REVAMP: challenges and innovation roadmap for variability management in round-trip engineering of software-intensive systems

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REVAMP: challenges and innovation roadmap for variability management in round-trip engineering of software-intensive systems

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Abstract
The Software Intensive Systems (SIS) has become dominant in industry. The Product Lines (PL) approach offers significant cost reductions in customisation and rapid development of products targeting various market segments. However, Product Lines Engineering often times requires a complex modelling and co-evolution of multiple assets. That hinders the proliferation of the PL approach and constraints its accessibility for SMEs and larger community of system developers.
The ITEA 3 project REVaMP² aims to conceive, develop and evaluate the first comprehensive automation tool-chain and associated executable process to support round-trip engineering of SIS Product Lines and thereby helping to profitably engineer mass customised products and services.

1. Introduction

An ever-higher proportion of B2B and B2C products and services acquire leading market positions by becoming more software-intensive. This trend is illustrated by buildings and vehicles evolving from electro-mechanical systems into Cyber-Physical Systems (CPS=) (Lee, 2015) and by services such as utilities, transportation and tourism evolving towards personalized, adaptive offers based on analytics of data generated by the Internet of Things (IoT, thereafter). (Madisetti, 2014). This technological trend mutually reinforces with the concurrent business model trend to shift away from one-shot product sale transactions towards service subscription packages, which include leasing a product as one item in a customized turn-key service offer. These Software-Intensive Systems and Services (SIS thereafter) create and adapt to innovative market disruptions and customer whims far quicker and at lower cost than their less software based competitors. However, they also raise new engineering challenges. In particular, they require more agile, *round-trip* engineering processes that better leverage legacy assets, and more systematic and *automated variability management*.

An engineering process is called *round-trip* when it combines *top-down* steps that refine abstract assets such as requirement specifications and high-level architectural patterns into more concrete ones such as executable simulation models and source code, with *bottom-up* steps that abstract such these more concrete assets into the more abstract ones. *Variability management* refers to a method to systematically (a) reuse common assets shared by a whole family (or line) of system (or product or service) variants on a common theme and (b) organize and relate distinct assets proper to each variant along commercially and technologically relevant characteristics and constraints.

In this paper, we first summarize the main variability management challenges that SIS engineering companies face today, given the current State-of-the-Art (SotA thereafter), when they attempt to round-trip engineer SIS families at optimal cost by reusing legacy artifacts from past assets from their product or service portfolio. We then overview a three year practical roadmap to these challenges, called REVAMP² (Round-trip Engineering for VAriability Management Platform and Process) that we are following in the context of a collaborative research and innovation project labeled by the Eureka program ITEA-3 in a consortium of 30 partners in 5 European countries.

2. Current round-trip variability management challenges

Product Line Engineering (PLE) is a mature paradigm for variability management. It enables defining a family of product configurations to satisfy different customer needs and to later systematically generate the associated product variants by combining predefined reusable components. Benefits of PLE include achieving large-scale productivity gains and

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improving time-to-market and product quality. For pure software systems[5], reports describe gains following PLE adoption by as much as tenfold in productivity and quality, cost reduction by as much as 60%, decrease labour needs by as much as 87%, and decrease time to market (new variants) by as much as 98%[6]. As all sorts of devices, systems and services become more software intensive, the more they can benefit from PLE adoption. Commercially successful implementations of the PLE paradigm can be found in companies from domains ranging from avionics and automotive software, to printers, mobile phones or web applications.

However, adopting an PLE approach is still a major challenge and represents a risk for a company [4,5]. First, compared to single-system development, PLE variability management implies a methodology that highly impacts the life cycle of the products as well as the processes and roles inside the company. Second, adopting an PLE from the beginning, an approach called *proactive* PLE [4], is subject to two main assumptions: 1) the company must have, in advance, a complete understanding of the variability to anticipate all possible variations; 2) the company should start from scratch to specify the variability and implement the reusable assets.

