A Meta-Process to Support Trade-Off Analysis in Software Product Line Architecture

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Abstract—The software product line approach has been applied as a successful software reuse technique for specific domains. Such an approach takes advantage of domain and application engineering concepts. One of its most important artifacts is the product line architecture because it explicitly represents similarities and variabilities of a product line, as well as the products that can be generated. Product line architecture evaluation can serve as a basis for analyzing the managerial and economical values of a product line for software managers and architects. Such an evaluation might be carried out in terms of a trade-off analysis of the architecture quality attributes. Thus, this paper presents a Trade-off Analysis Meta-Process for Product Line Architecture, the TAMPro-PLA. TAMPro-PLA must be instantiated to define the essential artifacts for product line architecture trade-off analysis, such as business drivers, quality attributes, and respective scenarios. Therefore, TAMPro-PLA can be used to carry out product line architecture evaluations. It differs from current literature as it allows the definition and application of product line architecture quality attribute metrics to provide support for performing quantitative and qualitative analysis. A proof of concept example based on the SEI’s Arcade Game Maker (AGM) product line is presented.

Keywords—meta-process, metrics, product line architecture, quality attributes, software product line, trade-off analysis.

I. INTRODUCTION

A Software Product Line (PL) represents a set of systems sharing common features that satisfy the needs of a particular market or mission segment [8], [14]. This set of systems is also called a product family. The family’s members are specific products developed in a systematic way from the PL core assets. The core asset has a set of common features as well as a set of variable parts, which represent later design decisions [14]. The composition and the configuration of such assets yield specific products.

The PL Architecture (PLA) is one of the most important asset of a PL because it abstractly represents the architecture of all potential PL products from a specific domain. The PLA addresses common design decisions, called similarities, as well as its postponed design decisions, called variabilities [16].

The results obtained from a trade-off analysis of PLA quality attributes are important from both academic and industrial view-points due to their potential to increase the productivity and the quality of products, decrease the time to market, improve the PL production capability [8], and to be used as a parameter for evaluating the PL in general [6]. PLA quality attributes take into account variabilities, which increase the effort to evaluate the quality of the overall PL [6]. Thus, we proposed a Trade-off Analysis Meta-Process for Software Product Line Architectures, the TAMPro-PLA.

TAMPro-PLA aimed at analyzing PLA quality attributes in order to prioritize them based on quantitative and qualitative analyzes. Such analyzes are carried out by instantiating TAMPro-PLA, performing its activities and defining its elements for a given PL, such as business drivers, scenarios, and metrics. The instantiation of TAMPro-PLA is illustrated, as a proof of concept, by performing its activities. Such activities generate the artifacts that allow PLA trade-off analysis taking into account the Arcade Game Maker (AGM) [15] PLA complexity and extensibility quality attributes.

This paper is organized as follows: Section II presents important concepts of quality attribute trade-off analysis for single product architectures as well as PLA principles; Section III describes the TAMPro-PLA meta-process, its activities, and essential artifacts for a PLA trade-off analysis; Section IV illustrates the application of TAMPro-PLA to the AGM PL; Section V discusses related work; and Section VI provides final remarks and directions for future work.

II. QUALITY ATTRIBUTE TRADE-OFF ANALYSIS AND PRODUCT LINE ARCHITECTURE

Trade-off is the term used when one wishes to balance one situation or quality against another, in order to produce an acceptable result. With regard to software quality attributes, trade-off analysis means analyzing between multiple conflicting quality attributes to satisfy user requirements and come up with a better overall system [2].

One of the most consolidated method applied in industry to perform software architecture evaluation by means of trade-off analysis is ATAM (Architecture Tradeoff Analysis Method) [4]. ATAM’s trade-off analysis allows discovering architectural problems during early software development phases. The cost to fix such problems in early stages is way less than in later stages.
Trade-off analysis usually takes into consideration the following artifacts of a software architecture [4]: (i) business drivers, which are statements about the architecture’s overall goals; (ii) quality attributes defined for an architecture; and (iii) scenarios specified to exercise such quality attributes by taking into account the business drivers.

