CLOUDSF - A CONTINUOUS INTEGRATION FRAMEWORK FOR THE DESIGN AND VALIDATION OF CYBER-PHYSICAL SYSTEMS

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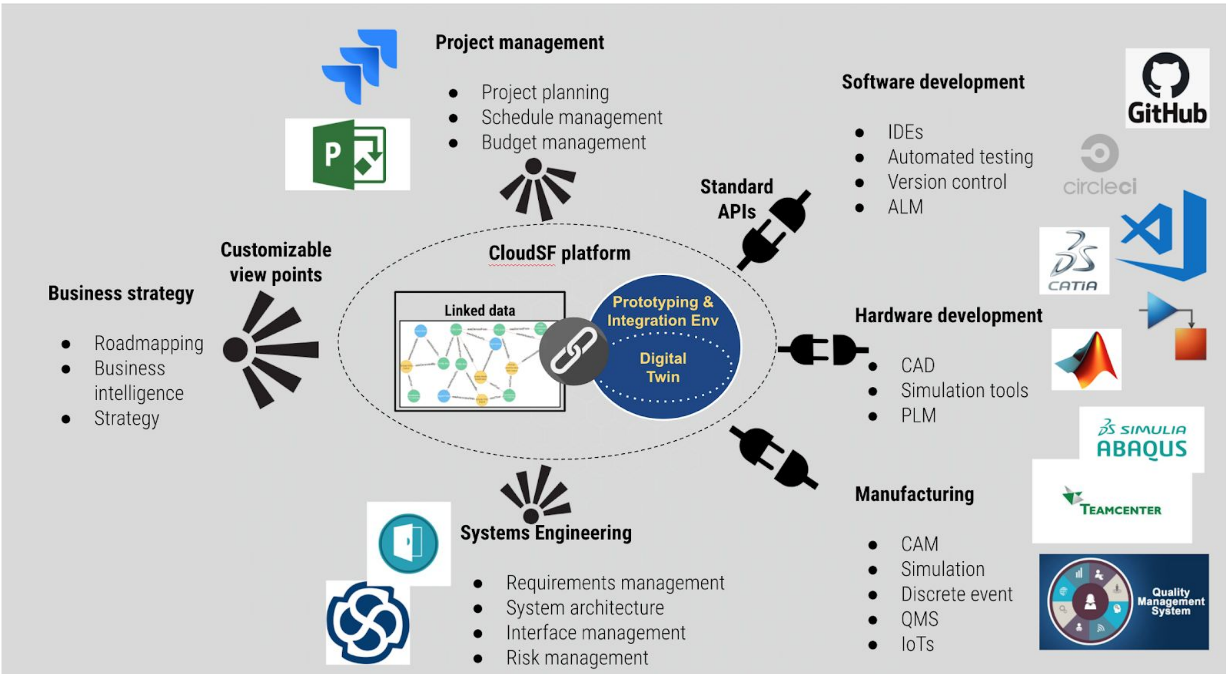

Figure 1. Schematic representation of Perpetual Labs' CloudSF platform in relation to the different engineering disciplines and business functions. These could be part of a single organization or being distributed across the supply chain (i.e. extended enterprise.

Introduction

The extensive use of virtual prototyping methods has become an indispensable tool in the context of Model-Based Design of complex space missions. Modelling the behaviour of such missions often requires considering systems that are composed of physical subsystems (usually from different physical domains) together with computing and networking. These are generally referred to as Cyber-Physical Systems (CPS).

A frequent problem in larger space projects is that, although component-level models and simulations are available, it is a big hurdle to integrate them into larger system-level simulations. This is because different development groups and disciplines, e.g., electrical, mechanical, power, and software, often use their own approaches and dedicated tools for modelling and simulation.

The Functional Mock-up Interface (FMI) [1] has been developed as a standardized exchange format for behavioural models to improve the interoperability of domain-specific models. Model components are exported as Functional Mock-up Units (FMUs) from their respective discipline specific tool. Then a dedicated simulator tool can import the FMUs in a co-simulation environment and integrate them into a composite model of the entire CPS using a suitable master algorithm for coupling the individual units.

However, coupling the different simulator codes contained in the individual FMUs to perform full-system simulation still presents major challenges and is an active research area. Some of the main challenges are:

- **Numerical stability**: modular simulation of a global system by coupling different simulator codes may easily result in an unstable integration [2].
- **Uncertainty quantification**: this is particularly important for large composite system simulations where the uncertainty propagation could rapidly undermine the confidence in the simulation results.
- **Computational scalability**: high-fidelity N-code simulations (FEA, CFD, logical) can take as much as 1 h CPU-time for every real-time second of behaviour prediction [3]. This type of analysis requires significant computational resources which in turn put high-demand on the High-Performance-Computing (HPC) infrastructure.

In addition to the core technical challenges listed above, there are challenges related to the adoption of such virtual prototyping environments at the organizational level. These include:

- **Integration with overarching SE framework and toolchains:** during system development, heterogeneous artefacts are generated, often using different lifecycle modeling languages and simulation tools, leading to integration and interoperability issues.
- **User Interface**: the virtual prototyping environment must be accessible through an integrated Modelling and Simulation Environment.
- **Multi-user collaboration**: design of complex CPS requires expertise in many different domains and often results in large cross-functional teams. Coordinating the exchange of data and information from the different domains is a major challenge and an active research area.

It is understood that collaborative web-based tools and model editors, supported by a powerful system ontology and data infrastructure in the backend, are key to tackle these problems.

