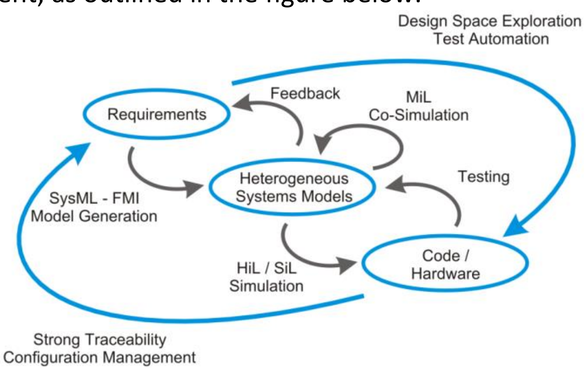
Integrated Tool Chain for Model-based Design of Cyber-Physical Systems

ABOUT INTO-CPS

Systems composed of closely coupled computing and physical elements are increasingly important in the modern world. Such Cyber-Physical Systems (CPSs) are characterized by a complex architecture and a design process involving different science and engineering disciplines. At this interface between disciplines, different formalisms and technical cultures meet, and the traditional approaches for designing systems vary significantly among the relevant fields. The developer of a CPS faces a large design space that is hard to cover with hardware prototypes, due to the high cost of their implementation. A common workflow for the model-based design of CPS – and the necessary tools – is currently missing.

To address these challenges, INTO-CPS seeks to create an integrated "tool chain" for comprehensive model-based design of CPSs. The tool chain will support multidisciplinary, collaborative modelling of CPSs from requirements, through simulation of multiple heterogeneous models that represent the physical elements as well as the computational parts of the system, down to realisation in hardware and software, enabling traceability at all stages of the development, as outlined in the figure below.



The goals of INTO-CPS are to:

- Build an open, well-founded tool chain for multidisciplinary model-based design of CPS that covers the full development life cycle of CPS.
- Provide a sound semantic basis for the tool chain.
- Provide practical methods in the form of guidelines and patterns that support the tool chain.
- Demonstrate in an industrial setting the effectiveness of the methods and tools in a variety of application domains.
- Form an INTO-CPS Association to ensure that project results extend beyond the life of the project.

Overleaf we provide an overview of INTO-CPS, outlining its approach.

INTO-CPS

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36 Months

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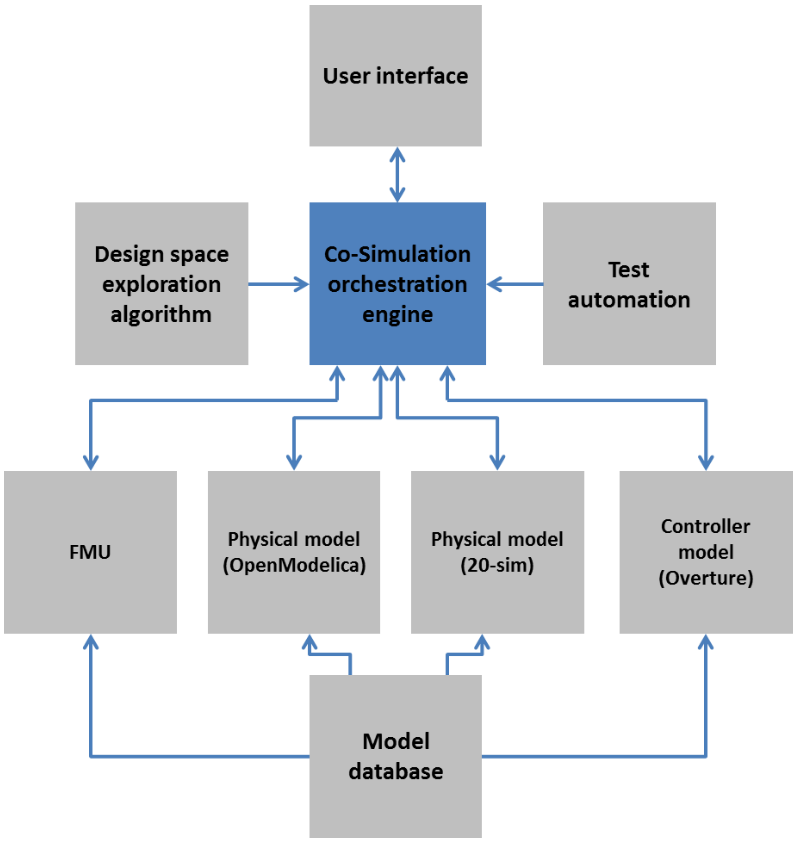
HOW INTO-CPS WORKS

The INTO-CPS consortium consists of 11 partners (4 academic, 7 industrial) who bring complementary knowledge, baseline technologies and applications. The baseline technologies support systems modelling (Modelio), simulation of physical systems (OpenModelica, 20-sim), discrete-event modelling (Overture), Co-Simulation (Crescendo, TWT Co-Simulation engine) and test automation (RT Tester).

A **co-simulation orchestration engine** will be built on these baseline technologies according to the requirements driven by the industry case studies outlined overleaf. This engine will combine previous experience from TWT's Co-Simulation engine and the Crescendo tool developed previously in the DESTECS project. The goals for the co-simulation orchestration engine include, among others, optimized scalability and performance, and data exchange between the different models, facilitated by the Functional Mockup Interface (FMI). Interfaces to further tools will be provided, so that the pervasiveness of requirements and artefacts will be fully exploited. The co-simulation orchestration engine and its most important connections are shown in the schematic below.



