A Computational Framework for Multi-Dimensional Context-aware Adaptation

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ABSTRACT

Most interactive applications often assume a pre-defined context of use of an able-bodied user, a desktop platform, in a stable environment. In contrast, users compose a heterogeneous group, interacting via different means and devices in varied environments; which requires, thus, context-aware adaptation. Adaptation has been largely investigated, but the studies are often constrained to one context dimension at a time: user or platform or environment. To address this issue and to bridge the gap between high-level adaptation goals and implementation of adaptation, this research aims at developing a computational framework for user interface adaptation based on distinct dimensions and contexts of use. This framework consists of four main contributions: a design space to characterize context-aware adaptation of user interface, a reference framework to classify adaptation techniques for distinct scenarios, an ontology of adaptation techniques based on a 3-level Adaptation Rules, and an interpreter of adaptation rules to address techniques defined in the design space and reference framework.

Author Keywords

Adaptation, context awareness

ACM Classification Keywords

D.2.2 [**Software Engineering**]: User interfaces. H.1.2 [**Information Systems**]: Human factors. H.5.1 [**Information Interfaces and Presentation**]: Multimedia Information Systems. H5.2 [**Information interfaces and presentation**]: User Interfaces – *User-centered design*.

General Terms

Human Factors, Design

INTRODUCTION

Adaptation transforms different aspects of the systems, regarding the needs, wishes and preferences of users [2]. An application can also be adapted concerning its context information, such as user profile, platform and environment [4]. The goal of adaptive applications is to improve the interaction providing users proper changes, according to their context. Context involves any information relevant to characterize an entity, typically related to user profiles, states, locations, and the technological resources [5].

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EICS'11, June 13–16, 2011, Pisa, Italy.
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Adaptation can be automatic, manual or combine approaches (mixed-initiative), but it must always take into account the context. Different dimensions in an application can be subject to adaptation, and also in different levels. Previous works grouped the dimensions in: navigation, presentation and content [13], and methods and techniques used in this domain were described [10]. Most studies of adaptation focuses in specific contexts, little attention is devoted to multi-dimensional context-aware adaptation in a unified and consistent way. Current applications rely on a pre-defined context, of an able-bodied user, in a stable environment, with a desktop PC. Actually, nowadays, users, not only compose a significantly heterogeneous group, but also interact via different means and using different devices. Adaptation started to be investigated in the 90's and since then new devices, technologies, applications and approaches arose, evolved and became more popular, e.g., idTVs, RIAs, AJAX and MDE. This thesis aims to develop a framework considering in a structured and systematic way both context information and adaptation dimensions. The main goal is to analyze current adaptation techniques to propose a framework that eases the development of adaptive applications. The specific goals include: a systematic review of the scientific literature to organize adaptation techniques, the definition of a taxonomy to describe context-information, a framework to support the development of adaptive applications, and the validation and evaluation of the developed methods with case studies.

In this paper, Section 2 presents the motivations, Section 3 describes related work, Section 4 explains the contributions of this research and Section 5 presents the final remarks.

MAIN MOTIVATIONS

Many applications domains benefit of context-aware adaptation, like: education (tele-teaching) [2], entertainment (museums) [13], geography (for map locations) [1], and electronic commerce [11]. This is a good motivation to advance the investigation of methodologies that support the implementation of adaptive and adaptable applications. Besides, the offer of new technologies increases, which makes a consistent methodology for user interface adaptation each day more necessary. Brusilovsky [3] stated that for the Future Internet users will be involved in multiple, dynamic and on-demand contexts of use, requiring high adaptation levels. These methodologies should be grounded on a conceptual modeling approach of the adaptation process of user interfaces leading to a computational framework based on these concerns.

RELATED WORK

This thesis aims to develop a computational framework for adaptation considering methods and techniques previously created; this Section summarizes efforts in this domain. As it is a result of an initial literature review, the coverage of related works is still limited. The execution of a Systematic Review, planned for the first phase of the project, intends to gather more information relevant in this domain.

Dieterich classified adaptation configurations and techniques according to four stages for adaptation [6]: *initiative*, *proposal*, *decision* and *execution*. This taxonomy does not cover the full adaptation life cycle (excluding, for instance, the feedback after adaptation) and it only considers that two entities can be responsible for the four stages, i.e. the user or the system (although a third party can be involved or any combination of these entities).

Brusilovsky [2,3] made an extensive effort to classify and structure adaptation techniques, but not explicitly based on context of use (e.g. supporting user, platform, and environment). The adaptation was analyzed concerning *what* (adaptation of what with respect to what), but the context of use was not fully exploited. Moreover, other dimensions of adaptation (e.g., when, how, with which constraints) were not extensively researched, thus raising the need for a multi-dimensional framework for adaptation.