As the number of scenarios tends to be large in an architecture evaluation [4], stakeholders usually rank and select the most important scenarios. Thus, a widely known technique, applied in ATAM for instance, is the stakeholders voting. Each stakeholder involved in the evaluation process must assign a priority for each scenario based on predefined factors, such as the importance of a scenario. Then, scenarios are ranked and the most important are taken into consideration for performing quality attributes trade-off analysis.

Trade-off analysis can be performed to a PLA [7], [13] to prioritize its quality attributes for PLA evolution and deriving PL products. PLA differs from a single product architecture as it must represent the single architecture of all products that can be generated from a PL for a specific domain. The PLA gives stakeholders a means to develop multi-product architectures, while keeping their explicit models and visualizations in single product architectures. It results in product reduced cost and high quality. In addition, the PLA encompasses similarities, as well as postponed design decisions, the variabilities [16].

III. THE TAMPro-PLA META-PROCESS

TAMPro-PLA aims at defining artifacts for PLA quality attribute trade-off analysis. This involves the definition of business drivers and scenarios, selection of the PLA quality attributes to be analyzed; definition of managerial and technical questions to be answered with respect to the selected quality attributes; and application of quality attribute metrics to support data collection and analysis.

TAMPro-PLA takes as input the PL quality attributes, PL models, including the feature model. TAMPro-PLA does not depend on specific model notations or approaches. It can take into consideration, for instance, UML models. Regardless their granularity, PL models represent the main source of information to support the definition of the TAMPro-PLA’s artifacts.

The artifacts that can be defined throughout TAMPro-PLA instantiation activities are:

- **Business Drivers (BD)**: represent the main goals of PLA, based on the PLA quality attributes;
- **Defined Scenarios (DS)**: a set of scenarios is defined for each PLA quality attribute;
- **Ranked Scenarios (RS)**: scenarios are ranked based on PLA factors such as cost/risk of a scenario;
- **Managerial and Technical Questions (MTQ)**: they should be answered in order to analyze a PLA and support the quality attribute metrics definition;
- **Quality Attribute Metrics (QAM)**: they are defined to support the prioritization of PLA quality attributes in a trade-off analysis.

Figure 1 presents a UML activity diagram, which represents the TAMPro-PLA’s activities (rounded rectangles) and their inputs and outputs (squared rectangles).

The following items present a brief description of each TAMPro-PLA’s activity:

The **Business Drivers Definition** takes as input the PL Models (PLM) and the PLA Quality Attributes (QA), and defines the Business Drivers (BD) that a PLA should reach to develop products. The defined business drivers support the definition of scenarios and managerial and technical questions, as well as they comprise the modeled PL variabilities.

The **Scenarios Definition** takes as input the Business Drivers, Feature Model (FM), and PLA Quality Attributes. It generates the Defined Scenarios (DS) for each PLA quality attribute to support its selection activity.

The **Scenarios Ranking** takes as input the Defined Scenarios (DS) and their ranked order to prioritize the scenarios.

The **Managerial and Technical Questions Definition** takes as input the Ranked Scenarios (RS) and their associated managerial and technical questions to support the prioritization of PLA quality attributes in a trade-off analysis.

The **Metrics Definition** takes as input the Selected Quality Attributes (SQA) and their corresponding quality attribute metrics to support the prioritization of PLA quality attributes in a trade-off analysis.

Figure 1. The TAMPro-PLA Meta-Process Activities and Artifacts.
narios (DS) in order to rank them based on the following PLA factors: (i) the overall importance of a scenario for the PLA, (ii) scenario generality (mandatory, alternative or optional), (iii) scenario cost/risk associated, and (iv) amount of variability associated to a scenario. It generates as output Ranked Scenarios (RS).

