



## **D6.5: Dissemination and Exploitation Report - final version**

M36

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## Executive summary

This is the last document of a series of three reporting the activities carried out in the last period in the context of WP6. The document contains information about how dissemination, communication, collaboration, standardization and exploitation have created the impact needed to ensure the sustainability of MegaM@Rt2 results.

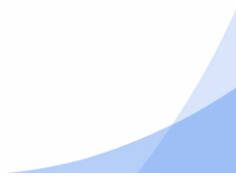
The document contains the list of publications and participation in events, and also those directly organized by the project. During the project duration, the consortium has been very active in scientific dissemination. In the last year, industry-oriented initiatives held by individual partners have been also performed through their organization to support the dissemination of MegaM@Rt2 results, aiming to foster a wider adoption of results. It also presents the final sustainability path of the project and the reached agreement for a joint exploitation of project results.

Everything is summarized in the analysis of KPIs measuring the reached impact of the project.

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**Acronyms**

<b>BM</b>	Business Model
<b>CAGR</b>	Compound Annual Growth Rate
<b>D</b>	Deliverable
<b>MoU</b>	Memorandum of Understanding
<b>T</b>	Task
<b>UC</b>	Use Case
<b>USD</b>	United States Dollar
<b>WP</b>	Work Package

## 1. Introduction

This document contains the list of activities, and the agreements reached, during the last period to maximise impact.

The document is structured as follows:

**Section 2.** Contains the impact measurement itself through a set of KPIs.

**Section 3.** Presents all the dissemination and communication activities performed.

**Section 4.** Summarizes in a comprehensive manner all the standardization activities performed within the project.

**Section 5.** Finally this section contains the agreements reached for the individual and joint exploitation of project results.

## 2. Impact Measurement

Previous deliverables presented the list of stakeholders and the messages to be transmitted. In order to be compliant with the proposed strategy, MegaM@Rt2 has focused on clearly identifying its use cases as the most representative results of the projects.

A set of fiches has been developed, to be published in the website, in order to show how real-world use cases can benefit of MegaM@Rt2 results.

KPI for Dissemination Output	Quantitative aim (FPP)	Achieved
<b>Scientific publications (and presentations) in conference proceedings</b>	21	127
<b>Presentations in conferences and events (talks, posters, etc.)</b>	Mixed with publications in proposal	49
<b>Workshops at specialized conferences</b>	5	9
<b>Videos</b>	2	1
<b>Scientific papers in peer-reviewed journals</b>	6	10
<b>White papers</b>	4	0
<b>Press releases</b>	6	5
<b>Website visits</b>	15000 (50% spending over 2 minutes)	233 unique visitors on average per month/1:23 time spent
<b>Presence in social media</b>	Twitter followers:400 LinkedIn discussions: weekly	134 followers in Twitter 186 connections in LinkedIn
<b>Postgraduate courses</b>	5	22

The project is mostly on track regarding the KPIs established at the beginning of the project. As it happened in previous periods, the project has been very active in publications and presentations, thus, reaching really impressive numbers over the threshold.

One of the not reached KPIs refers to the number of videos developed in the project context. Here it worth to say that only one video has been made available for the project, however there are several videos related to demos. There is an ongoing discussion with use cases regarding the possibility to make them available, as there are some confidentiality issues.

Although 4 white papers were planned at the beginning of the project, although finally none of them has been published. However, by the time this document is written, a position paper presenting the benefits open source can bring to companies and how it is addressed in MegaM@Rt2 has been accepted. Also, as it was commented before, instead of a single white paper several fiches, one per use case, have been developed to highlight the benefits the project can bring to businesses.

One final press release, although not accounted because it has not been yet published, will be presented in the coming days highlighting the project achievements.

Finally, although the number of followers in Twitter is still too low, the engagement rate has been increased, as well as the number of interactions. Furthermore, a dedicated profile for MegaM@Rt2 has been created to allow interactions. These represent a significant improvement in social media activity.

### 3. Dissemination and Communication actions

The main activities from MegaM@Rt2 project are described below and grouped by the type of action. The grouping is as follows:

- Publication and conferences
- Events organization and attendance
- Academic courses
- Social and online tools
- Marketing materials
- Community building activities

#### 3.1. Publications and Conferences

The following MegaM@Rt2 project results will be disseminated as scientific publications and presentations in conferences (such as posters, keynotes, tutorials, etc.) so that other technology vendors and industrial software development organisations are able to create tools and platforms that exploit or interoperate with MegaM@Rt2 technologies.

##### 3.1.1. Journal papers

- **Reasoning about UML/OCL Class Diagrams using Constraint Logic Programming and Formula**, Beatriz Perez and Ivan Porres, Information Systems, 2018  
Abstract: Model Driven Engineering promotes the use of models as the main artifacts in software and system development. Verification and validation of models are key activities to ensure the quality of the system under development. This paper presents a framework to reason about the satisfiability of class models described using the Unified Modeling Language (UML). The proposed framework allows us to identify possible design flaws as early as possible in the software development cycle. More specifically, we focus on UML Class Diagrams annotated with Object Constraint Language (OCL) invariants, which are considered to be the main artifacts in Object-Oriented analysis and design for representing the static structure of a system. We use the Constraint Logic programming (CLP) paradigm to reason about UML Class Diagrams modeling foundations. In particular, we use Formula as a model-finding and design space exploration tool. We also present an experimental Eclipse plug-in, which implements our UML model to Formula translation proposal following a Model Driven Architecture (MDA) approach. The proposed framework can be used to reason, validate, and verify UML Class Diagram software designs by checking correctness properties and generating model instances using the model exploration tool Formula.

<https://doi.org/10.1016/j.is.2018.08.005>

[https://www.thinkmind.org/download.php?articleid=icsea\\_2013\\_8\\_10\\_10352](https://www.thinkmind.org/download.php?articleid=icsea_2013_8_10_10352)

- **Distributing relational model transformation on MapReduce**, Amine Benellalam, Abel Gómez, Massimo Tisi, Jordi Cabot, Journal of Systems and Software, 2018  
Abstract: MDE has been successfully adopted in the production of software for several domains. As the models that need to be handled in MDE grow in scale, it becomes necessary to design scalable algorithms for model transformation (MT) as well as suitable frameworks for storing and retrieving models efficiently. One way to cope with scalability is to exploit the wide availability of distributed clusters in the Cloud for the parallel execution of MT. However, because of the dense interconnectivity of models and the complexity of transformation logic, the efficient use of these solutions in distributed model processing and persistence is not trivial. This paper exploits the high



level of abstraction of an existing relational MT language, ATL, and the semantics of a distributed programming model, MapReduce, to build an ATL engine with implicitly distributed execution. The syntax of the language is not modified and no primitive for distribution is added. Efficient distribution of model elements is achieved thanks to a distributed persistence layer, specifically designed for relational MT. We demonstrate the effectiveness of our approach by making an implementation of our solution publicly available and using it to experimentally measure the speed-up of the transformation system while scaling to larger models and clusters.  
<https://doi.org/10.1016/j.jss.2018.04.014> <https://hal.archives-ouvertes.fr/hal-01863897/file/distributed-atl%20%288%29.pdf>

- **ESPRET: A tool for execution time estimation of manual test cases**, Sahar Tahvili, Wasif Afzal, Mehrdad Saadatmand, MarkusBohlin, Sharvathul Hasan Ameerjan, Journal of Systems and Software, 2018

Abstract: Manual testing is still a predominant and an important approach for validation of computer systems, particularly in certain domains such as safety-critical systems. Knowing the execution time of test cases is important to perform test scheduling, prioritization and progress monitoring. In this work, we present, apply and evaluate ESPRET (EStimation and PRediction of Execution Time) as our tool for estimating and predicting the execution time of manual test cases based on their test specifications. Our approach works by extracting timing information for various steps in manual test specification. This information is then used to estimate the maximum time for test steps that have not previously been executed, but for which textual specifications exist. As part of our approach, natural language parsing of the specifications is performed to identify word combinations to check whether existing timing information on various test steps is already available or not. Since executing test cases on the several machines may take different time, we predict the actual execution time for test cases by a set of regression models. Finally, an empirical evaluation of the approach and tool has been performed on a railway use case at Bombardier Transportation (BT) in Sweden.

<https://doi.org/10.1016/j.jss.2018.09.003>

[http://www.es.mdh.se/pdf\\_publications/5223.pdf](http://www.es.mdh.se/pdf_publications/5223.pdf)

- **Model-driven Design-Runtime Interaction in Safety-Critical System Development: an Experience Report**, Romina Eramo, Florent Marchand de Kerchove, Maximilien Colange, Michele Tucci, Julien Ouy, Hugo Bruneliere, Davide Di Ruscio, Journal of Object Technology, AITO, 2019

Abstract : MegaM@Rt2 project is a collaborative initiative of the ECSEL Joint Undertaking under Horizon 2020 EU programme. The project regroups 26 partners from 6 different European countries who jointly address challenges of engineering modern cyber-physical systems by using model-based engineering methods. Since it is a model-based project, we adopted a similar approach for dealing with requirements analysis, architecture, design, roadmap planning and development status checking. In these tasks, document generation methods were particularly useful to create a set of “live” reference specifications and contractual reports. We believe that these methods perfectly demonstrate relevant benefits of the model-based approach and are applicable to many other contexts. Document generation has several challenges, since the produced documents should address several goals and target different audience. Hence, we describe this approach in detail in this paper in the form of an experience report. In essence, the MegaM@Rt2 project had a rather trivial task to document inception phase of the project. The challenge arises from the scale of the

project, we had to deal with hundreds of requirements from completely different users, hundreds of features of 29 tools, which had to be mapped to those requirements in order to analyze a gap and devise a roadmap for a consistent tool chain. With limited resource on technical coordination we had to be extremely efficient and thus we adopted a model-based approach that we describe in this paper. The paper should be helpful to project managers and architects who wish to discuss on model-based approaches from a practical side.

<http://dx.doi.org/10.5381/jot.2019.18.2.a1>,

<https://zenodo.org/record/3470880>

- **Model-based testing using UML activity diagrams: A systematic mapping study**, Tanwir Ahmad, Junaid iqbal, Adnan Ashraf, Dragos Truscan, Ivan Porres, Computer Science Review, Elsevier, 2019

Abstract: Context: The Unified Modeling Language (UML) has become the de facto standard for software modeling. UML models are often used to visualize, understand, and communicate the structure and behavior of a system. UML activity diagrams (ADs) are often used to elaborate and visualize individual use cases. Due to their higher level of abstraction and process-oriented perspective, UML ADs are also highly suitable for model-based test generation. In the last two decades, different researchers have used UML ADs for test generation. Despite the growing use of UML ADs for model-based testing, there are currently no comprehensive and unbiased studies on the topic. Objective: To present a comprehensive and unbiased overview of the state-of-the-art on model-based testing using UML ADs. Method: We review and structure the current body of knowledge on model-based testing using UML ADs by performing a systematic mapping study using well-known guidelines. We pose nine research questions, outline our selection criteria, and develop a classification scheme. Results: The results comprise 41 primary studies analyzed against nine research questions. We also highlight the current trends and research gaps in model-based testing using UML ADs and discuss some shortcomings for researchers and practitioners working in this area. The results show that the existing approaches on model-based testing using UML ADs tend to rely on intermediate formats and formalisms for model verification and test generation, employ a multitude of graph-based coverage criteria, and use graph search algorithms. Conclusion: We present a comprehensive overview of the existing approaches on model-based testing using UML ADs. We conclude that (1) UML ADs are not being used for non-functional testing, (2) only a few approaches have been validated against realistic, industrial case studies, (3) most approaches target very restricted application domains, and (4) there is currently a clear lack of holistic approaches for model-based testing using UML ADs.

<https://doi.org/10.1016/j.cosrev.2019.07.001>,

[https://www.researchgate.net/publication/334657530\\_Model-based\\_testing\\_using\\_UML\\_activity\\_diagrams\\_A\\_systematic\\_mapping\\_study](https://www.researchgate.net/publication/334657530_Model-based_testing_using_UML_activity_diagrams_A_systematic_mapping_study)

- **The MegaM@Rt2 ECSEL project: MegaModelling at Runtime – Scalable model-based framework for continuous development and runtime validation of complex systems**, Afzal, Wasif and Bruneliere, Hugo and Di Ruscio, Davide and Sadovykh, Andrey and Mazzini, Silvia and Cariou, Eric and Truscan, Dragos and Cabot, Jordi and Gomez, Abel and Gorrongoitia, Jesus and Pomante, Luigi and Smrz, Pavel, Microprocessors and Microsystems: Embedded Hardware Design, 2019

Abstract: A major challenge for the European electronic industry is to enhance productivity by ensuring quality of development, integration and maintenance while reducing the associated costs. Model-Driven Engineering (MDE) principles and techniques have already shown promising capabilities, but they still need to

scale up to support real-world scenarios implied by the full deployment and use of complex electronic components and systems. Moreover, maintaining efficient traceability, integration, and communication between two fundamental system life cycle phases (design time and runtime) is another challenge requiring the scalability of MDE. This paper presents an overview of the ECSEL1 project entitled “MegaModelling at runtime Scalable model-based framework for continuous development and runtime validation of complex systems” (MegaM@Rt2), whose aim is to address the above-mentioned challenges facing MDE. Driven by both large and small industrial enterprises, with the support of research partners and technology providers, MegaM@Rt2 aims to deliver a framework of tools and methods for: 1) system engineering/design and continuous development, 2) related runtime analysis and 3) global models and traceability management. Diverse industrial use cases (covering strategic domains such as aeronautics, railway, construction and telecommunications) will integrate and demonstrate the validity of the MegaM@Rt2 solution. This paper provides an overview of the MegaM@Rt2 project with respect to its approach, mission, objectives as well as to its implementation details. It further introduces the consortium as well as describes the work packages and few already produced deliverables.

<https://dx.doi.org/10.1016/j.micpro.2018.05.010>, <https://hal.archives-ouvertes.fr/hal-01810002>

- **Dealing with Non-Functional Requirements in Model-Driven Development: A Survey** Ameller, David and Franch, Xavier and Gomez, Cristina and Martinez-Fernandez, Silverio and Araujo, Joao and Biffi, Stefan and Cabot, Jordi and Cortellessa, Vittorio and Mendez, Daniel and Moreira, Ana and Muccini, Henry and Vallecillo, Antonio and Wimmer, Manuel and Amaral, Vasco and Bohm, Wolfgang and Bruneliere, Hugo and Burgueno, Loli and Goulao, Miguel and Teufl, Sabine and Berardinelli, Luca, IEEE Transactions on Software Engineering, 2019

Abstract: Context: Managing Non-Functional Requirements (NFRs) in software projects is challenging, and projects that adopt Model-Driven Development (MDD) are no exception. Although several methods and techniques have been proposed to face this challenge, there is still little evidence on how NFRs are handled in MDD by practitioners. Knowing more about the state of the practice may help researchers to steer their research and practitioners to improve their daily work. Objective: In this paper, we present our findings from an interview-based survey conducted with practitioners working in 18 different companies from 6 European countries. From a practitioner's point of view, the paper shows what barriers and benefits the management of NFRs as part of the MDD process can bring to companies, how NFRs are supported by MDD approaches, and which strategies are followed when (some) types of NFRs are not supported by MDD approaches. Results: Our study shows that practitioners perceive MDD adoption as a complex process with little to no tool support for NFRs, reporting productivity and maintainability as the types of NFRs expected to be supported when MDD is adopted. But in general, companies adapt MDD to deal with NFRs. When NFRs are not supported, the generated code is sometimes changed manually, thus compromising the maintainability of the software developed. However, the interviewed practitioners claim that the benefits of using MDD outweigh the extra effort required by these manual adaptations. Conclusion: Overall, the results indicate that it is important for practitioners to handle NFRs in MDD, but further research is necessary in order to lower the barrier for supporting a broad spectrum of NFRs with MDD. Still, much conceptual and tool implementation work seems to be necessary to lower the barrier of integrating the broad spectrum of NFRs in practice.

<https://dx.doi.org/10.1109/TSE.2019.2904476>,  
<https://hal.archives-ouvertes.fr/hal-02075976>

<https://hal.archives-ouvertes.fr/hal-02075976>

- **A Feature-based Survey of Model View Approaches**, Hugo Bruneliere, Erik Burger, Jordi Cabot, Manuel Wimmer, Software and Systems Modeling, 2019  
 Abstract: When dealing with complex systems, information is very often fragmented across many different models expressed within a variety of (modeling) languages. To provide the relevant information in an appropriate way to different kinds of stakeholders, (parts of) such models have to be combined and potentially revamped by focusing on concerns of particular interest for them. Thus, mechanisms to define and compute views over models are highly needed. Several approaches have already been proposed to provide (semi-)automated support for dealing with such model views. This paper provides a detailed overview of the current state-of-the-art in this area. To achieve this, we relied on our own experiences of designing and applying such solutions in order to conduct a literature review on this topic. As a result, we discuss the main capabilities of existing approaches and propose a corresponding research agenda. We notably contribute a feature model describing what we believe to be the most important characteristics of the support for views on models. We expect this work to be helpful to both current and potential future users and developers of model view techniques, as well as to any person generally interested in model-based software and systems engineering.

<https://dx.doi.org/10.1007/s10270-017-0622-9>,  
<https://hal.inria.fr/hal-01590674>

- **On a Tool-Supported Model-Based Approach for Building Architectures and Roadmaps: The MegaM@Rt2 Project Experience**, Sadovykh, Andrey and Afzal, Wasif and Truscan, Dragos and Pierini, Pierluigi and Bruneliere, Hugo and Bagnato, Alessandra and Gomez, Abel and Cabot, Jordi and Avila-Garcia, Orlando  
 Microprocessors and Microsystems: Embedded Hardware Design, 2019,  
 Abstract: MegaM@Rt2 is a large European project dedicated to the provisioning of a model-based methodology and supporting tooling for system engineering at a wide scale. It notably targets the continuous development and runtime validation of such complex systems by developing a framework addressing a large set of engineering processes and application domains. This collaborative project involves 27 partners from 6 different countries, 9 industrial case studies as well as over 30 different software tools from project partners (and others). In the context of the MegaM@Rt2 project, we elaborated on a pragmatic model-driven approach to specify the case study requirements, design the high-level architecture of a framework, perform the gap analysis between the industrial needs and current state-of-the-art, and plan a first framework development roadmap accordingly. The present paper describes the generic tool-supported approach that came out as a result. It also details its concrete application in the MegaM@Rt2 project. In particular, we discuss the collaborative modeling process, the requirement definition tooling, the approach for components modeling, as well as the traceability and document generation. In addition, we show how we used the proposed solution to specify the MegaM@Rt2 framework's conceptual tool components centered around three complementary tool sets: the MegaM@Rt2 System Engineering Tool Set, the MegaM@Rt2 Runtime Analysis Tool Set and the MegaM@Rt2 Model & Traceability Management Tool Set. The paper ends with a discussion on the practical lessons we have learned from this work so far.

<https://dx.doi.org/10.1016/j.micpro.2019.102848>,  
<https://hal.archives-ouvertes.fr/hal-02265575>

- **Information Flow in Software Testing – An Interview Study With Embedded Software Engineering Practitioners**, Per Erik Strandberg, Eduard Paul Enoiu, Wasif Afzal, Daniel Sundmark, Robert Feldt, IEEE Access, 2019

Abstract: Background: In order to make informed decisions, software engineering practitioners need information from testing. However, with the trend of increased automation, there is exponential growth and increased distribution of this information. This paper aims at exploring the information flow in software testing in the domain of embedded systems. Method: Data was collected through semi-structured interviews of twelve experienced practitioners with an average work experience of more than fourteen years working at five organizations in the embedded software industry in Sweden. Seventeen hours of audio recordings were transcribed and anonymized into 130 pages of text that was analyzed by means of thematic analysis. Results: The flow of information in software testing can be represented as feedback loops involving stakeholders, software artifacts, test equipment, and test results. The six themes that affect the information flow are how organizations conduct testing and troubleshooting, communication, processes, technology, artifacts, and the organization of the company. Seven main challenges for the flow of information in software testing are comprehending the objectives and details of testing; root cause identification; poor feedback; postponed testing; poor artifacts and traceability; poor tools and test infrastructure; and distances. Finally, five proposed approaches for enhancing the flow are: close collaboration between roles; fast feedback; custom test report automation; test results visualization; and the use of suitable tools and frameworks. Conclusions: The results indicate that there are many opportunities to improve the flow of information in software testing: a first mitigation step is to better understand the challenges and approaches. Future work is needed to realize this in practice, for example, on how to shorten feedback cycles between roles, as well as how to enhance exploration and visualization of test results.

10.1109/ACCESS.2019.2909093, <https://ieeexplore.ieee.org/document/8681096>
- **SystemC-based Electronic System-Level Design Space Exploration Environment for Dedicated Heterogeneous Multi-Processor Systems**, Luigi Pomante, Vittoriano Muttillio, Marco Santic, Paolo Serri, Microprocessors and Microsystems, 2019

Abstract: This work faces the problem of the Electronic System-Level (ESL) HW/SW co-design of dedicated electronic digital systems based on heterogeneous multi-processor architectures. In particular, the work presents a prototype SystemC-based environment that exploits a Design Space Exploration (DSE) approach able to suggest an HW/SW partitioning of the system specification and a mapping onto an automatically defined architecture. The descriptions of the reference HW/SW co-design methodology and the main design issues related to the developed DSE SW tools, supported by two reference use cases that allows to understand the role of the DSE step in the whole design flow, represent the core of the paper.

<https://doi.org/10.1016/j.micpro.2019.102898>,  
<https://zenodo.org/record/3506217#.XamxTugzZPY>
- **Clustering Structure Analysis in Time-Series Data With Density-Based Clusterability Measure**, Juho Jokinen, Tomi Rätty & Timo Lintonen, IEEE/CAA Journal of Automatica Sinica, 2019,

Abstract: Clustering is used to gain an intuition of the structures in the data. Most of the current clustering algorithms produce a clustering structure even on data that do not possess such structure. In these cases, the algorithms force a structure in the data instead of discovering one. To avoid false structures in the relations of data, a novel clusterability assessment method called density-based clusterability measure

is proposed in this paper. It measures the prominence of clustering structure in the data to evaluate whether a cluster analysis could produce a meaningful insight to the relationships in the data. This is especially useful in time-series data since visualizing the structure in time-series data is hard. The performance of the clusterability measure is evaluated against several synthetic data sets and time-series data sets, which illustrate that the density-based clusterability measure can successfully indicate clustering structure of time-series data.

