Ubiquitous, Pervasive and Mobile Computing: A Reusable-Models-based Non-Functional Catalogue

Milene Serrano[1] and Maurício Serrano[1]

[1] Universidade de Brasília (UnB/FGA), Curso de Engenharia de Software, Brasil.

{mileneserrano, serrano}@unb.br

Abstract. This paper reports on experiences in the development and use of a non-functional catalogue based on Goal-Oriented Requirements Engineering. This catalogue is specific for ubiquitous, pervasive and mobile computing domain, and it represents a common baseline focused on the concerns of this domain, their interdependencies and operationalizations. Moreover, our reusable models-based catalogue has been thoroughly evaluated by using different ubiquitous contexts. Therefore, it is in constant evolution. According to our evaluation process, the reuse of existing and shared models demonstrates, among others benefits, that: (i) it offers a suitable and reusable body of knowledge to deal with ubiquitous, pervasive and mobile quality criteria; and (ii) it reduces elicitation time and team efforts while working with non-functional issues. We also present an overview about the catalogue's development process, emphasizing the last obtained refinements.

Keywords: Non-Functional Requirements; Goal-Oriented Requirements Engineering; Reusable-Models-based Catalogue; Ubiquitous, Pervasive and Mobile Computing; Systematic Development.

1 Introduction

In the Ubiquitous, Pervasive and Mobile Computing domain, we must consider different issues, such as: devices heterogeneity, content adaptation, context awareness, mobility, ever-changing environments, and content server distribution. Various authors (e.g. [1][2]) agree with the fact that these issues are real concerns in that domain. Therefore, these concerns are intrinsic and commonly found when we are, for example, developing ubiquitous, pervasive and mobile systems and applications.

Although there is a consensus about the importance of those issues, unfortunately, there is a lack of support - for the mentioned domain - in order to guide developers from the requirements elicitation to implementation, specially while respecting non-functional requirements. Moreover, we know that the requirements engineering activities demand an adequate conceptual modeling support to be appropriately performed.

In order to contribute to this field, we have dedicated part of our work to develop a non-functional requirements catalogue, specifically for Ubiquitous, Pervasive and Mobile Computing domain. We also provide a method for using this catalogue to guide systematic developments by considering applications in this domain. Both, the catalogue as well as the method, are in constant refinement to attend new demands in this domain, in which the evolution is inherent to deal with emergent technologies.

Additionally, it is important to emphasize that the catalogue is constructed by using the NFR Framework. This framework was first proposed by [3], and it constitutes a Goal-Oriented Requirements Engineering (GORE) [4] approach for capturing non-functional requirements, by also defining their interdependencies and operationalizations. This kind of approach is interesting as it ends where the traditional approaches, i.e. Object-Oriented approaches (e.g. Rational Unified Process (RUP)), start. In other words, GORE approaches focus their contributions on activities that precede the requirements specification to facilitate the validation of architectural decisions. Therefore, the NFR Framework offers support to: (i) design alternatives for dealing with different non-functional issues; (ii) consider conflicts, tradeoffs and priorities, and (iii) evaluate the decisions impact based on non-functional isues that commonly influence the success of ubiquitous, pervasive and mobile applications.

In this paper, we briefly present our catalogue and its contributions. The paper is organized in sections. In Section 2, we mention the goals of our work. In Section 3, we describe the scientific contributions of the proposed non-functional catalogue for ubiquitous, pervasive and mobile applications development by offering an overview of the catalogue's development process and contents. In Section 4, we have the final considerations and, finally, in Section 5, we suggest directions for further work.

2 Objectives of Research

We have been investigated interesting non-functional-requirements-driven approaches, such as [5][6]. However, most of them are issue-specific-oriented and they support specific applications. Therefore, they do not provide a reusable models baseline for applications that do not match with these specific issues and application profiles.

Additionally, there is a lack of approaches that guide the development of ubiquitous, pervasive and mobile applications from the requirements to code, focused on different quality criteria, such as: user satisfaction, device heterogeneity, mobility, content adaptation, context awareness and ever-changing environments.

