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Modeling and Architecting of Complex Software Systems

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THIS EDITION OF the "Practitioners' Digest" covers recent papers on novel approaches and tools to assist developers in modeling and architecting software systems from two conferences: the 26th ACM/IEEE International Conference on Model Driven Engineering Languages and Systems (MODELS) and the 20th IEEE International Conference on Software Architecture (ICSA). Feedback or suggestions are welcome. Also, if you try or adopt any of the practices included in the column, please send us and the authors of the paper(s) a note about your experiences.

Requirements Modeling and Specification for Safety-Critical Software

Dealing with the appropriate level of detail in requirements specifications remains a challenge for practitioners and researchers, especially in the field of safety-critical software (SCS), where requirements specification and verification play an important role. In the paper "A Model-Driven and Template-Based Approach for Requirements Specification," Ikram Darif, Cristiano Politowski, Ghizlane El Boussaidi, Imen Benzarti, and Segla Kpodjedo present a template-based approach that combines controlled natural language and model-driven engineering.

The proposed approach uses two types of models: template models and system domain models. First, the template models constitute the metamodel/grammar of a semiformal specification language in which the elements and dependencies of each type of requirement are defined. This allows the analysis of safety-critical system requirements for certification purposes to be automated to some extent. Second, the system domain model allows automatically validating and autocompleting the information provided by the user when filling the placeholders of the templates using natural language.

The approach was implemented in an Eclipse-based tool, MD-RSuT, and validated through three case studies to ensure its applicability in different domains, with an industrial partner using the ARINC-653 standard from the avionics domain and the AUTOSAR specification from the automotive domain. This work leverages the characteristics of model-driven software engineering to raise the level of abstraction of the various aspects of a requirements specification in order to automate some verification analysis of those requirements and generate requirements documents that are compliant with standards of the SCS domain. The paper was presented at MODELS 2023. Access it at http://tinyurl.com/mpt257ss.

Real-Time Generation of Model Components From Sketches

Often, modeling is a process that converts informal sketches into formal models of a software system. Architecting of software often starts with informal sketches on whiteboards that often evolve to become formal architectural models. However, the process is not always well supported by tools. In the paper "SkeMo: Sketch Modeling for Real-Time Model Component Generation," Alisha Sharma Chapai and Eric J. Rapos present an approach and its supporting tool for automated and real-time generation of model components from sketches. The approach is based on a convolutional neural network capable of classifying sketches into model components, each of which is integrated into a web-based model editor compatible with a touch interface. The

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SkeMo tool has been validated both by calculating the accuracy of the classifier (the convolutional neural network) and through a user study with 20 participants. Currently, the tool supports classes, their attributes, and numerous types of relationships among them. The prototype also allows models to be updated through interactions with nonsketch interfaces. During the evaluation, the classifier performed with an average precision of over 97%. The user study indicated an average accuracy of 94%, with an observed accuracy for six subjects of 100%. This study shows how we can successfully employ machine learning to make the modeling process more natural and agile for users. The paper was presented at MODELS 2023. Access it at http://tinyurl.com/mr3uvjbh.

Model-Driven Development of Marine Data Quality Assessment Systems

Ocean observation and marine data processing systems are crucial for predicting extreme events, understanding ecosystem states, and regulating marine industries. In the paper "Marine Data Observability Using KPIs: An MDSE Approach," Keila Lima, Ludovico Iovino, Maria Teresa Rossi, Rogardt Heldal, Tosin Daniel Oyetoyan, and Martina De Sanctis present a model-driven monitoring platform for inferring the state of marine ecosystems by assessing marine data quality key performance indicators (KPIs).

Marine data are mainly obtained from autonomous sensing platforms using Internet of Underwater Things (IoUT) devices, which present technical challenges typical in land-based Internet of Things systems (e.g., limited battery life and computational resources) in addition to other challenges from the underwater environment, such as restricted wireless bandwidth that is also prone to errors and the cost of maintenance and access to the sensors.

This work instantiates a multilevel modeling framework for quality assessment that defines both the subject of the evaluation (i.e., the marine data platform) and the quality metrics to be used in the assessment (i.e., the marine data quality KPIs). The marine data platform represents interconnected marine sensors and nodes that form the backbone of the IoUT, and the marine data quality KPIs are defined in terms of aggregated quality metrics of interest to the marine domain. The approach was validated in a prototype implementation using real marine data recently collected in a consortium that aims to build a digital data ecosystem to support different stakeholders in the marine domain.

In conclusion, this paper shows the advantages of using a model-driven approach to abstract the marine domain and perform semantic mapping to the marine sensor infrastructure, which is used to implement a quality evaluation system for real-time assessment of marine data flows using quality metrics and KPIs. The paper was presented at MODELS 2023. Access it at http://tinyurl.com/5n77bju8.

Detecting Inconsistencies in Software Architecture Documentation

Detecting inconsistencies between model-based and textual documentation artifacts is important to reduce development and maintenance flaws, manage documentation implementation drift, and improve system comprehension. In the paper "Detecting Inconsistencies in Software Architecture Documentation Using Traceability Link Recovery," Jan Keim, Sophie Corallo, Dominik Fuchss, and Anne Koziolek present an approach for detecting inconsistencies between natural language software architecture documentation (NSLAD) and architectural models. The approach, Architecture Documentation Consistency (ArDoCo), uses traceability links and extends the Software Architecture Text Trace Link Recovery (SWATTR) approach previously proposed by the same authors.

