Managing Variability in Software Product Lines

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A software product line (SPL) is a set of software-intensive systems that share a common set of features for satisfying a particular market segment’s needs. SPLs can reduce development costs, shorten time-to-market, and improve product quality by reusing core assets for project-specific customizations. To enable reuse on a large scale, SPL engineering (SPLE) identifies and manages commonalities and variations across a set of system artifacts such as requirements, architectures, code components, and test cases. Many companies have adopted this development approach: Nokia, Philips, Bosch, Toshiba, Ericsson, Boeing, Hewlett-Packard, and Cummins are among the companies recognized in the Product Line Hall of Fame (http://splc.net/fame.html) for their success with SPLE.

Variability management (VM) is a fundamental SPLE activity that explicitly represents software artifact variations for managing dependencies among variants and supporting their instantiations throughout the SPL life cycle. Managing variability involves extremely complex and challenging tasks, which must be supported by effective methods, techniques, and tools. Researchers have studied these challenges and proposed solutions to them for nearly 20 years.

We recently undertook a study to systematically review this research. Our purpose was to synthesize and assess the evidence regarding the effectiveness of proposed solutions.

Challenges and Solutions

In 2001, researchers and industry representatives met to identify SPLE’s main issues and problem areas. To update these findings for our study, we organized group interviews with practitioners in 2008, asking them to identify the issues they experience on a daily basis. As a third data source, we reviewed the research literature published through January 2008. This review initially identified 261 papers that reported an approach to some aspect of VM in SPLE or an evaluation of an existing VM approach. The study assessed 97 papers that either claimed or provided some kind of evaluation of a VM approach, technique, or tool. (Details are available in a Web appendix to this article at www.computer.org/software/webextra.html.)

We grouped the issues from all three sources into 12 categories. Table 1 on p. 60 lists these issues, along with our subjective rating of how important each source ranked them. The table shows some changes in practitioner-identified issues from 2001 to 2008.

Although practitioners reported several challenges related to nontechnical issues, such as social, organizational, and human factors, we found no proposed solutions to these issues in our research. In our discussions of the approaches we found for the other 11 issues, we cite one review paper to represent each approach.

Commonality and Variability Identification

To identify SPL commonalities and variabilities, stakeholders must analyze and negotiate the meanings of domain concepts. This activity often proceeds informally, relying on personal domain experience. However, our study revealed four main approaches: feature-oriented domain analysis (FODA), feature-oriented reuse method (FORM), an approach we call domain requirements commonality and variability analysis, and another we call domain requirements modeling.

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All these approaches claim to help domain engineers systematically identify the common and variable features in a product family. FODA and FORM represent early work in applying feature-modeling techniques.

**Binding Decisions**

Early decisions to bind variation points reduce the flexibility of product lines, and late binding can be expensive. When practitioners lack a tool for investigating tradeoffs, they tend to make ad hoc and experience-based decisions. Our data analysis from the group interviews and literature review suggested that this approach is usually suboptimal.

Despite the importance of binding issues, only one study proposed a solution addressing them explicitly. Specifically, it proposes an infrastructure—that is, a representation mechanism and tools—for specifying variability at design time and resolving it anytime.

**Variability Modeling**

We found more research addressing variability modeling than any of the other issues, not only in VM but also in SPL overall.

Modeling issues concern the ability to satisfactorily capture, organize, and represent variability. FODA and several dozens of its derivates were the main approaches. A FODA approach that we call *cardinality-based feature modeling* combines feature modeling with staged configuration to achieve model specialization through a sequence of steps. Other approaches included COVAMOF, a framework for variability modeling, orthogonal variability modeling, and decision modeling.

**Architectural Design**

Software architects must select mechanisms for modeling variation points or choosing the best instantiation. The main proposed VM approaches for architectural design and evolution are integrated product- and component-based approaches such as SPL integrated technology (SPLIT) and Kobra. Our study also revealed a decision-model approach and an approach to integrate variability into IEEE Standard 1471 recommended practices for architectural description.

**Product Derivation**

Product-derivation issues attracted the second-most research efforts, after variability modeling. The main issues relate to methodological and tool support for building a system based on existing assets.

To derive different products, an SPL system must implement appropriate variation mechanisms at different points in its processes. The main proposed approaches are COVAMOF; Koalish, an architecture-centric product derivation approach; and a tool-based approach for product configuration at the file-system level.