Berger *et al.* showed in a recent survey with industrial companies that participated in industrial PLE, that around 50% of them cannot adopt proactive PLE [6]. On the one hand, the variability in these companies is discovered as customer needs emerge over time; so, it is very difficult if not impossible, to anticipate all the variations from the beginning. On the other hand, companies already have existing product variants that were implemented using an opportunistic reuse in an ad-hoc way to quickly respond to different different customer needs. As mentioned by Dubinsky *et al.* [7], instead of adopting PLE, many companies clone an existing product and modify it to fit the new customer needs. This approach, called *clone-and-own*, is widely used because it is initially faster to start with an already developed and tested set of assets [7].

Figure 1 illustrates, the three main PLE processes: proactive, extractive and round-trip. Proactive PLE is illustrated on the left of the figure. It must start at the inception of the project in a high-cost upfront investment step s0 called domain modelling. During this phase, the requirements for the entire product line must be simultaneously elicited. From the resulting PL, all product variants satisfying the variability model constraints can then be automatically generated in a second step s1. In Figure 1, the domain model mandatory features are grey squares, the variant-specific features are coloured squares, and constraints on features mutual exclusivity are annotated with the XOR operator. Extractive PLE is illustrated on the right of Figure 1. It starts by the rapid development of a Minimal Viable Product (MVP). If this MVP fits its market, it is then followed by sequentially and opportunistically cloning-and-owning variants to quickly target other niches for which many common features from the initial product can be reused (steps s1 to s5). When these variants and the constraints among them become too numerous to be efficiently managed without an explicit and systematic variability model, they are then refactored and consolidated in bottom-up fashion into a PL (step 5). Round-trip PLE combine both approaches.

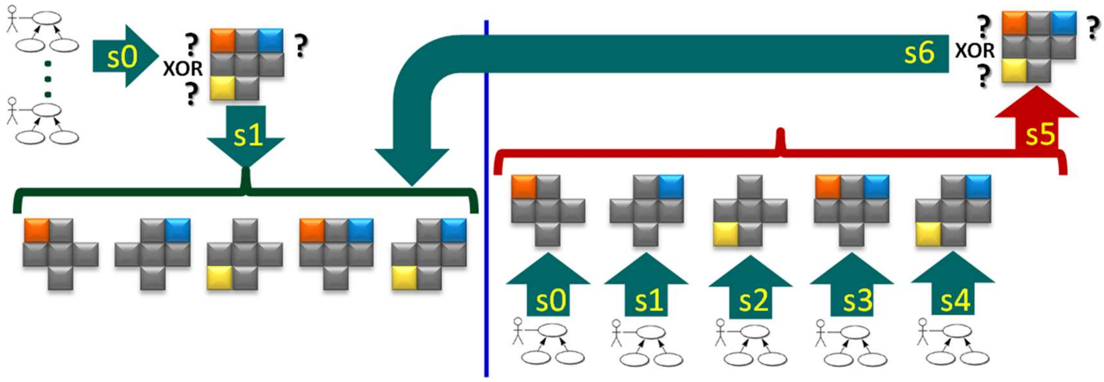

Figure 1: Round-trip PLEA adoption process

However, the industrial SotA in variability management is restricted to tools that automate top-down product variant generation from a variability model and reusable product assets (i.e., step s1 on the left of Figure 1). None tools is are currently available to automate the bottom-up extraction of a variability model and reusable PL assets (i.e., step s5 on the right of Figure 1).

Companies thus face the SPL adoption dilemma: on the one hand, they are aware that PL can enable them to achieve large-scale productivity gains, improve time-to-market and product quality. On the other hand, however, these same

[5] We define pure software systems in opposition to software systems that need to be designed along with the hardware it is going to interact with.

[6] CMU/SEI. Software Product Lines, Retrieved from http://www.sei.cmu.edu/productlines/, 7. Feb. 2016

companies already have existing variants created using the *clone-and-own* approach. Consequently, Therefore, they are This dilemma makes them practically unable to adopt PL. One solution to deal with this issue is to use round-trip engineering approach for PL adoption that consists in migrating, automatically or semi-automatically, the existing variants into an PL.
Today, innovative companies thus face the PLE adoption dilemma: the Return on Investment (ROI) of the proactive PLE adoption process is too uncertain, while the cost of late manual PLE is prohibitive. This dilemma considerably hinders PLE adoption. Many organizations eschew it, missing out on the massive long-term cost, robustness, customization, and competitiveness benefits that it would bring about for maintaining and developing their product portfolio. The REVaMP² project aims to provide the first solution to this dilemma by developing and validating on diverse industrial case studies, the first comprehensive round-trip engineering automation platform and process to support extractive, bottom-up PLE adoption and maximize reuse of legacy assets.

