Distributed Decision Making and Optimization with Swarms

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Abstract

The behaviours of social animals can provide valuable guidelines for designing artificial systems. The complex problem solving skills that developed out of the interactions of many simple individuals are called swarm intelligence.

This work has covered two distinct aspects of swarm intelligent systems. In the first part, several modifications to established swarm intelligence methods for optimization were described and evaluated. Also, new methods for a difficult real-world problem were introduced. The second part focused on intelligent behaviours of real honey bee swarms. Models of the underlying interactions were created to better understand the complex system behaviour.

The Particle Swarm Optimization (PSO) search method has been applied to many different optimization problems previously. In this work, several extensions and modifications of the basic PSO scheme were proposed, that are both generally applicable or designed for a specific application. In particular, we focused on modifying the population structure of PSO.
A hierarchical topology was created within the swarm for improving the optimization performance. Furthermore, the hierarchy could be utilized in dynamic environments to quickly readjust the swarm after a change of the search space and to detect a change under noisy conditions. With this hierarchical ordering an efficient parallel implementation with flexible tasks that can cope with variable resources could be obtained.

A multi-objective PSO approach using a more coarse-grained population structure was developed for the problem of docking a small drug molecule to a receptor. Here, the PSO population was dynamically clustered into several sub-swarms that searched independently. The obtained docking results were superior to those found with two standard search methods and the set of returned solutions was more diverse. Moreover, an efficient method for predicting a possible docking trajectory of low energy for the ligand was proposed.

Two biological swarm systems were studied with detailed models of the processes. Both examples are part of the reproductive cycle of a honey bee colony. When a colony grows too large, the queen and part of the worker bees move to a new nest site. The move is preceded by a collective decision making process for a new home by several scout bees. It could be shown, how with simple behavioural rules it is possible to regulate the number of bees actively searching for new sites, according to the quality of the currently discovered nest sites. Also, effects of distance and time of discovery of the alternatives on the final decision were taken into account. Once a unanimous decision has been reached, the scouts guide the swarm of uninformed bees by flying repeatedly through it in the direction of the new nest site. The model of swarming behaviour provided strong support for this hypothesis of guidance by visual cues, stated by Martin Lindauer.

With our models, issues of biological interest could be addressed. The detailed formulations helped to provide some understanding of the underlying principles. Moreover, the individual-based behavioural descriptions can provide