6th Int'l MPM4CPS Workshop

Multi-Paradigm Modeling for Cyber-Physical Systems

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Abstract: The networked combination of multi-physics systems (mechanical, electrical, hydraulic, biochemical, among others) with computational systems (control systems, signal processing, logical inference, planning, among others), often interacting with human actors, in uncertain environments, in a socio-economic context, has led to so-called Cyber-Physical Systems (CPS). The CPS that are engineered today are reaching a previously unseen level of complexity. To date, no unifying theory nor systematic design methods, techniques and tools exist for such systems. Individual (mechanical, electrical, network or software) engineering disciplines only offer partial solutions. Multi-Paradigm Modeling (MPM) proposes to *model* every part and aspect of such complex systems *explicitly*, at the most appropriate level(s) of abstraction, using the most appropriate modeling language(s)/formalism(s). This includes the explicit modeling of the often complex engineering workflows. Modular modeling language engineering, including model transformation and the study of modeling language semantics, are used to realize MPM, which has the potential to be an effective answer to the challenges of designing CPS. This **sixth edition** will be organised as a highly interactive workshop, promoting discussions and collaboration around a specific theme: we want to explore the notion of "appropriateness" (of formalisms, of processes, of abstraction levels, of views, of architectures, etc.) that is at the core of the MPM approach. The Workshop will host paper presentations in the morning, and discussions and collaborative work in the afternoon, by bringing together international experts in the field for an intense **one-day workshop**.

1 Motivation

Objectives and Scope. Tackling the complexity involved in developing truly complex, designed systems is a topic of intense research and development. In the past, system complexity has drastically increased once software components were introduced in the form of embedded systems, controlling physical parts of the system, and has only grown in CPS, where the networking aspect of the systems and their environment are also taken into account. The complexity faced when engineering CPS is mostly due to the plethora of cross-disciplinary design alternatives and inter-domain interactions. To date, no unifying theory nor system design methods, techniques, or tools to design, analyze, and ultimately deploy CPS exist. Individual (physical systems, network, software) engineering disciplines offer only partial solutions and are no match for CPS complexity.

Multi-Paradigm Modeling (MPM) offers a foundational framework for gluing the several disciplines together in a consistent way. The inherent complexity of CPS is

broken down into different levels of abstraction and views, each expressed in (the most) **appropriate** modelling formalisms. MPM offers processes and tools that can integrate the views, abstractions and components that make up a CPS.

MPM encompasses many research topics: from language engineering (for DSLs, including their (visual/textual) syntax and semantics), to processes to support multi-view and multi-abstraction modelling, simulation for full-system analysis, and deployment. The added complexity that CPS bring compared to embedded and software-intensive systems requires consideration of how MPM techniques can be applied or adapted to these new applications, tying together multiple domains. Many remaining research questions require answers from researchers in different domains, as well as a unified effort from researchers that work on supporting techniques and technologies. The community needs a workshop setting to meet up and align past and future research activities.

Workshop's Purpose. During this Workshop, we want to bring together researchers and practitioners in the area of MPM (specifically applied to developing CPS) in order to identify possible points of synergy, common problems and solutions, tool building aspects and the vision for the future of the area. The goal is to organize a **highly interactive workshop**, with a significant portion of the Workshop dedicated to **discussions**. **"Regular" Research papers** from academic and industry authors will present novel research results on the Workshop's topics of interest. We will encourage the submission of out-of-the-box presentations, which are not deeply researched yet, but can lead to new insights, discussions, and future collaborations. However, we will limit the number of "Regular" accepted papers so that their presentation only fits the morning sessions.

The afternoon will be dedicated to discussions and collaborative work. We will invite **Vision**, or **Expert's Opinion**, papers, on a topic that is at the heart of MPM4CPS: *what makes formalisms, views, abstraction levels, architectures,* the most appropriate *for a given context, task(s) and stakeholders?* Depending on the quality of the discussion, and the involvement of the participants, the afternoon discussions would potentially lead to other scientific achievements (a collaborative Journal paper, a special issue on this topic, or an extended workshop).

