Organic Computing – A New Vision for Distributed Embedded Systems

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Abstract

Organic Computing is becoming the new vision for the design of complex systems, satisfying human needs for trustworthy systems that behave life-like by adapting autonomously to dynamic changes of the environment, and have self-x properties as postulated for Autonomic Computing. Organic Computing is a response to the threatening view of being surrounded by interacting and self-organizing systems which may become unmanageable, showing undesired emergent behavior. Major challenges for organic system design arise from the conflicting requirements to have systems that are at the same time robust and adaptive, having sufficient degrees of freedom for showing self-x properties but being open for human intervention and operating with respect to appropriate rules and constraints to prevent the occurrence of undesired emergent behavior.

1. Introduction

The continuous trend towards smaller, more intelligent, and more numerous devices as characterized by Moore's Law is changing our environment dramatically. Within short time the visions of ubiquitous and pervasive computing [1, 2] will materialize, and we will be surrounded by multitudes of smart systems which offer special services in various areas of our life: Controlling our home (e.g. with respect to energy consumption), assisting us in driving and maintaining our car, monitoring our health and alerting us in case of dangerous conditions, supervising our children on their way to school, organizing our shopping lists, taking care of time-tabling and unified communication, providing all kinds of information and brokering services. Most of these devices are based on hardware and software concepts that are quite well known to us and present today.

If we look at our car, there are numerous components containing intelligent embedded systems responsible for keeping the car on the road, providing a comfortable environment and delivering information and entertainment services. Nowadays, there may be 50 to 80 intelligent control units in a single car, and this number will rise dramatically. And at the same time, these systems get more vulnerable. Although we (or our automotive engineers) may well be capable of designing correctly functioning components, there are numerous risks of unexpected behavior:

The automotive control units are connected to sensors and actuators; they will interact using various communication systems – dedicated point-to-point connections, buses, and even wireless networks like Bluetooth, UMTS, or waveLAN. This allows for adhoc-networking of systems (as desired when my personal devices get integrated into the automotive environment) within this car or within a certain vicinity of this car, but who can manage the complexity of a system consisting of that many actively interacting devices? Quality control usually is restricted to checking the functionality of components – but who can control the functionality arising from complex interactions between different systems? How can I determine who is actually controlling my car? Is it myself, is it my car, is it the car behind or on the next lane?

These questions exemplify the need for new methods to manage and control the behavior of complex systems and to create trustworthy systems adapting to our needs. This has been the motivation for starting the Organic Computing Initiative, which is a joint effort of special interest groups within the section of Computer Engineering within the Gesellschaft für Informatik (German Association for Informatics) and the Informationstechnische Gesellschaft (German Association for Information Technology). Based on the results of a series of "Workshops on Future Topics", the vision of Organic Computing was published in a position paper [3]. Meanwhile, the German Science Foundation (DFG) has approved a

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priority research program on Organic Computing, i.e. for the next six years the DFG will provide financial support for several research groups at German universities working on fundamental questions of Organic Computing [4]. One of the key statements of this initiative is the following:

It is not the question whether self-organized and adaptive systems will arise but how they will be designed.

In the following we shall outline the vision of Organic Computing and the research program of the corresponding priority program.

2. The vision of Organic Computing

Looking at the anticipated information and communication technologies of the year 2010 and beyond, we have to acknowledge the fact that we shall be surrounded by large systems of interacting intelligent devices. The design complexity of these systems will be no longer manageable and due to the effects of interaction the global behavior of these systems might be unexpected.

The remedy out of this threatening situation is provided by the vision of Organic Computing:

Future computing systems will have to show life-like behavior: They will have sufficient degrees of freedom to allow for a self-organized behavior which will adapt to dynamically changing requirements of the execution environment. Organic Computing systems will show the self-x properties as requested also in IBM's Autonomic Computing Initiative [5]. But while the latter initiative is directed towards creating server architectures which can be managed without active human interference, in Organic Computing we focus on large collections of intelligent devices providing services to humans adapted to the current requirements of their execution environment. Therefore, besides self-organization, man-machine interaction is an essential part of Organic Computing. Furthermore, organic computing systems shall provide robust services even in case of local faults, and they will support methodologies to create trust in their reliability and in the protection of privacy.

