Proc. of The Fifth int. Sym. on Artificial Life and Robotics (AROB 5th'00)
Oita, Japan, 26-28, January, 2000,

From Life to Robotics: Social Robots

S. Reimann
Institute for Autonomous intelligent Systems
German National Research Center for
Information Technology **GMD**
Birlinghoven, Germany.
email: stefan.reimann@gmd.de

A. Mansour
BMC Research Center
The Institute of Physical and
Chemical Research (**RIKEN**)
Nagoya, 463-003, JAPAN
email: mansour@nagoya.riken.go.jp

Abstract

The formation of groups is of essential importance in biology. Aggregation is based on a simple dynamical model for the motion of each individual. It is shown that a *swarm* is formed within a short time span and is stable under perturbations.

Keywords: *Grouping behavior, stochastic control.*

1 Introduction

Following the work by E. Haeckel, multicellular organisms had evolved from *volvox-like colonies* of unicellular, autonomously acting organisms. The aggregation of *Dictyostelium* cells to highly organized colonies is one of the best studied examples for this kind of self-organization in ensembles of interacting individuals. Aggregation may be induced by environmental changes. Under gentle environmental conditions, *Dictyostelium* cells live alone, while if, for example, nutrance becomes rare, 3-dimensional colonies are constituted, exhibiting a high degree of functional organization up to differentiation [**?**]. Higher organisms show grouping behavior as well: Particular tasks like hunting or defense against enemies may not be achievable by single individuals, but may be realizable by cooperation of many. In general, one may claim that the maintenance of the group, not necessarily the maintenance of single individuals, may be regarded as the most fundamental function of social behavior. As such the establishment of groups is of vital importance.

The formation of colonies has to be sufficiently fast and must be stable with respect to external disturbances. These particular features will be more closely studied in the following. The aim of this work is not to mimicke any particular biological phenomena, rather than to discuss these features from a principal point of view. To make this point clear, we call the objects under consideration agents. Our model of an *agent* is based on biological considerations [**?**] about simple organisms such as protozoa, bacteria, up to insects. We believe that the same functional architecture is analogously realized in higher organisms as well.

2 Restricted random walk

Motion patterns of simple organisms are commonly regarded as generated by random mechanisms. Accordingly, we base our model on a "random walk"-like mapping

$$x \mapsto \varphi(x), \qquad x \in X, \tag{1}$$

where $x \in X$ is the agent's position in some space X, and φ is a random mapping on X. We assume that the agent at each time approximately maintains its former direction, i.e.

$$0 \leq \frac{\langle x,\, \varphi(x) \rangle}{\|x\|\, \|\varphi(x)\|} \leq 1 - \alpha,$$

where $0 \leq \alpha \leq 1$ may be interpreted as the "flexibility" of the agent. Obviously, if $\alpha = 0$, then the motion of the agent is deterministic. Equivalently, we assume that the determinant of the linearized mapping associated with φ is non-negative. If it is zero, the agent is stationary. The motion due to (1) is a (restricted) random walk having trajectories of bounded mean curvature, determined by α.

If the motion of an agent would be due to a random walk, the mean time needed to reach a given target would be a quadratic function of the agent's initial distance from that point. Hence, it would take a quite long time to reach a point from a far distance. Moreover, as also known from the Theory of Diffusion Processes [**?**], the agent will come close to any given point only if X does not have a dimension larger than 2. In three dimensions it will not. Consequently purely diffusive motion does not provide a reliable strategy to sufficiently quickly form groups.

3 Weighted random Walk

The above elementary model can be extended as follows. As already stated in the basic model the determinant of the motion generating mapping is non-negative. The only extension consists in multiplying φ with a weight taking values in the set of real numbers. This weight depends on the actual motion of the agent, i.e. as a function, the weight depends on the agent's actual position and its position before. For details about the model and in particular about the definition of the weight function, see [**?**]. The motion is generated by the following mapping defined on $X \times X$ having its range in X

$$(x, x') \longmapsto \varphi_{c(x,x')}(x), \qquad (2)$$

where x' is the precursor of x. As such the determinant of the linearized mapping $\mathcal{L}_c$ corresponding to φ_c can be either $+1$ or -1 depending on the value of $c(x, x')$. Accordingly, the agent either continues or reverses its former direction.

This simple extension leads to fundamentally new motion features: Firstly, it can be shown [**?**] that the agent will reach a given point almost surely in all dimensions, in particular in those larger than 2. Secondly, its mean arrival time is only a linear function of its initial distance. Consequently, reaching a giving point happens much faster than in a purely diffusive setting. In summary, motion due to a weighted random walk as defined above provides reliable and fast target-reaching behavior.

4 Following behavior

The first step in analyzing group behavior is to consider only two agents. As our scenario we consider a "prey" moving along some given path, while it is hunted by a "predator". We assume that the motion of the prey is deterministic, while that of the predator is due to a weighted random walk. The question is: Will the predator reach its prey? The answer, roughly speaking is "Yes", if the predators speed is not too low compared with that of its prey. A second setting is that the prey moves completely randomly with some mean escape time. Again, the predator will reach the prey if its relative velocity is high enough. This stable reaching behavior is due to the stability of the dynamics generated by a weighted random walk, as defined above.