10.1109/JAS.2019.1911744, [http://www.ieee-](http://www.ieee-jas.org/article/doi/10.1109/JAS.2019.1911744?pageType=en)

[jas.org/article/doi/10.1109/JAS.2019.1911744?pageType=en](http://www.ieee-jas.org/article/doi/10.1109/JAS.2019.1911744?pageType=en)

- **Self-Learning of Multivariate Time Series Using Perceptually Important Points**, Timo Lintonen & Tomi Rätty, IEEE/CAA Journal of Automatica Sinica, 2019  
 Abstract: In machine learning, positive-unlabelled (PU) learning is a special case within semi-supervised learning. In positive-unlabelled learning, the training set contains some positive examples and a set of unlabelled examples from both the positive and negative classes. Positive-unlabelled learning has gained attention in many domains, especially in time-series data, in which the obtainment of labelled data is challenging. Examples which originate from the negative class are especially difficult to acquire. Self-learning is a semi-supervised method capable of PU learning in time-series data. In the self-learning approach, observations are individually added from the unlabelled data into the positive class until a stopping criterion is reached. The model is retrained after each addition with the existent labels. The main problem in self-learning is to know when to stop the learning. There are multiple, different stopping criteria in the literature, but they tend to be inaccurate or challenging to apply. This publication proposes a novel stopping criterion, which is called Peak evaluation using perceptually important points, to address this problem for time-series data. Peak evaluation using perceptually important points is exceptional, as it does not have tunable hyperparameters, which makes it easily applicable to an unsupervised setting. Simultaneously, it is flexible as it does not make any assumptions on the balance of the dataset between the positive and the negative class.  
 10.1109/JAS.2019.1911777, <http://www.ieee-jas.org/article/doi/10.1109/JAS.2019.1911777?pageType=en>
- **Regular Decomposition of Large Graphs: Foundation of a Sampling Approach to Stochastic Block Model Fitting**, Hannu Reittu, Ilkka Norros, Tomi Rätty, Marianne Bolla and Fulop Baszo, Data Science and Engineering, 2019  
 Abstract: We analyze the performance of regular decomposition, a method for compression of large and dense graphs. This method is inspired by Szemerédi's regularity lemma (SRL), a generic structural result of large and dense graphs. In our method, stochastic block model (SBM) is used as a model in maximum likelihood fitting to find a regular structure similar to the one predicted by SRL. Another ingredient of our method is Rissanen's minimum description length principle (MDL). We consider scaling of algorithms to extremely large size of graphs by sampling a small subgraph. We continue our previous work on the subject by proving some experimentally found claims. Our theoretical setting does not assume that the graph is generated from a SBM. The task is to find a SBM that is optimal for modeling the given graph in the sense of MDL. This assumption matches with real-life situations when no random generative model is appropriate. Our aim is to show that regular decomposition is a viable and robust method for large graphs emerging, say, in Big Data area.  
 10.1007/s41019-019-0084-x, <https://link.springer.com/article/10.1007%2Fs41019-019-0084-x>

- **Unsupervised online detection and prediction of outliers in streams of sensor data**, Niko Reunanen, Tomi Rätty, Juho Jokinen, Tyler Hoyt and David Culler, International Journal of Data Science and Analytics, 2019

Abstract: Outliers are unexpected observations, which deviate from the majority of observations. Outlier detection and prediction are challenging tasks, because outliers are rare by definition. A stream is an unbounded source of data, which has to be processed promptly. This article proposes novel methods for outlier detection and outlier prediction in streams of sensor data. The outlier detection is an independent, unsupervised process, which is implemented using an autoencoder. The outlier detection continuously evaluates if the latest data point  $x_i$  from a stream is an inlier or an outlier. This distinction is based on the reconstruction cost accompanied with Chebyshev's inequality and the EWMA (exponentially weighted moving average) model. The outlier prediction uses the results of the outlier detection to form the required training data. The outlier prediction utilizes LR (logistic regression), SGD (stochastic gradient descent) and the hidden representation provided by the autoencoder to predict outliers in streams. The results of the experiments show that the proposed methods (1) provide accurate results, (2) are calculated in reduced computation time and (3) use a low amount of memory. Our proposed methods are suitable for analyzing streams of sensor data and providing results with low latency. The experiments also indicated that the outlier prediction is able to anticipate the occurrence of outliers in streams of sensor data.

10.1007/s41060-019-00191-3  
<https://link.springer.com/article/10.1007/s41060-019-00191-3>
- **Robust methods and conditional expectations for vehicular traffic count analysis**, Jorma Kilpi, Ilkka Norros, Pirkko Kuusela, Fanny Malin and Tomi Rätty, European Transport Research Review, 2020

Abstract: We study the problem of making algorithmic statistical inferences about the dynamics of city traffic. Our data is based on loop detector counts of observed vehicles in various roads in the city of Tampere, Finland. We show that meaningful correlations can be found between traffic asymmetries at different measurement locations. The traffic asymmetry is the difference of the traffic counts of the opposite directions of a road. The correlations can be further quantified by estimating how much they effect on the average values of the traffic asymmetries at the neighboring locations. Conditional expectations, both sample and binormal model-based versions are useful tools for quantifying this effect. The uncertainty bounds of conditional expectations of the binormal model distribution are extremely useful for outlier detection. Furthermore, conditional expectations of the multinormal distribution model can be used to recover missing data with bounds to uncertainty.

10.1186/s12544-020-0399-8  
<https://link.springer.com/article/10.1186/s12544-020-0399-8>
- **Guest editors' introduction to the special issue on Model Driven Engineering and Reverse Engineering: Research and Practice**, Francesca Arcelli Fontana, Hugo Bruneliere, Hausi A. Müller, Claudia Raibulet, Journal of Systems and Software, 2020

Abstract: The systematic use of models in software engineering represents the foundation of Model Driven Engineering (or MDE). High-level domain-specific models are defined and further exploited for the implementation, testing, integration, and maintenance of software. One of the key ideas in MDE is that transformation of models from a high abstraction level to a lower level can be described and automated by using transformation languages. Source code can be then generated by limiting the amount of handwritten code, implying less effort and possibly less errors. Moreover,

during its life cycle, existing software needs maintenance, modification and evolution independently of its size and application domain. Most of the times, the related documentation (e.g., concerning its architecture, features, knowledge) quickly becomes obsolete. Hence, most companies are facing the problem of performing reverse engineering tasks to comprehend the software to be changed. In this context, models can play a key role for improving software understanding processes, by providing different views on existing software at a higher abstraction level than source code. Hence, Model Driven Reverse Engineering (or MDRE) approaches start from the source code, at a low abstraction level, and produce different kinds of models of the software at higher abstraction levels. These models represent various perspectives on the same software. Depending on the cases, model discovery from source code and further model transformations can be more or less automated. As a result, the obtained models can be analyzed by domain experts and tools or used as inputs to model-based processes (e.g., for forward engineering activities). This special issue contains papers reporting on various research efforts, experiences or practices in the area of Model Driven Engineering (MDE) and Model Driven Reverse Engineering (MDRE). These papers are the result of a rigorous peer-reviewing and selection process that started in March 2018 (the submission deadline was actually extended up to April 16, 2018 due to several requests). At this date, we got 13 full paper submissions in total. Among them, and after one-to-three rounds of reviews by at least 2 reviewers for each paper, 6 full papers were finally selected for publication in the present special issue. The papers contained in this volume cover a variety of MDE/MDRE-related topics going from extensions of the Knowledge Discovery Metamodel for aspect-orientation, metamodels for software protection and reverse engineering, structured assurance metamodels to model-driven IT governance process for long term objectives, retrieving behavioral model from black-box system, to approaches for reverse engineering of legacy systems and code migration.

10.1016/j.jss.2019.110446

<https://www.sciencedirect.com/science/article/pii/S0164121219302201>

- **An Evaluation of Monte Carlo-Based Hyper-Heuristic for Interaction Testing of Industrial Embedded Software Applications**, Bestoun Ahmed, Eduard Paul Enoiu, Wasif Afzal, Kamal Zamli, MDPI Designs Journal, 2020

Abstract: Hyper-heuristic is a new methodology for the adaptive hybridization of meta-heuristic algorithms to derive a general algorithm for solving optimization problems. This work focuses on the selection type of hyper-heuristic, called the exponential Monte Carlo with counter (EMCQ). Current implementations rely on the memory-less selection that can be counterproductive as the selected search operator may not (historically) be the best performing operator for the current search instance. Addressing this issue, we propose to integrate the memory into EMCQ for combinatorial t-wise test suite generation using reinforcement learning based on the Q-learning mechanism, called Q-EMCQ. The limited application of combinatorial test generation on industrial programs can impact the use of such techniques as Q-EMCQ. Thus, there is a need to evaluate this kind of approach against relevant industrial software, with a purpose to show the degree of interaction required to cover the code as well as finding faults. We applied Q-EMCQ on 37 real-world industrial programs written in Function Block Diagram (FBD) language, which is used for developing a train control management system at Bombardier Transportation Sweden AB. The results show that Q-EMCQ is an efficient technique for test case generation. Additionally, unlike the t-wise test suite generation, which deals with the minimization problem, we have also subjected Q-EMCQ to a maximization problem involving the general module clustering to demonstrate



the effectiveness of our approach. The results show the Q-EMCQ is also capable of outperforming the original EMCQ as well as several recent meta/hyper-heuristics including modified choice function, Tabu high-level hyper-heuristic, teaching learning-based optimization, sine cosine algorithm, and symbiotic optimization search in clustering quality within comparable execution time.

<https://doi.org/10.1007/s00500-020-04769-z>

<https://link.springer.com/article/10.1007%2Fs00500-020-04769-z>

- **Model Testing of Complex Embedded Systems using EAST-ADL and Energy-Aware Mutations**, Eduard Paul Enoiu and Cristina Seceleanu, MDPI Design Journal, 2020

Abstract: Nowadays, embedded systems are increasingly complex, meaning that traditional testing methods are costly to use and infeasible to directly apply due to the complex interactions between hardware and software. Modern embedded systems are also demanded to function based on low-energy computing. Hence, testing the energy usage is increasingly important. Artifacts produced during the development of embedded systems, such as architectural descriptions, are beneficial abstractions of the system's complex structure and behavior. Electronic Architecture and Software Tools Architecture Description Language (EAST-ADL) is one such example of a domain-specific architectural language targeting the automotive industry. In this paper, we propose a method for testing design models using EAST-ADL architecture mutations. We show how fault-based testing can be used to generate, execute and select tests using energy-aware mutants—syntactic changes in the architectural description, used to mimic naturally occurring energy faults. Our goal is to improve testing of complex embedded systems by moving the testing bulk from the actual systems to models of their behaviors and non-functional requirements. We combine statistical model-checking, increasingly used in quality assurance of embedded systems, with EAST-ADL architectural models and mutation testing to drive the search for faults. We show the results of applying this method on an industrial-sized system developed by Volvo GTT. The results indicate that model testing of EAST-ADL architectural models can reduce testing complexity by bringing early and cost-effective automation.

<https://doi.org/10.3390/designs4010005>

[https://www.mdpi.com/2411-](https://www.mdpi.com/2411-9660/4/1/5)

[9660/4/1/5](https://www.mdpi.com/2411-9660/4/1/5)

- **Improving Software Requirements Reasoning by Novices: An Empirical Evaluation**, Rubia Fatima and Affan Yasin and Lin Liu and Jianmin Wang and Wasif Afzal and Atif Yasin, IET Software, 2019

Abstract: Requirements elicitation is one of the essential steps towards software design and construction. Business analysts and stakeholders often face challenges in gathering or conveying key software requirements. There are many methods and tools designed by researchers and practitioners but with the persistent development of new technologies, there is a need to make requirements gathering and design-rationale process more efficient and adaptable. Storytelling is an emerging concept and researchers are witnessing its effectiveness in education, community building, information system, and requirement elicitation. Objectives of this study are to devise a method for requirements elicitation and improving design-rationales using story-based techniques and evaluate the effectiveness of the proposed activity. To answer the research objectives, the authors have conducted open-ended interviews to get feedback on the proposed method; the authors have case requirement from a running project to map how this method can be useful; and performed empirical evaluation of the proposed card-based activity. The estimated regression model, in our

study, has shown that participants' perception about the simplicity/easiness and the joy of playing the game has an eventual positive effect on requirements elicitation through enhancing user's desire to play the game, which in turn increases the collaborative learning outcomes of the game.

DOI: 10.1049/iet-sen.2018.5379

<https://www.es.mdh.se/publications/5572->

Improving\_Software\_Requirements\_Reasoning\_by\_Novices\_\_An\_Empirical\_Evaluation

- **An Improved Software Reliability Prediction Model By Using High Precision Error Iterative Analysis Method**, Gul Jabeen and Ping Luo and Wasif Afzal, Software Testing, Verification and Reliability, 2019  
 Abstract: Software reliability deals with the probability that software will not cause the failure of a system in a specified time interval. Software reliability growth models (SRGMs) are used to predict future behaviour from known characteristics of software, like historical failures. With the increasing demand to deliver quality software, more accurate SRGMs are required to estimate the software release time and cost of the testing effort. Software failure predictions at early phases also provide an opportunity for investing in proper quality assurance and upfront resource planning. Up till now, many parametric software reliability growth models (PSRGMs) have been proposed. However, several limitations of them mean that their predictive capacities differ from one dataset to others. In this paper, to enhance the prediction accuracy of existing PSRGMs, a high precision error iterative analysis method (HPEIAM) has been proposed based on the residual errors. In HPEIAM, residual errors from the estimated results of SRGMs are considered as another source of data that can combine the residual error modification with artificial neural network sign estimator. The repeated computation of residual errors by SRGMs improves and corrects the prediction accuracy up to the expected level. The performance of HPEIAM is tested with several PSRGMs using two sets of real software failure data based on three performance criteria. Moreover, we have compared the estimated failures predicted by HPEIAM with genetic algorithm (GA)-based prediction improvement. The results demonstrate that HPEIAM gives an improvement in goodness-of-fit and predictive performance for every PSRGM in initial few iterations.  
<https://doi.org/10.1002/stvr.1710>

<https://www.es.mdh.se/publications/5537->

An\_Improved\_Software\_Reliability\_Prediction\_Model\_By\_Using\_High\_Precision\_Error\_Iterative\_Analysis\_Method

- **SPOF - Slave Powerlink on FPGA for smart Sensors and Actuators interfacing for Industry 4.0 applications**, G. Valente, V. Muttillio, M. Muttillio, G. Barile, A. Leoni, W. Tiberti, L. Pomante, Energies, 2019  
 Abstract: We here present a new PLC-POWERLINK industrial solution for Industry 4.0 applications. The proposed solution provides the capability to separate the sensing functionality from the PLC-side, in demand for the reconfigurable FPGA implementation. In particular, we here provide a framework that supports the interfacing between the POWERLINK protocol and commonly used standards, such as I2C, SPI, and UART. This has been obtained by using a framework built around a soft IP-core Application Processor, which manages the interfacing with several POWERLINK slaves, able to support the data exchange with the POWERLINK Communication Processor. A practical application example and related implementation details are presented in the paper.

<https://doi.org/10.3390/en12091633>  
1073/12/9/1633/htm

<https://www.mdpi.com/1996->

- **A Two-layer Component-based Allocation for Embedded Systems with GPUs**, Gabriel Campeanu, Mehrdad Saadatmand, Designs Journal, 2019  
 Abstract: Component-based development is a software engineering paradigm that can facilitate the construction of embedded systems and tackle its complexities. The modern embedded systems have more and more demanding requirements. One way to cope with such a versatile and growing set of requirements is to employ heterogeneous processing power, i.e., CPU–GPU architectures. The new CPU–GPU embedded boards deliver an increased performance but also introduce additional complexity and challenges. In this work, we address the component-to-hardware allocation for CPU–GPU embedded systems. The allocation for such systems is much complex due to the increased amount of GPU-related information. For example, while in traditional embedded systems the allocation mechanism may consider only the CPU memory usage of components to find an appropriate allocation scheme, in heterogeneous systems, the GPU memory usage needs also to be taken into account in the allocation process. This paper aims at decreasing the component-to-hardware allocation complexity by introducing a two-layer component-based architecture for heterogeneous embedded systems. The detailed CPU–GPU information of the system is abstracted at a high-layer by compacting connected components into single units that behave as regular components. The allocator, based on the compacted information received from the high-level layer, computes, with a decreased complexity, feasible allocation schemes. In the last part of the paper, the two-layer allocation method is evaluated using an existing embedded system demonstrator; namely, an underwater robot.  
<https://doi.org/10.3390/designs3010006>,  
<https://www.mdpi.com/2411-9660/3/1/6>
- **sOrTES: A Supportive Tool for Stochastic Scheduling of Manual Integration Test Cases**, Sahar Tahvili, Rita Pimentel, Wasif Afzal, Marcus Ahlberg, Eric Fornander, Markus Bohlin, IEEE ACCESS, 2019  
 Abstract: The main goal of software testing is to detect as many hidden bugs as possible in the final software product before release. Generally, a software product is tested by executing a set of test cases, which can be performed manually or automatically. The number of test cases which are required to test a software product depends on several parameters such as the product type, size, and complexity. Executing all test cases with no particular order can lead to waste of time and resources. Test optimization can provide a partial solution for saving time and resources which can lead to the final software product being released earlier.  
 In this regard, test case selection, prioritization, and scheduling can be considered as possible solutions for test optimization. Most of the companies do not provide direct support for ranking test cases on their own servers. In this paper, we introduce, apply, and evaluate sOrTES as our decision support system for manual integration of test scheduling. sOrTES is a Python-based supportive tool which schedules manual integration test cases which are written in a natural language text. The feasibility of sOrTES is studied by an empirical evaluation which has been performed on a railway use-case at Bombardier Transportation, Sweden. The empirical evaluation indicates that around 40% of testing failure can be avoided by using the proposed execution schedules by sOrTES, which leads to an increase in the requirements coverage of up to 9.6%.  
[10.1109/ACCESS.2019.2893209](https://doi.org/10.1109/ACCESS.2019.2893209)  
<https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&number=8616828>

### 3.1.2. Conference and workshops papers

- Can Pairwise Testing Perform Comparably to Manually Handcrafted Testing Carried Out by Industrial Engineers?** Peter Charbachi, Linus Eklund, Eduard Paul Enoiu, International Conference on Software Quality, Reliability and Security Companion (QRS-C), 2017  
 Abstract: Testing is an important activity in engineering of industrial software. For such software, testing is usually performed manually by handcrafting tests based on specific design techniques and domain-specific experience. To support developers in testing, different approaches for producing good test cases have been proposed. In the last couple of years combinatorial testing has been explored with the goal of automatically combining the input values of the software based on a certain strategy. Pairwise testing is a combinatorial technique used to generate tests by varying the values of each pair of input parameters to a system until all possible combinations of those parameters are created. There is some evidence suggesting that these kinds of techniques are efficient and relatively good at detecting software faults. Unfortunately, there is little experimental evidence on the comparison of these combinatorial testing techniques with, what is perceived as, rigorous manually handcrafted testing. In this study we compare pairwise tests with tests created manually by engineers for 45 industrial programs. The tests were evaluated in terms of fault detection, code coverage and number of tests. The results of this study show that pairwise testing, while useful for achieving high code coverage and fault detection for the majority of the programs, is not quite as effective in terms of fault detection as manual testing. The results also suggest that pairwise testing is just as good as manual testing at fault detection for 64% of the programs.  
 978-1-5386-2072-4, <https://zenodo.org/record/3473474>
- Reconstructing timed symbolic traces from rtioco-based timed test sequences using backward-induction**, Junaid Iqbal, Dragos Truscan, Jüri Vain, Iván Porres, Proceedings of the Fifth European Conference on the Engineering of Computer-Based Systems, 2017  
 Abstract: As of today, model-based testing is considered as a leading-edge technology in the IT industry. In model-based testing, an implementation under test is tested for compliance with a model that describes the required behaviour of the implementation. Uppaal Tron is a popular tool for online model-based conformance testing of real-time systems; it uses the Uppaal verification engine to generate and convert on-the-fly timed symbolic traces into concrete test sequences. Among the advantages of online testing is the reduction of the symbolic state space needed for computing traces, better addressing non-determinism, as well as the possibility to execute longer-lasting test runs. However, analysing and debugging long test runs can be tedious and time-consuming especially when analysing root causes of failed tests. In game theory, backward-induction is a process to reason backwards in time, from the end of a problem or situation, in order to determine a sequence of optimal actions. In this paper, we propose an approach to reconstruct symbolic traces from test sequences generated by Uppaal Tron using backward induction. The resulting symbolic traces can be imported in the Uppaal tool and visualised in the Uppaal simulator. The evaluation of the implementation of the approach shows that it has the potential to satisfy the needs of industrial level testing.  
<https://doi.org/10.1145/3123779.3123813>,  
[http://tucs.fi/publications/view/?pub\\_id=inplqTrVaPo17a](http://tucs.fi/publications/view/?pub_id=inplqTrVaPo17a)

- **Short and Long Distance Marker Detection Technique in Outdoor and Indoor Environments for Embedded Systems**, Álvaro Díaz, Daniel Peña, Eugenio Villar, Proceedings of the XXXII Conference on Design of Circuits and Integrated Systems, DCIS 2017, Abstract: During the last years, the market of embedded vision-based systems has been growing at an accelerated rate. Virtual and augmented reality has the potential to become one of the most innovative technologies for the next decade. One of the most important aspects of these technologies is related to the spatial location of objects or people in defined environments, for which there are several techniques. One of the most widely used is based on visual marker recognition. The main problems of these approaches are related to the accuracy, the changing environments, the processing time, the operating range/distance and the price. The popularization of these technologies produces a pull effect toward the companies developing the best technology at the lowest price. This paper proposes a marker design and an algorithm to detect the markers under different ambient conditions, with a long range to be executed on embedded systems with low computational requirements. The proposed method reduces the existing problems in the state-of-the-art related to the use of different environments and conditions such as different distances or different illumination. Moreover, the requisites of the method are minimal to reduce the cost of deployment.  
DOI: 10.1109/DCIS.2017.8311629 ISBN 978-1-5386-5108-7  
[https://www.researchgate.net/publication/323818150\\_Short\\_and\\_long\\_distance\\_marker\\_detection\\_technique\\_in\\_outdoor\\_and\\_indoor\\_environments\\_for\\_embedded\\_systems](https://www.researchgate.net/publication/323818150_Short_and_long_distance_marker_detection_technique_in_outdoor_and_indoor_environments_for_embedded_systems)
- **The MegaM@Rt2 ECSEL Project: MegaModelling at Runtime - Scalable Model-Based Framework for Continuous Development and Runtime Validation of Complex Systems**, Wasif Afzal, Hugo Bruneliere, Davide Di Ruscio, Andrey Sadovykh, Silvia Mazzini, et al., Euromicro Conference on Digital System Design (DSD), 2017 Abstract: A major challenge for the European electronic industry is to enhance productivity while reducing costs and ensuring quality in development, integration and maintenance. Model-Driven Engineering (MDE) principles and techniques have already shown promising capabilities but still need to scale to support real-world scenarios implied by the full deployment and use of complex electronic components and systems. Moreover, maintaining efficient traceability, integration and communication between two fundamental system lifetime phases (design time and runtime) is another challenge facing scalability of MDE. This paper presents an overview of the ECSEL project entitled " MegaModelling at runtime – Scalable model-based framework for continuous development and runtime validation of complex systems " (MegaM@Rt2), whose aim is to address the above mentioned challenges facing MDE. Driven by both large and small industrial enterprises, with the support of research partners and technology providers, MegaM@Rt2 aims to deliver a framework of tools and methods for: 1) system engineering/design & continuous development, 2) related runtime analysis and 3) global model & traceability management, respectively. The diverse industrial use cases (covering domains such as aeronautics, railway, construction and telecommunications) will integrate and apply such a framework that shall demonstrate the validation of the MegaM@Rt2 solution.  
<https://dx.doi.org/10.1109/DSD.2017.5001557430> <https://hal.inria.fr/hal-01557430>
- **Towards Execution Time Prediction for Manual Test Cases from Test Specification**, Mehrdad Saadatmand, Markus Bohlin, Wasif Afzal, Sharvathul

Hasan Ameerjan, 43rd Euromicro Conference on Software Engineering and Advanced Applications (SEAA), 2017

Abstract: Knowing the execution time of test cases is important to perform test scheduling, prioritization and progress monitoring. This work in progress paper presents a novel approach for predicting the execution time of test cases based on test specifications and available historical data on previously executed test cases. Our approach works by extracting timing information (measured and maximum execution time) for various steps in manual test cases. This information is then used to estimate the maximum time for test steps that have not previously been executed, but for which textual specifications exist. As part of our approach, natural language parsing of the specifications is performed to identify word combinations to check whether existing timing information on various test activities is already available or not. Finally, linear regression is used to predict the actual execution time for test cases. A proof-of-concept use case at Bombardier Transportation serves to evaluate the proposed approach. 10.1109/SEAA.2017.10,

[https://www.researchgate.net/publication/316969151\\_Towards\\_Execution\\_Time\\_Prediction\\_for\\_Test\\_Cases\\_from\\_Test\\_Specification](https://www.researchgate.net/publication/316969151_Towards_Execution_Time_Prediction_for_Test_Cases_from_Test_Specification)

- **A Comparative Study of Manual and Automated Testing for Industrial Control Software**, Eduard Paul Enoiu, Adnan Causevic, Daniel Sundmark, Paul Pettersson, IEEE International Conference on Software Testing, Verification and Validation (ICST), 2017

Abstract: Automated test generation has been suggested as a way of creating tests at a lower cost. Nonetheless, it is not very well studied how such tests compare to manually written ones in terms of cost and effectiveness. This is particularly true for industrial control software, where strict requirements on both specification-based testing and code coverage typically are met with rigorous manual testing. To address this issue, we conducted a case study in which we compared manually and automatically created tests. We used recently developed real-world industrial programs written in the IEC 61131-3, a popular programming language for developing industrial control systems using programmable logic controllers. The results show that automatically generated tests achieve similar code coverage as manually created tests, but in a fraction of the time (an average improvement of roughly 90%). We also found that the use of an automated test generation tool does not result in better fault detection in terms of mutation score compared to manual testing. Specifically, manual tests more effectively detect logical, timer and negation type of faults, compared to automatically generated tests. The results underscore the need to further study how manual testing is performed in industrial practice and the extent to which automated test generation can be used in the development of reliable systems. 10.1109/ICST.2017.44,