**Variability Evolution**

Variability evolves as a result of adding, deleting, or updating variation points and variants. However, we found little support for systematically and sufficiently supporting evolution in variability models and other related artifacts.

A few studies address the issues explicitly. For example, Feature Description Language (FDL) claims to support evolution of variability models. Another study proposes using two views to model feature variability and dependencies, and another describes a method for detecting and removing obsolete variabilities.

**Tool Support**

SPL systems have far too many variation points, associated variants, and interdependencies for engineers to manage manually. That’s why SPL researchers have invested huge efforts developing several dozen VM tools—too many to list here. Some of the tools have entered the commercial arena. However, the practitioners in our study still reported the lack of integrated, standardized, and end-to-end tool support.

**Process Support**

VM tasks, inputs, and outputs require process support throughout an SPL life cycle. FAST (family-oriented abstraction, specification, and translation) and SPLIT are two prominent approaches to explicitly address VM process-related issues, but nothing yet provides full end-to-end process support. Our data indicated that practitioners recognize this challenge and are keen to find a complete solution.

**Scalability**

A VM approach should not only handle extremely large numbers of variabilities without compromising intuitiveness and comprehensiveness but also support small systems without incurring a huge over-
head. Scalability must be a vital property of any VM approach, but the published literature hasn’t emphasized it. We found only 19 of 261 papers concerned with it.

A few approaches claim to address one or more scalability dimensions. For example, two studies address separation of concerns, another looks at organizing information into a hierarchical structure, and orthogonal variability modeling offers a way to model variability separately from other artifacts. However, no comprehensive solution yet exists.

Quality Assurance Techniques
Researchers have given little attention to QA techniques such as testing, inspections, and reviews of variability models and artifacts. FAST addresses some questions related to product line testing. Inspections and reviews have been completely ignored, although QA techniques for single systems don’t help determine defects specific to SPL variants.

Shared Knowledge and Rationales
Failing to capture VM decisions and rationales makes subsequent product derivations and evolutionary tasks more difficult and risk prone. Our literature review found nothing specifically focused on sharing knowledge about VM decisions. However, practitioners reported severe problems arising from the lack of such knowledge. Our analysis of the interview data indicated a vital need for an approach that explicitly captures and sufficiently represents VM decision rationales.

Assessing the Evidence
More than just listing possible solutions to the technical issues, we also assessed the claimed or reported evaluations of VM approaches in 97 papers selected from 20 years of research. Figure 1 provides an overview of the temporal distribution of evidence types reported in these studies. An overall drop in the studies for which there was no evidence indicates that empirical evaluation improved slightly over the last decade. Still, in 2007, a majority (58 percent) of the studies provided no evidential support.

Looking at the kinds of evidence, we found that two-thirds of the studies were conducted in a laboratory environment with toy systems or a simple example from literature. We characterized these evidence types mostly as example applications, lab experiments-software, lab experiments-human subjects, or simulations, although the mapping isn’t exact. VM is primarily intended to solve the issues of large numbers of variations in commercial-scale applications and their complex dependencies, so approaches relying on these kinds of evidence might be quite challenging to transition into real project use.

We’d like to suggest that SPLE research focus not only on developing effective methods, techniques, and tools but also on rigorously and systematically evaluating them in industrial settings. In the meantime, because domains often have specific VM requirements, practitioners might want to evaluate a VM approach for domain suitability before selecting it for their project.

Figure 1. Distribution over time of evidence types in variability management studies. The percentage of studies for which there was no evidence dropped from 100 percent in 1996 to 58 percent in 2007, indicating some improvement over the decade.

References
organization hidden behind a complex acronym and rather purely commercial practices. Also, maximizing the number of obscure certifications on your resume may simply backfire. But even with a big name, if it offers an enormous palette of certifications driven mostly by commercial interests, the prestige might vanish. So, if you know how to reinstall Windows, you’re not alone.

My final bits of advice: Be clear with yourself why you want a given certificate, for what purpose. And an objective of just personal growth is perfectly laudable. Prefer the certifications that set the bar high rather than the easy ones, or the cheap ones. Look at the longer-term rewards, not only the immediate low-hanging fruit.

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References

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