (1999). This model is based on spatial learning, but otherwise only uses few assumptions concerning the animals. Besides providing a context for the testing of mechanism of spatial memory, the robot implementation will also improve understanding of territorial behavior in animals.

The building of this model on autonomous robots combines the challenges of navigation with the establishment of a territory. The navigation is based on poor sensory input and a parsimonious memory. Territory formation is a consequence of attractiveness values assigned to each place. This value reflects the probability of return which is dependent on the previous encounters with competitors in that patch of the habitat. The implications of external constraints, like changing environments, on a special behavior can be tested and favorable sensory and cognitive equipment adapted to the ecological niche can be determined. This relates to the question of the evolutionary consequences of changing properties of organisms and ecosystems which is posed by Bedau et al.(2000) as an open problem in artificial life.

The present work addresses the question which mechanisms of spatial memory subserve territorial behavior in a real world environment. We will introduce territoriality in animals and the open problems in this field. A summary of the model of territory formation (Stamps & Krishnan 1999) will be provided afterwards and the territorial robots will be presented.

Territoriality in Animals

A lot of research has been conducted focusing on territorial behavior in different animals. A territory is defined as the part of an individual's (or group's) home range, i.e. the part of the space the animal uses regularly and which it defends against conspecific competitors (Maher & Lott 1995; Stamps & Krishnan 1999). The animal thereby endures the costs of the defense in order to monopolize the resources of the territorial area. Hence, territoriality can only occur if the defended resources are not strongly clustered since the intruder pressure would become too high (Adams 2001).

Territorial behavior appears in various forms in diverse animals. However, similar principles might underly many of the observed behavioral patterns. Such principles are sought to be pinpointed by using models. Many models consider the optimal behavior of a single individual in a habitat which is already divided in territories. All other individuals are assumed to behave according to one fixed strategy (Adams 2001; Kokko & Lundberg 2001; Baird, Sloan, & Timanus 2001). Maynard Smith (1982) proposed a game-theoretical model in which two individuals "negotiate" the border between their territories. Depending on the costs of fights, an optimal strategy can be found which maximizes the territory size with minimal costs.

A Model of Territory Establishment

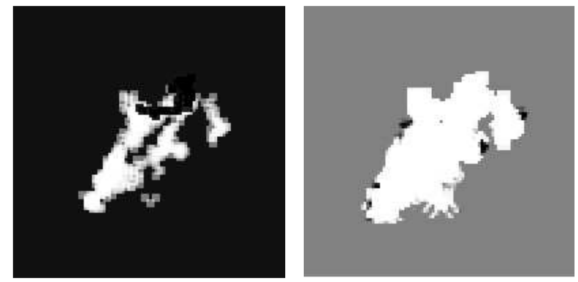
The mechanisms that lead to the division of a previously uninhabited area are not well understood. Stamps and Krishnan (1999) proposed a model for the establishment of territories in habitats with homogenous distribution of resources. The model is based on the animals' ability of spatial learning, i.e. the animals first explore their habitat starting from an arbitrary location and simultaneously gaining advantage over individuals that are not familiar with the same patch of the environment. However, the ability of spatial learning is only reflected in a value A_i associated to the patches; the representation of space by the individuals is assumed.

In the following, we summarize the model. It is assumed that the animal gains a better knowledge about an area, consisting of a small part of its habitat, each time it visits it. Since this knowledge is an advantage for the animal, it will return to this area with a higher probability as compared to areas which it visited less frequently. On the other hand, encounters with conspecifics always lead to fights and are thus considered as negative experiences. Hence, the probability of returning to an area where fights took place is reduced. These probabilities are reflected by "attractiveness values" A_i of each area i in the model. They are computed according to the following equation:

$$A_i = P_{\max}\left[1 - e^{-\frac{N_{pi}}{R_p}}\right] - F_{\max}\left[1 - e^{-\frac{N_{fi}}{R_f}}\right]$$

