The Grand Challenges in Computer Engineering – Facing the Future

Die großen Herausforderungen der Technischen Informatik

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1 Introduction

Already today, the rapid progress in information processing has led to a pervasion of computer based devices in our all-day’s life. In future, solutions and improvements developed by Computer Engineering will offer support in all areas of human living. Assistance systems in health care, traffic, automotive technology or service robotics have to be mentioned. This support shall be offered to humans in an unobtrusive way. Furthermore, we want to live in a clean environment saving raw materials and resources. By intelligent control, computer based information systems have the potential to reduce the energy consumption of technical systems and to contribute to a lower CO₂ emission. Another important aspect in our industrial society is the preservation of present and the creation of new jobs. Facing these goals for a bright future poses grand challenges in Computer Engineering ranging from necessary basic research up to the fields of application.

The Grand Challenges initiative [1] of the German “Gesellschaft für Informatik” (GI) and “Informations-technische Gesellschaft” (ITG) points out research and development topics for Computer Engineering. These topics can contribute to a long-term preservation of jobs. Research leading to applications and products relevant for industry in the next 20 years is of special interest. Future fields of business can be supported by goal-oriented and in-time run-up research.

Eight fields of topic have been identified as “Grand Challenges” in Computer Engineering. They represent enabling technologies for future industrial applications, which have to be researched with emphasis. Furthermore, five key application fields have been chosen which are expected to be of high commercial relevance and importance. Figure 1 sketches these challenges and applications.

The next section outlines the grand challenges while Sect. 3 gives an overview of the application fields. Section 4 describes a first sketch of a roadmap leading to the mentioned goals. Section 5 draws conclusions. A foundation is given for the other articles in this special issue, which focus on selected topics of the grand challenges and applications.

Figure 1 The Grand Challenges and applications.
2.1 Omnipresent Information Processing (GC1)
This challenge covers the aspects of overall available access, distributed storage and management of information. Especially interesting is the possibility to integrate sensor systems into the World Wide Web. This allows to access complex information about real-world processes in real-time from everywhere. The main challenge addresses the interoperability and the integrity of the databases, the configuration and cooperation of information sources, the reliability and trustworthy of information sources and appropriate filtering techniques. To balance the potential of worldwide online real-time data access and the needs of security and privacy will be a major research issue.

2.2 Future Communication Networks (GC2)
Wireless and wired future communication networks have to be improved regarding technology, logic structures, protocols and efficiency. They are the prerequisite for any kind of information processing, which covers the collection, abstraction, interpretation and spreading of information. According to Gilder’s law [2], communication bandwidth doubles each year. The same can be expected for the communication nodes. This puts an immense pressure on future communication networks. To manage the expected information density and to satisfy the large number of heterogeneous processing nodes is another grand challenge for Computer Engineering in the next years.

2.3 Trust and Reliability (GC3)
Our daily life is mainly influenced by the trust we have in the objects and entities surrounding us. This is especially true for information processing systems, which are expected to serve our needs and keep our most private data. Therefore, the different aspects of trust and reliability are a grand challenge for future information systems. These are mainly security, safety, dependability, robustness, availability and privacy. It has to be ensured that future systems are able to keep promises made regarding these issues. In case of system misbehaviour, responsibilities have to be clearly defined and enforced.

2.4 Organic Computing (GC4)
The complexity of future information processing systems makes it impossible to develop and maintain them in traditional ways. Organic Computing provides a visionary view of future system design and management in response to the growing need for dealing with self-organization and the emergent effects of interaction in ubiquitous environments. Besides the complexity of soft- and hardware, an increasing unreliability of the hardware platforms also has to be taken into account [3] and to be compensated. An organic computing system is expected to adapt dynamically and in a self-organizing way to changing conditions and needs of its operating environment and its users. Depending on the current circumstances it reacts in a self-configuring, self-optimizing, self-healing, self-protecting and context sensitive way (the so-called self-X properties). Research on how to create such systems has already been started [4] and has to be continued for the next years. More details can be found in the article written by Christian Müller-Schloer and Hartmut Schmeck for this special issue.

2.5 Energy Efficiency, Environmental Impact and Sustainability (GC5)
The ongoing discussion on the use of natural resources, pollution of our environment and climate change has to be picked up by Computer Engineering. Energy efficiency, environmental impact and sustainability are key challenges of mankind. The impact of Computer Engineering on these challenges can be twofold: firstly, computation and communication systems increase their energy consumption from year to year [5]. By researching more energy efficient hard- and software technologies, this can be counteracted. Secondly, intelligent control mechanisms provided by computer systems can reduce the energy consumption and CO₂ emission of other technical systems like cars, factories, etc.

2.6 Hardware-/Software-Architectures and Tools for Multi-Core and Many-Core Processors (GC6)
Processor design has undergone a paradigm shift. The further increase of clock frequencies is limited. Future performance improvements will be mainly based on parallelism driven by the increasing number of transistors on a chip. As a result, more than one processing core is implemented on a processor chip [6]. These multi- and many-core processors pose new challenges not only on hardware research, but as well on software like operating systems, applications and tools to exploit the offered level of parallelism. Existing, mostly sequential application programs have to be parallelized, new multi-core applications not realizable with single core processors will arise. Operating systems able to manage a large number of cores and software tasks have to be developed. The special issue article written by Theo Ungerer focuses on this grand challenge.