Intended Audience. The intended audience includes researchers as well as practitioners who are interested in MPM techniques in the context of CPS development. We expect to attract many attendees of earlier MPM-related events, those who contributed to the COST action, as well as a broader audience. This includes researchers that work on the fundamentals of language engineering, (visual) modelling environment construction, (co-)simulation techniques, as well as tool builders and users of these tools.

Topics of Interest. A list of topics of interest is given in the CfP available in Appendix. Note that we have explicitly included *appropriateness* as a topic, but required in the Submission Procedure that related contributions take the form of Vision/Expert's Opinion papers no longer than 5 pages.

Relevance. The MODELS conference is an ideal venue for organizing MPM4CPS since it brings together researchers that aim to advance the state-of-the-art in MDE and practitioners who have valuable application experiences to share.

Furthermore, in the previous edition at MODELS, we noticed a large interest from the modelling community (with, for the morning sessions, about 60 participants in 2022,

and 38 in 2023). This is a clear indicator that the workshop is actively relevant in the community.

Context. The MPM community has been actively researching new techniques for system design for over a decade, through many related events. One-week Computer Automated Multi-Paradigm Modeling (CAMPaM) workshops have been organized yearly since 2004 at McGill University's Bellairs campus, Barbados. Additionally, the International Summer School on Domain-Specific Languages - Theory and Practice (DSM-TP), focused on the education of language engineering techniques, and has been organized since 2009. Its target audience includes Ph.D. students, researchers, and software industry professionals. Most recently, a European Cooperation in Science and Technology (COST) research network has been active since 2015 on the use of MPM techniques for designing CPS, bringing together 29 European partner countries[4]. The chair and co-chair of this network (Hans Vangheluwe and Vasco Amaral) are members of the steering committee for this workshop.

The first edition of the workshop has led to the preparation of a theme section on the topic of MPM4CPS for the SoSyM journal[5]. The second and third editions were operated fully online, and therefore have been reduced to half-day workshops consisting solely of paper presentations, albeit with longer discussion periods (typically, 10-15 minutes after each presentation), and each paper presentation session still attracted ca. 20-25 participants with lively, interesting discussions. The fourth edition provided a hybrid virtual/in-person solution, with the morning session attracting ca. 60 people in the room, with many still actively partaking in the lively discussions at the end. Last year (2023), we attracted ca. 35 participants in the morning, with a more sparse participation due to the co-organisation of workshops on other popular topics, such as MoDDiT. We expect a similar participation rate this year, especially because MoDELS is held in Europe.

These initiatives, as well as the success of previous editions, demonstrates both the continued relevance of the topic, and the potential impact of a new edition of the workshop, especially when we are opting for a highly interactive and collaborative format that proved very successful in other venues (with the MPM series held with earlier MoDELS editions as examples).

Needs. The MPM4CPS workshop (series) follows a successful series of 9 MPM workshops (co-located with MoDELS, between 2006 and 2015). They attracted many participants, and the core topic is still relevant, although redirected to the CPS application domain. Those reasons make MPM4CPS worth organizing at MoDELS this year.

Historically, GeMoC and EXE, now merged into MLE (Modeling Language Engineering and Execution), were the closest workshops planned to be organised, and are regular workshops at MoDELS for several years now. More recently, ModDiT (MDE for Digital Twins) also has cross-concerns with MPM4CPS. However, these workshops focus mainly on two sets of topics: (i) the globalization of modelling techniques, which include techniques and processes to create and integrate heterogeneous languages, and the execution, animation and debugging of modelling languages; and (ii) the theoretical foundations, MDE techniques and tools, for supporting the design and deploy-

[4] https://www.cost.eu/actions/IC1404/ and http://mpm4cps.eu/

[5] https://link.springer.com/article/10.1007/s10270-021-00882-1

ment of Digital Twins, often by integrating piecemeal technologies. While both are concerned with specific aspects of *software* language engineering, MPM includes modelling languages for physical domains (e.g., electrical, mechanical, etc.) that require continuous-time solvers for simulation, and clean integration with other (SW/HW) languages. MPM4CPS further differentiates from those workshops by focusing on CPS, as opposed to often purely software Digital Twins. We believe that both workshops can strengthen each other by focusing on different (specialized) aspects of challenges within the MODELS community.

