Introduction to the Special Issue on Specification and Design Languages

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The **Forum on specification and Design Languages** (**FDL**) is an international event where academics and company representatives exchange their results, experiences, advances, and new trends related to languages, tools, and techniques for developing software and hardware systems. Targeted systems encompass cyber-physical systems, distributed systems, real-time systems, embedded systems, mechatronics, Internet of Things, and reactive systems.

FDL is based on the four following non-limiting scientific areas:

— *Languages:* Domain-specific languages for software, execution platforms, allocations, environment, contracts, abstractions, and refinements are of interest, together with the associated design methods, frameworks, and tools.
— *Semantics:* formal definitions, compilers, interpreters, typing, abstraction/refinement, are of interest, together with the underlying specification frameworks or new approaches for their specification, modeling, and model transformation.
— *Verification and Analysis:* innovative static analysis, testing, debugging, model checking, machine learning-based analysis, or design space exploration are of interest, together with the underlying models, tools, and frameworks.
— *Simulation:* innovative simulation techniques, virtual prototypes, digital twins, collaborative simulation, hybrid simulations, or runtime abstraction/refinement are of interest, with special attention on the efficiency and correctness of simulations and their underlying tools and frameworks.

The 2022 edition of the Forum on specification and Design Languages (FDL 2022) was held in Linz, Austria, September 14–16, and included three keynotes (Prof. Armin Biere, University of Freiburg; Ph.D. Rainer Findenig, Infineon Technologies; Prof. Stefan Wallentowitz, Munich University of Applied Sciences), five 5 technical sessions, two tutorials, one panel and one PhD Forum. The 2023 edition (FDL 2023) was held in Turin, Italy, September 13–15, and included two keynotes (Hayri Hasou, Infineon Technologies; Prof. Robert Wille, Technical University of Munich), seven technical sessions, two tutorials, one PhD Forum and a PhD School, running in parallel with the conference. Both the events gathered a large audience, including researchers, practitioners, students and company representatives.

To allow for more in-depth treatment of selected contributions and to further broaden the audience, an open call was made for this special issue in ACM TECS. As a result, six articles have been selected, either as new submissions or as extensions of contributions formerly accepted at FDL 2022 or FDL 2023.

Here is the list of the articles included in this special issue:

— "*PEak: A Single Source of Truth for Hardware Design and Verification*" by C. Donovick, R. Daly, L. Truong, P. Raina, P. Hanrahan, and C. Barrett. This article presents PEak, an

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open-source hardware design and specification language that unifies functional models, formal specifications, and RTL to improve both design productivity and verification. PEak bridges the gap between flexible hardware DSLs and static ISA specification languages, enabling early-stage design-space exploration.

—"*Bridging the Abstraction Gap: A Systematic Approach to Rule-Based Transformational Design for Embedded Systems*" by F. Bahrami, R. Jordao, I. Sander, and I. Söderquist. This article presents a rule-based transformational design methodology for heterogeneous multi-processor embedded systems. Building on design-transformation techniques, the methodology uses the RAMP view (requirements, application model, platform model, and mapping decisions) together with a unified abstract graph representation to support transformations. A pattern-matching approach and proof-of-concept tool automatically detect applicable transformations, enriching the design space and enabling effective application and platform co-exploration.

—"*A Proof System for the SMrCaIT Calculus*" by N. Chen, and H. Huibiao. This article presents a proof system for the SMrCaIT calculus, a process calculus designed to model the security, mobility, and real-time features of IoT systems. Building on this calculus, the article introduces a proof system based on time-extended Hoare Logic and incorporates a cooperation test to ensure correct message delivery between IoT entities. The system's soundness is established, and its practicality is demonstrated through analyses of a Vehicle Ad Hoc Network (VANET) and a Multi-UAV scenario.

—"*MLTL Multi-type: A Typed Logic for Cyber-physical Systems*" by G. Hariharan, B. Kempa, T. Wongpiromsarn, P. Jones, and K. Rozier, Kristin. This article presents MLTLM, an extension of Mission-time Linear Temporal Logic that enables clear and intuitive formalization of cyber-physical system-of-systems requirements over signals of differing types. MLTLM preserves the simplicity and verbal-to-formal correspondence of MLTL, supports heterogeneous signals, and improves efficiency on resource-constrained hardware. This article expands prior work with illustrative multi-type examples, full proofs, a succinctness result relative to MLTL, and a minimal translation from MLTLM to MLTL.

—"*Mixed-Level Modeling and Evaluation of a Cache-less Grid of Processing Cells*" by Vivek Govindasamy and Rainer Dömer. This article addresses the memory wall problem, by proposing a scalable parallel architecture called the Grid of Processing Cells (GPC). They model the GPC using SystemC TLM-2.0 at both instruction and functional levels, enabling efficient and accurate simulation. By testing streaming applications and analyzing software optimizations, GPC proves to significantly improve execution time, mainly by reducing main memory contention, with respect to traditional shared memory processors.

—"*Edge-cloud Orchestration of Assertion-based Monitors for Robotic Applications*" by S. Germiniani, N. Bombieri, F. Lumpp, and G. Pravadelli, Graziano. This article presents a runtime assertion-based verification (ABV) platform for autonomous robots that synthesizes monitors from signal temporal logic specifications and dynamically migrates them across edge and cloud resources. While ABV can effectively detect correctness issues in complex robotic systems, its runtime overhead can overwhelm resource-constrained architectures. The proposed platform mitigates this challenge through monitor synthesis, ROS-compliant integration, and Docker-based containerization for flexible deployment on edge and cloud devices.

—"*A Comprehensive Survey on Deep Learning-based Predictive Maintenance*" by U. Khan, D. Cheng, F. Setti, F. Fummi, M. Cristani, and L. Capogrosso. This article presents a comprehensive survey of learning-based Predictive Maintenance strategies in the era of Industry 4.0 and Industry 5.0. Motivated by the growing volume of industrial data and the central role of Predictive Maintenance in reducing downtime and extending equipment lifespan, it reviews the major learning models and paradigms, and outlines the data-driven

pipeline, including practical applications, datasets, evaluation metrics, and state-of-the-art hardware for Predictive Maintenance.

As we conclude, we would like to extend our gratitude to everyone involved in making this special issue a success. We want to start by thanking the authors for their outstanding contributions, delivering high-quality manuscripts. Our sincere appreciation also goes to the reviewers, whose valuable feedback significantly enhanced the quality of these manuscripts. We are especially grateful for the Editor-in-Chief, Prof. Tulika Mitra, and for the Special Issue Editors, Prof. Andreas Gerstlauer and Prof. Hiren Patel, for their gracious support and guidance throughout the process, and for the technical staff, for their professional assistance. Thank you all for your contributions and support.

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