Self-Organized Specilization and Controlled Emergence in Organic Computing Systems

Organic Computing is a new field of computer science that has the vision to make technical systems more life-like in order to address the challenging requirements raised by their increasing complexity. Complex natural systems are often self-organizing and show an emergent behavior that makes them robust, adaptive, and reliable. Organic Computing wants to identify and adapt principles of self-organization and emergence of natural systems, in order to endow technical systems with the same properties and to develop methods to control the resulting technical systems. The thesis covers all these aspects: the application of self-organization principles found in nature to technical systems, the utilization of emergence, and the development of control methods for emergent behavior.

We investigated two typical self-organizing systems that exploit emergent effects. Emergent Sorting Networks sort sequences of objects traversing the networks and DPClust is an algorithm for decentralized clustering in networks. In both systems large populations of interacting elements generate a macroscopic behavior not existent on the element-level. It was shown that these emergent behaviors scale well with the systems size, a typical property of self-organizing systems.

To control emergent effects a new approach called *swarm controlled emergence* was introduced. This approach uses a swarm of control components introduced in addition to the normal components. A proof of concept was given by successfully applying the approach to control the emergent clustering effect in a well known model of the clustering behavior of ants. It was shown that it is not a trivial task to design control swarms, since their inference with the system may lead to new or even stronger emergent effects.

For dealing with support and system care tasks in Organic Computing systems we introduced *Organic Support Systems*. These systems consist of so-called helper components which exhibit reconfigurable hardware to be able to adapt to the needs of the supported systems. Inspired from models of task allocation in social insects, we studied different task acceptance and reconfiguration strategies. A two helper system was investigated theoretically and it was shown experimentally that a large number of helpers can adapt well to dynamic situations. If service tasks can be split into subtasks the helper components must use local reconfiguration strategies to decide for which subtasks to configure. It was shown, that a strategy based on exponentially distributed thresholds performs better than simple strategies. The stability of a probability based strategy was shown theoretically. In case the supported system and the helpers are connected via a network, we proposed to allocate the support tasks using the DPClust algorithm. It was sown that such a system has a strong adaptive behavior and reduces the reconfiguration costs significantly.

In the last part of the thesis we studied an approach to generate suitable rule sets for solving classification problems in Organic Computing systems consisting of autonomous, memory constrained components. A multi agent system that uses interacting Pittsburgh-style classifier systems can evolve appropriate cooperating rule sets that overcome the restricted memory size of the components. It was shown that the communication topology strongly influences the average number of components that a request has to pass until its classificatin and that communication costs lead to a more even distribution of knowledge and reduce the communication overhead.