Two other workshops target concerns directly related to MPM4CPS. Hands-on Workshop on Collaborative Modeling (HoWCoM) specifically targets collaboration, which is required in CPS given the various expertise required. Model Management (MoM), a novel workshop submitted this year, specifically target the various methodologies, techniques and tools for managing and federating collections of models, which is also a core activity for MPM4CPS because of the large variety of models manipulated during the various phases of CPS Engineering. Both concerns deserve a dedicated forum for discussing topics that transcend MPM4CPS, as both collaboration and model management also directly contribute to MDE. However, the challenges to design and develop CPS, with a focus on MPM techniques as a foundational framework for supporting the multi-domain models, tools, and processes are fundamental enough to warrant a dedicated, workshop focuses on MPM4CPS.

As a result, we would really appreciate, to the best of the constraints the MoDELS Workshop Chairs have to deal with, that MPM4CPS gets a full-day slot that is not shared with at MLE, ModDiT, and MoM (if finally organised).

2 Organisation Details

The organisation team is made up of a good mix of junior and senior organisers.

A **tentative** PC is given in the CfP in Appendix. We request that MPM4CPS be run on its own as we plan half a day of discussions. We can merge with another workshop if this is a condition from the organization and the topics are similar enough.

Moussa Amrani obtained his Ph.D. in 2013 from the University of Luxembourg. He is currently a postdoctoral researcher at the University of Namur and the Namur Digital Institute in Belgium. He is (co-)author of over 50 papers on MDE, IoT and formal verification published in international conferences (MODELS, SLE, ECMFA, ASE, ETAPS, NFM, CAiSE, ...) and journals (SoSyM, JSS, JoT, ComLan, ...). He co-founded and co-organized the VoLT workshop at MoDELS from its inception in 2013, and co-organised the previous editions of the MPM4CPS Workshop.

Joeri Exelmans is a Ph.D. student at the University of Antwerp, Belgium, and has worked on the Flanders Make Collaborative Design Facility project aiming to facilitate collaboration in complex engineering workflows. His research interests are the engineering of hybrid modeling languages, model versioning, and inconsistency management and traceability in complex engineering workflows.

Randy Paredis is a Ph.D. student at the University of Antwerp, Belgium, and is exploring architectures and frameworks for model-based design of Digital Twins (and,

by extension, "Twinning"). His research interests are multi-paradigm modelling, using DEVS as a common denominator for discrete-event modelling languages, the Twinning paradigm, and co-simulation.

Robert Heinrich holds a Ph.D. from Heidelberg University, and is head of the Quality-driven System Evolution research group at Karlsruhe Institute of Technology (KIT). His research interests include modularization and composition of model-based analysis for performance, confidentiality and maintainability, etc. applied to information systems, business processes and automated production systems. One core asset of his work is the Palladio software architecture simulator. He is involved in the organization committees of several international conferences, established and organized various workshops, is reviewer for international premium journals (IEEE TSE and IEEE Software), and academic funding agencies.

3 Workshop Format

Deadlines & Paper Format Cf. CfP in Appendix

Evaluation Process At least three reviewers will evaluate each submission. Regular research papers will be reviewed using standard scientific criteria: alignment with the workshop topic(s), novelty, evaluation, and ability to generate discussion. Vision/Expert's Opinion papers will be evaluated based on the novelty of their propositions, as well as the likelihood to spark lively discussions.

Intended Workshop Format In the ideal case of a full day workshop, we will host two keynotes, ideally one from academia and the other from industry (depending on availability), to scope the afternoon discussions. The morning will be dedicated to paper presentations for accepted Regular papers. The afternoon will likely start with two short keynotes (20-25 minutes), to set the stage for the afternoon discussions. The afternoon will reserve time to discuss the Vision/Expert's Opinion papers. After a short phase to identify the main approaches related to the notion of "appropriateness", we will likely split into small groups to deepen the understanding of each approach. The afternoon will end with a wrapup discussion to formulate the workshop's conclusion, identify open challenges, and outline future work (and how to organise it). A summarizing publication will be included in the proceedings.

(Expected) Participants Number 25-35 (similar to previous editions.)

Equipment Whiteboard + Slide Projection

4 Additional Material

A draft **Call for Paper** is attached as Appendix.

