Model-Based Development of Technologies for Self-Organizing Decentralized Information Systems in Disaster Management

Each year, natural disasters cause a loss of life and property all over the world. This is the reason why the United Nations designated the 1990’s as the International Decade for Natural Disaster Reduction (IDNDR) which became the International Strategy for Disaster Reduction (ISDR). The goal is to use scientific and engineering know-how to reduce disasters within Disaster Management measures.

Self-organizing networks and information systems are the most promising technology to facilitate great advances in managing disasters. Model driven approaches will help with applying those technologies in the complex domain of disaster management. Our goal is to develop basic technologies and to research methodologies for applying these technologies to disaster management.

Disaster Management

Disaster management (DM) encompasses all measures taken to reduce the damages caused by disasters. These measures take place in phases: During the preparation phase knowledge about disasters is being collected. Based on this knowledge prophylactic and preparative measures are taken. Response-activities during an event aim at reducing the effects of disasters. After the disaster, reconstruction aims to restore the same state as before the disaster.

Information technology (IT) plays an important role in all phases. IT supports the collection of data to deduce scientific models. IT solutions facilitate simulations to enhance prediction and planning and provide communication facilities for victims and emergency personnel. The application of IT requires the integration of knowledge coming from different domains and combining theory and practice. This need for multidisciplinarity is a challenge when developing and using IT solutions in DM.

Enhancing the overall process of disaster management is the goal of our research in METRIK. Therein, we investigate a combination of model driven approaches together with advanced database, information system, and communication technologies.
A disaster management system (DMS) is designed to work even after a disastrous event. Therefore it cannot rely solely on the existing public information infrastructure. Dedicated networks are needed that are either robust enough to withstand the impact of the disaster, or can be deployed rapidly after the event. Yet, these dedicated networks should be inexpensive, or serve other purposes as well since the likeliness of a disaster might be small.

Wireless technologies and protocols for self-organization promise to fulfill these requirements. Devices are available at reasonable cost. Wireless networks can be deployed rapidly and inexpensively. Mesh-like topologies and distributed, self-organizing protocols ensure that networks are robust against failures of individual nodes or links.

METRIK investigates the use of wireless technologies for DMSs. We focus on decentralized networks and the design of protocols for self-organizing applications that use special properties of the technology. Research topics include routing, replication, effective gathering, and processing of decentralized data, dependable services, automated deployment and update of software components at runtime, and workload balancing among devices with limited resources.

Self-organizing information systems (SIS) for DM face new challenges: With respect to hardware, the integration of small, embedded real-time devices, e.g., sensor networks, into the information infrastructure is necessary for a faster system response-time and higher data accuracy. From the software perspective, future SISs must provide access to heterogeneous, distributed, and rapidly changing data sources while supporting dynamically changing workflows. Considering these challenges, METRIK focuses on the following research topics:

(a) We develop algorithms to efficiently gather data from wireless sensor networks (WSNs). In METRIK we use the publish/subscribe paradigm considering data-gathering as well as event-detection scenarios. We devise algorithms for efficient data retrieval based on optimized routing strategies and employ cost-based optimization of multiple queries.

(b) Workflows in disaster management are information-driven; they get adapted at run-time. SISs pose new challenges for the coordination and the reliable execution of distributed transactional workflow processes. We focus on methods for modeling and verifying the correctness of dynamically adaptive workflows and on an energy efficient distribution of workflow activities to heterogeneous, resource-constrained devices. We also investigate replication strategies for enhancing data and service availability in dynamic networks.

(c) To cope with heterogeneous data sources, we develop methods for semantic integration of spatiotemporal data. We focus on efficient information integration and query processing to timely provide integrated, spatially and temporally consistent data from a large number of data sources. Supplementary, we investigate methods to ensure data quality. Tent data from a large number of data sources.

Model-Driven Approach for Self-Organizing Information Systems in Disaster Management

The development of DMSs includes the following challenges: DMSs rely on domain-specific knowledge from different fields of geosciences, government agencies, and computer sciences. A development process for DMSs must guarantee correctness and dependability of the crafted systems. On the one hand, ongoing research in WSNs and SISs suggests an integrated development spanning all technological levels to satisfy resource constraints. On the other hand, available hardware is constantly changing and different scenarios require different functionalities: there cannot be an all-purpose DMS.

METRIK invests an investigation approach for guaranteeing flexibility, correctness, and cost reduction in the development of DMSs. Using several domain-specific languages (DSLs), experts of a domain express their approaches and solutions in terms of e.g., mathematics, workflows, and algorithms for WSNs and SISs, contributing to different aspects of a DMS.

We develop generic metamodel-based DSL tools that allow us to define, adapt, and test the languages and models as requirements develop. These tools support the development of specific model editors, simulators and code-generators. This approach enables us to research model coupling and integration of the various modeling languages to achieve a concise representation of the entire DMS. Such an integrated model might be used to build, to verify and to validate the DMS. We research tools for a model-based development and deployment of component-based systems to alleviate the complexity of a DMS. We investigate automatic model-based test generation to test all relevant application scenarios of the crafted system.