Considering these timely observations, our research is mainly motivated by the goals: (i) provide a guideline, based on reusable models, for ubiquitous, pervasive and mobile applications in order to orient software engineers from the requirements to code in the development of these applications, and (ii) as our non-functional catalogue is constructed by considering non-functional requirements that are commonly found in ubiquitous, pervasive and mobile applications, it provides generic support, and it also contributes to the reuse of these generic solutions in different applications, whose developers can concentrate their efforts on the specialization of these solutions to better attend specific concerns.

3 Scientific Contributions

Our non-functional requirements catalogue was developed by composing different conceptual non-functional requirements models in order to obtain a common reusable models baseline for ubiquitous, pervasive and mobile applications. In the catalogue's development process, we focused our attention on three main activities, non-functional requirements (1) elicitation; (2) decomposition, and (3) interdependencies identification. In order to perform these activities, we used ubiquitous, pervasive and mobile scenarios in different cognitive domains (e.g. e-commerce, educational and dental), consultation with experts, and our experimental research. Our objective was the elicitation of quality criteria commonly found while developing ubiquitous, pervasive and mobile applications. Moreover, we evaluated the elicited non-functional requirements with the users participation. This process also contributed to the catalogue's evolution and adequacy. Therefore, in practice, the activities described before as well as the evaluation were iteratively performed, by allowing to incrementally develop the catalogue as a knowledge baseline, specific for the domain of interest.

A briefly overview about the catalogue's development are presented through the following phases: (i) **Investigation**, in which we investigated the State-Of-The-Art to compile an adequate initial understanding of ubiquitous, pervasive and mobile concerns. At the end of this phase, we obtained a first version of the catalogue, which consisted of a top-level ubiquitous, pervasive and mobile requirements. Basically, at this stage, the catalogue included three top-level non-functional requirements (i.e. Ubiquity, Pervasiveness, and Mobility), and four sub-non-functional requirements (i.e. Content Adaptability, Context Awareness, Device Heterogeneity and Software Processes Complexity Invisibility); (ii) **Experimental Research**, in which we experimented the first version of our catalogue by using it to systematic develop ubiquitous, pervasive and mobile applications. As the result of our first experimental research, we obtained some interdependencies between the non-functional requirements as well as some operationalizations for them. We also identified the necessity of some improvements in our catalogue first version. Therefore, we evolved it by incorporating the non-functional requirement User Satisfaction as a seminal ubiquitous, pervasive and mobile issue. Moreover, we refined the User Satisfaction, decomposing it on Usability, Content/Service Accessibility, Ubiquitous, Pervasive and Mobile Profile Awareness, and others. This new catalogue version was constituted of 21 non-functional requirements; (iii) **Iterative Evolution**, in which we have performed, since 2007, several iterations in order to evolve the catalogue by following emergent technologies and others ever-changing elements in ubiquitous, pervasive and mobile contexts. Basically, during this phase, we iteratively (a) created new catalogue contents; (b) eliminated replications, redundancies and ambiguous specifications; and (c) improved the reusability condition of the catalogue. Some case studies that are used in this iterative evolution are detailed presented at [7][8][9][10][11][12]; and (iv) **Collaborative Evolution**, in which, based on the fact that we opened our catalogue to scientific community, we have incrementally refined the catalogue according to the feedback we obtained from others ubiquitous, pervasive and mobile groups' projects.

Based on this process, our catalogue's last version is composed of almost 700 interdependent non-functional requirements. They are organized according to their prioritizations in ubiquitous, pervasive and mobile applications. The prioritizations were obtained throughout the last five years. Actually, the non-functional requirements that are most commonly found in the ubiquitous, pervasive and mobile applications development received highest priority. Some of these non-functional requirements are Ubiquity, Pervasiveness, Mobility and User Satisfaction. Therefore, they are at the top-level of the catalogue's non-functional requirements hierarchy. Then, we have 17 non-functional requirements at the second level, which includes: Content Adaptability, Context Awareness, Device Heterogeneity and Transparency. Furthermore, there are almost 200 non-functional requirements at the third level, such as: Self-Regulation, Autonomy, Reactivity, and Controllability. According to our research, these non-functional requirements are applicable to a broad class of ubiquitous, pervasive and mobile applications. As the catalogue is in constant evolution, the refinements also involve refactoring in the non-functional requirements' prioritizations.

