Recent Advances in Shared Simulation Approaches in Systems Engineering Processes

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INTRODUCTION

Driving on earth and flying in space were two major challenges in the 20th century motivated not only by industrialization processes but also by the permanent curiosity of human beings to explore and construct the world around them. Inquisitiveness has been triggering the development of innovative concepts. Thus during the last years space industry experienced a significant transition traced back to organizations like Google, SpaceX, Facebook, which have entered the so far restricted space market with a public interest on space travels. But also new space faring nations and satellite networks as well as services in dual applications render space attractive.
Stronger competition on the space market demands decreasing time for product development processes, hence higher number of space missions are launched within shorter time scales. Advantageous here, is the support of digital product development[1]. Exemplary, in automotive industry the increase of maturity level in the early (digital) development phase improves the quality of first hardware prototypes and thus less real prototypes are produced and tested making production cycles more cost efficient. In addition, an increasing number of car variants calls for an increasing numbers of physical tests. For example, ESP-systems have to be validated for each variant of a model, which by means of physical tests is almost impossible. Therefore, innovative digital concepts and simulation based ESP homologation followed by certification by the Federal Motor Transport Authority were established[2].

Standardization

Standardization procedures were introduced for the model based development - the FMI[3] (functional mock-up interface) as standardized interface in automotive industry and the SMP2[4] (simulation model portability) for space industry. The list of FMU im-/exporting CAE software packages is already very long containing, e. g. CATIA, Dymola or various options of Matlab/Simulink. Applying such standardized interfaces users benefit from efficient processes and complete new simulation methods. This progress allows also for a further specialization of workforce, since the author of a component can use sophisticated authoring tool, which a simulating engineer does not necessarily needs to have access too. Due to the provision of only one tool-to-tool interface, tool provider can profit from decreasing development and test expenses. The FMI standard has not only attracted automotive engineers, but also spacecraft engineers and has shown to be highly useful to simplify digital development processes[5].
With the establishment of FMI as standard for model exchange and co-simulation exchange of simulation models beyond tool borders have been simplified and complex product simulation has been enabled. Various component models are coupled in co-simulation frameworks and mutually exchange information such as parameters, state variables or other numerical data - a set of models each representing a combination of parts following physical laws. The joint deployment of co-simulation represents a powerful tool for collaboration in systems engineering to calculate the product design and its operational performance during an early state of the development process. The majority of the models represent cost-sensitive and confidential information on the part of the OEM or the supplier. Therefore, safeguarding of intellectual property handling during model provision and co-simulation is indispensable.

Functional Mock-Up Trust Centre

Yet, if the intellectual property, which is enclosed in the models and parameters, is not adequately protected, the collaborative development effort can be impeded or rendered impossible altogether, leading to non-acceptance of such an approach from industry side. Therefore, the Functional Mock-Up Trust Centre (FMTC) of the TWT GmbH, also proposed to be extended for use with the SMP2 or its successor was developed by TWT GmbH during the

MODELISAR (ITEA2) project. The intellectual property rights are protected during co-simulation against unprivileged access and unauthorized modification.

The basic idea of a FMTC is a cryptographic protection and signature for simulators. The FMTC enables the integration of protected, FMI-compatible FMUs in a co-simulation environment, e. g. in a systems engineering domain to protect intellectual property rights. The safeguarded models can only be decrypted inside a trusted FMTC and if certain conditions are met, i.e. all symmetric and asymmetric keys are available and usage of licenses is approved. Hence, a potentially unsecure data management system, e. g. a PLM, can be used to store and version the simulation models. The FMTC provides the possibility for secure authentication and authorization of the model providers and users. Also, network communication is only allowed through secure protocols and interface-connectors.

SMP Adaption

The original FMTC has been developed for usage with FMI, which is an open standard for model exchange and co-simulation (incl. solvers) and was initially mostly used in the automotive domain. It is maintained by the Modelica Association. In space applications, the SMP2 standard is more common. In order to simulate safeguarded models inside an SMP Native Simulation Environment, the FMTC has to implement the necessary interfaces to the simulation services. Furthermore, in order to prevent different models from influencing each other, the FMTC has to offer interfaces between the models according to the XML Catalogue and Assembly files.