3. The REVAMP² roadmap

The REVaMP² roadmap consists in conceiving, developing and evaluating the first comprehensive automation tool-chain and associated executable process to support round-trip engineering of SIS Product Lines.. The first main end result of the project will be a prototype REVaMP² platform seamlessly integrating the following SIS Round-Trip PL Engineering (SIS RT PLE, thereafter) automation services:

- Extraction of a SIS PL and variability model from legacy assets of implicitly related SIS sets;
- Multi-view visualization of legacy assets, extracted variability models and PL assets;
- Verification that a SIS PL satisfies a set of hard constraints such as safety constraints;
- Refactoring of a SIS PL to optimize soft constraints on the refactored assets such as full exploitation of multicore processor power and to co-evolve related assets such as software algorithms and the hardware architectures on which they run.

By taking metamodels as parameters to generic algorithms, these services will be able to analyse or generate a wide spectrum of CPS engineering assets: requirements, system models, software models and code, computing hardware models and mechatronic sensor and actuator models. The second main end result of the project will be an executable model of the SIS RT PLE process to fully leverage the automation services provided by the REVaMP² tool-chain.

CPS and IoT-based SIS are two areas with very high expected growth in the next decade. The IoT-based SIS market is expected to grow 26.59% yearly to generate revenues of over $1.8M by 2020. As these new types of SIS PL spread across key economic sectors like manufacturing, utilities, construction, transportation, healthcare, etc., so will the demand for tool-chains such as REVaMP². This is due to higher levels of automation and reuse of legacy assets provided by the REVaMP² methods and tools, which enables more agile, reliable, and cost-efficient processes than current State-of-the-Art (SotA, thereafter) SIS PLE tool chains support.

The REVaMP² consortium brings together: (a) research teams demonstrators of SIS RT PLE automation proof-of-concept, (b) industrial tool-chain contributors for requirements, system, software, computing hardware and mechatronic engineering together with project and variability management and (c) providers of industrial SIS RT PLE use cases, covering domains such as the transportation CPS industry, the ES industry, the tourism industry and others. The industrial partners include SMEs and industrial giants (such as ABB, AVL, Bosch, SAAB, Scania, Siemens, Sony and Thales).