<http://www.diva-portal.org/smash/get/diva2:1034044/FULLTEXT01.pdf>

- **Using Timed Base-Choice Coverage Criterion for Testing Industrial Control Software**, Henning Bergström, Eduard Paul Enoiu, IEEE International Conference on Software Testing, Verification and Validation Workshops (ICSTW), 2017
- Abstract: The base-choice criterion was proposed as a suitable technique for testing software based on its nominal choice of input parameters. Test cases are created based on this strategy by varying the values of one input parameter at a time while keeping the values of the other parameters fixed on the base choice. However, this strategy might not be as effective when used on industrial control software for testing timed behaviour. We propose to incorporate time as another parameter when generating and executing tests by defining the timed base-choice coverage criterion. We

performed an empirical evaluation using 11 industrial programs written in the IEC 61131-3 programming language. We found that tests generated for timed base-choice criterion show better code coverage (7% improvement) and fault detection (27% improvement) in terms of mutation score than tests satisfying base-choice coverage criterion. The results demonstrate the feasibility of applying timed base-choice criterion for testing industrial control software.  
10.1109/ICSTW.2017.41, <https://zenodo.org/record/3473480>

- **Automatic Test Generation for Energy Consumption of Embedded Systems Modeled in EAST-ADL**, Raluca Marinescu, Eduard Paul Enoiu, Cristina Seceleanu, Daniel Sundmark, IEEE International Conference on Software Testing, Verification and Validation Workshops (ICSTW), 2017  
This article introduces an Eclipse plugin called Xmodeling Studio. This tool assists, initially, the language engineers for the design and implementation of executable DSL and their execution engine considering the business methods and the management of their data flow, then, secondly, Xmodeling is giving the possibility to the software engineers to integrate the language engineers' work in the environment of their choice.  
10.1109/ICSTW.2017.19, <https://zenodo.org/record/3473484>
- **The Refinement Calculus of Reactive Systems Toolset**, Iulia Dragomir, Viorel Preoteasa, Stavros Tripakis, International Conference on Tools and Algorithms for the Construction and Analysis of Systems, 2018  
Abstract: We present the Refinement Calculus of Reactive Systems Toolset, an environment for compositional modeling and reasoning about reactive systems, built on top of Isabelle, Simulink, and Python.  
[https://doi.org/10.1007/978-3-319-89963-3\\_12](https://doi.org/10.1007/978-3-319-89963-3_12),  
<https://arxiv.org/abs/1710.08195>
- **Model-based product line engineering in an industrial automotive context: an exploratory case study**, Damir Bilic, Daniel Sundmark, Wasif Afzal, Peter Wallin, Amlinger Christoffer, 1st Int. workshop on variability and evolution of software-intensive systems, 2018  
Product Line Engineering is an approach to reuse assets of complex systems by taking advantage of commonalities between product families. Reuse within complex systems usually means reuse of artifacts from different engineering domains such as mechanical, electronics and software engineering. Model-based systems engineering is becoming a standard for systems engineering and collaboration within different domains. This paper presents an exploratory case study on initial efforts of adopting Product Line Engineering practices within the model-based systems engineering process at Volvo Construction Equipment (Volvo CE), Sweden. We have used SysML to create overloaded models of the engine systems at Volvo CE. The variability within the engine systems was captured by using the Orthogonal Variability Modeling language. The case study has shown us that overloaded SysML models tend to become complex even on small scale systems, which in turn makes scalability of the approach a major challenge. For successful reuse and to, possibly, tackle scalability, it is necessary to have a database of reusable assets from which product variants can be derived.  
10.1145/3236405.3237200  
[http://www.es.mdh.se/pdf\\_publications/5385.pdf](http://www.es.mdh.se/pdf_publications/5385.pdf)
- **On the Benefits of Using Aspect-Orientation in UPPAAL Timed Automata** Vain, Jüri and Truscan, Dragos and Iqbal, Junaid and Tsiopoulos, Leonidas  
Conference on Infocom Technologies and Unmanned Systems ICTUS 2017, 2018

Abstract: We present an evaluation study on applying aspect-oriented modeling concepts in UPPAAL timed automata. The study is focusing on the modeling and verification effort that can be reduced when applying explicit aspect-oriented structuring principles in model construction. We discuss the drawbacks and benefits related to model update and verification effort. The approach suggested is benchmarked on a mission critical crisis management system case study. We demonstrate the usability of our approach by extracting the aspects such as resource authentication and mission execution. Finally, we demonstrate by experimental data how our approach is more efficient compared to verification and testing effort applied in the non-aspect-oriented model.

<https://doi.org/10.1109/ICTUS.2017.8285981>

<https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&number=8285981>

- **Vulnerability Assessment of Web Services with Model-based Mutation Testing**, Siavashi, Faezeh and Truscan, Dragos and Vain, Jüri, IEEE International Conference on Software Quality, Reliability and Security (SQRS 2018), 2018

Abstract: We present a model-based mutation testing approach, for evaluating the authentication and authorization of web services in a multi-user context. Model of a web service and its security requirements are designed using UPPAAL Timed Automata. The model is mutated to create invalid behavior which is used for test generation to reveal faults in the system under test. The approach is supported by a model-based mutation testing tool,  $\mu$ UTA, that automatically generates mutants, selects a collection of suitable mutants for testing and generates test cases from them. We modify a previously defined mutation operator and introduce three new operators for additional mutants. We define criteria for the mutation-selection and demonstrate the approach on a blog web service. Results show that the approach can discover authorization faults that were not detected by traditional methods.

<https://doi.org/10.1109/QRS.2018.00043>,  
[https://tucs.fi/publications/view/?pub\\_id=inpSiTrVa18b](https://tucs.fi/publications/view/?pub_id=inpSiTrVa18b)
- **A Systematic Mapping Study on API Documentation Generation Approaches**, Kristian Nybom, Adnan Ashraf, Ivan Porres, 44th Euromicro Conference on Software Engineering and Advanced Applications, 462–469, IEEE Computer Society, 2018

Abstract: Background: Application Programming Interfaces (APIs) are key to software reuse. Software developers can link functionality and behaviour found in other software with their own software by taking an API into use. However, figuring out how an API works is usually demanding, and may require that the developers spend a notable amount of time familiarizing themselves with the API. Good API documentation is of key importance to simplify this task.

Objective: To present a comprehensive, unbiased overview of the state-of-the-art on tools and approaches for API documentation generation.

Method: A systematic mapping study on published tools and approaches that can be used for generating API documentation, or for assisting in the API documentation process.

Results: 36 studies on API documentation generation tools and approaches analyzed and categorized in a variety of ways. Among other things, the paper presents an overview of what kind of tools have been developed, what kind of documentation they generate, and what sources the documentation approaches require.

Conclusion: Out of the identified approaches, many contribute to API documentation in the areas of natural language documentation and code examples and templates. Many of the approaches contribute to ease API users' understanding and learning of the API, but also to the maintenance and generation of API documentation. Most of the



approaches are automatic, simplifying the API documentation generation notably, under the assumption that relevant sources for the generation are available. Most of the API documentation approaches are evaluated either by exercise of the approach followed by analysis of the results, or by empirical evaluation methods.

<http://doi.org/10.1109/seaa.2018.00081>

[http://tucs.fi/publications/view/?pub\\_id=inpNyAsPo18a](http://tucs.fi/publications/view/?pub_id=inpNyAsPo18a)

- **Extracting software product line feature models from natural language specifications**, Anjali Sree-Kumar, Elena Planas, and Robert Clarisó, In Proceedings of the 22nd International Systems and Software Product Line Conference (SPLC '18), 2018

Abstract: The specification of a family of software products may include documents written in natural language. Automatically extracting knowledge from these documents is a challenging problem that requires using Natural Language Processing (NLP) techniques. This knowledge can be formalized as a Feature Model (FM), a diagram capturing the key features and the relationships among them. In this paper, we first review previous works that have presented tools for extracting FMs from textual specifications and compare their strengths and limitations. Then, we propose a framework for feature and relationship extraction, which overcomes the identified limitations and is built upon state-of-the-art open-source NLP tools. This framework is evaluated against previous works using several case studies, showing improved results.

<https://doi.org/10.1145/3233027.3233029>,

[http://gres.uoc.edu/pubs/SPLC2018\\_Kumar.pdf](http://gres.uoc.edu/pubs/SPLC2018_Kumar.pdf)

- **Applying graph kernels to model-driven engineering problems**, Robert Clarisó and Jordi Cabot, 1st International Workshop on Machine Learning and Software Engineering in Symbiosis (MASSES 2018), 2018

Abstract: Machine Learning (ML) can be used to analyze and classify large collections of graph-based information, e.g. images, location information, the structure of molecules and proteins, ... Graph kernels is one of the ML techniques typically used for such tasks. In a software engineering context, models of a system such as structural or architectural diagrams can be viewed as labeled graphs. Thus, in this paper we propose to employ graph kernels for clustering software modeling artifacts. Among other benefits, this would improve the efficiency and usability of a variety of software modeling activities, e.g., design space exploration, testing or verification and validation.

<https://doi.org/10.1145/3243127.3243128>,

[https://modeling-](https://modeling-languages.com/graph-kernels-model-driven-software-engineering/)

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- **Criticality-aware Design Space Exploration for Mixed-Criticality Embedded Systems**, V. Muttillio, G. Valente, L. Pomante, International Conference on Performance Engineering Companion, 2018

Abstract: This work focuses on Design Space Exploration for embedded systems based on heterogeneous parallel architectures and subjected to mixed-criticality constraints. In particular, it presents a criticality-aware evolutionary approach integrated into a reference Electronic System Level HW/SW Co-Design flow.

10.1145/3185768.3185769, <https://zenodo.org/record/3503597#.XamXQ-gzZPY>,

- **CC4CS: An off-the-shelf unifying statement-level performance metric for HW/SW technologies**, V. Muttillio, G. Valente, L. Pomante, V. Stoico, F. D'Antonio, F. Salice, International Conference on Performance Engineering Companion, 2018

Abstract: Outlining the general characteristics of embedded systems is an arduous task. In fact, the design of such kind of systems is heavily influenced by functional and non-functional requirements, and it is based on quite complex design flows. So,

there is often the need to adopt a HW/SW co-design methodology able to support the designers during high-level phases so that they can perform early analysis before dealing with low-level ones. Such a methodology, to be effective, should consider also performance estimation and ESL HW/SW timing co-simulation. The goal of this paper is to introduce a novel and fast performance metric able to speed-up the early analysis and design space exploration to identify the more promising architectures for different application domains. In particular, the paper presents a framework to evaluate such a metric and to perform some preliminary analysis to evaluate its meaningfulness when exploited in the HW/SW domain.

10.1145/3185768.3186291

<https://zenodo.org/record/3503967#.Xama1OgzZPY>

- **Design Space Exploration for Mixed-Criticality Embedded Systems considering Hypervisor-based SW Partitions**, V. Muttillio, G. Valente, L. Pomante, "Euromicro Conference on Digital System Design (DSD 2018)", 2018  
Abstract: This work faces the role of Design Space Exploration for embedded systems based on heterogeneous parallel architectures and subject to mixed-criticality system requirements, while considering the exploitation of hypervisor-based SW partitions to better manage isolation. In particular, it presents an evolutionary partitioning and mapping approach integrated into a reference Electronic System Level HW/SW Co-Design framework to propose and early validate design solutions by means of HW/SW Co-Simulations.

10.1109/DSD.2018.00115, <https://zenodo.org/record/3504593#.XamhYegzZPY>

- **Functional Dependency Detection for Integration Test Cases**, Sahar Tahvili, Marcus Ahlberg, Eric Fornander, Wasif Afzal, Mehrdad Saadatmand, Markus Bohlin, Mahdi Sarabi, The 18th IEEE International Conference on Software Quality, Reliability and Security, 2018  
Abstract: This paper presents a natural language processing (NLP) based approach that, given software requirements specification, allows the functional dependency detection between integration test cases. We analyze a set of internal signals to the implemented modules for detecting dependencies between requirements and thereby identifying dependencies between test cases such that: module 2 depends on module 1 if an output internal signal from module 1 enters as an input internal signal to the module 2. Consequently, all requirements (and thereby test cases) for module 2 are dependent on all the designed requirements (and test cases) for module 1. The dependency information between requirements (and thus corresponding test cases) can be utilized for test case prioritization and scheduling. We have implemented our approach as a tool and the feasibility is evaluated through an industrial use case in the railway domain at Bombardier Transportation (BT), Sweden.

10.1109/QRS-C.2018.00047

[http://www.es.mdh.se/pdf\\_publications/5143.pdf](http://www.es.mdh.se/pdf_publications/5143.pdf)

- **A System Modeling Approach to Enhance Functional and Software Development**, Saurabh Tiwari, Emina Smajlovic, Amina Krekic, Jagadish Suryadevara, First International Workshop on Model-Driven Engineering for Design-Runtime Interaction in Complex Systems, colocated with STAF, 2018  
Abstract: This paper presents a SysML-based approach to enhance functional and software development process within an industrial context. The recent changes in technology such as electromobility and increased automation in heavy construction machinery lead to increased complexity for embedded software. Hence there emerges a need for new development methodologies to address flexible functional development, enhance communication among development teams, and maintain traceability

from design concepts to software artifacts. The discussed approach has experimented in the context of developing a new transmission system (partially electrified) and its functionality. While the modeling approach is a work-in-progress, some initial success, as well as existing gaps pointing to future works are highlighted.

[https://doi.org/10.1007/978-3-030-04771-9\\_37](https://doi.org/10.1007/978-3-030-04771-9_37)

<https://arxiv.org/pdf/1906.08520.pdf>

- **Cluster-Based Test Scheduling Strategies Using Semantic Relationships between Test Specifications**, Sahar Tahvili, Leo Hatvani, Michael Felderer , Wasif Afzal, Mehrdad Saadatmand, Markus Bohlin, 5th International Workshop on Requirements Engineering and Testing, 2018  
 Abstract: One of the challenging issues in improving the test efficiency is that of achieving a balance between testing goals and testing resources. Test execution scheduling is one way of saving time and budget, where a set of test cases are grouped and tested at the same time. To have an optimal test execution schedule, all related information of a test case (e.g. execution time, functionality to be tested, dependency and similarity with other test cases) need to be analyzed. Test scheduling problem becomes more complicated at high-level testing, such as integration testing and especially in manual testing procedure. Test specifications are generally written in natural text by humans and usually contain ambiguity and uncertainty. Therefore, analyzing a test specification demands a strong learning algorithm. In this position paper, we propose a natural language processing-based approach that, given test specifications at the integration level, allows automatic detection of test cases semantic dependencies. The proposed approach utilizes the Doc2Vec algorithm and converts each test case into a vector in n-dimensional space. These vectors are then grouped using the HDBSCAN clustering algorithm into semantic clusters. Finally, a set of cluster-based test scheduling strategies are proposed for execution. The proposed approach has been applied in a sub-system from the railway domain by analyzing an ongoing testing project at Bombardier Transportation AB, Sweden.  
 10.1145/3195538.3195540  
<https://dl.acm.org/citation.cfm?id=3195540>
- **Adopting MBSE in Construction Equipment Industry: An Experience Report**, Jagadish Suryadevara, Saurabh Tiwari, 25th Asia-Pacific Software Engineering Conference, APSEC 2018  
 Abstract: This paper is an experience report about introducing Model-based Systems Engineering (MBSE) at Volvo (Construction Equipment) and describes lessons learned. The recent growth in technologies such as electromobility, automation etc. in heavy construction machinery such as loaders, haulers, excavators etc. leads to increased complexity being addressed within embedded systems and software. Hence there is an increasing need for model-based development methodologies to facilitate flexible and distributed development scenarios, enhance communication among cross-functional teams, more importantly, traceability from requirements to system and software architectures. In this paper, we describe how the MBSE methodology was initially conceived, applied in an ongoing project, the challenges faced, and lessons learned. The paper also points to related works and future directions towards a holistic Model-Driven Development (MDD) framework.  
 10.1109/APSEC.2018.00066  
[http://www.es.mdh.se/pdf\\_publications/5220.pdf](http://www.es.mdh.se/pdf_publications/5220.pdf)
- **Automated Functional Dependency Detection Between Test Cases Using Doc2Vec and Clustering**, Sahar Tahvili, Leo Hatvani, Michael Felderer , Wasif Afzal, Markus Bohlin, the First IEEE International Conference On Artificial

Intelligence

Testing,

2019

Abstract: Knowing about dependencies and similarities between test cases is beneficial for prioritizing them for cost-effective test execution. This holds especially true for the time-consuming, manual execution of integration test cases written in natural language. Test case dependencies are typically derived from requirements and design artifacts. However, such artifacts are not always available, and the derivation process can be very time-consuming. In this paper, we propose, apply and evaluate a novel approach that derives test cases' similarities and functional dependencies directly from the test specification documents written in natural language, without requiring any other data source.

Our approach uses an implementation of Doc2Vec algorithm to detect text-semantic similarities between test cases and then groups them using two clustering algorithms HDBSCAN and FCM. The correlation between test case text-semantic similarities and their functional dependencies is evaluated in the context of an on-board train control system from Bombardier Transportation

AB in Sweden. For this system, the dependencies between the test cases were previously derived and are compared to the results of our approach. The results show that of the two evaluated clustering algorithms, HDBSCAN has better performance than FCM or a dummy classifier. The classification methods' results are of reasonable quality and especially useful from an industrial

point of view. Finally, performing a random undersampling approach to correct the imbalanced data distribution results in an F1 score of up to 75% when applying the HDBSCAN clustering algorithm.

10.1109/AITest.2019.00-13,

[http://www.es.mdh.se/publications/5444-](http://www.es.mdh.se/publications/5444-Automated_Functional_Dependency_Detection_Between_Test_Cases_Using_Doc2Vec_and_Clustering)

[Automated\\_Functional\\_Dependency\\_Detection\\_Between\\_Test\\_Cases\\_Using\\_Doc2Vec\\_and\\_Clustering](http://www.es.mdh.se/publications/5444-Automated_Functional_Dependency_Detection_Between_Test_Cases_Using_Doc2Vec_and_Clustering)

[http://www.es.mdh.se/pdf\\_publications/5444.pdf](http://www.es.mdh.se/pdf_publications/5444.pdf)

- **Tuning DSE for Heterogeneous Multi-Processor Embedded Systems by means of a Self-Equalized Weighted Sum Method**, V. Muttillio, G. Fiorilli, T. Di Mascio, Proceedings of the 10th and 8th Workshop on Parallel Programming and Run-Time Management Techniques for Many-core Architectures and Design Tools and Architectures for Multicore Embedded Computing Platforms, 2019  
 Abstract: Heterogeneous multi-processor platforms are becoming widely diffused in the embedded system domain, mainly because of the opportunity to improve timing performance and, at the same time, to minimize energy/power consumption and costs. In using such kind of platforms, to be able to consider the trade-offs among different goals, a Design Space Exploration (DSE) is generally adopted. For this, existing DSE approaches typically rely on evolutionary algorithms to solve Multi-Objective Optimization Problems (MOOP) by minimizing a linear combination of weighted objective functions (i.e., Weighted Sum Method, WSM). The problem is then shifted towards the identification of weights able to represent desired trade-offs. In such a context, this paper focuses on DSE for heterogeneous multi-processor embedded systems and introduces an approach that, while still driven by a "decision maker", is able to self-tune weights to equalize objective functions contribution. In particular, this work presents a self-equalized WSM integrated into a genetic algorithm used to identify sub-optimal implementation alternatives in the context of an Electronic System Level HW/SW Co-Design flow.  
 10.1145/3310411.3310412,  
<https://zenodo.org/record/3504067#.XamcOegzZPY>
- **Exhaustive Simulation and Test Generation Using fUML Activity Diagrams**, Junaid Iqbal, Adnan Ashraf, Dragos Truscan, Ivan Porres,

International Conference on Advanced Information Systems Engineering, CAiSE 2019: Advanced Information Systems Engineering, 2019

Abstract: The quality of the specifications used for test generation plays an important role in the quality of the generated tests. One approach to improve the quality of the UML specification is the use of executable models specified using the Foundational Subset for Executable UML Models (fUML) and the Action language for fUML (Alf). Due to their precise semantics, fUML and Alf models can be simulated or executed using an fUML execution engine. However, in order to execute the models exhaustively, one must provide input data required to reach and cover all essential elements not only in the graphical fUML models, but also in the textual Alf code associated with the graphical models. In this paper, we present an approach for exhaustive simulation and test generation from fUML activity diagrams containing Alf code. The proposed approach translates fUML activity diagrams and associated Alf code into equivalent Java code and then automatically generates: (1) input data needed to cover or execute all paths in the executable fUML and Alf models and (2) test cases and test oracle (expected output) for testing the actual implementation of the system under development. We also present a tool chain and demonstrate our proposed approach with the help of an example.

[https://doi.org/10.1007/978-3-030-21290-2\\_7](https://doi.org/10.1007/978-3-030-21290-2_7),

[https://tucs.fi/publications/view/?pub\\_id=inplqAsTrPo19a](https://tucs.fi/publications/view/?pub_id=inplqAsTrPo19a)

- **On Measuring Combinatorial Coverage of Manually Created Test Cases for Industrial Software**, Miraldi Fifo , Eduard Paul Enoiu, Wasif Afzal, 8th International Workshop on Combinatorial Testing, 2019  
 Abstract: Combinatorial coverage has been proposed as a way to measure the quality of test cases by using the input interaction characteristics. This paper describes the results of empirically measuring combinatorial coverage of manually created test cases by experienced industrial engineers working with embedded software development. We found that manual test cases achieved on average 78% 2-way combinatorial coverage, 57% 3-way coverage, 40% 4-way coverage, 20% 5-way combinatorial coverage and 13% for 6-way combinatorial coverage. These manual test cases can be augmented to achieve 100% combinatorial coverage for 2-way and 3-way interactions by adding eight and 66 missing test cases on average, respectively. For 4-way interactions, full combinatorial coverage can be achieved by adding 658 missing test cases. For 5-way and 6-way interactions, full combinatorial coverage can be achieved by adding 5163 and 6170 missing test cases on average, respectively. The results of this paper suggests that manual test cases created by industrial engineers do not achieve a high combinatorial coverage and can be improved by adding more test cases to cover t-wise interactions at the expense of more test cases to execute  
 10.1109/ICSTW.2019.00062, <https://zenodo.org/record/3473495>
- **Test Agents: The Next Generation of Test Cases**, Eduard Paul Enoiu, Mirgita Frasher, 2nd IEEE Workshop on NEXt level of Test Automation, 2019  
 Growth of software size, lack of resources to perform regression testing, and failure to detect bugs faster have seen increased reliance on continuous integration and test automation. Even with greater hardware and software resources dedicated to test automation, software testing is faced with enormous challenges, resulting in increased dependence on centralized and complex mechanisms for automated test case selection as part of continuous integration. These mechanisms are currently using static entities called test cases that are concretely realized as executable scripts. Our key vision is to provide test cases with more reasoning, adaptive behavior and learning capabilities by using the concepts of software agents. We refer to such test cases as test

agents. The model that underlie a test agent is capable of flexible and autonomous actions in order to meet overall testing objectives. Our goal is to increase the decentralization of regression testing by letting test agents to know for themselves when they should be executing, how they should update their purpose, and when they should interact with each other. In this paper, we envision test agents that display such adaptive autonomous behavior. Existing and emerging developments and challenges regarding the use of test agents are explored-in particular, new research that seeks to use adaptive autonomous agents in software testing. 10.1109/ICSTW.2019.00070, <https://zenodo.org/record/3473497>

- **A Microservice Reference Case Study for Design-Runtime Interaction in MDE**, Daniele Di Pompeo, Michele Tucci, Alessandro Celi, Romina Eramo, International Workshop on Model-Driven Engineering for Design-Runtime Interaction in Complex Systems (MDE@DeRun2019) co-located to STAF 2019, 2019, Abstract: Model-Driven Engineering techniques may achieve major support to the software development of nowadays complex systems when they allow managing relationships between a running system and its design models. These relationships can be exploited for different goals, such as the software evolution due to new functional requirements. In order to address this challenge, researchers need to better understand the nature of the available runtime information and related correspondences as well as how leveraging such knowledge. Typically, to this end, they rely on reference applications.