Sixth International Workshop on Multi-Paradigm Modeling for Cyber-Physical Systems – MPM4CPS'24

22 – 24 September 2024 – Satellite event at MODELS 2023, Linz, Austria
http://msdl.uantwerpen.be/conferences/MPM4CPS/2024/

Organizing Committee

Moussa Amrani, Université de Namur
Joeri Exelmans, University of Antwerp
Randy Paredis, University of Antwerp
Robert Heinrich, Karlsruhe Institute of Technology

Steering Committee

Hans Vangheluwe, University of Antwerp – Flanders Make and McGill University
Pieter J. Mosterman, Raven Industries
Jeff Gray, University of Alabama
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Ashan Qamar, Ford, USA
Ivan Ruchkin, University of Florida, USA
Bran Selic, Malina Software Corporation, USA
Matthias Tichy, Ulm University, Germany
Mamadou Traoré, University of Bordeaux, France
Javier Troya, Universidad de Málaga, Spain
Clark Verbrugge, McGill University, Canada

Scope of the Workshop

Tackling the complexity involved in developing truly complex, designed systems is a topic of intense research and development. System complexity has drastically increased once software components were introduced in the form of embedded systems, controlling physical parts of the system, and has only grown in CPS, where the networking aspect of the systems and their environment are also considered. The complexity faced when engineering CPS is mostly due to the plethora of cross-disciplinary design alternatives and inter-domain interactions. To date, no unifying theory or system design methods, techniques, or tools to design, analyze, and ultimately deploy CPS exist. Individual (physical systems, software, and network) engineering disciplines offer only partial solutions and are no match for the complexity observed in CPS. Multi-Paradigm Modeling (MPM) offers a foundational framework for gluing the several disciplines together in a consistent way. The inherent complexity of CPS is broken down into different levels of abstraction and views, each expressed in appropriate modeling formalisms organized in specific processes. MPM offers processes and tools that can combine, couple, and integrate each of the views that compose a system.

MPM encompasses many research topics - from language engineering (for DSLs, including their (visual) syntax and semantics), to processes to support multi-view and multi-abstraction modeling, simulation for system analysis, and deployment. At the core of the MPM approach lies the notion of ***choosing the most appropriate*** formalism(s), process(es), abstraction level(s), etc. to tackle a task at hand (designing, deploying, etc.), with the objective of reducing accidental complexity, and promote specificity and accuracy to better perform this task, while ensuring that all those components integrate as smoothly as possible.

Topics of Interest (including, but not limited to)

- **Foundations of domain-specific modelling**, with a particular focus on classifications of the various dimensions around MPM (formalisms; processes; related activities such as V&V, deployment, calibration, etc.; tools, and methodologies);
- **Modelling language engineering**, modular design of modelling languages, with a particular focus on de-/composition;
- **Applications of MPM techniques** in automotive, aviation, manufacturing, etc.
- **MPM for (self-)adaptive systems**
- **MPM approaches, techniques, and tools** for related domains: IoT, Digital Twins, SmartCPS
- ***Appropriateness of approaches***, in terms of formalisms, processes, abstraction levels, viewpoints, etc. wrt. captured domain, context, stakeholder experts, etc. regarding definitions, metrics, relevance, methodologies, etc. related to the notion of "the most appropriate" in MPM4CPS.

Contributions should clearly address the foundations of Multi-Paradigm Modeling by demonstrating the use of ***several*** models to achieve the stated objectives and discuss the benefits of explicit modeling.

Important Dates

Paper submission deadline: 5 July 2024
Notification of acceptance: 9 August 2024
Workshop dates: 22--24 September 2024 (exact date TBA)

Submission Procedure

Papers should be submitted electronically in PDF using the ACM formatting instructions available here via EasyChair for one of the following topics. Each submission will be peer-reviewed by at least three PC members.

- **Regular research papers** (10 pages max) present a novel, innovative approach;
- **Vision papers/Expert's Opinion** (5 pages max) present new ideas, visions, experience feedback, on how, why, and whether it is even relevant, to talk, discuss, and actually practice this moto of "the most appropriate" for each task.

Regular papers will be published with the main conference's workshop proceedings; authors submitting Vision/Opinions will eventually be invited to contribute to a Special Issue to further develop their case.