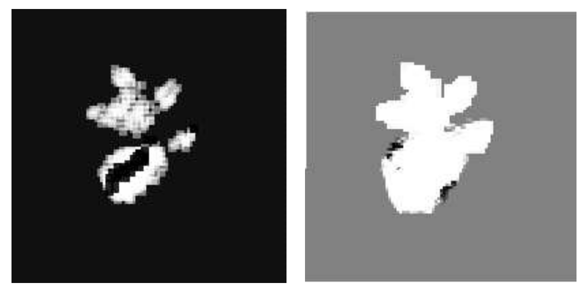
with

$P_{\max}$ = *maximal attractiveness of an area*



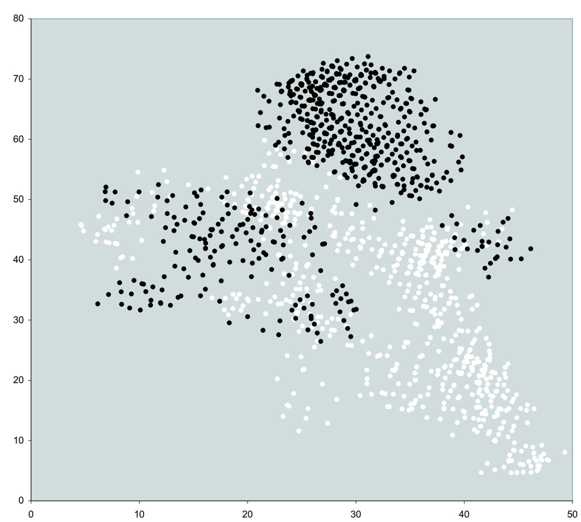
(a) Attractiveness values by robot 1 in robot coordinates.

(b) Occupancy grid by robot 1 in robot coordinates.



(c) Attractiveness values by robot 2 in robot coordinates.

(d) Occupancy grid by robot 2 in robot coordinates.



(e) Places visited by the robots in arena coordinates. Robot 1 is marked by black dots, the places visited by robot 2 are plotted in white.
Each robot made 700 steps.

Figure 1: Two robots establishing their territories.

N_{pi} = *number of positive visits to area i (i.e. without encounter of a conspecific)*
R_p = *constant defining the attractiveness increase per positive visit*
$F_{\max}$ = *maximal attractiveness reduction of an area*
N_{fi} = *number of visits to area i with fights (i.e. with encounter of a conspecific)*
R_f = *constant defining the attractiveness decrease per fight*

The agent in the model as well as the robot constantly move around in the environment, computing the new attractiveness value of an area after each visit. The selection of the next area is accomplished stochastically from the nearest neighbors, whereby the areas with the highest attractiveness values are more likely to be visited.

Territoriality in Robots

The territorial behavior is built on Khepera miniature robots. They are placed in an environment with obstacles of random locations and controlled via a radio module. Using its short-range infrared sensors, each robot can detect obstacles while its position information is provided externally. As a representation of the environment an occupancy grid was chosen that divides the environment in discrete cells (Elfes 1987). To each cell a probability value is assigned reflecting the robot's belief of finding an obstacle in this cell. Each time the robot detects an object in the area of a cell, it elevates the probability value associated to this cells. The integration of the probabilities over time are computed according to the algorithm presented by Thrun (1998).

Parallel to the grid map, a second map of the same size is built up. In this map, the attractiveness values of the patches in the environment are stored. Each time the robot moves to a new area, the attractiveness value is changed according to the model of Stamps and Krishnan (1999) as described above. In each time step, a new area in the neighborhood is chosen with a probability which is proportional to the attractiveness value:

$$p_i = \frac{A_i}{\sum_j^k A_j}, \quad \forall\, j : occ_j \leq 0.5$$

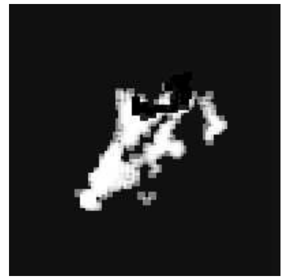
with

p_i = *visit probability for area i*
A_i = *attractiveness value of area i*
k = *number of neighbors of the area i*
occ_j = *occupancy probability of area j*

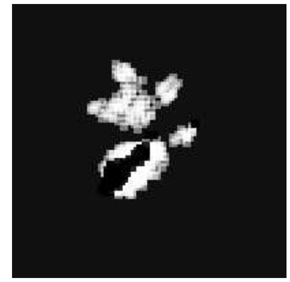
The robot considers its occupancy grid map by rejecting the areas which are occupied by obstacles from its choice of a new area.