In this paper, we present a reference case study for design-runtime interaction in MDE. It is based on Train Ticket, a microservice-based web application, and its monitoring infrastructure. Also, the case study provides its software modeling artifacts designed in UML, a dataset of monitoring logs, and the denition of design-runtime correspondence as traceability links. We invite researchers to consider this case study as a reference for extending or new contribution to this topic.

[http://ceur-ws.org/Vol-2405/06\\_paper.pdf](http://ceur-ws.org/Vol-2405/06_paper.pdf)

- **MATERA2-AlfTester: An Exhaustive Simulation and Test Generation Tool for fUML Models**, Junaid Iqbal,Adnan Ashraf,Dragos Truscan,Ivan Porres, Euromicro Conference on Software Engineering and Advanced Applications (SEAA), 2019, Abstract: The Foundational Subset for Executable UML Models (fUML) and the Action language for fUML (Alf) can be used for creating executable models in the Eclipse-based UML editing tool called Papyrus. An fUML execution engine in Papyrus, such as Moka, allows to simulate or execute fUML models along with their associated Alf code. However, for exhaustive simulation of such models, one must provide input data required to reach and cover all important elements not only in the graphical fUML models but also in the textual Alf code. In this paper, we present MATERA2-AlfTester, an Eclipse-plugin for exhaustive simulation and test generation for fUML models. MATERA2-AlfTester integrates with Papyrus and Moka tools and extends their functionality by allowing one to automatically generate test data, test suite with test oracle, and partial Java code at design time. We also present the simulation and testing process of MATERA2-AlfTester with the help of an example and demonstrate how exhaustive simulation and test generation with MATERA2-AlfTester can help designers in assessing and improving the quality of fUML models.

<http://doi.org/10.1109/SEAA.2019.00075978-1-7281-3421-5>

[http://research.abo.fi/converis/portal/Publication/24758271?auxfun=&lang=en\\_GB](http://research.abo.fi/converis/portal/Publication/24758271?auxfun=&lang=en_GB)

- **Exploratory Performance Testing Using Reinforcement Learning**, Tanwir Ahmad, Adnan Ashraf, Dragos Truscan, Ivan Porres, Euromicro Conference on Software Engineering and Advanced Applications (SEAA), 2019,  
 Abstract: Performance bottlenecks resulting in high response times and low throughput of software systems can ruin the reputation of the companies that rely on them. Almost two-thirds of performance bottlenecks are triggered on specific input values. However, finding the input values for performance test cases that can identify performance bottlenecks in a large-scale complex system within a reasonable amount of time is a cumbersome, cost-intensive, and time-consuming task. The reason is that there can be numerous combinations of test input values to explore in a limited amount of time. This paper presents PerfXRL, a novel approach for finding those combinations of input values that can reveal performance bottlenecks in the system under test. Our approach uses reinforcement learning to explore a large input space comprising combinations of input values and to learn to focus on those areas of the input space which trigger performance bottlenecks. The experimental results show that PerfXRL can detect 72% more performance bottlenecks than random testing by only exploring the 25% of the input space.  
<http://dx.doi.org/10.1109/SEAA.2019.00032>,  
[http://research.abo.fi/converis/portal/Publication/24756838?auxfun=&lang=en\\_GB](http://research.abo.fi/converis/portal/Publication/24756838?auxfun=&lang=en_GB)
- **MegaM@Rt2 Project: Mega-Modelling at Runtime - Intermediate Results and Research Challenges**, Andrey Sadovykh, Dragos Truscan, Wasif Afzal, Hugo Bruneliere, Adnan Ashraf, Abel Gomez, Alexandra Espinosa, Gunnar Widforss, Pierluigi Pierini, Elizabeta Fournieret, Alessandra Bagnato, TOOLS 50+1:Technology of Object-Oriented Languages and Systems, 2019  
 Abstract : MegaM@Rt2 Project is a major European effort towards the model-driven engineering of complex Cyber-Physical systems combined with runtime analysis. Both areas are dealt within the same methodology to enjoy the mutual benefits through sharing and tracking various engineering artifacts. The project involves 27 partners that contribute with diverse research and industrial practices addressing real-life case study challenges stemming from 9 application domains. These partners jointly progress towards a common framework to support those application domains with model-driven engineering, verification, and runtime analysis methods. In this paper, we present the motivation for the project, the current approach and the intermediate results in terms of tools, research work and practical evaluation on use cases from the project. We also discuss outstanding challenges and proposed approaches to address them.  
[https://dx.doi.org/10.1007/978-3-030-29852-4\\_33](https://dx.doi.org/10.1007/978-3-030-29852-4_33)  
<https://hal.archives-ouvertes.fr/hal-02177567>
- **An Integrated Model-based Tool Chain for Managing Variability in Complex System Design**, Damir Bilic, Etienne Brosse, Andrey Sadovykh, Dragos Truscan, Hugo Bruneliere, Uwe Ryssel, Models and Evolution Workshop (ME 2019), co-located with the IEEE / ACM 22nd International Conference on Model Driven Engineering Languages and Systems (MODELS 2019), 2019  
 Abstract: Software-intensive systems in the automotive domain are often built in different variants, notably in order to support different market segments and legislation regions. Model-based concepts are frequently applied to manage complexity in such variable systems. However, the considered approaches are often focused on single-product development. In order to support variable products in a model-based system engineering environment, we describe a tool-supported approach that allows us to annotate SysML models with variability data. Such variability information is

exchanged between the system modeling tool and variability management tools through the Variability Exchange Language. The contribution of the paper includes the introduction of the model-based product line engineering tool chain and its application on a practical case study at Volvo Construction Equipment. Initial results suggest an improved efficiency in developing such a variable system.

<https://dx.doi.org/10.1109/MODELS-C.2019.00045>

<https://hal.archives-ouvertes.fr/hal-02285013>

- **Proceedings of the 2nd International Workshop on Model-Driven Engineering for Design-Runtime Interaction in Complex Systems (MDE@DeRun 2019)**, Hugo Bruneliere, Romina Eramo, Abel Gomez, Software Technologies: Applications and Foundations (STAF 2019) federation of conferences, 2019

Abstract: This volume contains the technical papers presented at three satellite events collocated with the 2019 edition of the STAF (Software Technologies: Applications and Foundations) federation of conferences on software technologies. The workshops took place at the TU/e Science park of the Eindhoven University of Technology in Eindhoven, The Netherlands, during July 15-19, 2019. The STAF 2019 conferences and satellite events brought together leading researchers and practitioners from academia and industry to advance the state of the art in practical and foundational advances in software technology. They address all aspects of software technology, from object-oriented design, testing, mathematical approaches to modeling and verification, transformation, model driven engineering, aspect-oriented techniques, and tools. The satellite events provided a highly interactive and collaborative environment to discuss emerging areas of software engineering, software technologies, model-driven engineering, and formal methods. The three satellite events whose papers are included in this volume are the Junior Research Community Event (JRCE 2019), the 2nd International Workshop on Model-Driven Engineering for Design-Runtime Interaction in Complex Systems (MDE@DeRun 2019) and the Research Project Showcase (RPS 2019).

<http://ceur-ws.org/Vol-2405/>, <https://hal.archives-ouvertes.fr/hal-02180382>

- **Una Aproximación Basada en Modelos para la Definición de Arquitecturas Asíncronas**, Abel Gómez, Iker Fernandez de Larrea, Markel Iglesias-Urkia, Beatriz Lopez-Davalillo, Aitor Urbieta, Jordi Cabot, XXIV Jornadas de Ingeniería del Software y Bases de Datos (JISBD), 2019

Abstract: In the new era of the Internet of Things (IoT), our everyday objects have become so-called cyber-physical systems (CPS). The use and deployment of CPS has especially penetrated the industry, giving rise to the so-called Industry 4.0 or Industrial IoT (IIoT). Typically, IIoT architectures are distributed and asynchronous, communication being guided by events such as publication (and corresponding subscription) of messages. However, the improvements in scalability and tolerance to change of these architectures have their disadvantages, and it is easy for knowledge about messages and their categorization (topics) to be diluted among the elements of the architecture, leading to problems of interoperability between agents involved. In this article, we present our proposal to automate the design and implementation of these architectures using model-based techniques. For this reason, we rely on AsyncAPI, a proposal for the specification of message-driven APIs.

<http://hdl.handle.net/11705/JISBD/2019/035>

- **HW/SW Co-Design Framework for Mixed-Criticality Embedded Systems Considering Xtratum-Based SW Partitions**, Vittorio Muttillio, Luigi Pomante, Patricia Balbastre, Josè Simò, Alfons Crespo, Euromicro Conference on Digital System Design (DSD), 2019



Abstract: Heterogeneous parallel devices are becoming widely diffused in the embedded systems application field since they allow to improve time performances and other orthogonal metrics (e.g., cost, power, size, etc.) at the same time. In such a context, the introduction of safety requirements, as dictated by the relevant standards (i.e., DO-178 B/C and RTCA/DO-254 in airborne systems, ARINC 653 for avionics software, ISO-26262 in automotive domain, etc.) while considering shared resources on a heterogeneous parallel HW platform, adds further challenges to industrial and academic research. This kind of platforms that execute tasks with different levels of criticality are commonly called mixed-criticality embedded systems. So, the main problem in their management is to ensure that low criticality tasks do not interfere with high criticality ones. The final goal is to allow several applications to interact and coexist on the same platform. For this, the exploitation of virtualization technologies (i.e., hypervisors) allows to guarantee isolation and to satisfy certification requirements but introduces scheduling overhead and new HW/SW partitioning challenges. In such a scenario, this work focuses on a framework for modeling, analysis, and validation of mixed-criticality and real-time systems based on an existing "Model-Based Electronic System Level HW/SW Co-Design" methodology. The main contribution of this work is the integration of the considered framework with Xamber tool in order to provide systems implementations by exploiting a design space exploration able to consider Xtratum-based SW partitions.

10.1109/DSD.2019.00085, <https://zenodo.org/record/3605531#.XhtVFMhKhPY>

- **Analysis of large sparse graphs using regular decomposition of graph distance matrices**, Hannu Reittu, Lasse Leskelä, Tomi Rätty & Marco Fiorucci, IEEE International Conference on Big Data, 2018  
 Abstract: Statistical analysis of large and sparse graphs is a challenging problem in data science due to the high dimensionality and nonlinearity of the problem. This paper presents a fast and scalable algorithm for partitioning such graphs into disjoint groups based on observed graph distances from a set of reference nodes. The resulting partition provides a low-dimensional approximation of the full distance matrix which helps to reveal global structural properties of the graph using only small samples of the distance matrix. The presented algorithm is inspired by the information-theoretic minimum description principle. We investigate the performance of this algorithm for selected real data sets and for synthetic graph data sets generated using stochastic block models and power-law random graphs, together with analytical considerations for sparse stochastic block models with bounded average degrees.  
 10.1109/BigData.2018.8622118  
<https://ieeexplore.ieee.org/document/8622118>
- **Towards analyzing large graphs with quantum annealing**, Hannu Reittu, Ville Kotovirta, Lasse Leskelä, Hannu Rummukainen & Tomi Rätty, Real Time Systems Symposium, 2019  
 Abstract: The use of quantum computing in graph community detection and regularity checking related to Szemerédi's Regularity Lemma (SRL) are demonstrated with D-Wave Systems' quantum annealer and simulations. We demonstrate the capability of quantum computing in solving hard problems relevant to big data. A new community detection algorithm based on SRL is also introduced and tested.  
 10.1109/BigData47090.2019.9006174  
<https://ieeexplore.ieee.org/document/9006174>
- **Runtime Architect: Link Performance Design to Runtime Aspects**, Rafik Henia, Laurent Rioux, Nicolas Sordon, Adel Gasri  
 Abstract: Timing predictability is one of the most important concerns in real-

time systems. Today, timing predictability is however challenged by the high complexity of modern real-time systems, which is the consequence of the significant increase of the number of implemented software functions and the required computing and communication resources. Model-driven technologies (e.g. design modelling and timing verification tools) are considered as best adapted for the timing prediction of complex real-time systems. However, there is a lack of solutions ensuring that the model reflects the real system content and is causally connected with it. In this context, we present a demonstration of the Runtime Architect tool suite that permits system architects linking the system model with the system runtime aspects. This allows setting up a continuous performance engineering cycle between design and runtime, thus ensuring the quality of the running system while reducing the design and development efforts and costs. Runtime Architect encapsulates the Time4Sys real-time platform in order to ease the integration in any runtime, design or timing verification environment. A demonstration on an industrial avionics use-case will be presented to show the pertinence of our solution

<http://2019.rtss.org/wp-content/uploads/2020/01/RTSS@Work-2019-proceedings.pdf>

- **On the Measurement of Software Complexity for PLC Industrial Control Systems using TIQVA**, Adnan Muslija and Eduard Paul Enoiu, The 35th ACM/SIGAPP Symposium On Applied Computing  
 Abstract: In the safety-critical domain (e.g. transportation, nuclear, aerospace and automotive), large-scale embedded systems implemented using Programmable Logic Controllers (PLCs) are widely used to provide supervisory control. Software complexity metrics, such as code size and cyclomatic complexity, have been used in the software engineering community for predicting quality metrics such as maintainability, bug proneness and robustness. However, since there is no available approach and tool support for measuring software complexity of PLC programs, we developed a tool called TIQVA in an effort to measure complexity for this type of software. We show how to measure different software complexity metrics such as lines of code, cyclomatic complexity, and information flow for a popular PLC programming language named Function Block Diagram (FBD). We evaluate the tool using data provided by Bombardier Transportation from a Train Control Management System (TCMS). In addition, we report some empirical and industrial evidence showing how TIQVA can be used to provide some experimental evidence to support the use of these metrics to estimate testing effort for an industrial control software. The results from this evaluation indicate that other specific dimensions of PLC programs (e.g., function block relationships, block coupling and timing) could be used to improve the measurement of complexity for industrial embedded software.  
<https://zenodo.org/record/3695585>
- **MBRP: Model-based Requirements Prioritization Using PageRank Algorithm**, Muhammad Abbas, Irum Inayat, Naila Jan, Mehrdad Saadatmand, Eduard Paul Enoiu, Daniel Sundmark, 26th Asia-Pacific Software Engineering Conference (APSEC), 2019  
 Abstract: Requirements prioritization plays an important role in driving project success during software development. Literature reveals that existing requirements prioritization approaches ignore vital factors such as interdependency between requirements. Existing requirements prioritization approaches are also generally time-consuming and involve substantial manual effort. Besides, these approaches show substantial limitations in terms of the number of requirements under consideration. There is some evidence suggesting that models could have a useful role in the analysis of requirements interdependency and their visualization, contributing towards the improvement of the overall requirements prioritization process. However, to

date, just a handful of studies are focused on model-based strategies for requirements prioritization, considering only conflict-free functional requirements. This paper uses a meta-model-based approach to help the requirements analyst to model the requirements, stakeholders, and inter-dependencies between requirements. The model instance is then processed by our modified PageRank algorithm to prioritize the given requirements. An experiment was conducted, comparing our modified PageRank algorithm's efficiency and accuracy with five existing requirements prioritization methods. Besides, we also compared our results with a baseline prioritized list of 104 requirements prepared by 28 graduate students. Our results show that our modified PageRank algorithm was able to prioritize the requirements more effectively and efficiently than the other prioritization methods.

10.1109/APSEC48747.2019.00014

<https://zenodo.org/record/3695571>

- **Injecting hypervisor-based software partitions into Design Space Exploration activities considering mixed-criticality requirements**, V. Mutillo, G. Valente, 7th Mediterranean Conference on Embedded Computing (MECO), 2018  
 Abstract: This work faces the role of HW/SW Design Space Exploration for heterogeneous parallel embedded systems subject to mixed-criticality requirements, extended to consider also hypervisor technologies. In particular, it presents an evolutionary approach integrated into a reference Electronic System-Level HW/SW Co-Design flow able to consider and evaluate design alternatives while exploiting also Hypervisor-based SW partitions. Finally, some experimental results show the effectiveness of the proposed approach.  
 10.1109/MECO.2018.8406056, <https://zenodo.org/record/3505696#.XamsY-gzZPY>
- **HEPSIM: An ESL HW/SW co-simulator/analysis tool for heterogeneous parallel embedded systems**, D. Ciabrone, V. Mutillo, L. Pomante, G. Valente, 7th Mediterranean Conference on Embedded Computing (MECO), 2018  
 Abstract: Heterogeneous devices are becoming widely diffused in the embedded system domain, mainly because of the opportunities to increase application execution performance and, at the same time, to substantially reduce energy consumption. In such a context, this work faces the role of HW/SW co-simulators/analysis tools for embedded systems based on heterogeneous parallel architectures. In particular, it presents a SystemC-based tool for functional/timing HW/SW co-simulation and analysis within a reference ESL HW/SW co-design flow. The description of the main features of the tool, the main design and integration issues and an illustrative case study represent the core of the paper.  
 10.1109/MECO.2018.8406078, <https://zenodo.org/record/3505352#.Xamqh-gzZPY>
- **Executable Modeling for Reactive Programming**, Franck Barbier, Eric Cariou, Model-Driven Engineering and Software Development. MODELSWARD 2018  
 Abstract: After thirty years, it is reasonably time to critically look at Model Driven Software Development (MDS). Who may nowadays claim that MDS has been massively adopted by the software industry? Who may show numbers demonstrating that MDS allowed/allows massive cost savings in daily software development, but, above all, software maintenance? This paper aims at investigating executable modeling as a balanced articulation between programming and modeling. Models at run-time embody the promising generation of executable models, provided that their usages are thought and intended to cost-effective software development. To envisage this not-yet-come success, this paper emphasizes expectations from the software industry about "reactive programming". Practically, executable modeling standards like the SCXML W3C standard or the BPMN OMG standard are relevant supports for reactive

programming, but success conditions still need to be defined.  
[https://doi.org/10.1007/978-3-030-11030-7\\_1](https://doi.org/10.1007/978-3-030-11030-7_1), <https://hal-univ-pau.archives-ouvertes.fr/hal-02505865>

- **UMLto[No]SQL: Mapping Conceptual Schemas to Heterogeneous Datastores**, Gwendal Daniel, Abel Gómez, Jordi Cabot, 13th International Conference on Research Challenges in Information Science (RCIS), 2019  
 Abstract: The growing need to store and manipulate large volumes of data has led to the blossoming of various families of data storage solutions. Software modelers can benefit from this growing diversity to improve critical parts of their applications, using a combination of different databases to store the data based on access, availability, and performance requirements. However, while the mapping of conceptual schemas to relational databases is a well-studied field of research, there are few works that target the role of conceptual modeling in a multiple and diverse data storage settings. This is particularly true when dealing with the mapping of constraints in the conceptual schema. In this paper we present the UMLto[No]SQL approach that maps conceptual schemas expressed in UML/OCL into a set of logical schemas (either relational or NoSQL ones) to be used to store the application data according to the data partition envisaged by the designer. Our mapping covers the database queries as well required to implement and check the model's constraints. UMLto[No]SQL takes care of integrating the different data storages, and provides a modeling layer that enables a transparent manipulation of the data using conceptual level information.  
 978-1-7281-4844-1,  
[https://www.researchgate.net/publication/332849815\\_UMLtoNoSQL\\_Mapping\\_Conceptual\\_Schemas\\_to\\_Heterogeneous\\_Datastores](https://www.researchgate.net/publication/332849815_UMLtoNoSQL_Mapping_Conceptual_Schemas_to_Heterogeneous_Datastores)
- **Multi-platform Chatbot Modeling and Deployment with the Jarvis Framework**, Gwendal Daniel, Jordi Cabot, Laurent Deruelle, Mustapha Derras, Advanced Information Systems Engineering (CAiSE 2019), 2019  
 Abstract: Chatbot applications are increasingly adopted in various domains such as e-commerce or customer services as a direct communication channel between companies and end-users. Multiple frameworks have been developed to ease their definition and deployment. They typically rely on existing cloud infrastructures and artificial intelligence techniques to efficiently process user inputs and extract conversation information. While these frameworks are efficient to design simple chatbot applications, they still require advanced technical knowledge to define complex conversations and interactions. In addition, the deployment of a chatbot application usually requires a deep understanding of the targeted platforms, increasing the development and maintenance costs. In this paper we introduce the Jarvis framework, that tackles these issues by providing a Domain Specific Language (DSL) to define chatbots in a platform-independent way, and a runtime engine that automatically deploys the chatbot application and manages the defined conversation logic. Jarvis is open source and fully available online.  
[https://doi.org/10.1007/978-3-030-21290-2\\_12](https://doi.org/10.1007/978-3-030-21290-2_12),  
[https://www.researchgate.net/publication/332233685\\_Multi-Platform\\_Chatbot\\_Modeling\\_and\\_Deployment\\_with\\_the\\_Jarvis\\_Framework](https://www.researchgate.net/publication/332233685_Multi-Platform_Chatbot_Modeling_and_Deployment_with_the_Jarvis_Framework)
- **IntegrationDistiller: Automating Integration Analysis and Testing of Object-Oriented Applications**, Mehrdad Saadatmand, 20th IEEE International Conference on Industrial Technology (ICIT 2019)  
 Abstract: Software systems typically consist of various interacting components and units. While these components can be tested and shown to work correctly in isolation, when integrated and start interacting with each other, they may fail to produce

the desired behaviors and results. Integration testing plays an important role in revealing issues in interactions among cooperating components. Identifying different interaction scenarios, however, is not a trivial task when performing integration testing. On the other hand, most of the integration testing solutions proposed in the literature are manual which hinders their scalability and applicability when it comes to large industrial systems. In this paper we introduce IntegrationDistiller as an automated solution and tool to identify integration scenarios and generate test cases (in the form of method call sequences) for .NET applications. It works by analyzing the code and automatically identifying class couplings, interacting methods, as well as invocation points. Moreover, the tool also helps and supports testers in identifying timing issues at integration level by automatic code instrumentation at invocation points. The code analysis engine of IntegrationDistiller is built and automated using .NET compiler platform, known as Roslyn. Hence, this work is the first in utilizing Roslyn features for automatic integration analysis and integration test case generation. This work has been done as part of our collaboration with ABB Industrial Automation Control Technologies (IACT) in VästeråsSweden to address the integration testing challenges of the software part of the ABB Ability™ 800xA distributed control systems. 10.1109/icit.2019.8755027,

<https://arxiv.org/abs/1811.09661>

- **Enabling easy Web of Things compatible device generation using a Model-Driven Engineering approach**, Markel Iglesias-Urkia, Abel Gómez, Diego Casado-Mansilla, Aitor Urbieta, 9th International Conference on the Internet of Things (IoT 2019) Abstract: One of the main ongoing standardization efforts of the Internet of Things (IoT) at the application layer is the Web of Things (WoT), which aims to enable interoperability using already existing standards. However, keeping up the design and implementation of IoT applications with the exponentially increasing number of devices being interconnected is costly in workforce resources. Model-Driven Engineering (MDE) approaches increase the level of abstraction using models and allowing to reuse design and code. This lowers the use of resources for implementing solutions seamlessly. This is why in this work we implement a MDE approach based on the WoT, allowing easy WoT-based device generation. Besides, automated code generation is applied to reduce manual tasks even further. Using the Eclipse Modelling Framework (EMF) and its associated plugins, we provide a way of describing models graphically and generate the code automatically, reducing development and testing time. <https://doi.org/10.1145/3365871.3365898>, [https://www.researchgate.net/publication/337071015\\_Enabling\\_easy\\_Web\\_of\\_Things\\_compatible\\_device\\_generation\\_using\\_a\\_Model-Driven\\_Engineering\\_approach](https://www.researchgate.net/publication/337071015_Enabling_easy_Web_of_Things_compatible_device_generation_using_a_Model-Driven_Engineering_approach)
- **TRILATERAL: A Model-Based Approach for Industrial CPS – Monitoring and Control**, Markel Iglesias-Urkia, Aitziber Iglesias, Beatriz López-Davalillo, Santiago Charramendieta, Diego Casado-Mansilla, Goiuria Sagardui, Aitor Urbieta, Communications in Computer and Information Science, 2019 Abstract: Internet of Things (IoT) devices are advanced embedded systems within a Cyber-Physical System (CPS) that require to be monitored and controlled. Such necessities are becoming increasingly common due to the advent of the Industry 4.0 among other smart deployments. A recurring issue in this field is that existing and new projects are reinventing the wheel by starting the development and deployment of IoT devices from scratch. To overcome such loss of efficiency in development, we propose to use Software Product Line (SPL) and Model-Based Engineering (MBE) since they seem promising in the literature in order to accelerate and ease the development software while reducing bugs and errors, and hence, costs. Additionally, a

personalized solution is needed since not all Industrial CPSs (ICPSs) are composed by the same devices or use the same IoT communication protocols. Thus, we realized that a Domain Specific Language (DSL) along with a standard, will allow the user to graphically model the ICPS for this to be monitored and controlled. Therefore, this work presents TRILATERAL, a SPL Model Based tool that uses a Domain Specific Language (DSL) to allow users to graphically model ICPSs with a IEC 61850 based metamodel, a standard originally designed for electrical substations but that has also been used in other domains. TRILATERAL automatically generates an artifact in order to create a middleware between the ICPS and the monitoring system to monitor and control all the devices within the ICPS. This tool is designed, implemented and finally, validated with a real use case (catenary-free tram) where different lessons have been learned. 10.1007/978-3-030-37873-8\_16,

