Visualizing the Maintainability of Feature Models in SPLs

Luan Lima[1], **Anderson Uchôa**[2], **Carla Bezerra**[3], **Emanuel Coutinho**[3], **Lincoln Rocha**[1]

[1]Federal University of Ceará (UFC), Fortaleza, Brazil

[2]Pontifical Catholic University of Rio de Janeiro (PUC-Rio), Brazil

[3]Federal University of Ceará (UFC), Quixadá, Brazil

luan_pereira_lima@alu.ufc.br, auchoa@inf.puc-rio.br

{carlailane,emanuel.coutinho,lincolnrocha}@ufc.br

Abstract. *This paper presents data visualizations obtained from the application of 15 measures used to support the maintainability evaluation of Software Product Line (SPL) and Dynamic SPL (DSPL) Feature Models (FMs). To identify these visualizations, we applied a survey to classify a set of 40 measures for evaluating the (D)SPL FMs maintainability. Five visualizations were designed from this classification to analyze the extensibility, static variability, dynamic variability, and structural complexity of the FMs. As result, the experts concluded the designed visualizations assist in FMs maintainability interpretation.*

1. Introduction

Feature Models (FMs) are essential for modeling the variabilities of software intensive-systems [Asadi et al. 2016], such as Software Product Lines (SPL) and Dynamic SPL (DSPL). A well-designed FM makes easier the product configuration, helps identify poor decomposition of functionalities into features [Cafeo et al. 2016] and maps the requirements from the viewpoint of many stakeholders. However, a real development setting implies a high number of product configurations, which makes the FMs complex.

Maintainability measures have been shown helpful to support the maintenance of feature models [Bezerra et al. 2015]. Also, domain engineers might find difficult to assess several measures for multiple feature models [Bezerra et al. 2018]. Therefore, techniques that summarize maintainability measures, such as data visualization, may help domain engineers in the maintainability of feature models. Due to the limited knowledge provided by the literature on the topic, this paper assesses whether *maintainability measure visualizations are effective means to support the analysis of feature model maintainability.*

Visualization has mainly been applied in several areas of Software Engineering, including the support to FM configuration [Thüm et al. 2014, Asadi et al. 2016, Lopez-Herrejon et al. 2018]. However, to the best of our knowledge, we did not find studies on the visualization of maintainability measures for FMs. We hypothesize that visualizations are effective means to support the assessment of FM maintainability. [Shneiderman 1996] classified visualization techniques by data type and tasks. The techniques can be: one-dimensional (1D), temporal, two-dimensional (2D), three-dimensional (3D) and multidimensional (nD), directed to the visualization hierarchies and relationships (graphs), and can support tasks to obtain an overview, zooming, filtering, identification of relationships, history maintenance actions and extracting various information.

Thus, this paper presents an empirical study to identify visualizations that support the assessment of feature model maintainability. We summarize our main contributions as follows: (i) We first investigate visualizations as means to support the assessment of FM maintainability; (ii) through a survey with (D)SPL experts, we summarize an extensive catalog of maintainability measures from the literature. We aimed at supporting researchers and domain engineers to maintain their FMs; (iii) we survey (D)SPL experts to evaluate the defined visualization types, aimed at assessing whether these types fit the expectation of (D)SPL experts. Thus, the defined visualizations represent a sufficient starting point toward more robust visualizations for FM maintainability.

2. Related Work

Previous works [Cafeo et al. 2016, Duszynski et al. 2019, Hinterreiter et al. 2020] discussed the maintenance of FMs. [Cafeo et al. 2016] discussed the inherent difficult of decomposing the SPL functionalities into features, which consequently affect the maintenance of FMs. [Duszynski et al. 2019], proposed to use relation graphs for improved understanding of FM, supporting model maintenance, evolution, and configuration. [Hinterreiter et al. 2020] presented a visualization approach to extend FMs with feature evolution plots as a means to increase awareness about feature-level changes in distributed development scenarios. In summary, previous work agrees with the need for maintaining FMs. However, there is limited empirical knowledge on how to support developers in the maintenance of FMs.