ArDoCo consists of two major processing steps: traceability link recovery (TRL) and inconsistency detection. For TRL, the authors improve SWATTR by introducing the concept of phrases, adapting the heuristics, and including a refactoring of the similarity calculation. The inconsistency detection step analyzes whether all model elements are documented in the NSLAD [that is, unmentioned model elements (EMU)] and whether all architectural elements extracted from the natural specifications are present within the architectural model [that is, missing model elements (MME)].

The approach is evaluated in five different projects. The refined SWATTR TRL outperforms the previous version of SWATTR. The changes introduced in SWATTR improve the precision, recall, F_1 score, and ΦN by more than 20 percentage points. Accuracy and specificity achieve small improvements. Overall, the new SWATTR outperforms the previous SWATTR and the baseline on all metrics. In terms of inconsistency detection, the ArDoCo approach achieves excellent results in EMU detection, with an F_1 score of 0.86, while the accuracy, specificity, and ΦN range from 0.9 to 0.93 (excluding an outlier); in MME detection, ArDoCo achieves promising results, with a weighted

average F_1 score of 34%, while the accuracy, specificity, and ΦN range between 0.6 and 0.82. The paper was presented at ICSA 2023. Access it at http://tinyurl.com/bdd8fhcr.

Model-Driven Development of Industrial Digital Twins

Digital twins (DTs) are gaining importance for monitoring and development of cyberphysical systems, usually large ones like plants, vehicles, or large machines. However, the construction of DTs for this type of system still poses several challenges. In the paper "A Model-Driven Approach for Knowledge-Based Engineering of Industrial Digital Twins," Sushant Vale, Sreedhar Reddy, Sivakumar Subramanian, Subhrojyoti Roy Chaudhuri, Sri Harsha Nistala, Anirudh Deodhar, and Venkataramana Runkana present a new approach to constructing DTs for factories. Specifically, the paper introduces a method that enhances the efficiency of monitoring and predictive maintenance of industrial plants. Typically, DTs are created manually for each plant, which is a labor-intensive process. This paper proposes a model-driven method structured at three levels of abstraction: the metalevel, the plant type level, and the plant instance level.

The metalevel outlines universal structures and vocabulary, the plant type level focuses on specific knowledge of various plant types, and the plant instance level details a DT for a specific plant. These levels correspond to different user roles: platform builders, plant type experts, and plant experts, respectively. This hierarchical structure allows the reuse of elements across different plants and types, streamlining the DT development process. The effectiveness of this method is exemplified in a case study of an iron ore sinter plant. The process begins with the establishment of high-level KPIs, such as sinter throughput or a reduction degradation index. These KPIs are then translated into a mathematical model, followed by a causal graph and, finally, a DT design/model. Remarkably, this approach significantly reduces the time required to formulate the quality optimization problem to approximately one week, as opposed to two months, a substantial improvement in efficiency.

In conclusion, this paper demonstrates the substantial advantages of a multilevel modeling approach in DT design, offering a more efficient, standardized, and scalable solution. Presented at MODELS 2023, the paper is a significant contribution to the field. Access it at http://tinyurl.com/5n8y7th3.

Architecting DTs

As originally defined by Grieves and Vicker in 2002[1], a DT represents the conjunction of three elements: a real space, a virtual space, and a bidirectional link between the two. Although much progress has been made in the past 20 years, Aurora Macías, Elena Navarro, Carlos E. Cuesta, and Uwe Zdun, in their paper "Architecting

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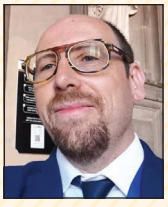

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Digital Twins Using a Domain-Driven Design-Based Approach," acknowledge that a domain-agnostic approach for architecting DTs is still missing.

Based on this preamble, they propose a general approach, based on bounded contexts (BCs) in domain-driven design (DDD). The main goal is to provide a DDD-based proposal that can outperform related proposals for architecting DTs available in the literature according to the ability of the design method to facilitate the satisfaction of DT properties.

The proposed architecting approach involves two main activities: strategic design and tactic design. During the first activity, the DT components are identified by simply enumerating the different physical objects in the given system; then, the DT types are mapped to a specific BC. This phase abstracts the preliminary model, focusing on the DT types rather than on the instances; the context mapping is then identified, whereby the contracts and the boundaries between the BCs are clearly defined. During the tactic design phase, the DT application architecture is identified; the hexagonal architecture reference model consisting of the domain, application, and infrastructure layers is used. Each of the 10 selected properties is mapped to the three layers.

The DT architecting approach is applied to a wind turbine DT, and its tactic design is presented. To check whether the proposal provides results with higher satisfaction of DT properties compared to other existing proposals, five software engineers were asked to compare the presented proposal for architecting DTs with the five-dimension model proposal presented in[2]. The results show that the presented approach provides higher satisfaction of the 10 DT properties than the alternative proposals. The paper was presented at ICSA 2023. Access it at http://tinyurl.com/58mvdhfy.

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