Executive Summary

Dagstuhl Seminar "Organic Computing – Controlled Emergence"

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The Goals

Organic Computing has emerged recently as a challenging vision for future information processing systems, based on the insight that we will soon be surrounded by systems with massive numbers of processing elements, sensors and actuators, many of which will be autonomous. Because of the size of these systems it is infeasible for us to monitor and control them entirely from external observations; instead they will need to help us monitor, control and adapt themselves. To do so, these components will need to be aware of their environment, to communicate freely, and to organize themselves in order to perform the actions and services that are required. The presence of networks of intelligent systems in our environment opens up fascinating application areas but, at the same time, bears the problem of their controllability. Hence, we have to construct these systems - which we increasingly depend on - as robust, safe, flexible, and trustworthy as possible. In particular, a strong orientation towards human needs as opposed to a pure implementation of the technologically possible seems absolutely central. In order to achieve these goals, our technical systems will have to act more independently, flexibly, and autonomously, i.e., they will have to exhibit life-like properties. We call those systems "organic". Hence, an "Organic Computing System" is a technical system which adapts dynamically to the current conditions of its environment. It will be self-organizing, self-configuring, self-healing, self-protecting, self-explaining, and context-aware.

The vision of Organic Computing and its fundamental concepts arose independently in different research areas like Neuroscience, Molecular Biology, and Computer Engineering. Self-organizing systems have been studied for quite some time by mathematicians, sociologists, physicists, economists, and computer scientists, but so far almost exclusively based on strongly simplified artificial models. Central aspects of Organic Computing systems have been and will be inspired by an analysis of information processing in biological systems. Nevertheless, the anticipated first generation of organic computing systems will still be based on well known silicon technology. Their life-like properties will arise from opening up certain degrees of freedom in the functionality of technical application systems and by the transfer of organizational concepts observable in natural systems into their system architecture.

This Dagstuhl seminar was meant as a forum for scientists from various disciplines working on key aspects of "Organic Computing" or on closely related concepts. Its objective was to initiate cooperative research on the major challenges of this vision of tomorrow's informatics systems. Although the occurrence of emergence has been well-documented in previous papers and conferences, the seminar addressed the new challenge of combining processes leading to emergence with system engineering. The challenge of "Controlled Emergence" is the possible contradiction of free running emergent processes generating new and unexpected results on the one hand, and the requirement of system engineering to design and manage a system with emergent properties in order to guarantee desired system behaviors and to avoid unwanted side-effects.

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These problems have been discussed from the perspective of different neighbouring disciplines (like physics, chemistry, biology) and computer science with the objective of investigating the applicability of self-organizing and emergent mechanisms to technical systems.

The Results

The crosscutting themes of the seminar were intensive discussions on the exact meaning of the terms self-organization and emergence, with the accompanying emphasis on creating not only better theoretical foundations for the use of these terms, but also better operational definitions, methods, and measurements of emergence and related phenomena. While no concise final definition could be reached, the terms have been narrowed down to a more practical and touchable meaning, excluding non-scientific notions of emergence and focusing on quantitative approaches.

The seminar was characterized by the very constructive search for common ground between engineering and natural sciences, between informatics on the one hand and biology, neuroscience, and chemistry on the other. The common denominator was the objective to build practically usable self-organizing and emergent systems or their components.

An indicator for the practical orientation of the seminar was the large number of OC application systems, envisioned or already under implementation, such as internet applications, robotics, wireless sensor networks, traffic control, computer vision, organic systems on chip, an adaptive and self-organizing room with intelligent sensors, or reconfigurable guiding systems for smart office buildings.

The application orientation was also apparent by the large number of methods and tools presented during the seminar, which might be used as building blocks for OC systems, such as

- an evolutionary design methodology,
- OC architectures, especially several implementations of observer/controller structures, which turn out to be a characteristic of OC systems,
- measures and measurement tools for emergence and complexity,
- assertion-based methods to control self-organization,
- Wrappings, a software methodology to build reflective systems,
- components for OC middleware.

Organic Computing is clearly oriented toward applications but is augmented at the same time by more theoretical bio-inspired and nature-inspired work such as:

- chemical computing,
- theory of complex systems and non-linear dynamics,
- control mechanisms in swarms of insects or simple robotic devices,
- homeostatic mechanisms in the brain,
- a quantitative approach to robustness,
- abstraction and instantiation as a central metaphor for understanding complex systems.

As an overall conclusion of the seminar, we want to emphasize the following three topics:

1. Organic Computing is coming of age. The OC vision is increasingly padded with meaningful applications and usable tools.
2. It has also become clear, however, that the path towards OC systems is still complex. Due to its multi-dimensional nature, there was no general agreement on a roadmap, although first steps were clear. One of these first steps was the considerable discussion of and agreement on the need for joint experimental testbeds, where a number of researchers could share methods and results and compare approaches and analysis tools. Closely related to the above was also the need to develop a number of benchmark application cases that could be used as part of the comparison process for the development of needed metrics on emergence and for clarifying the definitions of different types of emergent and self-organizing processes.
3. Emergence in self-organizing systems is an extremely interesting phenomenon. We are slowly coming to a more scientific understanding of emergent processes. But for OC to become mainstream in technical applications, we must study the nature of non-determinism in technical systems, be it unintentional (such as errors) or intentional (such as in learning systems). Technical systems with meaningful emergent properties, developing by self-organization, remain the long-term goal. In the short run, we must understand more clearly how to open the configuration space of technical systems for on-line modification. Finally,we must make sure that the human developers and users remain in full control while allowing the systems to self-develop and self-optimize. In practical terms, this means that a major challenge of OC is to make sure that one develops new strategies for instrumenting and analyzing the complex states of OC systems. It also requires new methods to support the dialog between system and human, e.g., both how a human's requirements of the system (many of which are qualitative) are represented and verified within the system and also, how an OC system self-reports its states and problems to a human participant.

In conclusion, the seminar's presentations and discussion successfully provided two critical functions to the new field of OC. First, it was an important "reality check", clarifying where the substantial progress has been made in the field, while at the same time, clearly showing the participants where more work is needed in the presented approaches as well as in generalizable approaches for the whole field. Second, it was a stimulating and community-building event, which encouraged the participants and motivated new collaborations. Such collaborations are essential for the work ahead and to meet the new challenges of combining system engineering with sophisticated OC systems that are robust, adaptive, and self-organizing.