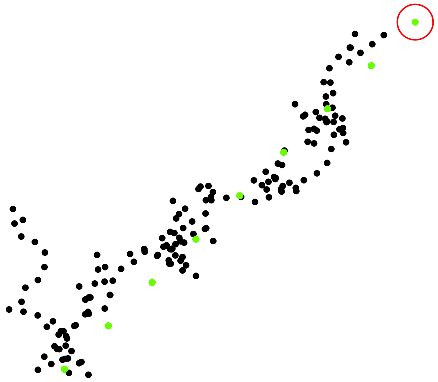

Figure 1: One robot moving along a nearly straight line (deterministic), while a second one follows it by our algorithm.

5 Grouping behavior

The generalization to an ensemble of n interacting agents is straight forward. For simplicity we may assume that interaction is distance-dependent, such as in interactions mediated by light, sound, or based on diffusing chemicals. As such, the motion of a single agent depends on the motions of all other agents in the group. Again we avoid to define the corresponding mapping generating the motion of an agent in a group of signalling agents in detail; however the motion is a function $\Phi_{\mathbf{c}} : X^{2n} \rightarrow X^n$ defined by

$$(\mathbf{x}, \mathbf{x}') \longmapsto \Phi_{\mathbf{c}(\mathbf{x},\mathbf{x}')}(\mathbf{x}), \qquad (3)$$

where $\mathbf{c}_i(x_i, \mathbf{x}')$ is the weight of the i-th agent depending on the motion of all other agents in the group. As above, $\mathbf{x}'$ is the precursor of $\mathbf{x}$. It can be shown that under fairly mild assumptions this mapping has a stable fixed point in X^n. This point corresponds to a stable configuration of the agents. If all agents are identical, the asymptotic configuration is a *finite* "cloud".

The time needed for establishing such a cloud also is a linear function of the initial distances (see [**?**]). Hence the formation of such groups can happen quite quickly. Because of stability, this cloud will be maintained under perturbances. In particular, if one agent moves along a given line without respect to influences by other agents, the ensemble will follow it. This can be regarded as elementary swarming behavior.

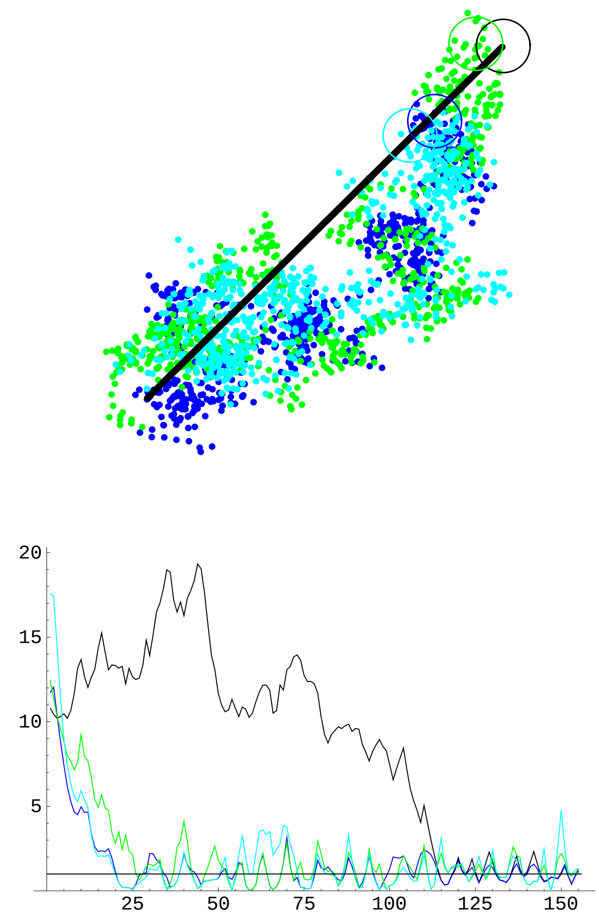

Figure 2: One robot moving along a nearly straight line (deterministic), while the rest (the cloud) follows it.

6 Summary

In this paper we have considered an elementary extension of a model generating random-like motion in space. It was shown that target-reaching was reliably achieved within a time-span, being less than that expected in purely random systems. As a consequence, stable following behavior was obtained, as well as the formation of groups of interacting agents. The computational effort needed is minimal and, hence, the performance is fast. Models based on "weighted random walks" may provide both, a general framework for modeling basic motion features of simple organisms, as well as a methodology to reliably control simple robot systems.

References

[1] J. D. Murray, *Mathematical Biology*, Springer Verlag, 1989.

[2] S. Reimann and A. Mansour, "Oriention by weighted randomness," *Artificial Life and Robotics*, vol. 4, 2000, To appear.

[3] J.L. Doob, *Stochastic Processes*, Wiley Publications in Statistics, 1953.

[4] S. Reimann and A. Mansour, "Navigation by weighted chance," in *The Second International Conference on Intelligent Processing and Manufacturing of Materials IPMM'99*, July 10 - 15 1999, pp. 1103 – 1107.

[5] S. Reimann and T. Krüger, "Reliable motion control," In preparation.