5th 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 **fifth edition** is aimed at furthering the state-of-the-art as well as defining the future directions of this emerging research area 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 appropriate

modeling 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.

Similar to last year, we will invite the submission of **Exemplars**, i.e., typical, yet relatively tractable use cases of CPS demonstrating typical activities required for CPS Engineering, and explicitly detailing the underlying formalisms, languages and tools deployed to support such activities, all expressed in a similar way to enable comparison and extract CPS Engineering common practices and design patterns.

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 *classification* and *exemplar* topics, as it is key to structure and discuss the future of MPM.

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 model-driven engineering and practitioners who have valuable application experiences to share.

Furthermore, in the previous edition at MODELS, we noticed a large interest from the modeling community (with about 60 participants in the morning session). 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[5]. 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 lead to the preparation of a theme section on the topic of MPM4CPS for the SoSyM journal (which has been finally published[6]). 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. We suspect there will be at least the same amount this year.

All these initiatives, as well as the success during the online editions, demonstrate both the continued relevance of the topic, and the potential impact of a new edition of the workshop.

Needs. The MPM4CPS workshop (series) follows the successful series of nine MPM workshops that were organized as part of the MODELS conference during the years 2006 through 2015. These workshops attracted many participants in the past, and we saw that the topic is still relevant, since the previous editions attracted many submissions and lively discussions. These two reasons make this workshop worth organizing at MODELS this year.

Historically, GeMoC and EXE, now merged into the 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-concerned 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 deployment 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.

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

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

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 focused workshop.

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, TSE, ToSEM, JoT, IST, 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.

Dominique Blouin is a research engineer at Telecom Paris, Institut Polytechnique Paris (France). He obtained an M.Sc. in Physics (Canada) and a Ph.D. in Computer Science (France) in 2013. He worked for many years in industry as a software architect and was the vice-chair of the Foundational Aspects Working Group in the MPM4CPS COST Action. He has been an active member of the SAE AADL standardization committee for the past 10 years. His research interests are MPM, model management, model transformation and (bi-directional) synchronization, requirements engineering, CPS.

Moharram Challenger is a research professor at the University of Antwerp, Belgium. He was the CTO of a software company involved-in/leading several national and international software intensive projects. He has served as an organisation committee member for SummerSim'20, ICSMM'20, AnnSim'21, IWCPS@FedCSIS'21, and AMSC'21. Also, he played the role of co-chair for several workshops organised in MoDELS and STAF 2020-21 (MDE-Intelligence, MPM4CPS, MDE4IoT, SERP4IoT, SEDES, MESS, EMAS, etc.).

Joeri Exelmans is a Ph.D. student at the University of Antwerp, Belgium, and has worked on a Flanders Make 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 within the context of Industry 4.0. His research interests are multi-paradigm modelling, using DEVS as a common denominator for discrete-event modelling languages, 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. Full research papers will be reviewed using standard scientific criteria: alignment with the workshop topic(s), novelty, evaluation, and ability to generate discussion. Short papers will be evaluated based on their 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 how people are available). A morning keynote will set the stage for the rest of the day, followed by paper presentations. A second keynote after the lunch break will set the discussion around exemplar presentations and new and provocative ideas, which will foster discussions and out-of-the-box ideas. Each talk throughout the day will be followed by discussions. The afternoon will reserve time to discuss the examplars, by starting discussions around identifiable patterns, common practices, popular formalisms/languages/tools, etc. The workshop will end with a wrap-up discussion to formulate the workshop's conclusion, identify open challenges, and outline future work. A summarizing publication will be included in the proceedings. Depending on the quality of papers/discussions, we may organise a Special Issue based on invitations (this/previous edition(s)) and open call.

(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.

Fifth International Workshop on Multi-Paradigm Modeling
for Cyber-Physical Systems – MPM4CPS'23

1 – 6 October 2023 – Satellite event at MODELS 2023, Västerås, Sweden
http://msdl.uantwerpen.be/conferences/MPM4CPS/2023/

Organizing Committee

Moussa Amrani, Université de Namur
Dominique Blouin, Télécom Paris
Moharram Challenger, University of Antwerp (TBC)
Joeri Exelmans, University of Antwerp
Randy Paredis, University of Antwerp
Robert Heinrich, Karlsruhe Institute of Technology

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Bran Selic, Malina Software Corporation, USA
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Antonio Vallecillo, Universidad de Málaga, Spain
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Andreas Wortmann, University of Stuttgart, Germany
Jamal El-Hachem, University of South Britanny, France
Hassna Louadah, University of Huddersfield, UK

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. 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. The added complexity that CPS brings compared to embedded and software-intensive systems requires looking at these new applications and how MPM techniques can be applied or adapted to them, 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.

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;
- **Co-simulation**, coordination algorithms ensuring correct simulation results.
- **Model Management** with, and for, MPM4CPS: challenges, techniques, tools.
- **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
- **Social impacts** processes in CPS, Large Data Management Modelling in CPS

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

Important Dates

Paper submission deadline: 20 July 2023
Notification of acceptance: 18 August 2023
Workshop dates: 1 - 6 October 2023 (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.
- **Full research papers** (10 pages max) present a novel, innovative approach;
- **Exemplar descriptions** (10 pages max) describing a CPS Engineering practice, highlighting both the processes at play and the formalisms, languages and/or tools used to support these activities, all expressed using the language described in the Workshop's webpage.
- **Short papers** (5 pages max) present new ideas or early-stage research, extensively discuss the experiences of the researchers with an MPM approach or demonstrate a tool;

All papers will be published with the main conference's workshop proceedings; authors submitting exemplars will eventually be invited to contribute to a Special Issue.