[https://link.springer.com/chapter/10.1007%2F978-3-030-37873-8\\_16](https://link.springer.com/chapter/10.1007%2F978-3-030-37873-8_16)

[https://www.researchgate.net/publication/338359641\\_TRILATERAL\\_A\\_Model-Based\\_Approach\\_for\\_Industrial\\_CPS\\_-\\_Monitoring\\_and\\_Control](https://www.researchgate.net/publication/338359641_TRILATERAL_A_Model-Based_Approach_for_Industrial_CPS_-_Monitoring_and_Control)

- **Integration of iUML-B and UPPAAL Timed Automata for Development of Real-Time Systems with Concurrent Processes**, Fatima Shokri-Manninen, Leonidas Tsiopoulos, Jüri Vain, and Marina Waldén, Proceedings of ABZ 2020 7th International Conference on Rigorous State Based Methods, Ulm, Germany, Springer-Verlag, 2020  
 Abstract: Developing safety-critical systems requires to consider safety and real-time requirements in addition to functional requirements. Event-B is a formalism that is visualized by iUML-B and supports the development of functional aspects having rich verification and validation tools. However, it lacks well-established support for timing analysis. UPPAAL Timed Automata (UTA), on the other hand, address timing aspects of systems, and enable model checking reachability and timing properties. By integrating iUML-B and UTA, we combine the best verifying and validating practices from the two methods achieving a formal development of systems. We present the mapping for translating iUML-B constructs to UTA. The novel aspect is the use of a multi-process trigger-response pattern to address the modelling and verification of reachability properties of complex systems with concurrent processes. The approach is demonstrated on an airport control system, where timing, fairness, as well as liveness properties play a vital role in proving safety requirements.  
[https://research.abo.fi/converis/portal/Publication/32397313?auxfun=&lang=en\\_GB](https://research.abo.fi/converis/portal/Publication/32397313?auxfun=&lang=en_GB)
- **Automatic exploratory performance testing using a discriminator neural network**, Ivan Porres, Tanwir Ahmad, Hergys Rexha, Sebastien Lafond, Dragos Truscan, Proceedings of the 4th International Workshop on Testing Extra-Functional Properties and Quality Characteristics of Software Systems (ITEQS 2020), collocated with International conference on Software testing (ICST 2020), 2020 (to appear)  
 Abstract: We present a novel exploratory performance testing algorithm that uses supervised learning to optimize the test suite generation process. The goal of the proposed approach is to generate test suites that contain a large number of positive tests, revealing performance defects or other issues of interest in the system under test. The key idea is to use a deep neural network to predict which test could be positive and to train this network online during the test generation process, designing and executing the test suite simultaneously. The proposed algorithm assumes that the system under test is stateless and the outcome of the tests is deterministic. Also, only integer and floating-point inputs are supported. Otherwise, the approach is completely automatic, and it does not require any prior knowledge about the internals of the system under test. It can also be used effectively in a continuous integration setting where small variations of a system are tested successively.

We evaluate our algorithm using two example problems: searching for bottlenecks in a web service and searching for efficient hardware configurations in a single-board computer. In both examples, the presented algorithm performed several times better than a random test generator and significantly better compared to our previously published algorithm, producing test suites with a large proportion of positive tests.

- **Applying Test-driven Development to Evaluating Student Projects**, Cuong Huy Tran, Dragos Truscan, Tanwir Ahmad, Proceedings of 6th International Conference on Higher Education Advances (HEAd'20). 2020 (to appear)

Abstract: Grading software projects submitted by students can become a heavy and time-consuming task, which for many students, can result in delayed feedback provided to them. Additionally, one would like to allow students to evaluate themselves early their projects before submitting the final version for grading. This paper presents a solution that improves the grading process of student projects not only for lecturers, but also for students. In our approach, we adopt a test-driven development methodology to provide a clear benchmark of the course project implementation. Our approach allows students to self-evaluate their progress at any moment, while lecturers can use it to automate the grading process. GitHub Classroom is used as a supporting tool to allow students to retrieve and implement their projects from the same initial skeleton project including the tests, and lecturers to retrieve the student projects and evaluate them automatically. The results show that test-driven development is a viable solution to be applied in an academic environment to improve the grading process. This study also shows that courses in Information Technology area could use our approach to increase learning and teaching efficiency.

- **MegaM@Rt2 EU Project: Open Source Tools for Mega-Modelling at Runtime of CPSs**, Jesus Gorroñoigoitia Cruz, Andrey Sadovykh, Dragos Truscan, Hugo Bruneliere, Pierluigi Pierini, Lara Lopez Muñiz, 16<sup>th</sup> International Conference on Open Source Systems (OSS 2020). 2020 (to appear)

Abstract: In this paper, we overview our experiences of developing large set of open source tools in ECSEL JU European project called MegaM@Rt2 whose main objective is to propose a scalable model-based framework incorporating methods and tools for the continuous development and runtime support of complex software-intensive Cyber-Physical Systems (CPSs). We briefly present the MegaM@Rt2 concepts, discuss our approach for open source, enumerate tools and give an example of a tools' selection for a specific industrial context. Our goal is to introduce the reader with open source tools for the model-based engineering of CPSs suitable for diverse industrial applications.

### 3.1.3. PhD and Master theses

- **Digital twin using multivariate prediction**, Jere Puolakanaho, <http://urn.fi/URN:NBN:fi:oulu-201906212621>, Oulu University, Finland, 2019  
Abstract: Digital Twin is a digital replica of physical assets, processes and systems that can be used for various purposes. Virtual model is constructed from the corresponding physical model and these two are then connected by generating real time data using sensors. Recent advances in technology have enabled this, because they have made digital environments cost-efficient. The goal is to simulate the real world with minimal physical resources using machine learning, multivariate analysis and other mathematical techniques. Optimally no physical resources go to waste in testing and development. Runtime validation means monitoring and validating a running system with both digital and physical models. Simulated (digital) model parameters

are used in the physical model and then the simulated model is updated with new data from the physical model. Simulated model gains more and more data over time becoming more accurate. This thesis studies the applicability of mathematical models as a prediction tool to predict and validate systems behaviour as a part of simulation. And further, be used in analysis in a digital twin model.

- **Model-based Verification and Testing of Web services Functionality, Robustness and Vulnerability Analysis**, Faezeh Siavashi, Doctoral Dissertation. Åbo Akademi University, 2020

Abstract: Web services are software systems that are designed to support machine-to-machine interactions over a network. These services enable people to access a wide variety of resources through their personal computers or mobile devices. Nowadays, most of the traditional business activities and manual services are being enhanced by web services. When using web services, users expect that not only they are continually available, but also they work correctly and provide secure access to data. However, ensuring the quality of web service implementations is not simple for several reasons. First, they are accessible using public communication protocols from anywhere in the world by a large number of users. Therefore, web services should be robust enough to be able to accept correct input and reject incorrect and malicious ones. Secondly, the reputation of web services greatly depends on how they perform as expected while securing users' data. Finally, the implementation of web services should be developed in such a way that it can ensure access control of users. Implementing new features or modifying a developed feature requires additional attention to ensure that access control is not altered. Software testing is one of the techniques used for quality assurance of software systems. In software testing in which a set of inputs is provided to the system under test and the outputs produced are compared against the expected outputs. Testing is typically a largely informal process, which in many cases is left at the end of the software development process and reduced to fit the project deadlines. Thus, there is a need to deploy novel testing methods that will make testing of web services both efficient and effective. In this thesis, we define a model-based testing approach to evaluate the behavior of web services and their compositions. The goal of using models is to introduce a verifiable specification of the web service that is used later on to generate tests that are executed against the implementation of the web service. In our approach, we use model checking to make sure that the requirements of the web service are satisfied by the model-based specification. Then, we use model-based testing to check that the implementation of the web service corresponds to verified specifications, and consequently to its requirements. As a first step, we study how the interaction of the web service with their environment can be modeled and used for test generation. To this extent, we conduct a systematic literature review on the use of environment models in model-based testing. Then, we provide a first approach in which the interactions of web services with their environment are modeled with UML sequence diagrams, while the behavior of the web services is specified with UML state machines. Both models are transformed into Uppaal Timed Automata, to verify that the behavior of the services allows the specified interactions. Besides, we verify that different requirements of the web service are satisfied. The resulting verified model is used for online test generation against the implementation of the web service. As another contribution of this thesis, we define an approach to assess the robustness and security vulnerabilities of web services in the presence of unexpected or invalid conditions and inputs. To that extent, we extend our previous MBT approach in the context of mutation testing. In model-based mutation testing, the original test model is altered via mutation operators to provide slightly incorrect behavior. The



mutant models are used to generate tests that will provide invalid test inputs to evaluate how robust the service implementation is to such inputs and if any security vulnerabilities are exposed. Furthermore, we extend the above approach with two contributions. We first define a set of mutation operators for Uppaal timed automata and we evaluate them empirically in the context of web services. Then, we propose a novel mutation-selection technique that eliminates the mutant models that are not useful for testing and we, consequently, reduce the test execution time. The results show that these techniques increase the efficiency and effectiveness of our approach. In this thesis, several tools that facilitate testing activities support the testing approach. In some cases, we used existing tools like the UPPAAL model checker and the Uppaal Tron test generator. In other cases, we have complemented the existing toolset with new tools. Notably, for the mutation testing approach, we implemented a tool called  $\mu$ UT A, which automates the mutant generation, mutant-selection, and mutant execution processes. The approaches defined in this thesis have been applied in two case studies. The results show that our testing methodology can create test cases that explore the behavior of the systems extensively and reveal new faults that remain undetected by traditional model-based testing methods.

<http://urn.fi/URN:ISBN:978-952-12-3936-6>,  
<https://www.doria.fi/handle/10024/176843>

### 3.1.4. Posters and presentations

- Full research paper presentation: TRT, **Improving and Estimating the Precision of Bounds on the Worst-Case Latency of Task Chains**, ESWEEEKS 2018, <https://www.esweek.org/> (Attendance: Academics & Industrials, about 30 people)
- Full research paper presentation: UAQ, **EASIER: An Evolutionary Approach for Multi-objective Software Architecture Refactoring**, IEEE International Conference on Software Architecture, ICSA 2018, <http://icsa-conferences.org/2018/> (Attendance: Academics & Industrials, about 100 people)
- Full research paper: UAQ, **A metamodel for the specification and verification of model refactoring action**, Proc. 2nd International Workshop on Refactoring, IWor@ASE 2018, <https://iwor.github.io/iwor2018/> (Attendance: Academics & Industrials, about 20 people)
- Poster & Demo presentation: TRT, **Time4Sys - Integrating Temporal, Performance Verification in your Engineering Practices**, RTSS 2018, <http://2018.rtss.org/rtsswork/> (Academics & Industrials, about 200 people)
- Tutorial presentation: UAQ, **HEPSYCODE: HW/SW Co-Design of Heterogeneous Parallel Dedicated Systems (2nd Edition)**, High Performance and Embedded Architecture and Compilation HIPEAC 2019 (Attendance: Academics & Industrials, about 20 people)
- Tool demo presentation: UAQ, **Automating Performance Antipattern Detection and Software Refactoring**, 26th IEEE International Conference on Software Analysis, Evolution and Reengineering, SANER 2019, <https://saner2019.github.io/program/sessionList.html#Energy,%20Performance,%20and%20OSS> (Attendance: Academics & Industrials)
- Journal first session conference presentation: UAQ, **Performance-driven software model refactoring**, 26th IEEE International Conference on Software Analysis, Evolution and Reengineering, SANER 2019, <https://saner2019.github.io/program/sessionList.html#Refactoring%20and%20Design%20Pattern> (Attendance: Academics & Industrials)

- Full research paper presentation: UAQ, **Exploiting Architecture/Runtime Model-Driven Traceability for Performance Improvement**, IEEE International Conference on Software Architecture, ICSA 2019, <https://swk-www.informatik.uni-hamburg.de/~icsa2019/index.html> (Attendance: Academics & Industrials)
- Paper presentation: UOC, **Enabling Performance Modelling for the Masses: Initial Experiences**, HIPEAC 2019, <https://www.hipeac.net/2019/valencia/#/schedule/sessions/7625/program/> (Attendance: Academics & Industrials, about 20 people)
- Paper presentation: MDH-INT, **On the Use of Hackathons to Enhance Collaboration in EU Projects - A Preliminary Case Study of the MegaM@Rt2 project**, DATE 2019, <https://www.date-conference.com> (Attendance: Academics & Industrials, about 30 people)
- Tutorial presentation: UCAN, **Megamodeling of complex, distributed, heterogeneous CPS systems**, Summer School on Cyber-Physical Systems and Internet-of-Things, CPS&IoT'2019, <http://embeddedcomputing.me/en/cps-iot> (Attendance: Academics & Industrials, about 35 people)
- Paper presentation: ABO, **Exhaustive Simulation and Test Generation Using fUML Activity Diagrams**, 31st International Conference on Advanced Information Systems Engineering, CAISE 2019, <https://www.caise19.it> (Attendance: Academics & Industrials, about 50 people)
- Paper presentation: ABO, **MATERA2-AIfTester**, Euromicro Conference on Software Engineering and Advanced Applications, [http://dsd-seaa2019.csd.auth.gr/seaa/?sec=call#page\\_header](http://dsd-seaa2019.csd.auth.gr/seaa/?sec=call#page_header) (Attendance: Academics & Industrials, about 40 people)
- Paper presentation: ABO, **Exploratory Performance Testing Using Reinforcement Learning**, Euromicro Conference on Software Engineering and Advanced Applications, [http://dsd-seaa2019.csd.auth.gr/seaa/?sec=call#page\\_header](http://dsd-seaa2019.csd.auth.gr/seaa/?sec=call#page_header) (Attendance: Academics & Industrials, about 40 people)
- Invited talk: TRT, **Integration of Schedulability Analysis in the Industrial Design Process**, Workshop on Advanced Technologies in Industrial Vehicular Systems DIVERSE@ETFA 2019, <http://www.etfa2019.org/ws03-diverse-a-workshop-on-advanced-technologies-in-industrial-vehicular-systems/> (Attendance: Academics & Industrials, about 30 people)
- Tutorial presentation: TRT, **Integration of Model-Based Performance Verification in the Industrial Design Process**, HW/SW Modeling and Performance Analysis of Heterogeneous Safety-Critical Systems, <https://www.esweek.org/events/2016/tutorial/hwsw-modeling-and-performance-analysis-heterogeneous-safety-critical-systems> (Attendance: Academics & Industrials, about 30 people)
- Invited talk: TRT, **MegaM@Rt2 Challenges and expected outcomes**, 4th International workshop on Timing Performance engineering for Safety critical systems, TIPS'19, <http://www.es.ele.tue.nl/tips19/>, (Attendance: Academics & Industrials, about 20 people)
- Invited talk: ARM, UOC, UAQ, **A model-based framework for continuous development and runtime validation of complex systems: MegaM@Rt2 EU Project results**, Second International Workshop on Model-Driven Engineering for Design-Runtime Interaction in Complex Systems, MDE@DeRun co-located with STAF 2019, <https://megamart2-ecsel.eu/mde-derun-2019/> (Attendance: Academics & Industrials, about 20 people)

- Presentation: UAQ, IN, **Challenges presentation and tools tutorials: Integration of HESYCODE and CHESSE, Ultimate CPS Metamodeling and online runtime intelligent analysis Hackathon, Synchronization a Time4Sysmodel**, Hackathon: High-performance Embedded Architecture and Compilation, HIPEAC2020, <https://www.hipeac.net/2020/bologna> (Attendance: Academics & Industrials, about 20 people)

### 3.2. Events organization and attendance

- Workshop: **DevOps for Embedded Systems, MegaM@Rt2, the devops for embedded systems**, co-located with HIPEAC 2019, <https://www.hipeac.net/2019/valencia/#/schedule/sessions/7625/> (ATOS, ABO, SOFT, IKER, MDH)
- Workshop: **Testing of extra functional properties and quality characteristics of software systems, ITEQS'2019** co-located with ICST 2019, <http://www.mrtc.mdh.se/ITEQS/2019/> (MDH, RISE SICS)
- Workshop: Testing of extra functional properties and quality characteristics of software systems, ITEQS'2020 co-located with ICST 2020, <http://www.mrtc.mdh.se/ITEQS/2020/> (MDH, RISE SICS, ABO)
- Workshop: **MDE for Design-Runtime Interaction in Complex Systems, MDE@DeRun2019** co-located with STAF 2019, <https://megamart2-ecsel.eu/mde-derun-2019>, (UAQ, UOC, ARM)

### 3.3. Academic courses

- **Automated Test Generation**, MDH, November 2019, Online, Course for european students, <https://www.mdh.se/utbildning/livslangtlarande/futuree/automated-test-generation-1.118797>,
- **Model Driven Engineering**, UAQ, February 2019 - June 2019, Master Degree in Computer Science, Dissemination of results to students of the Computer Science Department, <http://www.disim.univaq.it/didattica/content.php?corso=96&pid=86&did=0>
- **Software Architecture and Quality Engineering**, UAQ, September 2018 - January 2019, Master Degree in Computer Science, Dissemination of results to students of the Computer Science Department, <http://www.disim.univaq.it/didattica/content.php?corso=539&pid=86&did=0&lid=en>
- **Advanced Models for Software Engineering**, UAQ, February 2019 - June 2019, Master Degree in Computer Science, Dissemination of results to students of the Computer Science Department, <http://www.disim.univaq.it/didattica/content.php?corso=602&pid=86&did=0&lid=en>
- **Embedded Systems**, UAQ, September-December 2019, Master Degree in ICT, Dissemination of results to students of the Computer Science Department, <http://www.disim.univaq.it/didattica/content.php?corso=357&pid=86&did=0>
- **Software Testing course. ABO. March-May 2020. Master level course in IT at ABO. Dissemination of results to students.** <https://studiehandboken.abo.fi/en/course/452502.0/1445>

### 3.4. Social and online tools

#### 3.4.1. Project website

The project website <https://megamart2-ecsel.eu/> is the open window of the project to the outsiders and the unique access point to all project information. It is constantly updated with new information generated

from the MegaM@Rt2 progresses.

The structure of the website described in D6.5 has been extended to integrate the following contents:

- The Home page now contains a new video presenting an overview of the project with subtitles for people with hearing problems.
- Improved Use Cases page presenting updated MegaM@Rt2 use cases to the general audience, and showing how the project helps in solving these challenges.
- MegaM@Rt2 Catalog page presenting the set of tools offered in the project, and providing an uniformized way to download, navigate the documentation, and contact the tool providers.
- Publication & Scientific Results page gathering all the scientific publications related to the project.

In addition, the MegaM@Rt2 blog is continuously updated with summaries of new publications and results related to the project. Each post draft is reviewed by UOC and adapted if necessary before its final publication on the website. Specifically, the following 18 blog posts have been published since the last deliverable:

- [MegaM@Rt2 Toolset Catalog](#)
- [Code Change Based Test Selection in Continuous Integration Environment](#)
- [The MegaM@Rt2 Eclipse IDE](#)
- [Generic Model-based Approaches for Software Reverse Engineering and Comprehension](#)
- [Temporal models with TemporalEMF](#)
- [Exhaustive Simulation and Test Generation Using fUML Activity Diagrams](#)
- [Model-based testing using UML activity diagrams: A systematic mapping study](#)
- [A Two-Layer Component-Based Allocation for Embedded Systems with GPUs](#)
- [MDE@DeRun 2019 – 2nd Int. Workshop on Model-Driven Engineering for Design-Runtime Interaction in Complex Systems](#)
- [Adopting MBSE in Construction Equipment Industry: An Experience Report](#)
- [IntegrationDistiller: Automating Integration Analysis and Testing of Object-Oriented Applications](#)
- [Santander hosts, on October 2 and 3, the 6th Plenary Meeting of the MegaM@Rt2 project](#)
- [TRILATERAL: Software Product Line based Multidomain IoT Artifact Generation for Industrial CPS](#)
- [On the Use of Hackathons to Enhance Collaboration in Large Collaborative Projects](#)
- [MegaM@Rt2 presents in EF ECS Event in Helsinki its new proposal: AIDOaRt, an AI-augmented automation for efficient DevOps Copy](#)
- [Automating Performance Antipattern Detection and Refactoring in UML Models](#)
- [Hierarchical Block Diagram Translations](#)
- [MegaM@Rt2 will host a hackathon about modelling and traceability, runtime analysis and systems engineering](#)

The website averages 233 unique visitors per month with an average session duration of 1m 23s. The number of visitors has grown since the last deliverable mostly because of the new updates of the blog, as well as the hosting of the landing pages of MegaM@Rt<sup>2</sup>-related events. Visitors from the participant European countries are still frequent visitors of the website but the area of influence of the project keeps growing beyond the national clusters, as shown in the following map. Note that since the last report the project website audience has kept growing in the United States, but it also spread to many other new countries where until now we had no significant impact in terms of the number of visitors.

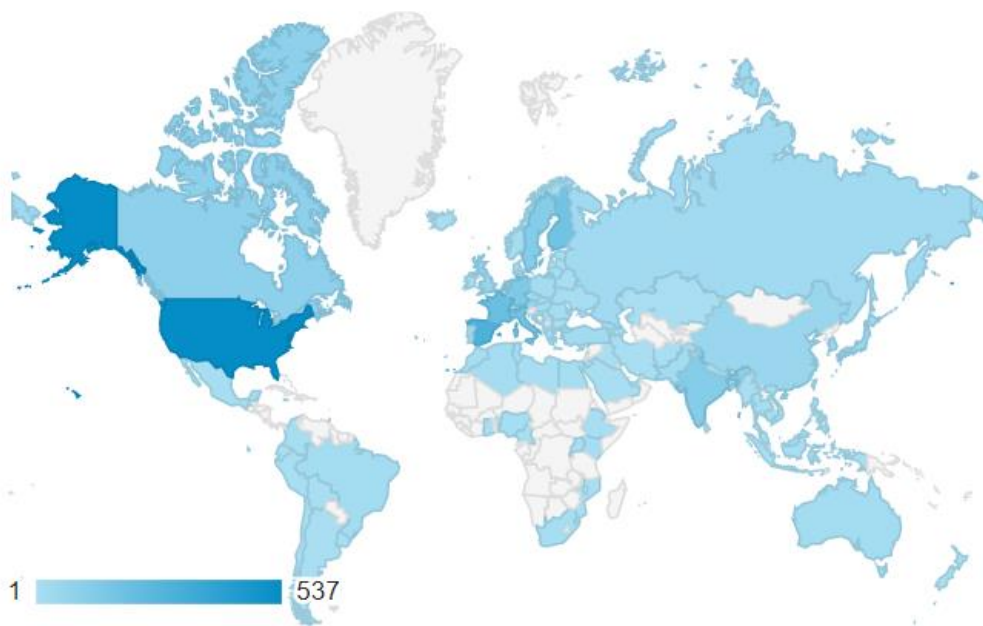


Figure 1 Influence area map for the project website

### 3.4.2. Social media

The Twitter account of the project (@MegaMart2\_ECSEL) continuously tweets relevant project information, especially new blog posts and major events attended or organized by the project, like the hackathons or plenary meetings where the project has been. In addition, the project monitors a set of hashtags in order to retweet technological content relevant to the project, and the account follows other related projects and initiatives in order to spread new results to a wider audience. Also, it collects the promotion of every event where MegaM@Rt2 would be present, posting each press release beforehand, photos of the event and the agendas, posters...