[Bezerra et al. 2017], have proposed a measures catalog (denoted by COfFEE - CatalOg of measures for Feature modEl quality Evaluation) to support the quality evaluation of an FM maintainability. This catalog is composed of 40 measures (8 are specific for DSPL and can be used with conventional SPLs). The sub-characteristics of COfFEE catalog related to the FM maintainability are: Analysability, Cognitive Complexity, Extensibility, Flexibility, Modularity, Structural Complexity, Static Variability and Dynamic Variability. In this study, we used the measures subset of the COfFEE catalog to design visualizations to obtain a better quality interpretation and understanding of one or more (D)SPL FMs. In this work, we have designed five visualizations that assist in the maintainability interpretation of the SPL and DSPL FMs, from the values obtained with the application of 15 measures [Bezerra et al. 2018].

3. Visualizations for Maintainability Measures of Feature Models

The visualization of maintainability measures of FMs is an important point to improve the understanding of the FMs quality. The use of visualizations has become a viable solution to deduce new knowledge from the relationships between different data. This way, the interpretation of the data obtained from the application of quality measures can help domain engineers in the understanding of the evaluation of the FMs quality. To identify these visualizations, we conducted four phases as follows.

Phase 1: Selecting and Prioritizing Measures and Sub-characteristics. To select and prioritize a subset of measures to design visualizations relevant to the maintainability evaluation of FMs, we applied a semi-structured questionnaire to classify the COfFEE catalog sub-characteristics and quality measures. We counted on the participation of five experts who were selected for their expertise in Domain Engineering (D)SPLs.

Experts are of three different institutions in Brazil. Two experts are master's students, two doctoral students and one Ph.D. All experts have at least two years of experience with (D)SPLs and have worked with at least two projects in (D)SPLs.

In this questionnaire, the experts classified quality measures and sub-characteristics of the COfFEE catalog according to their importance level, using the Likert scale. Each quality measure was evaluated in a range from least important to very important. The questionnaire can be found online[1]. After analyzing the classification of these quality measures, we grouped each quality measure according to its importance level to obtain a subset of the relevant measures to the visualization of the maintainability of SPL and DSPL FMs. Posteriorly, we obtained a subset of 15 quality measures grouped into 4 quality sub-characteristics classified as very important by the experts (see Table 1).

Table 1. Prioritized measures from COfFEE catalog [Bezerra et al. 2017].

Sub-characteristics	Acronym	Measure Name	Measure Description
Structural Complexity	NF	Number of Features	Number of features in the model
	NM	Number of Mandatory Features	Number of mandatory features in the model
	NTop	Number of Top Features	Number of descendants of the root
	CTC	Cross-Tree Constraints Ratio	NFRI/NF Where: NFRI: Number of features involved in the integrity constraints of the feature model
Static Variability	NO	Number of Optional Features	Number of optional features in the model
	NVC	Number of Valid Configurations	Number of possible and valid configurations of the feature model
	RoV	Ratio of Variability	$\sum$(Average number of daughters of the nodes)
Dynamic Variability	NC	Number of Contexts	Number of contexts of a feature model
	NAF	Number of Activated Features	Number of activated features in each context
	NDF	Number of Deactivated Features	Number of deactivated features in each context
	CFC	Number of Context Features in Constraints	Number of features that are related with constraints in a specific context
	CF	Number of Context Features	Number of features that are always present in the feature model, regardless of the context that is enabled
	AFCA	Number of Activated Features by context	Number of activated features in a specific context / NC
	DFCA	Number of Deactivated features by context	Number of deactivated features in a specific context / NC
Extensibility	FEX	Feature Extensibility	FEX = NLeaf + SCDF + MCDF Where: NLeaf: Number of children without features SCDF: Single cyclic dependent features MCDF: Multiple cyclic dependent features

Phase 2: Identifying and Prioritizing Questions to Design Visualizations. Using the same questionnaire of the Phase 1, we asked the experts what possible questions could be identified to design visualizations for the measures and sub-characteristics of the COfFEE catalog, where the experts specified *what*, *why* and *how* each question could be represented visually. As a result, we identified a set of 7 questions related to the 4 sub-characteristics, and 15 measures prioritized in the previous phase were selected and prioritized. This set of questions is presented in Table 2. Based on these questions, we design different visualizations that answered the selected subset questions. In the next subsection, the process of design these visualizations are discussed in detail.

