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Empirical validating the cognitive effectiveness of a new feature diagrams visual syntax

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ABSTRACT

Context: Feature models are commonly used to capture and communicate the commonality and variability of features in a Software Product Line. The core component of Feature models is feature diagrams, which graphically depict features in a hierarchical form. In previous work we have proposed a new notation that aims to improve the cognitive effectiveness of feature diagrams.
Objective: The objective of this paper is to empirically validate the cognitive effectiveness of the new feature diagrams notation in comparison to its original form.
Methods: We use two distinct empirical user-studies to validate the new notation. The first empirical study uses the survey approach while the second study is a subject-based experiment. The survey study investigates the semantic transparency of the new notation while the second study investigates the speed and accuracy of reading the notation.
Results: The results of the studies indicate that the proposed changes have significantly improved its cognitive effectiveness.
Conclusions: The cognitive effectiveness of feature diagrams has been improved, however there remains further research for full acceptance of the new notation by its potential user community.

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1. Introduction

Software product line engineering is emerging as an effective development paradigm that enables flexible response and mass customization [45]. Software product line engineering considers all development aspects for producing a set of related products that share more commonalities than variations [5]. Software product lines allow for mass customization, which is defined by Tseng and Jiao [59] as "*producing goods and services to meet individual customer's needs with near mass production efficiency*", in mass production environments [5]. Traditional mass production lines no longer suffice market needs and hence mass customization becomes a critical factor for development success [45].

Features in a software product line are commonly specified as feature models. A feature model consists of one or more feature diagrams, a system feature catalogue, issues and decisions, and composition rules [29]. Feature diagrams provide a visual summary of the features in a software product line in a hierarchical form with different logical relationships amongst the features. Kang et al. [29] first introduced the visual language of feature diagrams in 1990. Similar to other types of diagrams, feature diagrams are created to brainstorm and convey the mental model of a modeler to a reader of the model. This paper sheds light on the cognitive effectiveness of the visual language of feature diagrams. In the software engineering notations domain, cognitive effectiveness is defined as "*the speed, ease and accuracy with which a representation can be processed by the human mind*" [38]. The cognitive effectiveness of diagrams is a very important aspect to consider. If feature diagrams suffer from a low level cognitive effectiveness, then there is a high likelihood that the reader of the diagram will misread or misinterpret it. Consequently, the intrinsic goal of the modeling exercise has failed. In particular with feature diagrams, this may lead to the development of end products that do not possess the correct set of features as intended by its stakeholders.

Feature diagrams have garnered the focus of many researchers since its introduction in 1990. Many of these research works have been directed towards enriching the visual syntax of feature models to extend its expressiveness to capture additional semantics and operations. Certainly such research works provide invaluable contributions. However, evaluating and improving the cognitive effectiveness

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of feature diagrams have little attention from the research community, which is arguably equally as important to consider and research.

In summary, many research works focused on enabling the modeler, but few have focused on enabling the model reader. The most likely reason that this important stream of research has been neglected is the lack of a theoretical basis to conduct notation evaluations [36]. This fact has recently changed as a theoretical basis to conduct notation evaluations scientifically has been proposed in 2009 by Moody [36]. The result of Moody's work is the Physics of Notations (PoN) framework which consists of a set of nine principles for evaluating and designing cognitively effective notations in what is considered the seminal paper in the area of cognitive effectiveness evaluation in the software engineering field. Moody defined the nine principles based on theory and empirical evidence mainly from the cognitive science field, amongst other fields. These principles do not focus on the semantic expressiveness of a notation but rather focuses on their visual perception. In previous work [52], we have ventured into a new stream of research for feature diagrams modeling by presenting an evaluation of cognitive effectiveness of the feature diagrams visual syntax using the nine principles defined in [36]. The results of the evaluation reveal many suboptimal design aspects of the feature diagrams visual syntax. In Saeed et al. [63] we presented suggestions to improve the feature diagrams notation in line with Moody's nine principles.

Despite the proposed new notation being based on Moody's nine evidence-based principles, the proposed improvements will remain as mere heuristics unless they are empirically proven. Empirical validation is performed via two user studies. In this paper we provide a more comprehensive evaluation and presentation of the original notation and the proposed notation. However, the main contribution this paper is to present the two empirical validations. The first empirical validation is survey-based and its goal is to evaluate the semantic transparency of the new notation. The second empirical validation is subject-based and its goal is to investigate the effect of the new notation on how quick and accurate its readers can read it in comparison to the original notation.