In order to improve the use of our catalogue, we developed a Web-application to deal with the huge number of non-functional requirements reusable models shared in our baseline. It facilitates the access of these reusable models and it helps in the presentation and browsing of the catalogue's contents based on an exploration tree to navigate and select a desired non-functional requirements, their meanings, and links to the models of their interdependencies. Moreover, we also developed a method to allow the use of our catalogue as a guideline to orient the systematic development of ubiquitous, pervasive and mobile applications from the requirements to code by focusing on non-functional requirements commonly found in these applications. The catalogue's use method is based on five activities, some of them decomposed on others sub-activities. They are: Explore, Collect, Model, Operationalize and Validate.

The Explore activity is divided into Consult and Extract sub-activities. It assists the developers in catalogue's exploration by improving the investigation of different ubiquitous, pervasive and mobile concerns, and in the knowledge extraction from the catalogue by improving the deduction of what knowledge - i.e. catalogue's predefined non-functional requirements - is pertinent for the application under development.

The Collect activity is composed of Pick-up and Instantiate/Evolve sub-activities. It helps in the requirements elicitation by picking them up from our baseline. The developers can decide to use the requirements as they are specified in the catalogue, or they can instantiate these requirements and evolve them to better attend the specific concerns of the application under development. When the non-functional requirements match with the ubiquitous, pervasive and mobile application's needs, the developers can basically reuse them as they are defined. Although, some adjustments can be necessary. Thus, the non-functional requirements must be instantiated and evolved.

The Model activity is based on Decompose or Determine Interdependencies. It assists in the design by guiding the non-functional requirements modeling. If the developers only picked-up the non-functional requirements from the baseline without the necessity of adjustments, the Model activity is not necessary in this case. The developers can obtain the model from the catalogue and use it as it is specified. However, if the developers modified and adapted the non-functional requirements by instantiating

and evolving them, it is necessary to decompose and/or determine their new interdependencies. We suggest a modeling based on the NFR Framework's notation, which is centered on a graph called Softgoal Interdependencies Graph (SIG). In a SIG, the non-functional requirement is a softgoal that has interdependencies with others non-functional requirements. More about the NFR Framework can be obtained in [3].

The Operationalization activity assists the developers in low abstraction level by offering predefined operationalizations' set, which can be viewed as a set of possibilities and strategies in order to facilitate and guide the implementation of different issues. However, when the catalogue's offered support does not address the developers' needs, it is also possible to establish new support using the developers' expertise.

The Validate activity is divided into Evaluate and Solve Conflicts sub-activities. It helps in the non-functional requirements evaluation using the notion of propagation rules and offspring labels - *denied*, *weakly denied*, *undecided*, *weakly satisfied*, *satisfied* and *conflict* - provided by the NFR Framework [3]. Here, it is possible to check interdependencies using specific correlation rules and also considering the stakeholders' participation. Moreover, it is also possible to identify conflicts in both, non-functional requirements interdependencies and operationalizations. In our case studies, for each application under development, we scheduled meetings with the stakeholders to evaluate the non-functional requirements, their interdependencies and operationalizations by considering specific scenarios to test/investigate the applicability, pertinence and adequacy of the requirements obtained by exploring, collecting, modeling, and operationalizing centered on the catalogue. The method also contemplates the feedback notion, allowing refinements when misconception or misunderstanding occurs from faulty judgment, deficient knowledge or lack of forethought.

4 Conclusions

In this paper, we report on our experiences with our reusable models-based catalogue centered on GORE. The main purpose of our initiative on constructing this catalogue is to provide a common baseline of ubiquitous, pervasive and mobile concerns - i.e. a framework for this domain - in order to guide the development of applications in this domain from the requirements to code. It is possible as the catalogue is centered on different non-functional requirements as well as it contains the interdependencies between these requirements and also possible ways to operationalize them.