W3C (http://www.w3.org/TR/di-atdi/) documented adaptation techniques, but mainly concerning the platform (device and web browser). This dimension is an important constraint for adaptation, but it is not the only one. The structure of the document of techniques types could be expanded with refined categories, and linked to current techniques.

The Project MyMobileWeb [12] focused also in the creation of an adaptation framework, but for the domain of mobile web applications to multiple handsets and web browsers. Other modalities and platforms were not considered.

The research conducted in context-aware adaptation is often restricted to one dimension. Although each dimension is important and has been investigated, different dimensions influence each other and must be considered integrally. There is a lack of general techniques, methods and tools for adaptation [11], thus the generated systems are inflexible and their adaptation knowledge is hard to reuse. This thesis aims to investigate context-aware adaptation globally, gathering and considering possible dimensions and levels in a unified and consistent way.

A COMPUTATIONAL FRAMEWORK

Shortcomings and Requirements

An initial analysis of the literature revealed shortcomings in the domain of context-aware adaptation. Some of them receive special attention in this thesis; they consist in limitations in current approaches:

1. The context information is usually constrained to one or two dimensions (either user or platform, for instance);
2. The technological space is limited;
3. The methodologies are not extensible or out of date;
4. Current approaches are not unified and consistent (e.g., different names were associated to the same technique);
5. Current approaches do not support the whole development life-cycle.

The concerns and shortcomings observed for context-aware adaptation delineate the problem space of this project. They lead to conclude requirements and improvements in this domain, which consider different dimensions and state that:

1. The information context must be considered broadly;
2. All possible technological spaces must be considered;
3. The methods must be extensible (allowing update);
4. The techniques must be consistent;
5. Methodologies must support adaptation in the entire life-cycle of development (considering, for instance, the feedback from the user to (re)adapt the application).

The methodology presented in the next subsection intends to fulfill these requirements and tackle the shortcomings.

Methodology

In a *first step*, literature is extensively reviewed to gather and analyze adaptation studies. The goal is to identify the state-of-the-art of context information, dimensions, methods and techniques for adaptation. A **Systematic Review** supports and formalizes these tasks. In this review, an initial question is defined, and then the answer is searched with a systematic analysis of documents that report related works. The goal is to gather the state-of-the-art in a specific topic, trends and gaps [8]. Systematic Reviews are time-consuming and require significant efforts to be conducted, however, it is apparently the most appropriate technique in this case, in which many documents need to be analyzed and consistently synthesized to obtain relevant information.

In a *second step* the context-aware adaptation framework will be created based on the results of the systematic review. It includes four methods: a Taxonomy, a Design Space, a Reference Framework, and an Ontology.

The **Taxonomy** lists context information relevant for adaptation concerning user, platform and environment, and organizes it in domains. Figure **1** illustrates a sample of context information of the user. The **Context-aware Design Space** (CADS) identifies design dimensions and levels relevant to accommodate different requirements and scenarios (Figure 2). The CADS supports the whole adaptation life cycle allowing each step being performed by the user, the system, a third party or any combination of them. The CADS addresses 3 virtues of such a design space: *descriptive* to consistently describe an adaptation dimension, *comparative* to identify similarities and differences between two or more applications, and *exploratory* to identify underexplored aspects. A **Context-Adaptation Reference Framework** (CARF) defines adaptation related to the context of use based on the Cameleon Reference Framework (CRF) [4], where the context of use is distributed into user, platform, and environment [16], which are in turn described through an individual model. Each model is based on traditional contextual properties and normative properties, e.g. from W3C Delivery Context Ontology (DCO).

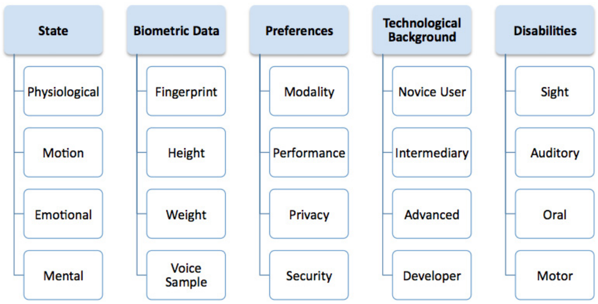

Figure 1. Taxonomy for Context-Information – User example.

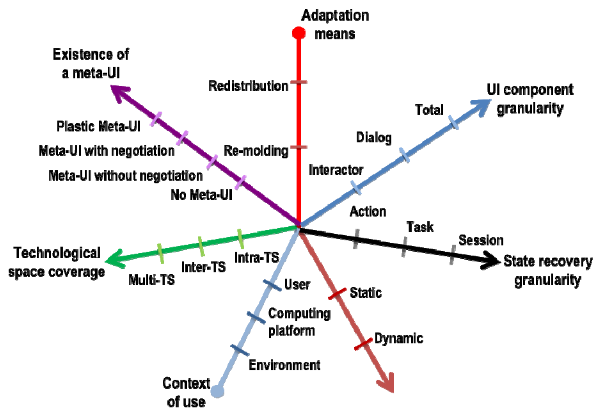

Figure 2. A Context-Aware Design Space composed by 7 dimensions of an application that are related to adaptation.