3. Self-organization and emergence

Before making statements about some major challenges of Organic Computing one has to look at the key notion of self-organization.

In the most general way the essence of self-organization is that system structure appears without explicit pressure or involvement from outside the system. This definition applies also to the many facets of self-organization called self-x properties [5]. For example, a system is self-healing, if it can eliminate the effects of mal-functioning units without needing for this corrective action any external assistance.

Obviously, this requires the capability to detect deviations from the correct functionality of the system on a global or local level.

The notion of self-organization has been an active area of research for many years, as can be seen from one of the extensive FAQ-lists [6].

An important effect of self-organization in large systems is the occurrence of differences between local and global behavior or functionality. In general, whenever global behavior can be observed to be a nonlinear combination of local behavior, we call this an effect of emergence. Typical examples are the formation of traffic jams or the creation of "green waves" by appropriate control of traffic lights. In physics, pressure and temperature are emergent effects of atomic behavior. A quite general characterization of emergence is given in [7]:

- Local actions/behavior of the members of a self-organizing system may lead to observable, emergent global patterns, structure, or behavior.
- This global behavior is of a different kind than the behavior of its components (in particular, not a linear combination of the individual actions).
- The removal of (single) components does not lead to a failure of the global functions of the system.
- The global behavior is completely new compared to that of the existing components, i.e. the emergent behavior seems to be unpredictable and not deducible from the individual components of the system, and it cannot be reduced on these.

One of the major points of this characterization is the statement that the emergent global behavior of a system cannot be predicted or deduced from local properties. This should make us very suspicious of any technical system being able to self-organize since we might have to experience unexpected behavior.

Nevertheless, in nature we observe many examples of robust systems being able to provide certain functionality in a completely self-organized way. Therefore, there is some hope that methods observed in natural systems might be transferable to technical systems. A standard example for this is the ability of ants to find shortest paths by indirect communication via pheromones. The transfer of these ant algorithms (or methods of swarm intelligence [8]) has resulted in powerful metaheuristics for optimization [9].

4. Challenges of Organic Computing

As outlined in the last section, the use of self-organization in technical systems might lead to unpredictable global effects. But, as mentioned before, within few years, we shall be surrounded by collections of systems which can interact and organize themselves. Furthermore, in order to allow for adaptive behavior in dynamically changing environments, it seems to be necessary to leave certain degrees of freedom in the design of technical systems. Hence, we have to work on letting the vision of Organic Computing become reality. In particular, answers are needed to the following challenges:

How can we guarantee that a self-organizing system does not show undesired global behavior? This will need carefully designed observer controller architectures similar to the MAPE paradigm of Autonomic Computing [5].

How can we determine appropriate rules and patterns for local behavior in large networks of smart devices which should deliver some requested global functionality?

How can an organic computing system find out the relevant information to act according to human needs? One aspect of this refers to adequate methods for artificial vision, a topic that is addressed by von der Malsburg [11].

How do we actually open up the necessary degrees of freedom for adaptive behavior? We definitely will need reconfigurable systems for this [12], and there are recent approaches to provide for autonomic behavior even on the transistor level [13].

What kind of methods can be designed to generate trust in the behavior of organic computing systems? The potential of self organizing, adaptive systems in our personal environment will only get exploited, if these systems show acceptable behavior, and an important prerequisite for acceptance is the development of trust. This might turn out to become one of the greatest challenges for organic computing.

This list of challenges is by no means complete, but it should be sufficient to indicate the necessary directions of research in Organic Computing.

The new priority program will focus on methods and architectures for controlled emergence and it will come up with a tool-box of concepts and technologies to support the realization of organic computing systems.

5. Conclusion

One of the most fascinating driving forces for research is the presence of challenging visions for the shaping of future technical systems. Organic Computing provides such a vision based on the urgent necessity to find methodologies for managing the complexity and controlling the behavior of large scale distributed embedded systems. The question is no longer whether self-organizing systems will arise, but how they will be designed. Extensive research efforts like our priority program are needed to come up with appropriate answers, major contributions are to be expected also from various related initiatives in autonomic computing, ambient intelligence, and cognitive systems. The appropriate combination of results from these research programs will be essential for realizing the vision of Organic Computing.

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