Project Partners
Aarhus University (DK)
Newcastle University (UK)
University of York (UK)
Linköping University (SE)
Verified Systems International (DE)
Controllab Products (NL)
ClearSy (F)
TWT GmbH - Science & Innovation (DE)
Agro Intelligence (DK)
United Technologies (UK)
Softeam (F)

The co-simulation orchestration engine connects different models, either in the encapsulated form of a functional mock-up unit (FMU), or running in their native modelling environment, to a system model. Large parameter spaces are swept by using an algorithm for design space exploration, while the system's robustness can be evaluated by using test automation tools that can manipulate the simulation. Models can be kept in a database to allow for versioning. The entire co-simulation is controlled from a user interface.

CASE STUDIES

Four industry-led case studies from different application domains will allow us to evaluate the emerging INTO-CPS tool chains:

The **Railways** case study aims to develop CPSs for controlling screen doors for metro platforms. The focus is on validating the safe and secure function of sensors and actuators. This will allow faster development of prototypes and less need for experimental validation. The modelling of the case study will include the controllers as well as those parts of the physical environment (trains, optical sensors etc.) that have an impact on the correct and safe functioning of the screen doors.

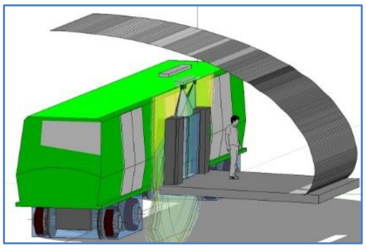
The **Agriculture** case study is an automated control system for more efficient removal of weeds in between crop plants. The challenge is to simulate the behaviour of physical components (such as mechanical loading on certain elements) together with controls of the automated system. These controls access local data (e.g. sensors) and external data (e.g. GPS). Model-based design will allow for accelerated time-to-market and virtual validation, reducing the need for multiple physical prototypes.

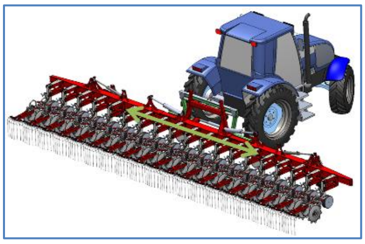
In the **Building Automation** case study, CPSs for control of Heating, Ventilation and Air-conditioning (HVAC) will be developed. These CPS need to be adaptable to components of various manufacturers and different building patterns and the corresponding requirements. The various parts that influence an HVAC system will be modelled and simulated, such as the fan-coil unit that distributes air, the buildings and rooms, as well as the controllers of the fan-coil units.

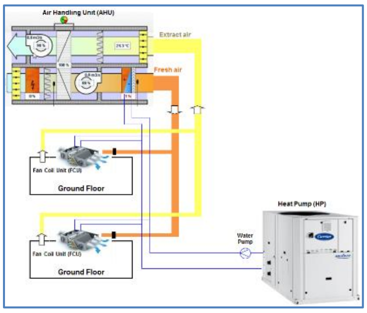
In the **Automotive** case study, a range optimization assistant for electric vehicles will be developed. In order to maximize the range without compromising other qualities such as comfort or speed, a comprehensive assessment of the vehicle and its environment are necessary. To achieve this goal, all relevant parts of the system will be modelled, such as battery, drive train, topography, traffic, weather, and cabin thermal control. These models are created in native tools (such as Matlab) and coupled, using the TWT Co-Simulation Engine as baseline technology. In the progress of INTO-CPS, the co-simulation orchestration engine and related tools will be used to further develop the assistant system.

Key features

- Well-founded tool chain for multidisciplinary model-based design of CPS that covers the full development life cycle of CPS.
- Practical methods in the form of guidelines and patterns that support the tool chain.
- Demonstration of the effectiveness of the methods and tools in a variety of application domains in an industrial setting.







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The development of tools and methods will be based on a sound **semantic description** of the co-simulation. The semantic description will focus on VDM-RT as a discrete-event language, and Modelica as a continuous-time language. Furthermore, a formal basis for co-modelling with FMI will be provided, and a semantic mapping of SysML to FMI. Together, these foundations will allow for the formal checking of the results' validity.

In addition to the software development and the semantic foundations, practical **guidelines and templates** will be generated to assist potential users of the INTO-CPS tools. These guidelines will cover all aspects of INTO-CPS, such as the optimal use of design space exploration, methods for traceability and practical examples that result from pilot case studies.

The results of INTO-CPS will be disseminated ways geared to the needs to different communities of interest. Scientific results will be published in peer-reviewed journals and conferences. Students will be engaged through summer schools and partners' academic activities. Results that can be incorporated into standards (such as the FMI standard) will be brought into the respective bodies. Interested parties from industry may join the **Industry Follower Group** (IFG), allowing them to be involved in the progress of INTO-CPS by means of surveys, workshops, webinars or pilot studies, using the latest INTO-CPS tools. This will allow IFG members to provide valuable input and profit from the up-to-date information on progress.

PROGRESS AND OUTLOOK

By the end of the first year, the INTO-CPS consortium aims to have a first prototype of the co-simulation orchestration engine. The case studies will be specified and implemented using the baseline tools. A first edition of the semantics will be described, and interfaces from different languages and standards (e.g. SysML, FMI) or tools (e.g. for design space exploration, test automation, code generation) to the INTO-CPS tools will be initially described.

By the end of the project (after three years), the INTO-CPS tools (existing and newly developed) are intended to be stable. The case studies will have been implemented using the INTO-CPS tools, providing an assessment of utility and the priorities for future development. To ensure the long-term impact of the INTO-CPS results, an INTO-CPS association will be established which – among other activities – will seek to transfer results into relevant standardisation bodies and provide a solid foundation for an ecosystem of new tools and business in CPS design.