The results obtained by evaluating our framework at both, Software Engineering Laboratories at PUC-Rio and at UnB/FGA, indicate that we are in the right direction, mainly if we focus our attention on: (i) improving the elicitation process centered on non-functional requirements of ubiquitous, pervasive and mobile applications; (ii) reducing the spent elicitation time; (iii) reducing the team efforts in dealing with common found ubiquitous, pervasive and mobile non-functional requirements, by allowing that the team concentrate the efforts on specific issues, and (iv) providing a guideline for the developers of ubiquitous, pervasive and mobile applications that orients them from the requirements to code. Thanks to the GORE nature, the proposed framework also maintains the traceability for Requirements Engineering activities.

It is relevant to consider that we are also conscious about our unsolved challenges, such as: (i) the demand of time to maintain and evolve our catalogue; (ii) the necessity of advanced mechanisms for knowledge management and version controller; and (iii) the necessity of a tool support to improve the catalogue's reuse. As presented in Section 5, we have experimented with possible strategies to deal with these challenges.

5 Ongoing and Future Work

In order to maintain our catalogue up to date, we have opened access to our baseline. Our intention is the constant refinement of it by (i) providing more precise methods; (ii) changing the priorities of the non-functional requirements specified into the catalogue, and (iii) incorporating new quality criteria as well as their interdependencies with others criteria, and operationalizations based on emergent technologies. We also envision further work on offering a tool support to facilitate the catalogue's use.

References

1. Weiser, M.: Some Computer Science Issues in Ubiquitous Computing. CACM, vol. 36(7), pp. 75-84 (1993)
2. Landay, J.A., Borriello, G.: Design Patterns for Ubiquitous Computing. IEEE, vol. 36, no. 8, pp. 93-95 (2003)
3. Chung, L., Nixon, B., Yu, E., Mylopoulos, J.: Non-Functional Requirements in Software Engineering. Int. Series in Soft. Engineering, vol. 5, 476 pages (2000)
4. Mylopoulos, J.: Goal-Oriented Requirements Engineering. In: XI Conf. Iberoamericana de Soft. Eng., pp. 13-17 (2008)
5. Pashazadeh, S.: Modeling Non-Functional Requirements in Designing Middleware for Pervasive Healthcare System. In: 5th Int. Conference on Application of Information and Communication Technologies, pp. 1-5 (2011)
6. Kavakli, E., Kalloniatis, C., Loucopoulos, P., Gritzalis, S.: Incorporating Privacy Requirements into the System Design Process. In: vol. 16(2), pp. 140-158 (2006)
7. Serrano, Milene: Reuse-oriented Approach for Incremental and Systematic Development of Intentional Ubiquitous Applications. Doctoral Thesis, 228 p. (2011)
8. Serrano, Milene, Lucena, C.J.P. de.: Dynamic Content Adaptation in Mobile Applications driven by Intentional Multi-Agent Systems. Chapter in the Handbook of Research on Mobile Software Engineering, 18 p. (2011)
9. Serrano, Milene, Lucena, C.J.P. de.: Dynamic Interface Adaptation for Ubiquitous Devices driven by Agents and Ontologies. In: 1st Int. Conf. on Pervasive and Embedded Comp. and Communication Systems, 10 p. (2011)
10. Serrano, Milene; Lucena, C.J.P. de.: Intentional Mobile Agents in Ubiquitous Systems. In: 3rd Int. Conf. on Agents and Artificial Intelligence, 10 p. (2011)
11. Serrano, Milene, Lucena, C.J.P. de.: Applying FIPA Standards Ontological Support to Intentional-MAS-Oriented Ubiquitous System. In: 12th Int. Conf. on Enterprise Information Systems, pp. 114-121 (2010)
12. Serrano, Milene, Serrano, Maurício, Lucena, C.J.P. de.: Ubiquitous Software Development Driven by Agents' Intentionality. In: 11th Int. Conf. on Enterprise Information Systems, pp. 25-34 (2009)