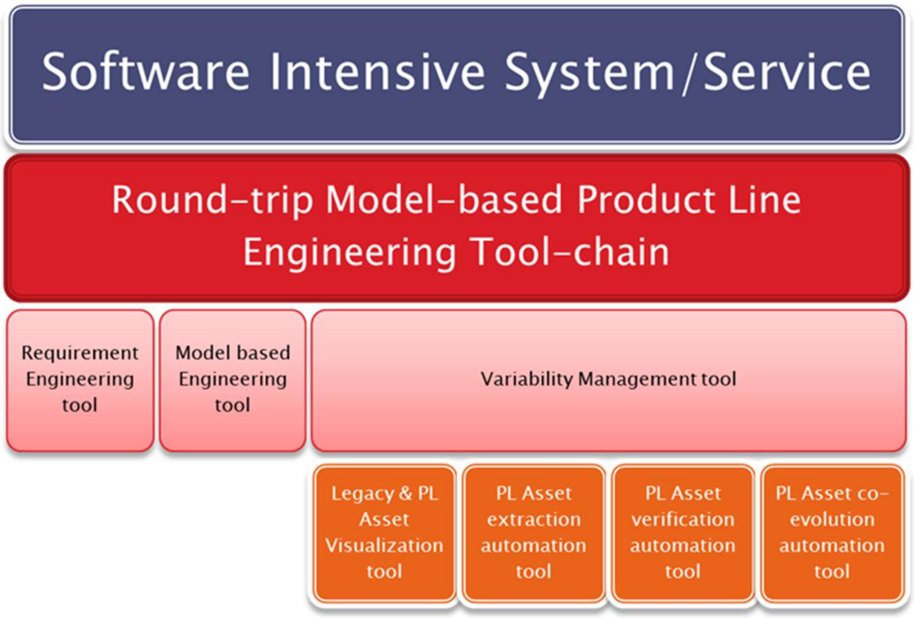

Figure 2: REVAMP approach

The REVaMP² platform to prototype during the project will be the first pioneer element of such class. It is shown in Figure 2 by the class Round-trip Model-based Product Line Engineering Toolchain. Its starting point will be currently available tools for Manual Variability Modelling and Product Variant Configuration Automation from such manually created models. They will be complemented by new classes of innovative tools and services for Legacy and PL Asset Visualization, PL Asset Extraction Automation, PL Asset Verification Automation and PL Asset Co-Evolution Automation. The first and second classes address the need to automate the extraction and visualization of product lines from legacy assets. This is needed because the extraction, verification and refactoring tools will not simultaneously reach 100% automation and quality. Human expertise will always be needed to adjust their parameters to trade-off automation for quality, evaluate their results and manually edit them. The realistic goal of REVaMP² is to minimize such manual edition steps, not to entirely eliminate them. The third class addresses the need to automate the formal verification of constraints on product line variability models and assets. These constraints can be for example, inter-feature consistency constraints, safety and real-time constraints that must hold for the whole configuration space or the existence of a nonempty intersection of this space with some business configuration goal. The fourth class addresses the need for PL refactoring automation.

4. Related Work

During the last two decades, multiple approaches have been proposed to address mainly proactive PLE. This includes research contributions (e.g., [3]) and industrial projects (e.g., VARIES, DiVA). Existing extractive PLE adoption frameworks, such as the tool-supported Bottom-Up Technologies for Reuse framework [2], enable the migration from single-systems development to PLE practices through feature identification and location, feature constraints discovery, reusable assets extraction and variability model synthesis. However, this covers only the bottom-up part of the envisioned REVaMP² round-trip engineering platform and, in addition, its integration in this life-cycle should not be underestimated.

5. Work in Progress and Conclusions

The REVaMP² project has started in November 2016 and is planned for 3 years. The project is currently in the initial phase of collecting the user's requirements from numerous case studies and specification of the tool-chain. In the coming year the experimentation results and demonstration will appear.

The main benefits for the early adopters of the new class of SIS RT PLE tools and services that REVaMP² aims to pioneer are the following:

- Lower engineering cost and faster time-to-market through higher automation, agility and reuse;
- Diversify target markets towards the long tail of lower-end clients currently unable to afford the tool and service prices at which a healthy profit margin can be secured with current engineering tools;
- Support affordable mass customization;
- Improve the agility and reduce the cost of safety constraint certification and qualification;
- Improve performance through a better exploitation of multicore processor power by largely automating the parallelization of legacy sequential algorithm models;

The main benefits for the providers of the REVaMP² tools, will be to become the global pioneer in SIS RT PLE tools and services providers, which will give them first mover advantage to establish a leading position in the market.

The main output of the project will be the REVaMP² tool-chain, which will integrate the SIS RT PLE automation services to be built during the project; forming a radically far more comprehensive set of than any tool-chain that could be quickly assembled with currently available tools. The services provided by the project industrial partners target software intensive markets. This market is expanding quickly, by generating an increasingly heterogeneous offer, whose variability is not supported by current software development tools. Nonetheless, this market is well known for being driven by the capacity to innovate and adapt existing software to new uses and scenarios. The project particularly targets CPS and IoT-based SIS; two areas with very high expected growth in the next decade. As these new types of SIS PL spread across key economic sectors like manufacturing, utilities, construction, transportation, healthcare, etc., so will the demand for tool - chains such as REVaMP². This is due to higher levels of automation and reuse of legacy assets provided by the REVaMP² methods and tools, which enables more agile, reliable, and cost-efficient processes than current State-of-the-Art (SotA, thereafter) SIS PLE tool chains support.

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