These investments have gathered 45 new followers at the time of writing this deliverable, since October (+57'14%). Also, during this period the project earned an average of 506 impressions per day. In comparison with the same period next year, where it earned an average of 300 impressions per day. We increased the engagement by 68%.

Also, it was created a LinkedIn account for community building where the project could keep connected with partners, companies and institutions that want a closer bond with MegaM@Rt2. These investments have gathered 186 new connections at the time of writing this deliverable, since October 2019. Also, on LinkedIn, it created a company page more reachable to anyone that may be interested in these types of projects. This company page has gathered 59 new connections at the time of writing this deliverable, since February 2020.

The main goal of the MegaM@rRt2 social media accounts was to give people easy, fast and important information. Both of the accounts are friendly, informal and easy-going. The main efforts were into creating something where people that are interested in engineering could find information and support, but also a platform for someone that doesn't know about this project could find a good foundation of information.

The main activity that took place was to post every use case with the link to the web page to get more engagement into that. The aim of the project was to post these use cases in two ways. First one, a photo

con with the logo of the company and a little bit of text, explaining what it is. The other way was just to publish a photo of the theme of the use case.

### 3.5. Marketing material

The project aims to build a branding recognition around its communication material, making it easily distinguishable from competitors. The overall strategy of dissemination and communication within MegaM@Rt2 aims at a) raising awareness and acceptance of the scientific soundness of the MegaM@Rt2 approach and b) supporting the engagement of key stakeholders in MegaM@Rt2 to get a significant impact on the software modelling arena. For this reason, marketing material is periodically released to let the audience stay tuned for the latest news and releases.

#### 3.5.1. Project video

In order to make the project understandable for a wider audience, a video with the latest project results was produced in the middle of Y2. The video has been available on the front page of the website and in the YouTube channel created for MegaM@Rt2 to make it easily reachable. One of the goals that was established at the beginning of the project was to make our content accessible to all types of communities. That is why it is updated this promotional video with subtitles that can be read on the YouTube channel as well as on all our social media. The updated video can be found here: <https://www.youtube.com/watch?v=-Esy3BS436w>.

#### 3.5.2. Posters

To get MegaM@Rt2 more approachable for the audience, the communication team created posters and agendas specially designed for each meeting that you could find on social media. One example of the *New integration challenges featuring more than 2 tools* in Santander Hackathon can be found here: [https://twitter.com/MegaMart2\\_ECSEL/status/1179274821747826689](https://twitter.com/MegaMart2_ECSEL/status/1179274821747826689).

#### 3.5.3. Press Releases

The project periodically releases press notes in order to let others know about the latest news, including events and software releases. These press releases are published on the website, but also printed and taken to events to be given as companion documentation of flyers.

On top of both press releases, the project decided that it would be a good way of communicating, disseminating and getting more people involved, divulging a notice to every event that we were going to assist, where the readers could find information about the event, our project and our goal in that conference.

All of them can be found on the website: <https://megamart2-ecsel.eu/press-releases/>

Specifically, during this last year we have published the following press releases:

- [The European MegaM@Rt2 Project uses AI and advanced modeling techniques for the continuous development and runtime validation of complex systems](#)
- [Santander hosts, on October 2 and 3, the 6th Plenary Meeting of the MegaM@Rt2 project](#)
- [MegaM@rt2 presents in EF ECS Event in Helsinki its new proposal: AIDOaRt, an AI-augmented automation for efficient DevOps Copy](#)

- [MegaM@Rt2 will host a hackathon about modelling and traceability, runtime analysis and systems engineering](#)

### 3.6. Community building activities

A hackathon is an event, typically lasting several days, in which a large number of people meet to engage in collaborative computer programming. MegaM@Rt2 has adopted hackathons as a way to foster collaboration and cross-fertilization among individuals with different profiles, creating positive synergies between use case and technology providers, ensuring that all challenges have several participants involved, helping use case providers to bootstrap experimentations with dedicated technology demonstrators on a clearly limited subset based on realistic concrete material, e.g., models, code, etc. and, track project progress with respect to project deliverables, illustrate results as well as to spot the innovation at early stages in only one day.

This activity follows a process that starts before the exercise itself. First, there is a call for experiments, where a problem is proposed and output demo or presentation, then there is a call for teams, which have previously expressed interest, where they can ask questions and prepare for the hackathon day.

Hackathons are not limited only to education and learning environments. They are also useful for rapidly exploring new business ideas and producing software prototypes. However, to generate revenue and create real business value, promising prototypes must be developed further and transformed into finalized products.

Three hackathons were organized this year:

1. *MegaM@Rt2 Prague Internal Hackathon*, Prague, 22nd May 2019
2. *New integration challenges featuring more than 2 tools* in Santander, 2nd October 2019.
3. *Modelling and traceability runtime analysis and systems engineering*, co-located in HiPEAC, Bologna, 20th January 2020.

The first two hackathons were internal. The Prague hackathon focused on strengthening cooperation between industrial case study providers and the tool and method providers in the project. In the hackathon, different tool and method providers solved concrete challenges raised by case study providers. The Santander hackathon focused in increasing the efficiency of the 6th Plenary Meeting allowed creating positive synergies between use case and technology providers, helping use case providers to bootstrap the baseline experiments by providing use case providers dedicated technology demonstrators on a limited subset of their specific industrial challenge. Demonstrators were also used to track project progress concerning project deliverables, illustrating results as well as spotting the innovation at early stages and ensuring that all the case studies have several partners involved.

The Bologna hackathon was an open event and different challenges were proposed:

1. Integration of HEPHYCODE and CHESS. Two tools designed for HW/SW co-design of heterogeneous parallel dedicated systems and for modelling and analysing real-time embedded systems.
2. Evaluate the proposition of AIPHS taking into account monitoring requirements from literature and validate the proposed approach by the tool.
3. Synchronize a Time4Sysmodel, obtained from runtime traces, with the performance verification tools MAST and/or pyCPA and the design tool Papyrus. Communication with Papyrus must be bi-directional..

4. Use the MegaM@Rt2 Toolbox Catalog to present, and solve, a new challenge that may affect organizations on their daily activities

This event was open, but not limited, to companies that want to gather expertise and new ideas on interesting practices, find interns, find a team for an MSIT studio project, promote your Company; students to find an interesting area to work on after graduation; find an idea for a start-up; find a company for internships; researchers aiming to investigate on different areas of software engineering and engineers to share their expertise, and gain a new one, on software engineering practices.



## 4. Standardization actions

Along this final period (M25-M36), MegaM@Rt2 activities on standardization have been concentrated on shaping the evolution of the MARTE OMG standard, some additional though less strong efforts have also been done regarding SysML, and only observation actions have been taken regarding other standards like fUML and their related specifications.

In brief, we may summarize our last year standardization efforts as:

- Main efforts have been devoted to the preparation of responses to the MARTE 2.0 RFI issued by the OMG. A comprehensive collective response of MegaM@Rt2 partners was prepared and sent to the OMG (OMG Document number: ad/19-08-11). Also, individual partners of MegaM@Rt2 prepared and sent their responses, this was the case of TRT, INT, and UCAN.
- A summary of responses has been presented at the September-2019 OMG Technical meeting (OMG Document number: ad/19-09-10)
- Towards taking leadership of the finalization of the current version of MARTE, Laurent Rioux from Thales (TRT) has become Co-Chair of the MARTE 1.3 RTF
- Along SysML the work has been the specification of its semantics in the context of its current version with the idea of being able to define the corresponding profile in the context of SysML V2.
- We have also worked reviewing and contributing to solve current pending issues of SysML and MARTE.

### **Activities related to MARTE**

Regarding MARTE, our main commitment has been the formalization of responses to the recent Request for Information (RFI) for MARTE 2.0 issued by the OMG. Among others, the response from MegaM@Rt2 various partners, as well as those from TRT, INT, and UCAN can be retrieved from the corresponding page at the OMG site: [https://www.omg.org/schedule/MARTE\\_2.0\\_RFI.html](https://www.omg.org/schedule/MARTE_2.0_RFI.html)

The document numbers that correspond to these efforts are listed here. For convenience, this list includes links to the official OMG page in the document numbers (accessible to OMG members only) and to a copy offered to the consortium in the MegaM@Rt2 repository in the name of the documents (which appear between parenthesis):

- [ad/19-08-05 \(Intecs Solutions response to MARTE 2.0 RFI\)](#)
- [ad/19-08-11 \(MegaM@Rt2 project response to the MARTE 2.0 RFI\)](#)
- [ad/19-08-10 \(Universidad de Cantabria MARTE 2.0 RFI response\)](#)
- [ad/19-02-01 \(THALES response to the MARTE 2.0 RFI\)](#)

Regarding the efforts in the Revision Task Force for the improvement of the current version of MARTE, there was a meeting programmed for the March 2020 Technical Meeting of the OMG in Reston VA USA, but due to the COVID-19 contention actions it was cancelled. Further actions will be taken by interested partners in the next Technical Meetings.

### **Activities related to SysML**

The pace for the preparation of SysMLv2, as well as the Revision Task Force for SysML1.7 have slightly slowed down in recent months, resulting in certain delays in their presentation at the OMG. Along this period the contribution from MegaM@Rt2 partners has focused in the discussion of already ongoing technical issues and the participation in the formal procedures for the enhancement of SysML 1.7 semantics formalization.

### **Relation between MegaM@Rt2 components and standardization efforts**

The need to contribute to or at least to closely follow the evolution of standards like MARTE, SysML and fUML, responds to the need to maintain and somehow assure further compatibility between the tools and methodologies on which the components and assets brought by MegaM@Rt2 rely.

Hence the efforts in this task go in both directions, on the one hand to influence the standards so that capacities in MegaM@Rt2 tools become general trend and shape the features expected by the community in future tools, and on the other hand to monitor and learn as soon as possible the trends that can consolidate in future versions of the standards so that we can keep our tools and methodologies updated, expanding their compatibility and prospective life cycles.

Following recommendation from the reviewers, here we include a table that relates MegaM@Rt2 components, owners, and standards on the scope of which activities have been performed:

Component	Owner	MARTE	SysML	fUML	Activities/Relation
<a href="#">S3D</a>	UCAN	X			Besides timing annotations, many required capabilities in MARTE have been reported in <a href="#">UCAN RFI Response</a>
<a href="#">PADRE</a>	UAQ	X			Performance related capabilities have been required in <a href="#">MegaM@Rt2 RFI Response</a>
<a href="#">CHESS</a>	INT	X	X		Besides the strong use of SysML requirements formalization, several other requirements have been stated in <a href="#">INT RFI Response</a>
<a href="#">MOKA</a>	ATOS	X	X	X	It has a strong dependency on fUML execution semantics. It also requires support from MARTE for timing annotations and from SysML for modelling of structural elements.
<a href="#">MATERA2</a>	ABO			X	Both, MATERA2-ADCT and MATERA2-ALFTester components use fUML activities in the context of MOKA and rely on its standard execution semantics. In addition, MATERA2-ADCT

					introduces timing notations and semantics to fUML activity diagrams.
<a href="#">MODELIO</a>	SOFT	X	X		SOFT is a voting member of the SysML 1.7 RTF. Also, Modelio relies on MARTE for the support of extra-functional properties (Requirement MODELIO-040 in D3.2 section 6.18)

Following the efforts reported in previous periods, in the direction towards potential standard adaptations, the efforts realized by MegaM@Rt2 partners have consisted mainly in the identification of requirements for an enhanced version of MARTE. These efforts have led to the documents prepared in response to the Request for Information Issued by the OMG (mentioned in the subsection Activities related to MARTE above). In order to bring visibility to the project, besides the individual partners' responses we have prepared a collective response labelled with the name of the project ([MegaM@Rt2 project response to the MARTE 2.0 RFI](#)), which included contributions from several partners of the project.

As required by the reviewers, further details for each potential standard adaption are to be provided. Concretely, reviewers requested:

- 1) a short description of the concrete potential standard adaptation,
- 2) its relation to the MegaM@Rt2 project (proposed by certain MegaM@Rt2 partners or consortium / supported by certain MegaM@Rt2 partners or consortium / ...),
- 3) its relation to a project artefact (standard adaptation roots in a concept already part of a MegaM@Rt2 tool / standard adaptation would directly improve main functionality of MegaM@Rt2 tool / standard adaptation has been proposed due to experiences gathered in certain MegaM@Rt2 use cases / ...), and also
- 4) the status of the standard adaptation (proposed+in discussion / proposed+rejected / proposed+accepted /

In order to respond to these requests, please consider:

- 1) The table below shows the concrete technical contents proposed for MARTE. Further details of each can be seen in the documents that are linked under the acronym of the partner. The Id of the requirements are consistent with the nomenclature used in each independent document.
- 2) Only requirements from MegaM@Rt2 partners (see third column) are included here.
- 3) Partners included in this list are owners of the tools mentioned in the table above. Their requests correspond to improvements of their corresponding tools or methodologies. TRT requirements come from the modeling of its use cases.
- 4) The standardization process for MARTE 2.0 at this point is in its initial phase. The formalization of its Request for Proposals (RFP) that was planned for this March meeting has been delayed due to the COVID-19 situation, but will surely recover once the situation stabilizes. Technically, the content for MARTE 2.0 is in its largest part driven by the foundational requests provided by MegaM@Rt2 partners.

ReqID	Description	Partner
22	A version of the MARTE profile compatible with the Eclipse UML2 standard implementation so that we can use it with tools based on ECLIPSE/EMF	<a href="#">ARM</a>
23	Support for performance driven model refactoring	<a href="#">UAQ</a>
24	Support for analysis results annotated back in the model.	<a href="#">UAQ</a>
25	Generic capabilities might be introduced in order to reduce the effort needed for developing/using external analysis tools	<a href="#">UAQ</a>
26	<p>Resource demands over Hw AND/OR Sw resources:</p> <p>Some performance engineering methodologies ground on the specification of resource demands over:</p> <ul style="list-style-type: none"> <li>○ only hw resources (i.e., platform-specific) having their own service rates and “primitive” services (e.g., cpu cycles, RAM r/w accesses, disk r/w accesses)</li> <li>○ sw resources (i.e., platform-independent); such demands are then mapped to hw resources having their own service rates, through an overhead matrix that specifies how many “primitive” hw resource units (e.g., cpu cycles, RAM r/w accesses, disk r/w accesses) of each hw resource are requested by each sw resource (platform-specific)</li> </ul> <p>Hw resources can be considered in their “classical” sense, i.e. hw nodes with their own devices.</p> <p>Sw resources may be considered as features spanning from low-level functionalities such as computation and memory access, to more complex functionalities such as log entries and displayed pages.</p>	<a href="#">UAQ</a>
27	Some methodological guidance seems to be necessary for the use of Resource usage in more complex arrangements of resources (Hw/Sw)	<a href="#">UAQ</a>

28	In the performance analysis sub-profile, allow the servDemand tag of <<GaStep>> to target <<HwResource>> (not just <<GaRequestedService>>)	<a href="#">UAQ</a>
29	Generic capabilities to reduce the effort needed for developing/using external analysis tools dealing with UML-MARTE models. In particular specific stereotypes for distinguishing model elements that have to be considered during external analyses (optionally, it would be interesting to have the possibility of specifying analysis activities in some way, maybe through properly annotated UML Activities), as well as legacy model entities (Components and Nodes at least)	<a href="#">UAQ</a>
30	Enhance the capacity for <<GaAcqStep>> and <<PaResPassStep>> to express resource demands. By changing the multiplicity of acqRes and resource tags of <<GaAcqStep>> and <<PaResPassStep>> from [0..1] to [0..*], and by changing the type of resUnits tag of <<GaAcqStep>> and <<PaResPassStep>> from NFP_Integer to NFP_Real	<a href="#">UAQ</a>
31	<p>Change attributes of &lt;&lt;GaWorkloadGenerator&gt;&gt; to reduce the gap between hw/sw models and performance models.</p> <ul style="list-style-type: none"> <li>· Type of pop tag from NFP_Integer to NFP_Real</li> <li>· In addition to the population (pop), a generic delay can be specified for closed workloads, like thinking time [0..1] thinkingTime tag of type NFP_Duration</li> <li>· Add the capacity to have open workloads to &lt;&lt;GaWorkloadGenerator&gt;&gt;</li> </ul>	<a href="#">UAQ</a>

32	Support queuing annotations with <<RtUnit>>. To do this add the InstanceSpecification metaclass to the set of <<RtUnit>> base metaclasses. In this way, an InstanceSpecification representing a (hw/sw) <<Resource>> can specify a queue size and a scheduling policy, which is reasonable. In fact, think to two identical hw nodes where two instances of the same webserver are running, each on a different node. In general, requests arrive at each hw node heterogenously, thus the latter will show different queue sizes. In addition, they could also implement different scheduling policies.	<a href="#">UAQ</a>
33	Change the type of <i>queueSize</i> tag of <<RtUnit>> from NFP_Integer to NFP_Real. By making this tag as real, it is possible not only to intend it as a maximum capacity parameter, but also as a performance index such as the average queue length	<a href="#">UAQ</a>
34	Support for contract-based design	<a href="#">INT</a>
35	Contract-based design for system specification, stepwise refinement, compositional reasoning and component reuse, evidence/argument fragments reuse, static and run-time usage	<a href="#">INT &amp; MDH</a>

36	<p>Support of contracts at run-time for open collaborative systems. Currently MARTE has limited support for contract specification (NfpConstraint with kind=contract). It needs to:</p> <ul style="list-style-type: none"> <li>· Be able to discern between assumption and guarantee properties, e.g. to enable finer-level traceability to requirements, different criticalities allocation</li> <li>· Support for strong and weak contracts concepts</li> <li>· A component having a strong contract associated cannot operate in a scenario where the assumption is not fulfilled by the environment</li> <li>· A component heaving a weak contract associated can operate in a scenario where the assumption is not fulfilled, but its guarantee is discarded</li> <li>· Support for contracts decomposition, as for requirements</li> <li>· Support for contracts-based design at component-classifier and instance level E.g. be able to associate a set of weak contracts to a component-classifier Instantiate the component-classifier in a given context and select the weak contracts which hold.</li> </ul>	<a href="#">INT</a>
37	<p>Support for dependability information (consider support available from OMG Dependability Assurance Framework for SafetySensitive Consumer Devices™ (DAFTM)). But needs:</p> <ul style="list-style-type: none"> <li>· Modelling of fault-error-failure (states) for a given component</li> <li>· Modelling of failure propagation between components</li> <li>· To allow quantitative/qualitative dependability analysis</li> </ul>	<a href="#">INT</a>
38	Improve instance level view	<a href="#">INT</a>

39	The notion of component instance is of particular relevance when dealing with NFP attributes, e.g. to specify NFP values, refine classifier-level NFP values, to store values coming from analysis results Currently MARTE support modelling at instanceSpecification level with some limitation: we found no-support for instanceSpecification level for MARTE RtSpecification construct... Current UML support for instance specification representation is poor. Often in practice composite structure diagram is used to model instances, not parts of a classifier	<a href="#">INT</a>
40	Needs proper view to represent InstanceSpecifications, their properties and hierarchical structure	<a href="#">INT</a>
41	Alignment with latest UML specification	<a href="#">INT</a>
MARTE2_INT_001	Support for contract-based modelling should be enhance in MARTE, allowing to model weak and strong contracts as pair of assumption and guarantee properties, and contract refinements in the context of parent-child components.	<a href="#">INT</a>
MARTE2_INT_002	Support for dependability concerns modelling should be provided by extending MARTE core capabilities. In addition, support to formalize dependencies between performance and dependabilities properties should be provided.	<a href="#">INT</a>
MARTE2_INT_003	Support for instance-level modelling, in particular related to performance attributes/constraints, and representation should be improved	<a href="#">INT</a>
Req2.1	All the MARTE 2.0 packages shall be formalized by metamodels.	<a href="#">TRI</a>
Req2.2	MARTE 2.0 shall formalize NFPs with NFPs models.	<a href="#">TRI</a>
Req2.3	MARTE 2.0 shall better formalize units by reusing QUDV from SysML.	<a href="#">TRI</a>
Req2.4	MARTE 2.0 shall improve the concrete syntax of VSL. Some examples: definition of scope, simplification of expressions with units	<a href="#">TRI</a>



Req3.1	(same of Req 2.1) MARTE 2.0 shall be defined by a consistent and unique metamodel	<a href="#">TRT</a>
Req3.2	MARTE 2.0 shall also be defined as UML Profile	<a href="#">TRT</a>
Req3.3	MARTE 2.0 shall have precise and non-ambiguous semantics.	<a href="#">TRT</a>
Req3.4	MARTE shall provide a standard metamodel to model timing results provided by the analysis tools including the Gantt charts results provided by some simulation or analysis tools to assure data interchange of the results.	<a href="#">TRT</a>
Req3.5	Merge concepts from Modelling part and analysis parts of MARTE so as to avoid duplication of concepts and sometimes miss matches. We should be able to apply performance verification directly on top of the design model of the real-time embedded system done with MARTE	<a href="#">TRT</a>
Req3.6	Need to add input and output ports to schedulable elements. These ports will be used to carry scheduling analysis or simulation data. These ports could be also used to model communications data between schedulable elements.	<a href="#">TRT</a>
Req3.7	Add the possibility to add input and output event models to schedulable elements. This will allow the capability to compute output event model from input event model. These event models could be attached to input and output ports.	<a href="#">TRT</a>
Req3.8	Missing activation event models in MARTE	<a href="#">TRT</a>
Req3.9	It appears that some activations of SaStep could be complex and defined by logical operations of events models. Therefore, we need to extend MARTE with the capability to define an activation event model defined with logical operators (and, or, xor, nor) of different activation event models. These logical operators could be carried by the input or output ports of schedulable Elements	<a href="#">TRT</a>

Req3.10	Need to extend the Periodic activation event model properties with the property of « phase » to model the dephasing between different periodic sources.	<a href="#">TRT</a>
Req3.11	It appears that sometimes execution time of treatment could follow a specific schema; we need to model this to be able to have more precise analysis and simulation prediction. A basic way to achieve it, is to use a (cyclic) duration table.	<a href="#">TRT</a>
Req4.1	MARTE shall NOT support anymore ArrayOL, since it introduces unnecessary complexity inside MARTE that is not used.	<a href="#">TRT</a>
Req5.1	MARTE 2.0 must be compliant with key standards for system properties. We recommend to consider what aspects of the MARTE standard would best contribute/facilitate the creation of an inter-standard mediation protocol, enabling trade-offs and traceability of interdependencies. Safety and security standards are of particular relevance	<a href="#">TRT</a>
Req5.2	The scope of MARTE 2.0 shall not be extended to treat specific concepts of safety, security or generalised reliability and dependability	<a href="#">TRT</a>
Req7.1	Specific stereotypes of SRM and HRM shall be replaced by model libraries. SRM and HRM must contain only general stereotypes. Specific entities shall be specified as classes on which the general stereotypes are applied.	<a href="#">TRT</a>
Req7.2	The concept and the notation of duration needs to be simplified by offering two different manners to model it: a very simple duration expression (could be just a triple: [Min, Max, Unit] and a more precise expression by using CCSL and/or ideal clock	<a href="#">TRT</a>
Req7.3	Sometimes the clocks are drifting, so we need to be able model this by defining time drifts in ppm between clocks	<a href="#">TRT</a>

Req7.4	MARTE 2.0 shall be able to model new kinds of processors/chips used in Artificial Intelligence (AI) like a neuronal network processor, etc.	<a href="#">TRT</a>
Req7.5	To apply performance analysis of multicores, we need to model interferences between cores. MARTE 2.0 shall enable the modelling of such interference models that support multicore simulation and analysis techniques.	<a href="#">TRT</a>
Req7.6	Since a few years now, hypervisors have appeared on the market to better control the operating system and provide space and timing isolations between cores. MARTE 2.0 shall provide new mechanisms to model such hypervisors	<a href="#">TRT</a>
01	Need to have extensions for handling mixed criticalities in NFP annotations and constraints.	<a href="#">UCAN</a>
02	A high-level application modelling semantics for analyzability and executable UML conformance	<a href="#">UCAN</a>
03	Design, performance and safety assessment for embedded systems that are connected through general purpose and ad-hoc networks	<a href="#">UCAN</a>
04	The inclusion of specific analysis domains. Either as normative examples, sub-profiles, or providing a way to plug them into the language. Domains like: Dependability, profiling cache and stack usage (for wcet estimation), power consumption, temperature spatial distribution/heat dissipation, cost and security impact of design decisions, inner complexity, criticality aware allocation, contract-based design, ...	<a href="#">UCAN</a>
05	Extended allocation tactics that include multiple choices for model-based design space exploration.	<a href="#">UCAN</a>
06	Hardware and/or Software synthesis. This is an enlarged design space trend for which links to hardware description languages, and again richer kinds of allocation will have to be explored	<a href="#">UCAN</a>

07	Managing views and tracing mechanisms along the development process and iterative validation strategies. An enhanced version of MARTE should help practitioners to link models with specific phases of the development process followed	<a href="#">UCAN</a>
08	A normative coherent and complementary version of all the domain models of the current version of MARTE. Defining very precise and decoupled modeling scopes and associating to them exclusive modeling elements that may conform complementing dialects of MARTE. The needed dialects might be defined in the form of inter-related domain specific languages. All of them would be supported by a complete common meta-model whose semantics must be fixed in accordance to the UML meta-model and the executable UML related specifications. The normative or non-normative quality of this complete meta-model would need to be discussed and clearly specified in the requirements of the RFP. Alternatively, stricter conformance cases (see clause 6 or MARTE) may be used instead to define the dialects able to be used in that strict normative way	<a href="#">UCAN</a>
09	Concrete simple variants could be proposed as strict subsets of the profile for their exclusive applicability in specific domains. This would encompass extending the applicability of the compliance cases as strict usability clauses, though more precise modelling intents should be defined and made part of the normative body of the standard	<a href="#">UCAN</a>
10	A specific serialization format for collecting observations (UML TimeObservation and MARTE TimedInstantObservation) so that they can serve to asses/predict/retrieve run time execution traces	<a href="#">UCAN</a>
11	A means to compare timing diagrams obtained from different tool vendors would be a contribution of MARTE to the various tools that are around for visualizing tasks executions	<a href="#">UCAN</a>
12	A standard set of traces for describing all kinds of scheduling (as well as other kernel relevant) events and a format to serialize them would also be of great help	<a href="#">UCAN</a>

## 5. Exploitation and sustainability

The last year of the project has been focused on what will happen with MegaM@Rt2 once the project ends and how to properly allocate it in the current market context. An IPR analysis was already included in D6.4 and, as no more new tools have been developed, it is not necessary to include it here again.