The Scenario-based Quality Attributes Selection takes as input the Ranked Scenarios (RS) and selects which quality attributes will be evaluated for a certain PLA as they tend to be in a large number. Its output is a set of Selected Quality Attributes (SQA), which is a subset of the Quality Attributes (QA) set.

The Managerial and Technical Questions Definition takes as input the Business Drivers (BD), Feature Model (FM), and Selected Quality Attributes (SQA). It defines the Managerial and Technical Questions (MTQ) that might be answered by defining metrics to support trade-off analysis. Such questions are defined with regard to the PLA business drivers, and they take into account the roles involved in the PL process as in [3].

The following items show some examples of roles and questions. More examples can be found in [16]:

- PL Manager: carries out activities such as planning, monitoring, and controlling the PL. Example of PL manager questions are: (i) what is the effective investment for adopting the PL approach for a company? and (ii) which PL configuration is most feasible for a certain domain?.

- PL Architect: in charge of the management of the PLA evolution, as well as for providing quantitative and qualitative design decision support. Examples of PL architect questions are: (i) what is the required amount of effort to develop a product from a PL, based on the PL artifacts and their variabilities? and (ii) what is the impact of adding/modifying/removing the features of/from a PL on its PLA quality attributes?.

The Metrics Definition: takes as input the PL Models (PLM), Selected Quality Attributes (SQA) and the Managerial and Technical Questions (MTQ). It defines Quality Attributes Metrics (QAM) to answer such questions and support data collection and quantitative analysis in PLA evaluations.

Although TAMPro-PLA contains the cited activities, performing all of them are not mandatory. Stakeholders might already have defined, for instance, quality attribute scenarios and/or metrics. Therefore, TAMPro-PLA might be partially instantiated, as predefined artifacts might be incorporated.

IV. TAMPro-PLA Instantiation Example

As a proof of concept, this section illustrates the instantiation of TAMPro-PLA to perform a trade-off analysis to the Arcade Game Maker (AGM) [15] PLA quality attributes.

AGM is a pedagogical PL created by the Software Engineering Institute (SEI) to support learning and experimenting based on PL concepts. It has a complete set of documents, as well as a set of tested classes and source code for three different games: Pong, Bowling, and Brickles. Although AGM is not a commercial PL, it has been used to illustrate the concepts of several different PL approaches, as well as to support performing PL and architecture evaluation case studies [5], [9].

For this example, it is taking into account the AGM models, specially the feature model, as they are provided by the SEI [15]. The feature model, presented in Figure 2, is concerned with four top-level features for AGM products, which are: services, rules, configuration, and action.

In order to illustrate the TAMPro-PLA instantiation, complexity and extensibility quality attributes are considered. Thus, the activities of Figure 1 are realized. TAMPro-PLA takes as inputs the AGM PL models, its feature model and the PLA quality attributes. Therefore, next items present the TAMPro-PLA instantiation by realizing each of its activities.

Business Driver Definition: for the AGM example, we defined two business drivers based on [13] and [7] suggestions, as well as the analysis of the AGM PL models and the complexity and extensibility quality attributes:

- BD.1 - keep game complexity degree lower than 0.7 (70%), compared to the overall PLA complexity, for at least 50% of produced products: uphold low maintainability and low cost rates by focusing on complexity. Complexity degrees can provide an indicator of how difficult is to maintain the products derived from a PLA.
- BD.2 - keep game extensibility degree higher than 0.75 (75%), compared to the overall PLA extensibility, for at least 50% of produced products: maintain high reuse rate by focusing on extensibility. Extensibility factors can provide an indicator of how reusable is a product in terms of its components.
Scenarios Definition: taking into account the feature model, defined business drivers, and PLA quality attributes, Tables I and II present AGM defined scenarios. Features support the scenarios definition by linking a business driver to one or more scenarios and quality attributes.

Table I
AGM DEFINED SCENARIOS FOR COMPLEXITY.