The remainder of this paper is organized as follows: a brief background on feature diagrams is presented in Section 2. A discussion of related works is presented in Section 3. The evaluation results of the feature diagrams visual syntax are presented in Section 4. In Section 5, the suggestions for improvements to the feature diagrams notation are presented. Section 6 presents a survey-based empirical study to validate the suggested notation improvements. Section 7 presents a subject-based empirical study to provide further validation of the suggested notation improvements. Finally, Section 8 concludes and suggests future work.

2. A brief background on the feature diagrams visual syntax

In this section we provide a brief background on feature diagrams. A review of the literature was required to identify the most state-of-the-art and canonical notational constructs due to the absence of a formal standard for feature diagrams. The conducted evaluation was based on this derived set of notational constructs. Feature diagrams first appeared in the literature as part of the Feature Oriented Domain Analysis (FODA) [29]. Feature diagrams of FODA are referred to as FODA FD. Fig. 1 presents the original form of feature diagrams.

Many research works have since extended the notational set of feature diagrams in order to increase the semantic expressiveness of feature diagrams ([5], 2005; [11,12,25,30,54]). Other types of variability models have been introduced to provide alternative views to FODA FD, such as the Common Variability Language (CVL) [27] and Orthogonal Variability Model (OVM) [45]. CVL and OVM were introduced to allow modelers to express variability in relation to a base model (for example, a UML model). We consider FODA FD in this paper as it is arguably the most prominent visual notation of variability models.

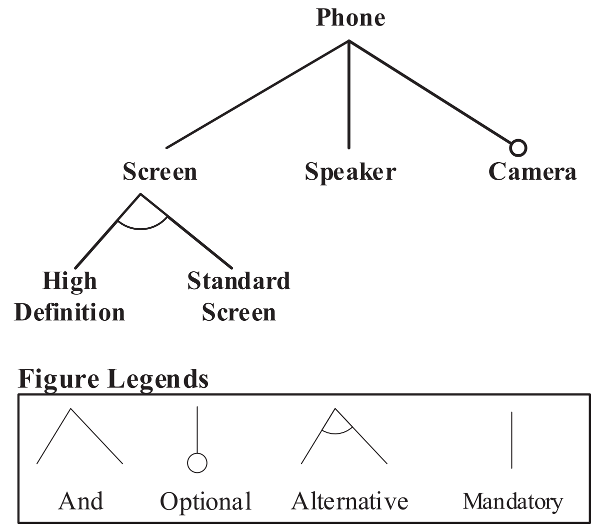

Fig. 1. The original FODA feature diagrams notation set [52].

The notational set of FODA FD and a brief definition of each symbol's semantics are shown in Table 1 (previously presented in Saeed et al. [52]). The literature references where each symbol was first introduced are also presented in Table 1. It should be noted that the FODA FD notational set shown in Table 1 has not appeared entirely in any one research work. Fig. 2 presents an example FODA FD that shows the entire notational set which we used in this paper as a basis of our evaluation. To the best of the authors' knowledge, this notational set is the most state-of-the-art and canonical notational constructs for FODA FD. The inclusion criteria are as follows:

- Is the given notational construct related to FODA FD?
- Is the given notational construct used in newer papers that also refer to FODA FD?
- If a replacement construct is presented in a newer paper, has the replacement been consistently used in newer papers that also refer to FODA FD?

3. Related work

Perhaps the most relative research is that presented in Reinhartz-Berger and Figl [51]. In Reinhartz-Berger and Figl [51], the authors conducted an experiment to evaluate the comprehensibility of the orthogonal variability modeling languages CVL [27] and OVM [45]. The results of the experiment indicate that CVL and OVM did not differ with respect to comprehensibility as subjects were able to complete the assigned tasks in proximate times. However, the subjects rated CVL as more comprehensible than OVM. The authors speculate that this preference is due to shortcomings in the visual notation of OVM.

The area of visual notation evaluation has been increasingly gaining attention in the research community. An evaluation of BPMN (Business Process Modeling Notation) [40] was presented in Genon et al. [20]. BPMN is a notation for modeling business processes with an aim to be easily understood by all stakeholders. The evaluation found several shortcomings according to the principles of cognitive effectiveness that hinder its comprehension by some of its stakeholders. The authors of Genon et al. [20] argue that multiple dialects are required for different classes of users as it is difficult to have one dialect that is easily understood by all. In the broader area of business process modeling there has been another study that used Moody's principles to determine the influence of notational deficiencies on process model comprehension [18]. The empirical study presented in Figl et al. [18] analyzed four different symbol sets. The results of the study have shown that notational deficiencies have negatively