Results

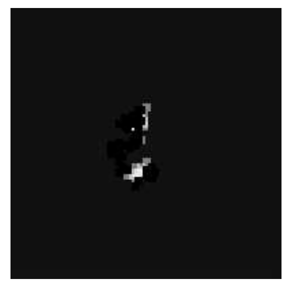
It is shown that the simple model presented above leads to the formation of territories, even though parsimonious



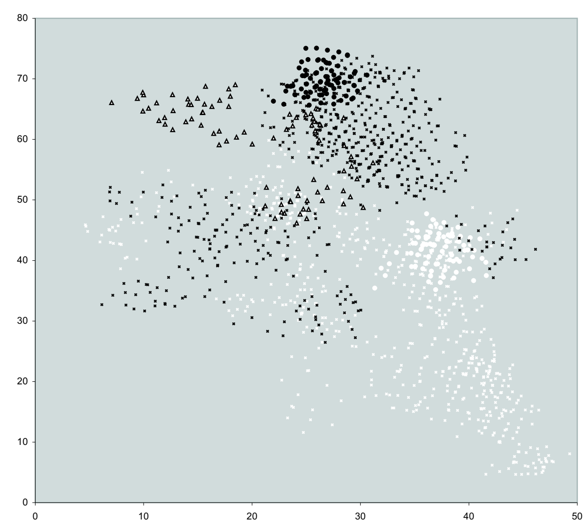
(a) Attractiveness values from robot 1 in its own coordinates after introduction of the newcomer.



(b) Attractiveness values from robot 2 in its own coordinates after introduction of the newcomer.



(c) Attractiveness values from the newcomer in its own coordinates.



(d) Places visited by the three robots in arena coordinates. Robot 1 is marked with black, robot 2 white signs. The places which were visited before the introduction of the third robot are marked by small crosses (compare Fig.1e). The places visited by the newcomer are plotted as triangles. Each robot visited 80 places since the introduction of the newcomer.

Figure 2: Introduction of a newcomer in a system of two established territories.

spatial representation and sensors are used. Each robot in the arena builds up a territory, i.e. it does not use all the accessible space, but stays restricted to a part located around its starting position. The territory is defined as the space that covers all the positions visited by the robot (Fig.1e). The shape of the territory is reflected in the known parts of the occupancy grid (Fig.1b/d) as well as in the areas of elevated attractiveness values (Fig.1a/c). Between the territories of the two robots exploring the environment simultaneously, a buffer zone visited by both robots can be observed. However, the buffer zone is visited less frequently by both individuals (Fig.1e).

In the attractiveness grids, gaps become obvious (Fig.1a/c). These arise if a robot meets an opponent in an area that it visited before. By decreasing the attractiveness value of this area, the areas lying behind it become separated from the main territory region.

After 700 time steps and the formation of two territories, a third robot was introduced (Fig.2). In order to observe the impact of a new individual on already established territories, the third robot was placed in between the two existing territories. While the effects on the existing territories is small, in 80 steps the new robot was not able to establish a stable territory which is reflected in the low number of areas with increased attractiveness values (Fig.2c).

Conclusions

In the present paper, territorial behavior was implemented on mobile Khepera miniature robots. This behavior will provide a platform for the investigation of navigational mechanisms in a biologically relevant context.

The establishment of a territories in two robots roaming around in the same environment was shown. The resulting territories are exemplary. The arena was chosen larger than the space which two territories would claim. However, the introduction of a third individual in the border zone between two established territories shows that limited space complicates the formation of a stable territory.

The relatively simple mechanisms that were used in our presented work suffice for the appearance of a complex behavior. In future work, individuals with different sensory and computational equipment will be run against each other. The performance of the navigation mechanisms can be determined directly by comparing the individuals. On the other hand, the influence of changing parameters of the environment will be tested.

Acknowledgments

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