<table>
<thead>
<tr>
<th>Business Drivers</th>
<th>Quality Attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td>BD.1</td>
<td>Complexity</td>
</tr>
<tr>
<td>BD.2</td>
<td>Extensibility</td>
</tr>
<tr>
<td>BD.3</td>
<td></td>
</tr>
<tr>
<td>BD.4</td>
<td></td>
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<tr>
<td>BD.5</td>
<td></td>
</tr>
<tr>
<td>BD.6</td>
<td></td>
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</tbody>
</table>

Table II
AGM DEFINED SCENARIOS FOR EXTENSIBILITY.

Scenarios Ranking: stakeholders might take into consideration the following attribute concerns to support ranking each scenario as High (H), Medium (M), or Low (L):

- its overall importance for the PLA and its business drivers;
- the generality of the scenario with respect to the PLA. It is ranked as mandatory (High), alternative (Medium), and optional (Low) as in [13];
- its cost/risk, i.e., the effort involved in providing proper responses to the scenarios, as well as its perceived risk;
- the number of variability, encompassed by a scenario.

Table III presents the complexity and extensibility quality attribute scenarios ranking for our AGM example.

Scenario-based Quality Attribute Selection: in a trade-off analysis the number of PLA quality attributes can be large. Stakeholders might wish to select a subset of them to analyze. A widely known adopted strategy is the voting system as in the ATAM method [1], [4]. However, stakeholders can define their own strategy. For the AGM example both complexity and extensibility quality attributes are analyzed. However, as a matter of illustration, we present the rationale for it based on Table III: scenarios Sc.1, Sc.4, and Sc.5 are mandatory and have high number of variability and overall importance to the PLA with medium cost/risk; scenario Sc.6 is optional and it has the same ranking for amount of variability and overall importance as Sc.1, Sc.4, and Sc.5, as well as a low cost/risk; scenario Sc.2 is alternative and it has a high amount of variability and cost/risk, with medium importance to the overall PLA; and scenario Sc.3 is alternative and it has a low cost/risk, and high importance to the AGM PLA.

Thus, scenarios Sc.1, Sc.4, and Sc.5 are the most important for the AGM example. Sc.1 is related to the business driver BD.1, whereas Sc.4 and Sc.5 are related to BD.2. Therefore, both complexity and extensibility quality attributes are related to important scenarios and are selected for the AGM example.

Managerial and Technical Questions Definition: Table IV presents questions defined by analyzing the AGM feature model, business drivers, selected quality attributes, and scenarios.

Table IV
AGM MANAGERIAL AND TECHNICAL QUESTIONS FOR THE PLA BUSINESS DRIVERS.

The Metrics Definition activity is not completely presented in this paper, as its realization involves theoretical and empirical validation of metrics. Thus, it was previously defined and validated [11] metrics for complexity and extensibility based on a basic metrics suite [10] for UML models [12]. Therefore, Figure 3 presents a GQM (Goal-Question-Metric) model relating the defined business
drivers, questions and metrics.

Once TAMPro-PLA is instantiated and its artifacts are defined, stakeholders are able to perform a PLA trade-off analysis. As such analysis is usually based on the stakeholders analysis experience and knowledge of the domain, and they do not have a systematic realization of activities, some guidelines are suggested. They allow performing a PLA quality attributes analysis based on the instantiated TAMPro-PLA and its defined artifacts. Such guidelines are as follows:

1) generate a set of PLA configurations (PL products), sufficient to apply statistical normality tests and parametric or non-parametric methods for data interpretation;
2) collect quality attributes metrics from the generated configurations;
3) analyze the collected metrics descriptive statistics and present its important data, such as mean, median, and standard deviation;
4) identify how many scenarios satisfy the analyzed quality attributes and verify if either these scenarios are appropriated to the quality attributes or they must be re-stated; and
5) verify which quality attributes satisfy the PLA business drivers.

Therefore, based on such guidelines, stakeholders might decide which quality attribute(s) must be prioritized for PLA development and evolution. Stakeholders can also: provide potential PL products and PLA analyzes; share all data, keeping it for future analyzes; and write a final trade-off analysis report.