Use Case: Co-Simulation

Since the involved models are often written and integrated by individual programmers and collaborators, common co-simulation environment setups often involve several machines with each of them running specific simulators in software and/or hardware. A co-simulation environment connects single simulation models for various parts of a system to a common simulation of the entire system. Co-simulation is the parallel execution of separate simulators with synchronous or asynchronous communication. The single simulations can be executed on individual computers in a network. Next to exported, FMI-compliant models - Functional-Mock Ups (FMUs), also external simulations can be integrated. Therefore, existing and already validated component models can be coupled to protected complete models, without the necessity to bring each model into a common simulation environment. The expenditure of additional modelling is dropped and time as well as costs are saved. Furthermore, troubleshooting is avoided, since every simulation model is executed in its native environment. The individual simulations are executed completely independent from each other and are only synchronised in time steps of the co-simulation. This enables acceleration of the computation time due to parallel execution of calculation. Moreover, the possibility to run the models on different computers in a network enables the integration of highly complex, non-functional simulations like structure analysis, multi-body systems or fluid-dynamics as well as versatile combination of these, e. g. fluid-structure-thermo simulations. Since providers may not be willing to share insights in the details of the simulator with the collaborators, the safeguarding of intellectual property is particularly challenging. The FMTC provides a method to embed a simulator to a co-simulation environment and use shared libraries, but provides a secure and encrypted environment for execution of the model. A Socket based bridge separates the FMTC sandbox from the communication layer of the co-simulation. A solution to embed the FMTC into existing service landscapes and engineering toolchains by a service-oriented architecture (SOA) was presented in [[6]].

Recent Advances in Co-Simulation

(Co-)simulation is only one, albeit crucial, step in the whole design process. To connect the co-simulation to other tools along the workflow, the Horizon2020 project INTO-CPS[7] builds upon the FMI standard as an interface between tools. The project aims at an integrated tool-chain for the design of Cyber-Physical Systems, supporting the engineers from abstract system design in SysML, through modelling and (co-)simulation to code generation[8]. SysML profile is developed to describe Cyber Physical System (CPS) architecture that includes software physical and networking elements. From the architectural models FMI can be generated and imported by different simulation tools. Constituent models can be either in the form of discrete event models or on the form of continuous-time models combined in different ways.
Furthermore, test automation is supported to verify if the system-under-test fulfils its requirements. In the design phase, systematic variation of design parameters is supported by algorithms for Design Space Exploration. To ensure that the collaboration between different people and teams, using different tools, is running smoothly, traceability of design artefacts (such as requirements and models) will be supported. The supported toolchain is depicted in figure 1.

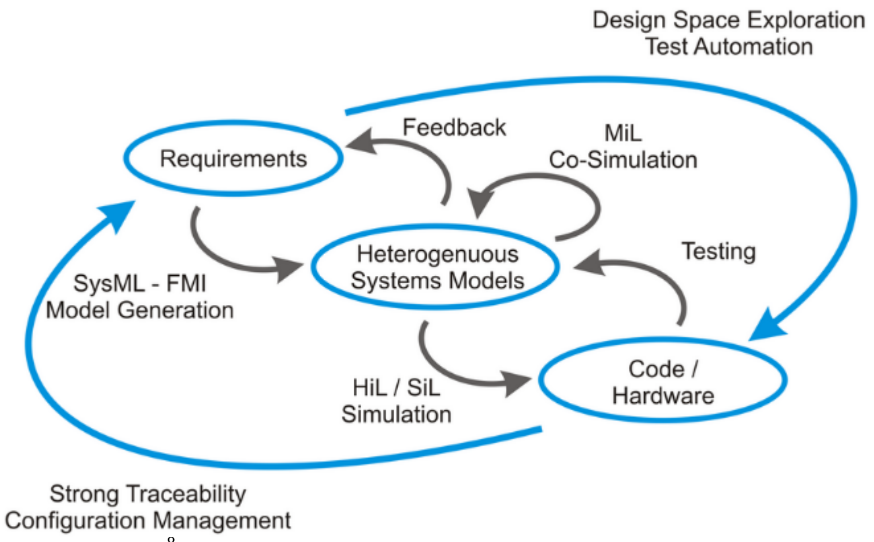

Figure 1: The INTO-CPS approach[8].

Real-Time Co-Simulation

Advances in research enable co-simulation to couple real-time systems. One or more components, which are available as real hardware (like engine test-beds) are directly coupled into an existing system model. Early forecasts and therefore, early concept decisions are significant factors of success in modern development processes. Currently, the development of novel vehicles is distributed among many partners in different locations and across different countries. This does not even include development processes with real components and systems but also early development of models and simulation. Within the ITEA project ACOSAR (Advanced Co-Simulation Open System ARchitecture) a non-proprietary interface will be developed, namely Advanced Co-simulation Interface (ACI), where real-time systems of different developer are able to connect over topological distances and are connected to a virtual simulated entire system.

