

PhD: Approaches for Managing Model Evolution

Supervisor: `ciprian.teodorov@ensta.fr`

Advisors: `sylvain.guerin@imt-atlantique.fr`, `dominique.blouin@telecom-paris.fr`

Location: ENSTA, Brest Campus, France

Keywords: Model-Driven Engineering (MDE), Model Federation, Model Evolution and Versioning

Team: P4S Lab-STICC (UMR 6285), <https://p4s.enstb.org>

Abstract

In many domains (industry, defense) where systems are becoming increasingly complex and involve numerous stakeholders and concerns, Model-Based Systems Engineering (MBSE) approaches are now widely used. MBSE is recognized for its potential to improve the specification, design, and development of systems.

However, several major challenges remain for the broad industrial adoption of MBSE. The heterogeneity and diversity of models and tools to be considered constitute a first obstacle. Model Management approaches attempt to address this issue, notably through initiatives such as ACMoM or Openflexo with the FML language (model federation). A second challenge is managing model evolution, to ensure that all artifacts produced by different tools remain relevant and consistent over time. In this context, the notion of an Authoritative Source of Truth (ASoT) captures the need to guarantee consistency in evolving systems.

The goal of this PhD is to analyze how models evolve over time and to investigate mechanisms that ensure smooth transitions between different versions. The objective is to develop approaches to track, manage, and formalize these evolutions, thereby ensuring continuity throughout the design process.

Context

This PhD will take place within the AUGMENT project (funded by the DGA, coordinated by CIEDS), in collaboration with Télécom Paris, ENSTA Bretagne, and IMT Atlantique. It will be carried out within the P4S team of the Lab-STICC, located at ENSTA's Brest campus. Research on Model-Driven Engineering (MDE), and more specifically on Model Management and Model Federation, is one of P4S's strategic research areas.

Research Problem

Modeling is a universal practice at the core of human reasoning—used to design, understand, imagine, analyze, and communicate. A model is a simplified representation of reality tailored to a particular concern. Model-Driven Engineering (MDE) aims to systematize the use of models in all tasks related to the software lifecycle. MBSE (Model-Based Systems Engineering) extends this principle to all engineering activities across the lifecycle of complex systems.

In many domains (industry, defense), where systems grow ever more complex and involve many stakeholders and disciplines, MBSE approaches are widely adopted. MBSE is valued for its ability to improve traceability between requirements, functions, and architecture, and to reduce errors thanks

to improved information consistency, clear visualization, better team understanding, and easier cross-disciplinary collaboration (mechanical, software, electronics). Companies such as Safran Electronics and Defense (SED), Safran Aerosystems, Airbus, Thales, as well as the US DoD and NASA, have already integrated MBSE at the core of their digital engineering strategies.

Yet, MBSE faces significant challenges related to the diversity of models, their languages, and their paradigms. This heterogeneity complicates consistency management and limits adaptability to evolving operational requirements. Model Management (MoM) approaches aim to tackle heterogeneity [1]. Methods and tools for addressing the semantic interoperability of numerous models used in complex systems development have been explored in both academic and industrial contexts [2]. The “model federation” approach, implemented in the Openflexo technology [5, 4, 8], allows models to be federated by defining viewpoints while preserving their technical environments (formats and tools) and maintaining consistency. Similarly, the ACMoM (Architecture-Centric Model Management) project, funded by the US DoD, developed a tool-supported model management approach [3, 6, 7], enabling formal representation of multiple modeling languages and models, as well as their interrelations, ensuring coherence across complex system design.

Nevertheless, one of the main barriers to MBSE adoption is the lack of systematic strategies for managing model evolution, which is essential to ensure that models remain both relevant and consistent over time. The notion of an Authoritative Source of Truth (ASoT) is central here, as it determines which models need to be updated to preserve coherence. Without careful ASoT management, engineering teams risk working with obsolete or inconsistent models—potentially jeopardizing mission success, especially in critical domains such as defense.

This PhD aims to study the management of model evolution. System engineering activities will serve as a business reference framework. The research will focus on observing, analyzing, and characterizing model evolution over time, while investigating mechanisms to ensure smooth transitions between versions. The ultimate objective is to provide approaches for tracking, managing, and formalizing model evolution, thereby improving continuity in the design process.

Research Directions

The general methodology will rely on mechanisms for organizing and managing models. As a first step, the Openflexo model federation approach will be compared to the ACMoM framework.

Next, the research will focus on observing, analyzing, and characterizing model evolution across different business contexts. This will involve multiple experiments related to system engineering activities and industrial case studies. The work will investigate the evolution of artifacts (models) created by various tools and actors across different processes. This raises business concerns such as co-evolution management [9]. From a technical perspective, the research will explore reification and semantics of the “version” concept. Some artifacts may be versioned using version control systems (e.g., *git* or *svn*¹), others may follow *ad hoc* naming strategies in file systems, while some tools may themselves provide versioning of artifacts.

