Natural optimization: An analysis of self-organization principles found in social insects and their application for optimization

The application in computer science of the behaviour found in decentralized self-organizing animal collectives -- also known as swarm intelligence -- has brought forward a number of state-of-the art control and optimization mechanisms. Further study of such self-organizing biological systems can foster the design of new robust and adaptive algorithms, as well as aid in the understanding of self-organizing processes found in nature.

This thesis covers both of the aspects described above, namely the use of computational models to investigate open questions regarding the organization and behaviour of social insects, as well as using the abstraction of concepts found in social insects to generate new optimization methods.

In the first part of this work, general aspects of division of labour in social insects are investigated. First the adaptiveness of different-sized colonies to dynamic changes in the environment is analysed. The findings show that a colony's ability to react to changes in the environment scales with its size. Another aspect of division of labour which is investigated is the extent to which different spatial distributions of tasks and individuals influence division of labour. The results suggest that social insects can benefit from a spatial separation of tasks within their environment, as this increases the colony's productivity. This could explain why a spatial organization of tasks and individuals is often observed in real social insect colonies.

The second part of this work investigates several aspects of self-organization found in honeybees. First the influence of spatial nest-site distribution on the ability of the European honeybee Apis mellifera to select a new nest-site is studied. The results suggest that a swarm's habitat can influence its decision-making process. Nest-site rich habitats can obstruct a swarm's ability to choose a single site if all sites are of equal quality. This could explain why in nature honeybee species which have less requirements regarding a new nest-site have evolved a more imprecise form of nest-site selection than cavity-nesting species.

Another aspect of honeybees which is investigated is the guidance behaviour in migrating swarms. Two potential guidance mechanisms, active and passive guidance, are compared regarding their ability to reproduce real honeybee swarm flight characteristics. The simulation results confirm previous empirical findings, as they show that active guidance is able to reflect a number of characteristics which can be observed in real moving honeybee swarms, while this is not the case for passive guidance.

Nest-site selection in honeybees can be regarded as a natural optimization process. It is based on simple rules and achieves local optimization as it enables a swarm to decide between several potential nest-sites in a previously unknown dynamic environment. These factors motivate the application of the nest-site selection process to the problem domain of function optimization. First, the optimization potential of the biological nest-site selection process is studied. Then a general algorithmic scheme called ``Bee Nest-Site Selection Scheme'' (BNSSS) is introduced. Based on the scheme the first nest-site inspired optimization algorithm ``Bee-Nest'' is introduced and successfully applied to the domain of molecular docking.