2.7 Hardware-/Software-Architectures and Tools for Massively Parallel and GRID Systems (GC7)
High performance computing systems are necessary to handle many urgent problems of mankind, e.g., climate simulation to address climate change. The integration of the mentioned multi- and many-core processors will lead to a performance leap in high performance and GRID computing. Many open questions like how to overcome administrative limitation in GRID systems or how to use
mainly local management techniques when combining resources for transparent access have to be answered. High computation performance in the peta-FLOP range will help many scientists and engineers to run better simulations and to provide more accurate results.

2.8 Unconventional Computing (GC8)
Besides the traditional computing approaches, new and alternative computing mechanisms have to be researched. These principles called unconventional computing cover interdisciplinary research on optical computing, DNA computing, quantum computing, the use of nanostructures or analog computing. The combination of nano-structures with classical transistor technology is a promising field of work. Furthermore, nano-electromechanical systems offer an enormous commercial and economic potential. The article written by Dietmar Fey and Steffen Limmer will provide deeper insights.

3 The Fields of Application
Besides these eight general topics, five key application fields have been selected. These fields will be driven by the mentioned technologies of the grand challenges and are expected to gain high commercial importance.

3.1 Ambient Assisted Living (A1)
Ambient assisted living represents assistance systems in health care and life. Similar technical requirements are given as well for sick and operating rooms in hospitals, rehabs, senior homes and fitness centres. The mentioned grand challenges will provide new technologies to improve the quality of living not only for elder or sick people, but for every one of us. Future scenarios cover a multitude of monitoring, diagnosis and therapy devices, which will be placed in our environment or be worn with our clothes. Low energy consumption, environmental friendliness, respect of privacy, etc. are important features to be respected.

3.2 Smart Mobility (A2)
This field of application refers to our favourite transportation vehicle, the car. Several requirements have to be met for smart mobility. First of all, cars have to become more environmental friendly by better engine techniques. Furthermore, the use of vanishing resources like fuel has to be addressed. Electro mobility, hybrid engines, etc. are promising approaches. The increase of safety by avoiding accidents and protecting passengers is another issue. Growing comfort and robustness are as well important topics. The growing number of electronic components will increase our comfort in driving, but at the same time makes the car more vulnerable regarding malfunctions.

3.3 Service Robotics (A3)
Service robots are a growing market. Robots can be used in our private living area, in offices or in public buildings to perform routine or cleaning tasks. Robotics is an interdisciplinary field between mechanics, electronics and computer science. Embedded systems play a major role in this game. Improved sensing capabilities allow a better recognition of the environment, but demand for more processing power. Powerful processing hardware like, e.g., many-core processors furthermore can help making service robots smarter. Energy efficiency is a key issue in service robotics. Trustworthy, adaptivity, and self-organization are further demands to be handled. Erik Maehle’s article on service robotics will deliver more detailed information on this application field.

3.4 Computers for Health (A4)
Computers themselves can play a major role in health care. Starting with simple tasks, they can be used for administrative purposes like maintaining and organizing patient files. Improved interoperability in the rescue and treatment chain can help to save lives. More challenging, computers can be used to simulate organs, sicknesses and medication thus making animal experimentation unnecessary. This would additionally lead to a better understanding of processes in our body thus keeping us well and sane and prolonging our lifespan.

3.5 Smart Energy (A5)
Smart energy applies techniques for improved energy efficiency in various fields like our home area, cars, factories, etc. Driven by results of the grand challenge “Energy Efficiency, Environmental Impact and Sustainability”, key applications will profit in many ways. Being able to develop better products consuming less energy for important areas in the next years will increase the competitiveness of industries significantly. This will not only protect our environment, but as well preserve present and create new jobs.

4 A Sketch of a Roadmap
An active group of about 20 scientists is currently developing a roadmap to predict the future development for the mentioned grand challenges and applications up to the year 2030. Based on this roadmap, recommendations can be given for necessary research activities to reach the desired goals.

To give some selected examples, the grand challenge “Organic Computing” will lead from basic organic computing mechanisms available today to intensively communicating organic computing systems in about 10 years and to an overall use even in safety critical areas in about 20 years from now. Regarding the challenge “Many-Core and Multi-Core Processors”, we will face processor chips with more than 500 cores in 10 years and probably non silicon based processor technology in 20 years. This will as well drive the application field “Service Robotics”, where we can expect partly autonomous robots to help us with things like simple housekeeping, sanitation, training or artificial pets in 10 years. In
20 years, fully autonomous walking robots can relieve us from all routine work in our house and office.

These three examples show the close relationship and interaction between challenges like Organic Computing, Many-/Multi-Core Processors and applications like Service Robotics. Progress on one side enables and drives the progress on the other side.

5 Conclusions
The identified grand challenges and applications will have an influence on general problems of mankind. Figure 2 gives an overview. The darker the spheroid, the stronger the influence is. As can be seen, the grand challenges and applications can have a significant impact in contributing to the solution of main problems in our world. Therefore, success is necessary. With intensive research efforts and supported by reasonable funding, Computer Engineering can achieve important improvements for our living.

The following contributions in this special issue will give deeper insights in selected topics of the described grand challenges and applications. The reader should be enabled to understand and actively support the research work to be done.

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References

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