A business model for the framework has been developed. It is important to highlight here that the result of MegaM@Rt2 is a set of tools that can be integrated, or not, based on the use case where they are applied to.

### 5.1. Market Positioning

Global software market growth at a CAGR of 11.6% from 2014 to 2018, reaching USD 484.2 billion. While the most lucrative segment was the IT management one which represents a 31% of the markets' overall value, with a total revenue of USD 150.3 billion [1]. At the same time, business software was valued at USD 322.91 billion in 2018 and it is expected to grow at a CAGR of 10.7% until 2025 due to the rise of automation [2]. However, both markets present the same constraint: the high costs of licensing that sometimes can be even more increased by support and maintenance costs.

*In this sense, MegaM@Rt2 offers a set of tools, most of them open source, that can be offered at a lower price than those commercial ones already existent in the market. Furthermore, the complementarity of the tools available in the catalog allows potential customers to build their own toolset on demand at reasonable prices.*

Project Results	Type	IP Owners and percentages of Ownership	Licence
AIPHS	Software	UAQ	Apache 2.0
CertifyIt	Software	SMARTESTING	Commercial
CHESS	Software	INTECS	EPL 2.0
DBCAE	Software	VTT	Commercial
Collaboro	Software	UOC	EPL 2.0
CompleteTest	Software	MDH	Commercial, free for academia non-profit applications
Convex Hull	Software	VTT	Commercial
EMF Views	Software	IMT	Dual (EPL 2.0, GPLv3)
EMFtoCSP	Software	UOC	EPL 2.0
Hepsycode	Software	UAQ	GPLv2
JTL	Software	UAQ	EPL 2.0
Lime Testbench	Software	SSF	GPL
MATERA2	Software	ABO	Commercial, free for academia non-profit applications
MBeeTle	Software	SMARTESTING	Commercial
Modelio	Software	SOFTTEAM	Dual (GPL, Apache 2.0)
Modelio Constellation	Software	SOFTTEAM	Commercial
Moka Extensions	Software	ATOS	EPL 2.0

Project Results	Type	IP Owners and percentages of Ownership	Licence
NeoEMF	Software	UOC	EPL 2.0
PADRE	Software	UAQ	EPL 2.0
Papyrus Extensions	Software	ATOS	EPL 2.0
PauWare engine	Software	UNIPAU	LGPLv3
RCRS	Software	SSF	MIT
S3D	Software	UNICAN	Free for academia non-profit applications
VeriATL	Software	IMT	EPL 2.0
Xamber	Software	FENTISS	Commercial
XPM	Software	FENTISS	Commercial

This is need for automation is also pushing the global software engineering market that is expected to grow at a CAGR of 11.72% by 2022, reaching USD 37.4 billion by the same time [3].

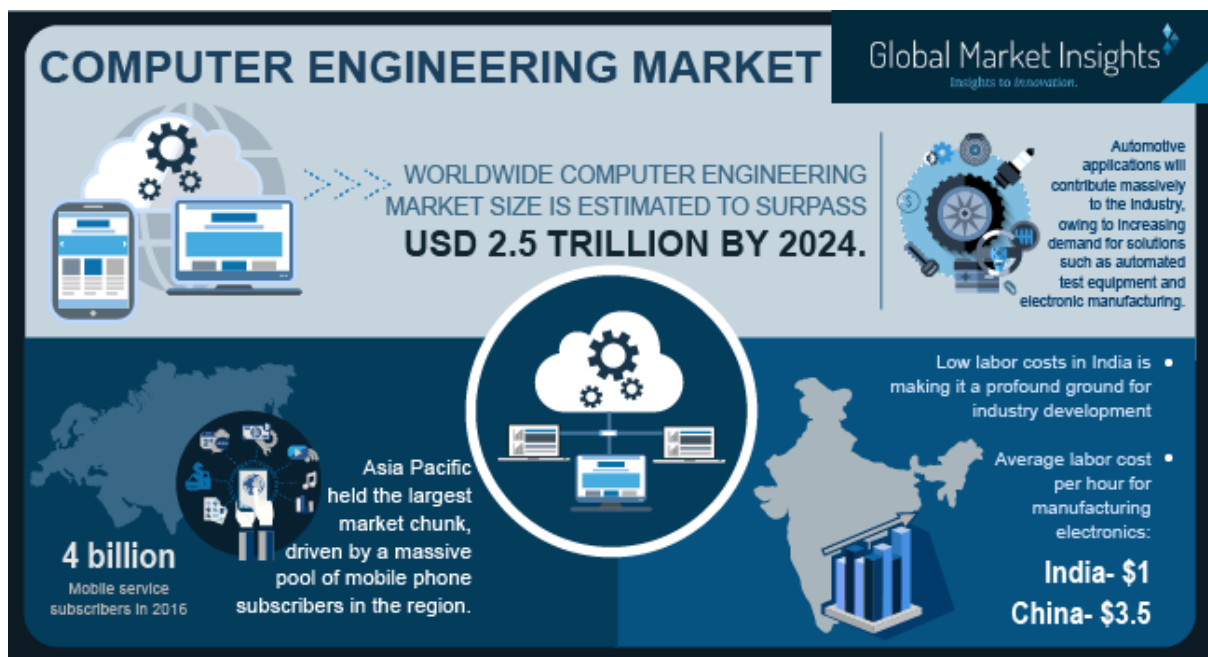


Figure 2 Computer Engineering Market [4]

Other reports predict a slightly bigger growth at a CAGR of 15% from 2019 to 2025 due to the increasing demand in different verticals such as IT, automotive or manufacturing [5].

This market is highly fragmented, as there are many players providing tailored solutions for solving specific issues. In this sense, players are adopting different strategies of collaboration in order to be able to offer more complete solutions while each organization focus on a very defined area. Talking only about commercial products, including open source ones that can be also licensed but not research ones, the overall software products market is growing at a CAGR of 9% and will reach USD 742.12 billion by 2022 [6].

*MegaM@Rt2 due to its collaborative nature is per se more well prepared to establish liaisons, with external or external participants, to build customizable solutions that can satisfy customer needs.*

Software engineering market growth is fueling, at the same time, the global embedded market valued at USD 140.32 billion in 2013. The market is growing at a CAGR of 6.3% and will reach USD 214.39 billion by 2020 [7].

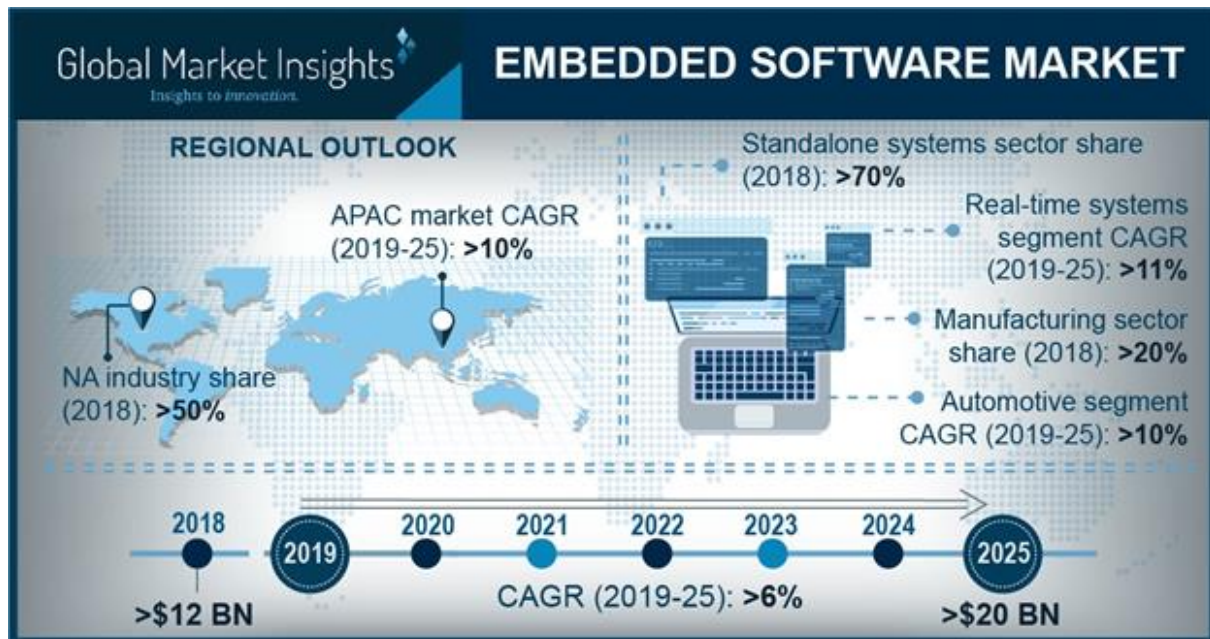
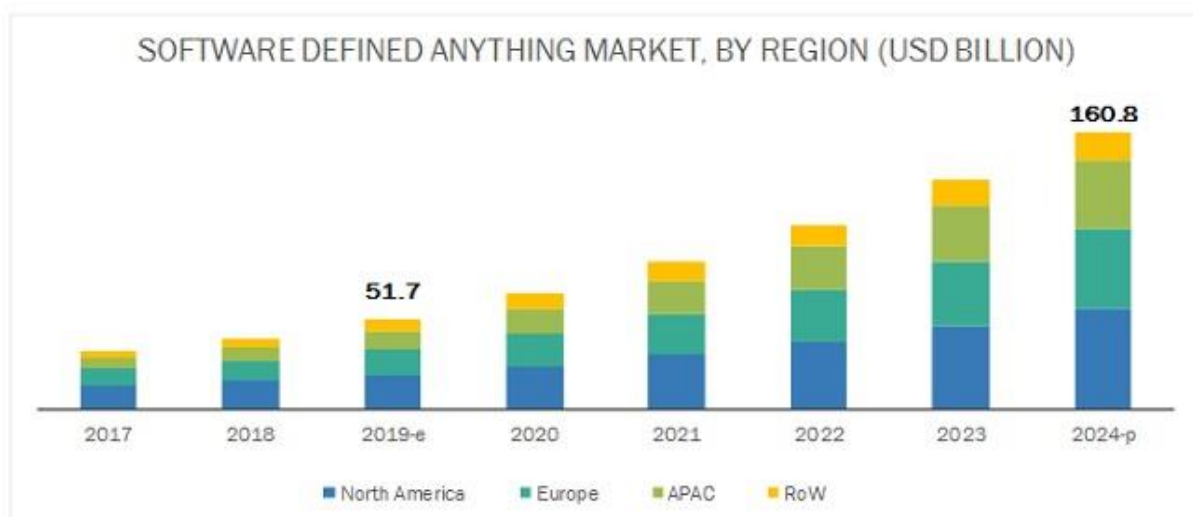


Figure 3 Embedded Software Market [8]

Automotive application is the highest segment, representing a 20.8% of the total, and it is expected to continue growing in the coming years.

Three of the MegaM@Rt2 use cases focus on the automotive and transportation sector, going from a Flight Management System, to the Train Control and Management System, including an engine control subsystem. These cover a wide range of applications that can be used to highlight the benefits that the project can bring to this industry.

Finally, the Software-Defined Anything (SDx) market is expected to grow from USD 51.7 billion to USD 160.8 billion by 2024 at a CAGR pf 25.5% [9].



Source: MarketsandMarkets Analysis

Figure 4 SDx market by region [9]

MegaM@Rt2 offering can be a complementary option to SDx technologies to support organizations to lower costs while increasing quality.

## 5.2. MegaM@Rt2 Business model

The proposed business model for MegaM@Rt2 is a combination of different ones based on a combination of its open source approach and the commercial tools available in its catalogue. MegaM@Rt2 tools are completely independent of the application domain and can be used to enrich other offerings in different areas such as cloud computing or HPC.

Key Partners	Key Activities	Value Proposition	Customers Relationships	Customer Segments
<p><b>Consortium:</b> who has the knowledge for developing MegaM@Rt2.</p> <p><b>Standardization bodies:</b> that provides a set of recommendations to be followed for maximising industrial uptake.</p> <p><b>Software and hardware providers:</b> who provide the mechanisms to run MegaM@Rt2</p> <p><b>Investors:</b> as investment capital is needed to evolve the solution.</p>	<p>Dissemination for attracting and engaging stakeholders and foster results adoption, business planning for developing the appropriate go-to-market strategy, IPR management for ensuring the sustainability of project results, validation against stakeholders to ensure that MegaM@Rt2 is close to market needs</p>	<p>MegaM@Rt2 provides a set of tools, that can be easily integrated, to reach time and cost savings in the design of complex systems, without losing performance and correctness on outcomes</p>	<p>Building up the MegaM@Rt2 community: stakeholders' engagement through consortium networks</p>	<p><b>Software providers:</b> who will be able to reduce cost and time investments in software development</p> <p><b>Developers:</b> who will be able to easily download and install tools to support their daily activity</p> <p><b>Researchers:</b> who will have access to latest trends on software engineering</p> <p><b>Software engineering communities:</b> who will benefit of publicly available results</p> <p><b>General public:</b> who will indirectly benefit of the implementation</p>
	<p><b>Key Resources</b></p> <p>Infrastructure for maintaining the MegaM@Rt2 toolset catalog</p> <p>Know-how for developing workflows</p> <p>MegaM@Rt2 catalog</p>		<p><b>Channels</b></p> <p>Consultancy</p> <p>Networks</p> <p>Social media</p> <p>Commercial procurement</p>	
<b>Cost Structure</b>		<b>Revenue Streams</b>		
Marketing and promotional costs Maintenance		Audit fees		



Personnel PoC development	Consultancy and added value services (integration, new developments, etc.) License fee Direct sales
------------------------------	--

### Key Partners

In order to provide a business model that can be further adapted to different business cases, it is important to identify all needed stakeholders to launch MegaM@Rt2. One of the main key players here, apart from the MegaM@Rt2 providers, is the investor role. Being a research project, some of the tools still have a low TRL for directly going to market. Thus, further investment is needed to develop a market-ready product. This investor(s) can be internal to the organization providing the tool, or external participating in i.e. other research and innovation projects.

### Key Activities

Key activities foreseen for the future are the same as the ones developed within the project duration: IPR management, dissemination (or more specialized marketing campaigns) and, more specifically, stakeholders' engagement. Once the project is finished is not only a matter of scientific dissemination, that it is also appropriate, but to try to reach others who may be interested on achieving tools for their own businesses.

### Key Resources

The consortium compromise to keep results available and acknowledge MegaM@Rt2 whenever and wherever it fits. This is important to highlight how MegaM@Rt2 was the origin of any business opportunity derived from it.

### Value Proposition

MegaM@Rt2 value proposition is the introductory card of the project results to external stakeholders. Thus, supporting the idea of acknowledging MegaM@Rt2 in further opportunities.

### Customer Relationships

During the project the work has been focused on letting external stakeholders know about the MegaM@Rt2 tools and attract them to the different updates. Once the project ends, the focus is on disseminate the possibilities that MegaM@Rt2 offers and show the use cases as 'success stories' and the benefits the project has brought to them.

### Channels

The consortium will continue using media channels while increasing the activity in their own networks to disseminate results to a wider audience and, in some cases, more commercially oriented.

### Customer Segments

Several customers must be taken into account, from researchers or students that may request access to the source code of those tools under an open source licensing schemes, to industry or public administration who may request their own toolset under a commercial procurement.

### Cost Structure

MegaM@Rt2 must do a small investment to keep the current activities alive. In this sense, public repositories such as GitHub for the source code or ResearchGate and Zenodo to minimize costs. Some partners will also request external investments through other research projects, while others prefer to use internal resources.

### Revenue Streams

It is important to understand the differences on the revenue streams based on the different customers addressed any time: licenses can be offered to customers based on an integrated set of tools; while added value services will be offered to those betting only for open source tools. Consultancy and audit fees will be charged to all customers in order to clearly identify their requirements and needs.

### 5.3. Individual exploitation plans

In order to understand the benefits brought by MegaM@Rt2 to each partner, and update of exploitation plans presented in D6.4 is listed below. Each plan presents a clear overview of the tools involved, their TRL, actions already undertaken and plans for the future.

#### 5.3.1. MDH

MegaM@Rt2 results have been exploited in different dimensions, covering both research and education. New research collaborations have been established with a number of consortium partners, resulting in joint publications. Examples of collaborators are Åbo Akademi University, Finland and Softeam, France. MDH has further strengthened its collaboration with local industrial partners (Bombardier Transportation and Volvo CE) through joint case studies based on their use cases, resulting in KPI evaluations and joint publications. We also have exploited our participation in MegaM@Rt2 for sustainability of our research collaboration, through participating in a project funding application for 2020 call of ECSEL projects, where many of MegaM@Rt2 partners participate. Lastly on the research front, exploitation of tools provided by tool providers in the consortium have led to competency development in the MDH team regarding new tools, such as MBeeTle from Smartesting. On the education front, MDH has exploited its tools (CompleteTest, SeaFox) in courses such as in automated test generation and model-based testing.

#### 5.3.2. SOFT

SOFT has made significant updates to its core tools Modelio and Constellation (TRL9) with regards to the system architecture modelling, document generation and management of the models. Moreover, SOFT has created two new tools that are Modelio DDS Designer and Modelio Variability Designer (TRL 5). The Modelio DDS Designer helps to integrate Data Distribution System modelling to the design in UML and generate specific gluing code. The Modelio Variability Designer allows to model product lines with system architecture models. All tools were validated in the MegaM@Rt2 case studies and hackathons - in particular, IKER and VCE.

SOFT distributes most of its tools under dual licensing: open source Apache v2 and commercial. This allows us to provide best possible services to both paying customers and the community of specialists. As for the time-to-market, SOFT has received Requests for Proposals in the area of product line engineering, that boosted the development of commercial offers on top of the MegaM@Rt2 results. The expected commercialization period is 1 year.

#### 5.3.3. THALES

THALES worked together with University of Cantabria and Fentiss in order to develop solutions allowing to help the architect in the process of performance verification and validation of the Flight Management System (FMS).

THALES has already started the exploitation of the developed solutions by transferring them to the Flight Management System Team in THALES AVIONICS. A transfer roadmap was already established in 2018. Its objective is to move from the current ad-hoc process using Excel sheets for the timing performance verification to a fully automated model-based approach. Today, the FMS is able to automatically generate a performance model of the complete FMS in the Time4Sys (as done in MegaM@Rt2). The next step is to implement the connection from Time4Sys to a timing verification tool in order to validate the timing properties in the model.

The solutions developed in MegaM@Rt2 have several benefits and allow to develop reliable timing critical systems much faster and with much less effort. They also allow a fine-grained modelling of the system architecture compared to the current used approach, which reduces the gap between the virtual system (design model) and the implemented system. The implemented solutions for performance prediction could be also easily mastered by the whole performance engineering team (usually, the ad-hoc solutions are only mastered by one or two engineers in the team).

### 5.3.4. SMARTESTING

Smartesting within MegaM@Rt2 introduced new features, two exploitable assets extensions of CertifyIt, to model for verification and validation at runtime (TRL7) and MBeetle for runtime testing (TRL 7), that together compose a model-based solution for testing embedded systems at runtime.

The project assets are compositing the Certify solution for embedded systems testing and will impact to increase the market penetration for embedded systems, in particular, CPS domains from MegaM@Rt2 and open perspectives for a new market positioning in the IT. As an achievement for the last year of the project, Smartesting has sold 1 license at the French DoD, at Q3 2019.

In terms of exploitation of MegaM@Rt2 assets, Smartesting is interested in the following:

- **New market segment penetration**

The MegaM@Rt2 results will allow the products to expand to other application domains. Smartesting is very interested in extending its reach to domains with critical systems, as they require thorough testing and ensuring conformance to standards and regulations. Its targeted clients for the new solution on Model-Based Runtime Testing are from two domains: Cyber-Physical systems (ALSTOM Transportation, Thales Air Operation, French DoD) and IT (Dassault Systems).

- **Product innovation for IT**

The project asset on runtime testing has shown its benefits within the project experiments and Smartesting is keen to integrate its asset in its novel product for visual test conception in the IT domain, Yest, that will increase further the market penetration in IT. This would be the very first product that will be presented by Smartesting in the IT market for runtime testing bringing the value in a DevOps context.

- **Functionality enhancement**

The results from MegaM@Rt2 have given direction for further evolution of the Smartesting CertifyIt tool suite for test case generation and model inference based on log analysis to improve regression testing for embedded systems.

Smartesting will develop a two steps strategy for market access depending on the players it addresses.

We will combine a direct approach with (i) end users, product developers, with direct sell for the tool suite use including support in testing for their solutions, existing or under deployment and (ii) a parallel strategy with direct sell of the solution for test service providers, as a new tool suite for runtime testing that they will run on their own customers. All offers will be built on a minimum service offer including training and a support contract. For any custom-made development or specific needs in tools, for log analysis, or support, Smartesting will develop extra services to generate revenues, updating the tool suite in the meantime.

### 5.3.5. CSY

Using MegaM@Rt2 gives CLEARSY the possibility to treat and analyse large quantities of logs that were unused before. Through new tools developed during MegaM@Rt2 and in collaboration with partners, we were able to improve the analysis of logs from current implementations of COPPILOT (currently in service) and detect potential dysfunction on those products. The gain in analysing logs is estimated to 28 % (from 70 to 50 hours in the analysis of a set of logs). This reduces the maintenance costs for those projects where the after sales service has a fixed cost.

We also developed a new method of test based on automatic analysis; this new method helped reduce the development time to 21% (from 280 to 220 hours) with a large reduction of the testing phase time. This will reduce the development time for the next implementation of COPPILOT and will potentially be re-used on different projects.