Table 2. Set of selected questions.

ID	Question Description	ID	Question Description
Q1	Which feature model is easy to extend?	**Q5**	What is the impact that the software product line would suffer to extend a particular feature?
Q2	What is the dynamic variability of the feature model?	**Q6**	What is the evolution of the complexity of the feature model when a feature is added or removed?
Q3	Which of the contexts present in a feature model has a greater dynamism in activation and deactivation of features?	**Q7**	What is the increase in the number of configurations from the inclusion of new features?
Q4	What the complexity of the feature model?		

Phase 3: Designing Visualizations. Using the prioritized questions (see Table 2), we designed visualizations based on the subset of 4 sub-characteristics and 15

[1]Study questionnaire script - http://bit.ly/2jeEJoM

measures to answer these questions. These visualizations are presented in Subsection 3.1 and developed for the DyMMer tool. DyMMer is a tool developed to support the automatic maintainability analysis of FMs from the set of measures of the COfFEE catalog [Bezerra et al. 2016]. However, the tool does not yet present an efficient way of visualizing the data collected from the quality measures. Thus, to design visualizations that respond to the subset of selected questions, we extended the DyMMer tool by adding a data visualization layer and a measures visualization process. Aimed at designing the visualizations, we used *JavaScript* programming language, with the libraries *Chart.js*[2] and *D3.js*[3]. These libraries have several forms of data visualization, and they are widely used in industry and academia. In the next subsections, the visualization process added to the tool will be presented, as well as the designed visualizations, to answer the subset of questions presented in Table 2.

Phase 4: Measures Visualization Process. To validate the maintainability visualization of FMs, we added to the DyMMer tool a set of FMs extracted from the *MAcchiaTO dataset*, *AFFOgaTO dataset* and *ESPREssO dataset* [Bezerra et al. 2016]. These datasets are available online[4].

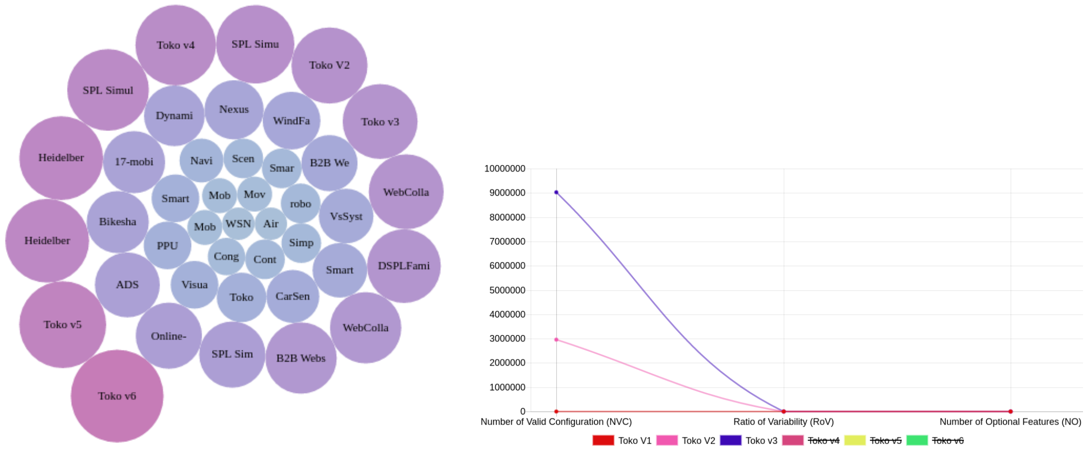
3.1. Visualization of Measures Subset

To answer the subset of questions presented in Table 2, we designed five different visualizations. These visualizations and their respective questions are:

Extensibility of the FM (Q1). FEX measure captures the extensibility of the FM. Extensibility refers to the ability to extend an FM and the level of effort required to implement the extension [Bezerra et al. 2017]. Analyzing the extensibility, it is possible to identify if a specific FM is easy to extend if compared to its different versions or other FMs. The larger the FEX, the higher the extensibility of the FM. Figure 1(a) presents a two-dimensional (2D) visualization, using circular visual representations that correspond to an FM. This graph is a variation of the scatter plot. However, it does not use axes to represent categories. It encodes data in the circles' area. Although less perceptually-accurate than bar charts, it can pack many values into a small space. The FMs with a larger size, darker colors, and more distant from the center have higher FEX that the FMs are more centralized, while the smaller and more centralized FMs with light colors have lower FEX. Thus, the *Toko V6* respectively have the largest and smallest FEX.

Static Variability of the FM Versions (Q7). The following measures in Table 1 can represent the static variability of an FM: NVC, RoV, and NO. Variability refers to the ability of an artifact to be configured, customized, extended, or changed for use in a particular context [Bezerra et al. 2017]. Figure 1(b) presents a two-dimensional (2D) visualization, using the line graph as a visual representation to illustrate the evolution of the static variability in versions of an FM from the values obtained for each measure. The lower the value of the measures of variability, the lower the variability. This visualization selects different versions of an FM and, then, it represents the values obtained with the application of the measures by versions. From the visualization, we can see when comparing the V1, V2 and V3 versions of the *Toko* FM, the V3 version has a higher NVC than

[2] http://www.chartjs.org
[3] https://d3js.org
[4] Datasets - http://bit.ly/2qKiOF5



(a) (b)

Figure 1. (a) Visualizing the extensibility of FMs e (b) Visualizing the static variability of the FM versions

the V1 and V2 versions. In contrast, the RoV and NO do not have any variations, so the V3 version of the *Toko* FM has greater static variability.

Dynamic Variability (Q2 and Q3). Dynamic variability (i.e., variability at runtime) of a FM can be represented by the following measures in Table 1: NC, NAF, NDF, CF, CFC, AFCA and DFCA. The dynamic variability is applied only to DSPLs FMs. The FM that we consider are that the context is represented along the FM. The dynamic variability is the level of adaptation of the FM with respect to context features, context adaptations, and constraints of the FM [Bezerra et al. 2017].

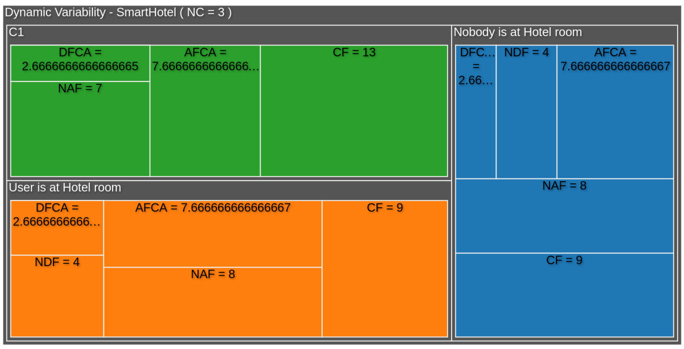
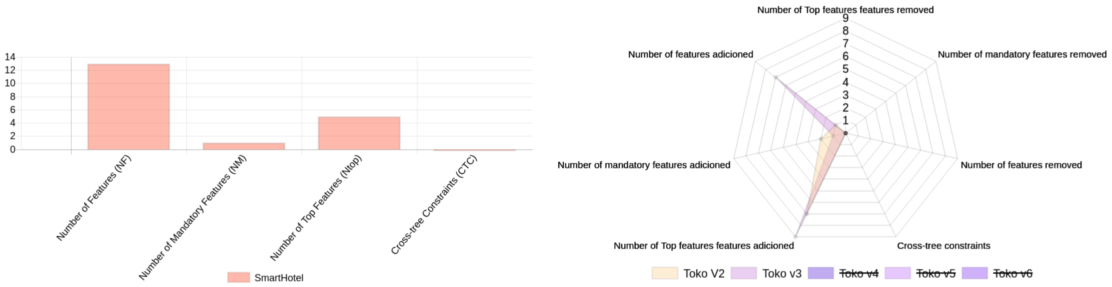