V. RELATED WORK

Current literature presents two main works related to ours. Both are extensions of the ATAM method for PLA evaluation and encompass quality attribute trade-off analysis.

The EATAM (Extended ATAM) method is proposed by Kim et al. [7]. Its main goal is PLA evaluation based on four methods: (i) identification of quality attributes, (ii) identification of architectural views, (iii) definition of PLUC (Product Line Use Case) tags for quality attribute variation points, and (iv) perform ATAM activities to validate the PL products single architecture separately. Basically, they use the first three methods to identify and represent variability and the fourth method to analyze the PL products architecture. The first method is strictly based on four main quality attributes: modifiability, portability, scalability, and extensibility. Thus, ATAM PLA trade-off analysis concerns general PLA quality attributes for qualitative analyzes. EATAM does not take into account nor provides metrics to support PLA quantitative analysis. EATAM provides, by means of the PLUC tag, directions of how to identify and relate scenarios to PLA variabilities which is used to perform trade-off analysis. TAMPro-PLA takes some of these directions to create scenarios. However, TAMPro-PLA does not use specific tags to represent variability as it does not depend on the type of the PL models.

The HoPLSAA (Holistic Product Line Software Architecture Assessment) approach, proposed by Olumofin [13], is aimed at evaluating PLA by means of qualitative analysis of variation point scenarios. It encompasses two stages: (i) PLA analysis and (ii) single product architecture analysis. Its outputs are similar to the ATAM’s outputs. Thus, it allows performing trade-off analysis based on PLA quality attributes during its first stage. HoPLSAA does not explicitly provide quantitative analysis due to its ATAM qualitative nature. In addition, HoPLSAA does not take into account metrics for performing trade-off analysis nor quality attribute metrics to support quantitative analysis. However, HoPLSAA allows the statement of scenarios based on PLA variabilities, providing TAMPro-PLA interesting directions for the scenarios definition activity.
VI. Final Remarks and Future Work

This paper presented the TAMPro-PLA, a Trade-off Analysis Meta-Process for PLA to support performing PLA quality attribute trade-off analysis. TAMPro-PLA provides important artifacts for PLA trade-off analysis, such as: business drivers, scenarios, and metrics. Stakeholders must realize the TAMPro-PLA activities to instantiate TAMPro-PLA and produce its artifacts. As it does not depend on the type of PL models, it can be applied in general to perform PLA analyzes.

TAMPro-PLA differs from existing trade-off approaches as it both provides activities, that are realized systematically to produce essential trade-off analysis artifacts for a PLA, and allows the definition and application of quality attribute metrics, corroborating its quantitative and qualitative analysis results.

An example of how to instantiate TAMPro-PLA for quality attribute trade-off analysis of the Arcade Game Maker (AGM) PLA was demonstrated. In addition, guidelines to perform PLA trade-off analysis were suggested. At the end of the trade-off analysis process, stakeholders are able to: (i) decide which quality attribute(s) must be prioritized for PL development and evolution; analyze the potential PL products to predict their generation behavior; confirm the PLA accuracy of its modeled variabilities; share all data, keeping it for future analyzes and write a final trade-off analysis report; and use performed trade-off analyzes as parameter to evaluate overall PLs.

Based on current results, some directions for future work and contribution might be: (i) the application of TAMPro-PLA to a commercial PL; (ii) the establishment of TAMPro-PLA’s feasibility and effectiveness by carrying out experiments taking into account well-qualified industry professionals; (iii) the definition of relevant PL domains to apply TAMPro-PLA in several case studies; (iv) the development of an automated tool to support the TAMPro-PLA instantiation, as well as trade-off analysis; (v) the investigation of how TAMPro-PLA can provide Model-driven Architecture (MDA) support for definition and transformation of PL models; and (vi) how to incorporate TAMPro-PLA into PL evaluation approaches.

REFERENCES


