Model-driven Engineering for Environmental Modeling with Cellular Automata

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Problem statement

Simulation models play an important role in disaster management, since they are a common means to generate, store, and communicate relevant data and information. In order to meet common modeling requirements, simulation model descriptions should be *transparent* and *reusable*.

However, model reuse and transparency is an issue in environmental science. A major reason for limited reuse is that simulation model descriptions are usually dependent on specific implementation technologies (e.g. tools and programming languages). Moreover, many model descriptions lack transparency, since they often are not complete (e.g. natural language) or hardly comprehensive, especially for domain experts. Complete formal descriptions, such as source code, may lack transparency, particularly for technically less trained domain experts, since many languages used for modeling are rather aligned with the needs for generic programming than with expressing simulation models. In particular, these shortcomings are obstacles for multi-disciplinary modeling, where complex systems are modeled with contributions from different domains with different domain-specific modeling formalisms and tools.

Approach

A well known approach to address transparency issues is the use of domain-specific modeling languages (DSLs) that are specifically tailored to the needs of modelers. However, the development of DSLs is costly when applying traditional development methods, in particular, when different DSLs should be integrated for multidisciplinary modeling. The meta-model based model-driven approach addresses both, the costs of developing coupled DSLs and the reusability of models.

With this approach, a meta-model prescribes the abstract syntax of a DSL that is used to express *technology independent* model descriptions. *Technology specific* executable code is automatically generated. Thus, a model can be reused with several target technologies. Object-oriented meta-modeling facilitates a straightforward coupling of different meta-modeled DSLs. By this, models can be reused within different modeling contexts.

Meta-model based language tools help to automate the implementation of necessary tools, such as model editors, model transformators, and code generators, thus leading to efficient implementation processes.

However, to make this approach work, it is necessary to identify and formalize adequate concepts, that fit high-level modeling needs and relate to several relevant technologies for simulation. The presented work is concerned with the realization of this approach for the domain of environmental modeling.

In particular, this work focuses on environmental modeling with Environmental Cellular Automata (ECA). ECA are widely used to model DM-related processes, such as fire spreading, seismicity, or the evacuation of buildings. In contrast to traditional simple CA, ECA are usually more complex with a relatively *great number of states*, a more *complex transition function*, and an explicit *geospatial reference*. There is a plethora of tools for CA and ECA-modeling, but there are still the above mentioned shortcomings related to transparency and reusability.

Outcomes

Relevant concepts for the model-based development of coupled environmental simulation models have been identified. These concepts originate in the domain of compositional event-driven simulation and standards from Geographic Information Systems (GIS). They do not relate to ECA only, but can rather be applied to a wide range of environmental modeling formalisms.

A proof-of-concept implementation has been realized for Environmental Cellular Automata. This includes a DSL for coupled time-driven ECA. Language coupling has been exemplified by coupling a simple DSL for agent-based modeling and a language to describe experiments to the ECA language.

The generated executable code conforms to a combination of the process-oriented simulation library *jDisco* and a library for geospatial data handling (*Geotools*). These technologies represent a variety of existing technologies that provide the same functionality.

To show applicability and completeness of the language, a representative set of published models has been reimplemented with the ECA language.

PUBLICATIONS

Published papers:

- Daniel Sadilek, Falko Theisselmann, and Guido Wachsmuth. *Challenges for Model-Driven Development of Self-Organising Disaster Management Information Systems*, International Research Training Groups Workshop 2006, Dagstuhl, Germany
- Haubrock, S., Theisselmann, F. Dransch, D.; *Service-Oriented Architectures for Natural Disaster Management*, CIG/ISPRS: Proceedings of the Joint CIG/ISPRS Conference on Geomatics Solutions for Disaster Management, CIG/ISPRS Joint Conference (Toronto, Ontario, Canada 2007), 2007
- Theisselmann, F., Haubrock, S., Vorogushyn, S. Dransch; D. Clemen, C. (ed.) *NaDiNe-Deich: Ein Geoinformationsservice für das Katastrophenmanagement*, Entwicklerforum Geoinformationstechnik 2006 - Junge Wissenschaftler forschen, Shaker Verlag Aachen, 2006, 27-36
- Theisselmann, F., Dransch, D.; Bernard, L. Friis-Christensen, A. Pundt, H. Compte, I. (ed.) *Reusable Simulation Models: An MDE-approach to Spatiotemporal Modeling with Cellular Automata*, 11th AGILE International Conference on Geographic Information Science, 2008
- Theisselmann, F., Dransch, D.; Ruas, A. Gold, C. (ed.) *Improving the reusability of spatiotemporal simulation models: using MDE to implement cellular automata*, Headway in Spatial Data Handling : 13th International Symposium on Spatial Data Handling, 2008, 177 - 195
- Kühnlenz, F.; Theisselmann, F. and Fischer, J. I. Troch, F. B. (ed.) *Model-driven Engineering for Transparent Environmental Modeling and Simulation*, Proceedings MATHMOD 09 Vienna, 2009
- Theisselmann, F.; Dransch, D. and Fischer, J.; *Model-driven Development of Environmental Modeling Languages: Language and Model Coupling*, 23rd International Conference on Informatics for Environmental Protection, Berlin, 2009
- Theisselmann, F; Dransch, D. and Haubrock S.; *Service-oriented Architecture for Environmental Modelling - The Case of a Distributed Dike Breach Information System*, IMACS-MODSIM 18th World Congress on Modelling and Simulation, Cairns, July 13-17, 2009
- Haubrock, S.N., Theisselmann, F., Rotzoll, H. and Dransch, D.; *Web-based management of simulation models - concepts, technologies and the users' needs*, IMACS-MODSIM 18th World Congress on Modelling and Simulation, Cairns, July 13-17, 2009