In this context of heterogeneous modeling (tools, versioning), the PhD will propose, develop, and compare approaches for ensuring consistency in the evolution of interconnected models.

The notion of the *design multiverse* [10] may also be explored as part of this research.

Expected Candidate Skills

The candidate should possess (or be able to rapidly acquire) skills in the following areas:

- Software development
- mModeling and metamodeling (Model-Driven Engineering - MDE)

¹How to handle multiple coexisting versions of an artifact to support explicit co-evolution?

- Interest in domain-specific engineering challenges
- English proficiency (daily communication, professional use)

As with any PhD, the candidate should be motivated by research, and demonstrate openness, curiosity, and autonomy.

Research Team

The P4S team is part of the SHARP research cluster of the Lab-STICC laboratory (UMR 6285). Its name is an acronym for *"Processes for Safe and Secure Software and Systems"*.

The team focuses on methods and tools for specifying and describing systems and software to ensure their safety and security. P4S relies on strong expertise in system and process modeling and metamodeling.

This PhD proposal lies at the heart of P4S's activities, especially in ongoing work on model federation. It offers an excellent opportunity to join a dynamic team already actively engaged in these research topics.

Contact

For inquiries and applications, please contact:

- `ciprian.teodorov@ensta.fr`
- `sylvain.guerin@imt-atlantique.fr`
- `dominique.blouin@telecom-paris.fr`

References

- [1] Moussa Amrani, Rakshit Mittal, Miguel Goulão, Vasco Amaral, Sylvain Guérin, Salvador Martínez, Dominique Blouin, Anish Bhowe, and Yara Hallak *A Survey of Federative Approaches for Model Management in MBSE*, First International Workshop on Model Management (MoM), 27th International Conference on Model Driven Engineering Languages and Systems (MODELS), 2024
- [2] Yara Hallak, Dominique Blouin, Laurent Pautet, Layale Saab, Baptiste Laborie, and Rakshit Mittal *Model Management at Renault Virtual Simulation Team: State of Practice, Challenges and Research Directions*, First International Workshop on Model Management (MoM), 27th International Conference on Model Driven Engineering Languages and Systems (MODELS), 2024.
- [3] Rakshit Mittal, Dominique Blouin, Anish Bhowe, Soumyadip Bandyopadhyay *Solving the instance model-view update problem in AADL*, Proceedings of the 25th International Conference on Model Driven Engineering Languages and Systems (MODELS), 2022.
- [4] Sylvain Guérin. *FML: a model federation language for semantic interoperability of heterogeneous information sources*. <https://theses.hal.science/tel-04555528v1>. PhD Thesis, ENSTA Bretagne. 2023
- [5] Jean-Christophe Bach, Antoine Beugnard, Joël Champeau, Fabien Dagnat, Sylvain Guérin, and Salvador Martínez. *10 years of Model Federation with Openflexo: Challenges and Lessons Learned*. In Proceedings of the ACM/IEEE 27th International Conference on Model Driven Engineering Languages and Systems (MODELS '24). <https://doi.org/10.1145/3640310.3674084>

- [6] Ankica Barišić, Ivan Ruchkin, Dušan Savić, Mustafa Abshir Mohamed, Rima Al-Ali, Letitia W. Li, Hana Mkaouar, Raheleh Eslampanah, Moharram Challenger, Dominique Blouin, Oksana Nikiforova, Antonio Cicchetti *Multi-paradigm modeling for cyber-physical systems: A systematic mapping review*, Journal of Systems and Software (JSS), Volume 183, 2022
- [7] Moussa Amrani, Dominique Blouin, Robert Heinrich, Arend Rensink, Hans Vangheluwe, Andreas Wortmann *Multi-paradigm modelling for cyber-physical systems: a descriptive framework*, Softw Syst Model (SoSyM), 611–639, 2021
- [8] Sylvain Guérin, Joel Champeau, Jean-Christophe Bach, Antoine Beugnard, Fabien Dagnat, Salvador Martínez *Multi-level modeling with Openflexo/FML- A contribution to the MULTI process challenge*, EMISA Journal, 2022.
- [9] HOMOLKA, Marcel, MARCHEZAN, Luciano, ASSUNÇÃO, Wesley KG, et al. *Don't Touch my Model!" Towards Managing Model History and Versions during Metamodel Evolution*. In : Proceedings of the 2024 ACM/IEEE 44th International Conference on Software Engineering: New Ideas and Emerging Results. 2024. p. 77-81.
- [10] Sylvain Guérin and Salvador Martinez and Ciprian Teodorov *Modeling in the Design Multiverse*. 2025. <https://arxiv.org/abs/2509.06530>