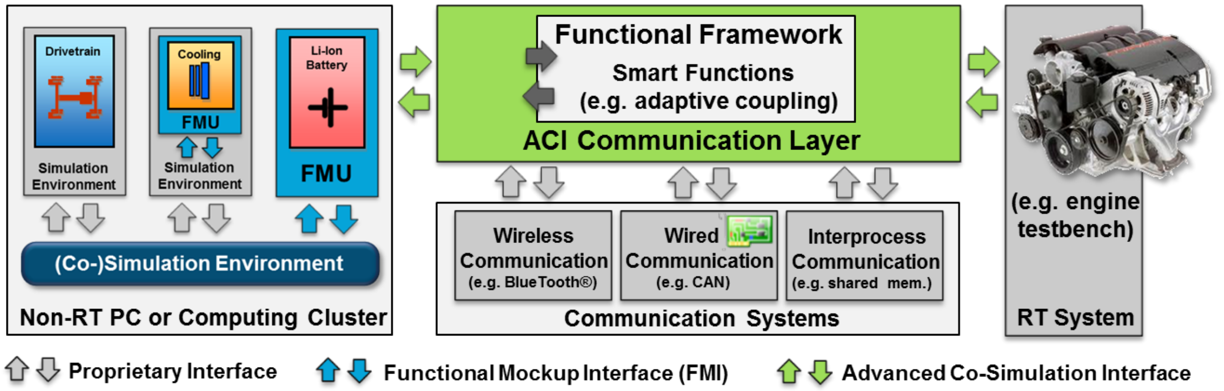

Figure 2: To enable effective and efficient RT-System integration, ACOSAR will provide innovations on different levels[9].

A modular co-simulation approach is applied to support flexible system development integrating domain specific sub-systems. Successful extension of co-simulation to real-time coupling enables the continuation of co-simulation in the whole product development cycle. The approached standardization is expected to be as valuable as FMI (MODELISAR) and will drastically reduce the required configuration expenses and increase the efficiency of tests and simulation itself. The open ACOSAR ACI will enable not only for the extension of cloud-simulation based applications in real-time systems, but also allows for an optimal dedicated complete system with reduced troubleshooting for specific problems, e. g. connection of distributed HiL (hardware-in-the-loop) test benches. The high versatility of the standardization of ACI will enable for novel business models. Innovative collaborations like test bench sharing or cloud simulation are conceivable.

Advanced engineering and information technologies of both worlds, space and automotive industry, where human fascination and passion created sophisticated products and knowledge transfer is the key to highly disruptive inventions. This presentation is focused on the existing and ongoing standardization approaches to improve systems engineering processes with regard to cost and time savings. The focus there will be on co-simulation and model exchange, as well as the protection of the intellectual property rights. Recent advances in real-time co-simulation are presented and possible applications in the space domain are discussed.

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[1] Chen, Y./Faessler, V.: In 22 months from the idea to the functional Vehicle Prototype. 14th Automotive Technology Workshop. Nanjing (China), 2004

[2][2] Horak, J./Pfitzer, S./Keckeisen M./Neumann, C./Wüst, K.: Simulation-Based Homologation of Truck ESC Systems. 21st Aachen Colloquium Automobile and Engine Technology 2012, 1621-1633, RWTH Aachen 2012.

[3] Blochwitz, T./Otter, M./Åkesson, J./Arnold, M./Clauss, C./Elmqvist, H./Friedrich, M./Junghanns, A./Mauss, J./Neumerkel, D. et al.: Functional mockup interface 2.0: The standard for tool independent exchange of simulation models. 9th International Modelica Conference, 2012.

[4] Lei, Y. L./Su, N. L./Li, J. J./Yang, F./Li, Q.: New simulation model representation specification SMP2 and its key application techniques [J]. Systems Engineering-Theory & Practice, 5, 019, 2010.

[5] Wurstbauer U. / Herrnberger M. / Raufeisen A. / Fäßler V.: Efficient Development of Complex Systems using a Unified Modular Approach. Deutscher Luft- und Raumfahrtkongress, 2015, urn:nbn:de:101:1-20151109518

[6] Mezger J./Ditze M./Keckeisen M./Kübler C./Relovsky B./Fäßler V.: Protecting Know-How in Cross-Organisational Functional Mock-Up by a Service Oriented Approach with Trust Centres. 9th IEEE International Conference on Industrial Informatics (INDIN), 2011.

[7] http://into-cps.au.dk/

[8] Larsen P. G. *et. al:* Integrated tool chain for model-based design of Cyber-Physical Systems: The INTO-CPS project, DOI: 10.1109/CPSData.2016.7496424.

[9] http://www.acosar.eu/overview.php