Figure 2. Visualizing the dynamic variability.

Figure 2 presents a two-dimensional (2D) visualization, using the TreeMap graph as a visual representation to illustrate the values of the measures of each context present in an FM. The TreeMap graph is a hierarchical display structure where there is a distribution of data within a limited space, as well as its subdivisions, and where the size of its dimensions is proportional to the associated numerical value. This figure allows the identification of aspects or problems that stand out by simply visualizing the areas that stand out, facilitating decision making. Dynamic variability is characterized by the presence of context and context constraints in an FM. The lower the values of dynamic variability measures, the lower the dynamic variability. Figure 2 presents three different contexts of dynamic variability: (i) "*C1*"; (ii) "*Nobody is at Hotel room*"; and (iii) "*User is at Hotel room*". For each context present in the FM, the values of the measures associated with



(a) (b)

Figure 3. (a)Visualizing the structural complexity of a FM e (b) Visualizing the structural complexity of the FM versions

dynamic variability are presented. Measures that are not shown in the visualization have a value equals to zero.

Structural Complexity of an FM (Q4). Structural complexity of an FM can be represented by measures in Table 1: NF, NM, NTop and CTC. Structural complexity is related to understanding the structure of the FM [Bagheri and Gasevic 2011]. The lower the value of the measures of complexity, the lower the complexity of the FM. Figure 3(a) presents a two-dimensional (2D) visualization, using the bar graph as a visual representation of the values of the measures. In Figure 3(a), the values of each measure are presented. Thus, the higher the height of the bar, the greater the value associated with a measure.

Structural Complexity of the FM Versions (Q5 and Q6). The evolution of the structural complexity can be represented by the versioning of an FM, analyzing the variations of the following measures: NF that were added and removed, NM that were added and removed, NTop that were added and removed, and CTC in each version. Figure 3(b) presents a two-dimensional (2D) visualization, using the radar chart to illustrate the evolution of the structural complexity of an FM according to its versions. A radar chart displays multivariate data in the form of a two-dimensional chart of three or more quantitative variables represented on axes from the same point. In this visualization, different versions of an FM are selected and analyzed from the values obtained for each measure. In this visualization, six different versions of the *Toko* FM were analyzed. The visualization shows that when comparing V2 and V3 versions, there was an increase in the number of features (7), mandatory features (1), the number of top features (9), and no features have been removed.

4. Results and Findings

To validate the visualizations, the application of a semi-structured questionnaire was conducted to verify if the visualizations answered the subset of questions shown in Table 2. The questionnaire included a mix of close-ended and open-ended questions, and it was available online. The open-ended questions allowed the experts the possibility to provide feedback on the visualizations. The close-ended questions followed Likert scales with the following items: (i) totally agree; (ii) agree; (iii) indifferent; (iv) disagree; and (v) totally disagree. The questionnaire used to validate the visualizations can be found online[5]. It

[5]Validation questionnaire script - http://bit.ly/2jnCB9g

is important to highlight that for each visualization, interpretation, and initial description of its visual elements was provided to each expert. For the data analysis, we performed a qualitative analysis. The analysis of the close-ended questions was conducted through a frequency analysis of each item of the questionnaire. The open-ended questions were analyzed based on the expert's feedback on each visualization interpretation. For each question, we present their corresponding visualization. Moreover, we asked each expert if, from the interpretation of the visualization, it was possible to answer their corresponding question, according to Table 3.