The Cloud System Factory (CloudSF) platform

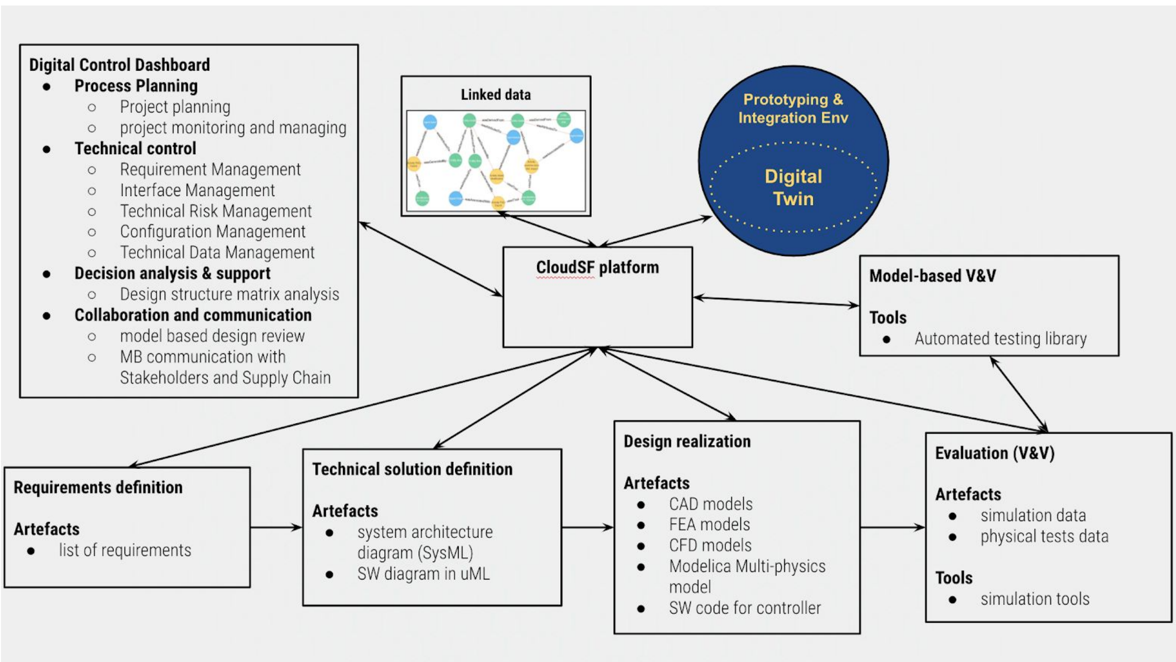

Figure 2 Schematic representation of Perpetual Labs' CloudSF platform in relation to the different stages of the system development life cycle and the corresponding systems engineering processes.

Perpetual Labs is developing a new software platform for collaborative design of CPS called Cloud System Factory (CloudSF). It enables all the stakeholders of a complex engineering system to exchange system data and engineering artefacts independently of the specific tools that they are using (see figure 1). It includes the following key components and features:

- **Conceptual Data Model (System Ontology) environment**. It uses a Linked Data approach to capture traceability information and create semantic links that relate heterogeneous artefacts through the product design lifecycle. The traceability data is stored in a graph database which enables artefacts from different tools to be connected and queried through a standardized interface and language.
- **Virtual Prototyping and system verification environment (ViPro)**: It enables scenario-based simulation at the system-level (composite model) for model-based verification of system requirements. It significantly reduces the need for physical integration and requirement verification testing. It enables the application of Continuous Integration practices to the design of CPSs.
- **Web-based Integrated Design, modelling and simulation Environment (IDE)**: It provides support for the major development phases, such as requirements analysis, system modelling, verification and maintenance through well-integrated and easy-to-use functions. It automates the process of submission of simulation tasks to computing platforms, monitoring, retrieval and analysis of results. It provides real-time collaborative model editing features.
- **Digital Dashboard (Dashboard)**: It enables the creation of customizable viewpoints on the engineering data depending on the specific domain and business function. It allows users to leverage the power of semantic query languages (such as SPARQL) to interrogate the system ontology and engineering database in a fast and intuitive way to support system analysis and automated report generation.

The CloudSF platform supports a Linked Data approach through the adoption of the Open Services for Lifecyle Collaboration (OSLC) standard connectors [4]. This solution enables the definition of the semantic relationships between the different engineering artefacts in a tool-independent fashion and the easy creation and maintenance of a global system ontology. The OSLC standard natively supports any RDF-based ontology language such as WeB Ontology Language (OWL) [5] and, for extension, the Object Role Methodology (ORM) [6] and Ontological Modelling Language (OML) [7]. For an updated list of lifecycle tools that support OSLC APIs, see [8]. The use of Linked Data, supported by a global system ontology, allows to easily establish and maintain a single source of truth across the structure of the extended enterprise and throughout the product development lifecycle (see figure 2).

Technology application

There is an urge for developing novel Robotics, Automation and AI (RAAI) technologies that will facilitate in-space manufacturing and assembly of Large-Aperture Space Telescopes (LASTs), instead of Earth-based assembly (figure 3). Advancements in RAAI is also indispensable for active debris removal missions, spacecraft servicing operations in LEO/GEO (life extension, refuelling, orbit correction), space-based power generation and in-space assembly of other larger structures like super-large Radars and Synthetic Aperture Radars.

The main challenge in the development of RAAI technologies for space missions is the increasing complexity of these systems. In particular, this is due to the rising importance of connectivity and non-deterministic software components (such as Machine Learning and Artificial Intelligence for machine vision and manipulation). Another important challenge is the necessity for collaboration of multiple entities with different design processes and tools.