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Outlook

This chapter summarizes the project and briefly outlines the project contributions. In addition, it provides insights into open challenges in the engineering of software-intensive embedded systems that have been triggered by the efforts undertaken in the SPES 2020 project. The chapter outlines the impact of these challenges on future research.

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A major goal of the Federal Ministry of Education and Research (BMBF) is to support specific research endeavors in which academia and industry join forces to address challenges in the field and to provide a solid foundation for the engineering of software-intensive embedded systems in the future. The BMBF thereby ensures that Germany remains a significant location for high-tech industries. The SPES 2020 project has substantially contributed to achieving this goal.

SPES 2020 has established a fundamental modeling approach and has investigated in a number of issues comprising key concepts for advanced modeling of embedded systems. SPES 2020 has created a seamless development framework for the model-based engineering of embedded systems — this framework integrates and consolidates different existing approaches. The SPES 2020 modeling framework is defined based on three core concepts:

- *Viewpoints:* The SPES 2020 modeling framework distinguishes between four viewpoints: the requirements viewpoint defines the concepts and techniques for the systematic elicitation and specification of requirements; the functional viewpoint defines the concepts and techniques required to specify and model the system functions and their relationships; the logical viewpoint defines concepts and techniques required to decompose the system function into a system architecture of logical components; the technical viewpoint defines the concepts and techniques required to detail the logical architecture into a physical architecture that, amongst other things, specifies the hardware components of the system and the deployment of the software on those components.
- *Abstraction layers:* The SPES 2020 modeling framework explicitly defines abstraction layers to facilitate the definition of the embedded system at different levels of granularity. The concrete abstraction layers chosen for a particular system depend, amongst other things, on the application domain.
- *Seamless modeling of crosscutting properties*: In addition to the viewpoints and abstraction layers, the SPES 2020 modeling framework defines concepts and techniques for the seamless modeling of crosscutting system properties such as safety or real-time behavior.

To validate the framework, SPES 2020 has conducted extensive evaluation activities by means of case studies and experiments in five application domains. The evaluation clearly indicates that the SPES modeling framework is applicable in a wide variety of application domains and development settings, substantially supports the interplay of different engineering disciplines such as software development and mechatronics, and is well suited for the systematic engineering of complex safety-critical embedded systems.

In fact, by developing the SPES 2020 modeling framework and evaluating it in five diverse application domains (automation, automotive, avionics, energy, and healthcare), the SPES 2020 project has delivered an elaborated methodology that supports the systematic, integrated, and seamless engineering and operation of software-intensive embedded systems. Thus, SPES 2020 has established a firm basis for the model-based development of embedded systems.

Nevertheless, there are still open challenges in the area of engineering and operating embedded systems that go far beyond the work and scope of SPES 2020. These challenges pertain to the current state of practice and are triggered by a number of key requirements in the field. Examples are:

- *Long-term system evolution:* SPES 2020 was very much focused on model-based forward engineering of embedded systems. A key challenge of embedded systems today is that they are in operation and under further development for a long period of time, frequently spanning decades. Managing the evolution of such systems is thus an essential issue, as changes in the context of the system during its operation must be anticipated and considered systematically during the system lifetime. The SPES modeling framework already ensures a systematic consideration of the system's context and thus also supports system evolution. However, in order to support the evolution of embedded systems adequately, the SPES 2020 modeling framework has to be extended by concepts for defining context adaptability and context sensitivity. Another open issue is the adequate support for the step-by-step migration from today's legacy processes for the development of embedded systems to a systematic, model-based long-term software and system evolution process.
- *Variability management:* In many cases, individual systems or networks of systems are developed that comprise a large set of similar functionality and that share similar architectures and implementations. Providing a clear separation between common and system-specific parts in the engineering of embedded systems will leverage a large potential for saving development costs and time, as well as increasing quality. It is quite obvious that modeling techniques used in product line engineering are very well suited to supporting the engineering of product and system families. However, the increasing complexity of embedded systems and networks of systems poses additional challenges for managing the variability of

such systems. Open issues include the integration of variation points into a comprehensive system modeling framework and the resource-efficient management of different variants of embedded systems, components, and networks of systems.

- *Cyber-physical systems:* Today and more so in the future, embedded systems will form networks of interacting elements that feature a tight combination and coordination of the system's computational and physical parts, i.e., a tight relation between the digital and physical worlds. One open question is how to capture the nature and the interaction between the physical systems' context and the digital nature of embedded software systems in the development process. Another big challenge is the question of how to put embedded systems into a manageable relationship to global networks such as the Internet. In the past, embedded systems were typically closed systems with a static architecture, statically fixed sets of functions, and clearly defined static interfaces to their context. When embedded systems are connected to the Internet, those characteristics change. This creates various research challenges such as the challenge of dynamic system models, hybrid system models, dynamic interface models, and dynamic models of the architecture that address these different characteristics of systems and system parts, together with certain quality requirements such as safety and security. While SPES 2020 laid a foundation for addressing these challenges, further research is required to extend the SPES modeling framework with concepts and techniques that provide solutions for these challenges.

Overall, many scientific and practical engineering challenges remain to be solved. Hence, significant research effort is still required. Moreover, dedicated effort is required to ensure that the techniques and methods developed can be easily deployed to and adopted by industries. In order to support industrial uptake, process descriptions and guidance for system engineers that can be easily adapted to the specific requirements of the individual development processes have to be developed.

In addition, future research for embedded systems has to be strongly related to the sociological and to the economic contexts of embedded systems, as most technical devices will be mutually connected, enhanced by embedded software, and connected to the cloud. Issues of man-machine interaction and advanced assistance will become dominant. Systems will be ubiquitous, pervasive, and globally connected. Only if the engineers are able to construct such systems with a proven correctness, high reliability, and usability such systems will positively enhance our reality, and make our life easier, richer, safer, and more secure.