Table 3. Results of questions from the experts' answers.

ID	Results of questions
Q1	Extensibility is an important feature of the maintainability of FMs because it verifies whether models can accommodate new features with low effort. All experts totally agreed the designed visualization aided in interpreting which FM is easier to extend whether compared with a set of FMs. The experts did not present any observation about the visualization.
Q2	The majority the experts (60%) totally agreed the designed visualization aided in interpretation and analysis of the dynamic variability of a FM, while (40%) partially agreed and did not present any observation about visualization. Probably the (40%) of non-agreement is due to the fact that all measures of the dynamic variability are present in a single visualization.
Q3	The majority the experts (80%) totally agreed that from the visualization it is possible to identify which context present in the FM presents a greater dynamism, while only (20%) of the experts agreed. However, the experts observed if the dynamic variability of the FM corresponds to the number of activated and deactivated features in a given context, the designed visualization answers the question completely. Meanwhile, if there is a need to know which features have been activated or deactivated, the visualization is not able to answer the question.
Q4	Complexity is a critical factor in the FM maintainability. As the model grows, the complexity of the model's structure grows. Due to this, all experts totally agreed the designed visualization aided in interpreting the complexity of the FM. The experts did not present any observation about the visualization.
Q5	The majority the experts (80%) totally agreed that from the visualization it is possible to identify the impact that the software product line would suffer to extend a particular feature, while only (20%) of the experts disagree of visualization. Although, (20%) from the experts disagree to the visualization, they did not present any observations.
Q6	In the same way that complexity affects the first version of the features model, the insertion, deletion or changes of features also impacts the evolution of a FM, increasing or decreasing its complexity. Due to this, all the experts totally agreed the designed visualization assisted in the interpretation of the evolution of the complexity of the FM. The experts did not present any observation about the visualization.
Q7	All experts totally agreed the visualization assisted in the interpretation of the correlation between the inclusion of new features and the increase in the number of configurations of the FM. This agreement is due to the fact that the increase in the number of configurations of a FM is directly related to the increase of the model variability. The experts did not present any observation about the visualization.

From of results analysis, it is possible to state the visualizations created to analyze the SPL and DSPL FMs maintainability through the interpretation of the extensibility of the FM, dynamic variability, structural complexity of the FM, structural complexity and static variability of the FM versions, could be useful support for domain engineers. The experts indicated that most of the visualizations provided them with adequate assistance to evaluate the maintainability of FMs. Only the question (Q2), related to the dynamic variability, obtained a partial agreement of the specialists. It is probably necessary to indicate other forms of visualizations for representing the dynamic variability. However, we understand it is necessary to evaluate the visualizations with more experts to gather more concrete results.

Some limitations of our study can be reported. Although the number of experts was reduced, they were selected based on previous experiences in SPL, DSPL and software maintainability. The measures may not reflect all aspects of maintainability of FM, but experts agreed that they are very important. A threat to validity of the study is that no criteria were used to choose visualizations. On the visualizations, there may be other more appropriate visualizations to analyze the maintainability of FM. Still, the visualizations were presented and selected based on the measures that were considered very important by experts. In this way, the selected visualizations represent an initial step toward more robust visualizations for the interpretation of FM maintainability.

5. Conclusion and Future Work

In this work, we presented visualizations to support FMs maintainability interpretation. We selected and prioritized a subset of 15 quality measures grouped into 4 quality subcharacteristics extracted from the COfFEE catalog according to its importance level, from the application of a questionnaire with experts. As a result, the experts concluded the designed visualizations assist in FMs maintainability interpretation. The visualizations presented in this study represent an initial step toward more robust visualizations for the FM maintainability interpretation. As future work, we plan to design new visualizations that answer a larger set of questions related to maintainability and other quality characteristics that assist in the FMs evaluation. In addition, we also plan to conduct an exploratory study on the maintainability evolution of the FMs based on visualizations interpretation.

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