### 5.3.6. ARM

The work performed during MegaM@Rt2 and the obtained results have been, are currently being and are planned to be exploited in the following ways:

- Consolidate and strengthen our international research collaborations with various consortium partners, such as UOC or UAQ. For example, this particular collaboration notably resulted in 9 scientific papers published in high-level international venues (journals, conferences), the creation and running of a new workshop series (MDE@DeRun), the writing and defense of a related PhD thesis. We plan to continue this research effort in the same line, notably related to our ongoing collaborations around the EMF Views and NeoEMF tools as well as their combined applications to solve different research and industrial challenges (cf. the items hereafter). For instance, we currently study the possibility of writing a paper on this for a MODELS 2020 workshop or another Modeling/MDE conference in the coming months.
- Design, develop and largely extend the capabilities of our open source model-based tools EMF Views (ARM/IMTA), NeoEMF (ARM/IMTA in collaboration with UOC), and also VeriATL (ARM/IMTA) to a lesser extent, in addition to promote further these approaches and Eclipse-based technologies both inside and outside the MegaM@Rt2 consortium. As said before, we will continue extending these tools by providing new features addressing particular research and industrial challenges. For example, we already plan to extend EMF Views with more advanced model view inference and update capabilities (e.g., by relying on Machine Learning techniques).
- Develop complementary research collaborations with national industrial partners, such as SOFT and CSY. In addition to the scientific papers mentioned before, this notably resulted in our active participation in 9 project communications (journal and conference papers, workshop presentations). Again, we plan to push further these industrial collaborations in order to get more concrete scenarios for applying our research approaches and related tools. To realize this in practice, we are already working on a common ECSEL project proposal that could be the perfect host for such a collaborative Research & Development effort.
- Work on new funding/grant applications both at the European level (as a core member of the recently submitted AIDOaRT ECSEL proposal, notably to research on the combination of our advanced model-based techniques with state-of-the-art Machine Learning technologies) and at the French national level (as a core member of the SeMaFoR ANR proposal to be submitted very soon, to apply and extend our model-based techniques in a Fog Computing context).

### 5.3.7. UPAU

UPAU tools focus on model execution. Before the MegaM@Rt2 project, UPAU has developed PauWare which is a Java API for programming UML state machines and an execution engine to execute them associated with business operations.

During the project, three tools have been developed:

- An extension of PauWare for adding runtime verification and trace generation features of PauWare programs (TRL 3-4).
- A code generator from UML models designed with UML modelers (such as Modelio from Softeam) to the PauWare API (TRL 3-4). It is provided as a Web application without requiring any installation.
- XModeling Studio which aims to design executable DSL and help in developing its execution engine (TRL 3). It is provided as an Eclipse/EMF plugin.

These tools are available as open source software (LGPL license for PauWare).

The exploitation plan of UPAU will be mainly scientific and academic:

- Publication of scientific papers validating the features of the developed tools
- Use of the tools in software engineering and model-driven engineering courses at the university of Pau (master and undergraduate degrees)
- Work on collaboration and future projects with partners of the project or other ones, at national or European level

### 5.3.8. ATOS

ATOS developed two tools within MegaM@Rt2 project: Papyrus and Moka extensions, for UML simulations and Aspect Oriented Modeling. Both tools, included in the MegaM@Rt2 catalog and the IDE release, are licensed under EPL 2.0 and reach TRL 6.

However, the company does not have a large percentage of projects in the embedded domain as most of the software produced is mainly for users' applications and services, and MDE techniques are not widely adopted in this context. However, based on the experience gained within the project developing use case, ATOS foresees potential on these tools by taking advantage of runtime metrics to feed and re-design code in the most automatic manner, improving productivity and reducing development and maintenance costs.

For this reason, ATOS took an incremental approach summarized as follows:

1. Identify those domains where Papyrus and Moka can bring an added value to the current developments, satisfying DevOps needs. In this sense, two main domains were identified: Cloud and HPC. Where the tools can help improve development phases.
2. Establish contacts with the appropriate stakeholders to transfer tools to improve their daily businesses. An internal meeting has been held with the representatives of Internet of Everything Lab and HPC Lab and the Software Engineering Lab within the company in order to show them the work performed in MegaM@Rt2 and how it can be applied by their development teams. The team has also participated in a meeting with the University of Cantabria to find common points for future collaborations in order to promote MegaM@Rt2 joint results.
3. Execute liaisons for technology transfer. As a result of the previous step, after the internal meeting the technical team participating in MegaM@Rt2 is participating in a new project, SODALITE, with the Software Engineering Research Line and the HPC and Cloud Labs. Within this project, new modeling techniques for DSL (Xtext, Sirius) are being used to design the application deployment on Cloud/HPC hybrid infrastructures. These modeling techniques will be further extended to be applied on the Edge, which makes possible to integrate them with MegaM@Rt2 results to enhance the current ATOS proposition. These results are planned to be integrated, once the new project finishes, to develop a proper offering to be presented to other companies of the Group.

### 5.3.9. UC

The main result from the participation of the University of Cantabria in the MegaM@Rt2 project is S3D, the Single-Source, System Modeling and design Framework (s3d.unican.es). The framework had already TRL6 as it was experimented on several industrial demonstrators in previous projects such as the FP7 Contrex project and the ECSEL EM2. The main improvements to the S3D previous background are the following:

- New Mega-Modeling techniques improving flexibility, reusability and scalability,
- New timing constraint modeling and automatic generation of simulation traces based on them,
- New trace analysis techniques able to verify the timing constraints,
- Run-Time back annotation methods.

All these improvements have been assessed on the UC1 from TRT so that they have TRL6.

MegaM@Rt2 results will be exploited by the University of Cantabria in two main ways:

#### Technology Transfer

- The S3D modeling and design framework will open new technology transfer opportunities to industry,
- In this sense, a FTI proposal is being prepared with TRT and INTECS,
- The S3D framework opens new research opportunities. In fact, the MegaMart2 results will be the background technology to be further improved in the ECSEL Comp4Droines project,

#### Academics

The MegaM@Rt2 results will certainly improve the contents of the System Design courses in the Telecom Engineering Master and the Informatics Engineering Degree.

### 5.3.10. UOC

The work performed during MegaM@Rt2 and the obtained results have been / are being exploited in the following ways:

- Consolidate and strengthen our international research collaborations with various consortium partners, such as UOC, ARM/IMTA or Ikerlan. This notably resulted in 18 scientific papers published in high-level international venues (6 journals, 12 conferences), and the creation and running of a new workshop series (MDE@DeRun) and their corresponding proceedings (two series).
- Design, develop and largely extend the capabilities of our open source (EPL v2.0) model-based tools Collaboro, EMFtoCSP, and NeoEMF (in collaboration with ARM/IMTA), and the initial prototype of the AsyncAPI toolkit (used in Ikerlan's case study).
- In addition to the scientific papers mentioned before, UOC actively participated in 7 project communications (journal and conference papers, workshop presentations) aiming at strengthening collaboration with other project partners.
- Build-up on all these items in order to work on new funding/grant applications specially at the European level as a core member of the recently submitted AIDOaRT ECSEL proposal.
- Finally, the exploitation plans in the short term also focuses on new publications and dissemination of results. Together with Ikerlan, and related to its case study where the AsyncAPI toolkit is being exploited, we aim to: (i) present a publication in the session "Practice and Innovation Track" in the upcoming MODELS conference (18-23 October 2020 Montreal, Canada); and (ii) send a research article to the Model-Driven Engineering for the Internet of Things (MDE4IoT) special issue of the International Journal on Software and Systems Modeling (SoSym) (2021).

### 5.3.11. IKER

As a result of the end of the project, the exploitation plans that we foresee in the short- and medium-term focus on three areas:

- Publication and external dissemination of results

Together with the UOC and related to the practical use of the AsyncAPI device toolkit

- Presentation of a publication in the session "Practice and Innovation Track" in Models. 18-23 October 2020 Montreal, Canada
- Presentation of a publication to the Model-Driven Engineering for the Internet of Things (MDE4IoT) in International Journal on Software and Systems Modeling (SoSym). 2021

- Internal Dissemination

During 2020 Ikerlan has begun an internal process of reviewing its project development methodology. As a result of the experience in Megam@Rt2, it is planned to promote the use of automatic test generation tools in the validation phase for those projects that adapted well to them. (Many functional requirements, long life cycle)

- Service to our customers

Ikerlan can offer now a faster time to market in its DDS and IoT solutions. Through our usual channels (presentations, webinars, newsletters) we will communicate the results to our clients.

### 5.3.12. FENTISS

The work developed in the MegaM@Rt2 project has allowed FENTISS to understand the tradeoffs of model-based development and to adapt their timing analysis tools to time modelling tools produced by others. The effort has enabled the automatic generation of scheduling plans for a safety critical application as is the case of a Flight Management System developed by Thales Research thus contributing to optimize the development time of these complex systems. The project results are substantiated in XPM, a tool which is able to import and export Xtratum configurations to/from Time4Sys the open source time modelling tools developed by Thales. The Xamber fentISS scheduling generation tool which produces feasible schedules for mixed-criticality applications developed with XtratuM, can also interface with Time4Sys to allow time simulation with the generated schedules.

The innovation of fentISS within the project can be described as follows.

- Enabling the use of scheduling analysis tools with model-based development for embedded safety-critical systems.

- Integrating fentISS solution for Time and Space Partitioning with model-based development thus enabling the use of fentISS products in other markets in which MBD is widely used. This is the case of the aeronautics market and also of the automotive industry. The much larger size of these markets will enable fentISS to grow their customer base much faster than in the current space market.

fentISS follows a “Customer Development” approach to introduce innovation in the market. The first stage, customer discovery, has started to be implemented during the project. The next step for fentISS will be to test the project results with early adopters in the space domain. This will include current customers such as CNES, Airbus Defence and Space (France) and Thales Alenia Space (Italy) but also new potential customers as Sener Aerospace (Spain) who have been already contacted for their interest in model-based development. The objective of this early stage will be to validate the interest of the customers for the products developed in the project. The creation of a wider customer base will start in the space market but if it is successful, we intend to extend it to other adjacent markets like aeronautics and automotive. This will require additional investment and company growth with new sales and marketing resources specific for those markets. The strategy is in line with other company efforts related to the certification of fentISS products for aviation and the exploration of the automotive domain which will take place in other innovation projects starting in the forthcoming months.

### 5.3.13. TEKNE

TEK experimented MegaM@Rt2 model-based tools by developing its use case and so validated the gain that derives from them, specifically for the aspects it was more interested in:

- improvement of early identification of design problems thanks to design-time models verification;
- reduction of testing work time thanks to model-based run-time verification;
- reduction of development work time and improvement of code quality and maintainability thanks to model-based automatic code generation.

TEK will exploits MergaM@Rt2 results adopting model-based system engineering in its industrial process for the new system it is developing:

- wireless communication security;
- electric vehicle for professional applications (the software subsystem).

To this end, during the project TEK organized two courses, held by UAQ, for its technicians not involved in the MegaM@Rt2 project.

### 5.3.14. UAQ

The work performed during MegaM@Rt2 and the obtained results have been / are being exploited in the following ways:

- Consolidate and strengthen our international research collaborations with various consortium partners, such as UOC and ARM. This notably resulted in 13 scientific papers published in high-level international venues (journals, conferences), the creation and running of a new workshop series (MDE@DeRun)
- Design, develop and largely extend the capabilities of our open source model-based tools JTL, PADRE, AIPHS, and HEPSYCODE to promote further these approaches and Eclipse-based technologies both inside and outside the MegaM@Rt2 consortium.
- Develop complementary research collaborations with national industrial partners, such as RO and TEKNE. In addition to the scientific papers mentioned before, this notably resulted in further 14 publications (journal and conference papers, workshop presentations).
- Build-up on all these items in order to work on new funding/grant applications both at the European level (as scientific coordinator of the recently submitted AIDOaRT ECSEL proposal, to research on the combination of our techniques with Machine Learning technologies).

### 5.3.15. INTECS

INT will exploit the MegaM@Rt2 project results and the acquired knowledge for increasing its technical lead and competitive edge in its core domains, and for opening up domains where MegaM@Rt2

technologies are essential for the development of trusted and reliable systems. Intecs will therefore expand and integrate its development and consultancy portfolio in relation with best practices and standards improved within MegaM@Rt2.

Intecs has delivered the CHESSE toolset, in origin, under Eclipse Polarsys project, the open source industry collaboration to focus on tools for safety critical and embedded system design and development. Now, it is available as Eclipse incubation project (<https://projects.eclipse.org/projects/polarsys.chess>), and the major release of CHESSE 1.0.0 is under Review.

The extensions developed for CHESSE in MegaM@Rt2 integral part of CHESSE 1.0.0 Release. The open source distribution of the MegaM@Rt2 products, specifically addressing markets of interest for Intecs, is expected to increase the company visibility, competitiveness and the returns in terms of support, training, consultancy and customization services.

With respect to the MegaM@Rt2 project, the following exploitation activities will be carried out by INT:

- Encourage INTECS internal divisions to use the project technologies;
- Evaluate the ability of the project technologies to support additional applications and configurations beyond those addressed within the project
- Commercialize the pre-competitive technologies developed within the project for use in delivering commercial development services
- Provide supporting services to assist organizations to use the project technologies for the development of new solutions in Industrial environments

A jointly commercial initiative between INT, UC and TRT is in progress, based on the evidences of the TRT Case Study results, exploring the opportunity of a tighter integration between INT CHESSE tool and UC S3D, VIPPE and ESSYN tools, currently presented as "MOODS" proposal under Fast Track Innovation calls.

In addition, INT is planning further exploitation of MegaM@Rt2 results in other research projects under submission (i.e. AIDOaRT and VINDICATOR).

#### **5.3.16. RO**

ROTECH experimented with MegaM@Rt2 general purpose command-line tool for runtime monitoring of timing and State Machine status, which uses software level acquisition of hardware timing of State Machine information and real time embedded systems. Using this tool is possible to:

- reduction of collected data needed for testing work time of about 15% thanks to model-based run-time verification.

Moreover, high scalability of the solution improves quality and maintainability.

ROTECH will exploit MergaM@Rt2 results adopting CMA Tool in its industrial process for the new system it is developing:

- Telecommunication solutions;
- Microcontroller product chain systems.

#### **5.3.17. ABO**

During the project our MATERA2 tool set for model-based validation and testing has been enriched with new features. Some features have been added to existing components and some have been incorporated into new tools, as follows.

- MATERA2-MBMÅÅ - model based monitoring using UPPAAL TA has been improved with better scalability and stability of the execution



- MATERA2-MBPeT - Model-based load generator scalability and user interface improved
- MATERA2-iPerfXRL - A new tool for exploratory performance testing of systems with multidimensional-input spaces that uses reinforcement learning to detect performance bottlenecks.
- MATERA2-AIfTester: A new tool for test generation from fUML activity diagrams using Papyrus tool and Moka engine.
- MATERA2-ADCT: An Eclipse plugin for online conformance testing with timed fUML Activity diagrams using the Papyrus tool and Moka simulation engine.

The tools are on TRL 4-5. They are stable academic prototypes which can be taken in use by industrial partners. The MATERA2 tool set is distributed under a commercial licence, but free to use for academic and non-profit applications.

The development of the above tools allowed ABO to increase its research portfolio and also establish a competence center in the area. We plan to use the developed set of tools and the supporting technologies to conduct further research and experiments on the topic, which will result in new publications in high ranked venues. Also, we plan to disseminate them to our local and European partners via future research projects. We also plan to use the MATERA2 tool set in the ECSEL project that we applied for namely VINDICATOR and AidoRT, the first one focusing on hardware virtualization for software testing and the second on deploying artificial intelligence methods of DevOps. In addition, most of the MATERA 2 tools will be used in the newly funded H2020 project, VeriDevOps, on addressing cybersecurity challenges at different levels of the DevOps.

Last but not least, we plan to integrate the tools in our master level and doctoral courses for disseminating the results of the project to our students

### 5.3.18. SSF

During the project SSF (currently Huld) has extended existing tools (Lime testbench and RCRS toolset) and also developed a new tool and methodology for selection of relevant tests in a continuous integration environment. We have also built simulation tools for Aina (currently Telia) to support testing of their GSM gateway. The improvements and the new features are outlined below:

1. LIME testbench is a tool for monitoring dynamic properties of Java programs as well as for generating tests that cover all execution paths. The monitoring component checks if the program exhibits a certain dynamic property, specified by linear temporal logic or regular expression. Within the project we extended this tool for C++ programs in addition to Java.
2. RCRS (Refinement Calculus of Reactive Systems) is a compositional reasoning framework consisting of a modeling language for non-deterministic and non-input-receptive reactive systems and a formal semantics implemented in the Isabelle theorem prover. RCRS Toolset comes with a translator of Simulink models into RCRS language, allowing for analyzing different properties like compatibility of compositions. In the project we used RCRS in one of the case studies proposed by Bombardier. We extended RCRS to model PLC (programmable logic controllers) systems.
3. For Aina we developed simulators to allow them to test their GSM gateway.
4. Within the project we have also developed a testing methodology using machine learning to select relevant tests to detect possible issues with project changes in a continuous integration setting. We successfully applied the technique to a project in our company.

The tools LIME and RCRS are TRL 4 – 5. The testing methodology is TRL 3, while the GSM simulators are TRL 5-6, and can be readily used in similar applications. The LIME testbench is distributed under GPL, while RCRS toolset is distributed under MIT license.

Within the project, SSF could experiment with different testing methodologies by building tools and by applying some of the techniques to our own software development, and to case studies provided by the partners. We have employed a master student that has written the master thesis within the project. We have also produced four scientific publications (2 conferences, 1 workshop, 1 journal).

**5.3.19. NOKIA**

Nokia has ongoing activities included in the SoC roadmap to utilize MegaM@Rt2 methodology results and lessons learned in Modeling and Analytics for Model Based System Engineering in general; and in Model Based System Design specifically for SoC.

MM2 results are evident in Nokia's SW Shift-Left approach, which is to be further improved in massive MIMO (mMIMO) and OTAVA (Over The Air Validation Area, <https://www.youtube.com/watch?v=0vyqaDelsRk>) projects. These projects are proposed as Nokia use case for Vindicator.

**5.3.20. VTT**

In MegaM@Rt2, VTT developed methods and technologies related to machine learning, this includes new smart technologies, profitable solutions and innovation services. This included the telecommunications sector for anomaly detection and root cause analysis.

The areas of potential exploitation of the results of MegaM@Rt2 are broad, including sport analytics, the energy sector, home security, and automation. Machine-learning technologies which include basic functionalities, such as anomaly detection and root cause analysis, are in high demand in sectors where electronically readable time-series data is utilized.

The developed machine-learning technologies will be exploited indirectly in future customer projects (as the competences of researchers) and directly in future research projects (further development of prototypes.)

VTT published/will publish the results of the developed research in conferences and journals. The impact and quality of these outlets will serve as the KPIs to indicate the degree of research achieved in MegaM@Rt2 by VTT.

**5.3.21. BOMBARDIER**

There is an on-going effort to adopt model-driven development practices within Bombardier Transportation. MegaM@Rt2 results have contributed towards:

- Building in-house knowledge into tools for model-driven development and testing, through a selection of consortium tool providers as well as through development of new tool prototypes in cooperation with Mälardalen University.
- Showing improvement in identified requirements bugs, requirements review time, requirements reuse and fault detection.
- Enabling results to be taken across departments within Bombardier Transportation (from TCMS to Propulsion division).

Bombardier has exploited several tools from the MegaM@Rt2 framework (e.g., Mbeetle from Smartesting, Modelio from Softeam, CompleteTest from MDH). In addition, Bombardier has contributed to exploitation of several newly developed tools (e.g., SAGA, NATLABS, VARA, SEAFOX) and the open sourcing of these tools. We have exploited these tools by integrating them in our requirement and test automation platforms and other departments inside Bombardier are using and will be using these tools during development after MegaM@Rt2.

**5.3.22. VOLVO**

Volvo CE has ongoing activities towards the adoption of model-based systems engineering for the development of heavy machinery. The focus in MegaM@Rt2 was on managing and modelling variants in the model-based systems engineering paradigm. Mega@Rt2 contributed towards:

- Building knowledge on methodologies and tools for model-based systems engineering and product line engineering
- Enabling the management of diesel engine system variants with models
- Increasing quality of products by enabling early detection of design issues
- Internal initiative to evaluate product line engineering not only the engine but on the complete machine

During MegaM@Rt2, Volvo has been mainly using the tool Modelio from Softeam. Currently, an internal team of modeling experts are looking into the results of MegaM@Rt2 in order to assess how the modeling methodology developed during MegaM@Rt2 as well as the tools can be applied on a larger scale.

### 5.3.23. CAMEA

We will exploit the outcomes of the project (targeting runtime profiling and optimization) during development of our traffic monitoring systems and sensor devices based on hybrid platforms (such as Xilinx Zynq). It will help us with mapping of individual tasks to target hardware and allows subsequent optimization. Both needed a lot of manpower before which has been significantly reduced.

### 5.3.24. BUT

BUT's exploitable results of the MegaM@Rt2 project are primarily the knowledge and technologies related to developed methods and processes relevant to model-based hardware-software co-design of embedded intelligence for vision-based intelligent transport solution (especially to those linked to the Camea's use-case and demonstrator in the project). The key direction of the exploitation path will be represented by the technology transfer towards new commercial projects that cooperating companies give to the Faculty of Information Technology, BUT. Recent projects that are directly linked to our experience and knowledge from the project are paid by Honeywell and NXP – two business partners involved in the mentioned cooperation.

New research and development opportunities brought by the experience from MegaM@Rt2 are also visible in new research and development projects awarded by the end of the funding period of MegaM@Rt2, as well as new proposals prepared on related topics. BUT has been granted by the ECSEL project Comp4Drones and Czech-Korean project VIBES. We also participate in the proposal AIDOaRT that is directly linked to the topics of MegaM@Rt2. Another relevant proposal prepared by our team is linked to 5G networks and advanced robotics.

Last but not least BUT will exploit project results in its academic activities in extending the content of the current courses and in new student projects, assignments, and other activities. In particular, the topics explored by our team will appear in specialized lectures of the IVS course - Practical aspects of the software development, which is attended by a large number of students in our Bachelor degree, as well as in specific projects in embedded intelligence for our new engineering (Master) study programme Information Technology and Artificial Intelligence.

### 5.3.25. RISE

RISE SICS has developed and extended two main tools in the scope of the MegaM@Rt2 project: i) SaFReL which is a self-adaptive fuzzy reinforcement learning framework for performance evaluation, and ii) VARA: a variability-aware requirements reuse analysis tool based on natural language processing (NL) and machine learning.

RISE SICS also organized the ITEQS workshop jointly with Mälardalen University and ÅBO Akademi promoting MegaM@Rt2 project.

RISE SICS intends to further extend the results of the MegaM@Rt2 project in future projects and for new industrial partners. Moreover, MegaM@Rt2 results have opened up new collaborations and research directions which we will be considered in future project applications. The project has

also provided opportunity for junior members at the Software Testing Group at RISE to gain experience and grow.

#### 5.4. Joint exploitation agreement

MegaM@Rt2 consortium is composed of a set of representatives from industry and academia, including software providers and end users. Thus, different interests must be taken into account for developing a sustainability path that can support most of the expectations.

The consortium decided to sign up a multilateral agreement to be used as a regulatory framework to act under the MegaM@Rt2 umbrella. This is reflected into a memorandum of understanding (MoU), which although not legally binding, represents a friendly approach that collects all terms and conditions from all interested parties.

Due to confidentiality issues in commercialization, explicit economic conditions are not included in it and will be further developed in dedicated commercial contracts per customer.

The underlying idea of this MoU is to ensure the IP protection of all partners who have developed tools within the project duration and create alliances between them to develop commercial opportunities. Use cases are excluded of this agreement as they didn't develop software. However fair conditions will be established for them in further business negotiations so they can still benefit of project results after the end of the project.

This document also solves any potential IP issue that may arise when integrating tools in a commercial offering, providing mechanisms to protect it.

As the document is still under discussion, it will not be included in this document. However, it can be shared under demand.

## 6. Conclusions and Lessons learnt

MegaM@Rt2 is a complex and ambitious project where several partners, from many different countries, with a high variety of interests are working together to reach a set of common objectives and goals. Due to these particularities, there is no one single path to ensure the sustainability of project results. For this reason, an exploitation agreement was selected as the most suitable tool to establish a framework for the MegaM@Rt2 exploitation. In this way, each partner can individually exploit its results but is still able to interact with the rest of the consortium for offering an integrated solution to an external stakeholder.

A business model covering all individual expectations is also provided to be use as the basis for further commercialization. It is flexible enough to be adapted to each specific case and partners can have at least a reference.

Standardization activities have played a crucial role during the project duration. It is of paramount importance not only to use standards but to propose also some improvements. Most of the tools strongly relies on the current standard definition and can be totally out of date if a close follow-up is not performed.

Finally, dissemination activities are also very important for the project in order to ensure the impact of results. These activities will be continued after the project end.

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