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EDITORIAL

Model hybridization: towards a unifying theory for inductive and deductive reasoning

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While software is revolutionizing the modern world, software engineering practices must keep pace accordingly. Modern software-based systems operate under rapidly changing conditions and face ever-increasing uncertainty. These dynamics demand **accelerated adaptability**, or more precisely, **temporal adaptability**—the ability to adapt not only to a fixed set of requirements but also to an evolving sequence of variable requirements, which are often increasingly driven by newly incoming usage and context data. This adaptability corresponds to how humans handle uncertainty in dynamic environments by continuously updating their mental models to accommodate new information. As a result, the traditional boundary between development-time and operations-time is blurring.

To address such a pressing context, current development processes often implement agile methodologies that increase the release frequency to leverage the available runtime and telemetry data, eventually driving the overall roadmap. These **continuous engineering** processes promise tremendous potential for gaining insights, optimizing operations, and improving decision-making. This is true in the software industry, but also in the broader scope of cyber-physical systems accompanied by so-called digital twins, across various industries, including manufacturing, healthcare, transportation, and more. Recent developments show that MDE can—or maybe even must—play a central role in systematically leveraging the runtime and telemetry data to cope with this new temporal adaptability, and many researchers from the MDE community have investigated MDE technology to provide a smooth continuum between development and operations.

In the future, predictive capabilities in the context of continuous engineering will be leveraged for dynamically evolving ecosystems to address challenges such as sustainability at a much more complex scale. To this aim, techniques for the coordinated use of heterogeneous descriptive, predictive, and prescriptive models need to be elaborated, and the propagation of uncertainty investigated, leading towards the definition of a **unifying theory for inductive and deductive reasoning**.

At the heart and soul of the combination of inductive and deductive reasoning is the need for **model hybridization**. With this term, we mean that there is an urgent need and opportunity for a systematic approach to combine heterogeneous models, such as architectural models, continuous and discrete-event behavioral models, and statistical models (e.g., machine learning models).

Numerous topics need to be investigated to enable this hybridization. Technically, a homogeneous and sound "model interface" must be established for querying and manipulating models. Queries should identify potential synergies, such as shared properties, complementary domains of validity, or suitable fidelity and scale for intended uses. Model interfaces also must enable the composition of models, while retaining their model artifacts as independently reusable development units. Thus, semantically sound modeling languages and composition techniques (e.g., those based on shared properties) are needed to provide a solid technical foundation. Model management should allow for commonly updating, refactoring or modifying specific parts to incorporate new knowledge or requirements. A second form of model interface is needed to enable simulation executions. With such interfaces, appropriate hybridization operators must be defined for the actual technical composition of heterogeneous models. Such operators are needed for **hybrid modeling** in the form of coordinated use along possibly complex workflows specifying causal relationships, but also scenarios of **adaptive modeling** where some models are used to adapt

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the others. Careful attention must also be given to reliability and systematic management of uncertainty, variants and underspecification (i.e., missing or open decisions).

While we anticipate the importance of principles, tools, and methods leading towards a more continuous software and systems engineering, SoSyM highly welcomes contributions in this context, and more specifically, on the challenges related to model hybridization.

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