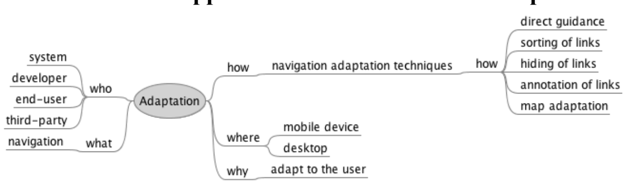

Figure 3. A Context-aware Reference Framework for navigation adaptation, techniques defined by Koch (2000).

Figure 3 exemplifies a CARF for navigation with 5 techniques. A website was created to organize techniques, systematically (with the use of a description template). This template contains 11 information fields, for each technique: the name, description, references, rationale, example, context, advantages, disadvantages, a code sample (e.g. an algorithm), a picture and additional comments. The template can be seen in **Table 1** that details the resizing of text content. The template is being filled for all the techniques gathered with the Systematic Review. The content will be iteratively refined to keep it consistent (e.g. identifying and associating alternative names for identical techniques). The adoption of a well-defined methodology permits constant updates (once new techniques may rise), assuring extensibility. An **Ontology** is a formal and explicit specification of shared concepts [7]. It provides semantic description, classification and relationships among different concerns involved in advanced adaptation logic. It will be the main formalism to support and represent adaptation knowledge.

The computational framework produced will be used during the *third step* to compose adaptation rules based in context information, adaptation dimensions, levels and adaptation techniques. User studies are planned to identify their preferences and to obtain their feedback. An adaptation rule can be considered as *first-order rule* (e.g., any rule for adapting a UI to its context of use such as R1="replace a radio box by a drop-down list if platform is mobile" or R2="replace a radio box with an edit field with codes if platform is mobile with limited entries"), *second-order rule* (e.g., a second-order adaptation rule is a rule that govern other first-order adaptation rules – such as "prefer R1, then R2"), or *third-order rule* (i.e., all adaptation strategies that promote or demote sets of second-order rules, such as "reverse the order of "prefer R1, then R2" if the user is expert") with different adaptation strategies depending on the context of use expressed in a more structured and intelligent way (e.g., by factoring out common parts). These rules can be examined by a parser to select rules proper for specific situations defined along the axes of the CADS. An evolution model to capture the dynamic aspects of context changes over time and space is also planned. The ultimate goal is a system that learns from the adaptations according to designers and end-users. Machine learning techniques, such as *Markov Chain Decision Process*, *Markov Models depending on Features*, *Bayesian Networks*, and *Cross-Entropy Methods* seemed at a first moment to support correctly the automatic and dynamic adaptation in user interfaces. Figure 4 illustrates the enlargement of the size of a push button when the cursor is hovering it in order to speed up the selection and to increase the legibility of the label based on animation techniques [15].

Name	Font Resize
Reference	http://www.w3schools.com/css/tryit.asp?filename=trycss_font-size_px
Description	Change the font size according to the context.
Rationale	Given a text content, an adaptation rule is applied in order to change the text size, increasing or decreasing it.
Example	A visually impaired user accesses a news portal but the font size is inappropriate for reading. The font size can be increased, allowing the user to read the text.
Context	User with visual impairments, small, far screens, content in small sizes.
Advantages	The readability of the text will become possible or it will be improved.
Disadvantages	The flow of the content may change, parts of the text may be hidden, scrolling may be required, the quality of the content may decrease (according to its resolution).
Sample (CSS)	`h1 {font-size:40px;}` `h2 {font-size:30px;}` `p {font-size:14px;}`
Picture	**This is heading 1** **This is heading 2** This is a paragraph.
Comments	The results of the adaptation must be evaluated once the information flow or content distribution may be affected.

Table 1. Template for Adaptation Techniques - Text resize example.

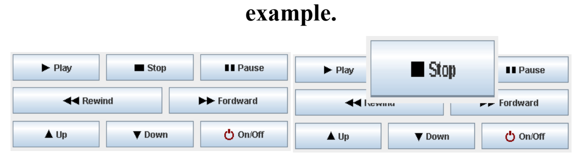

Figure 4. Enlarging the push buttons in a small screen.

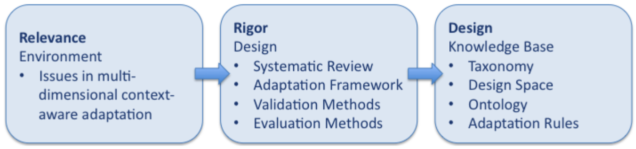

Figure 5. The environment defines the problem and research opportunities; the design artifact and process defines the methodology; and the knowledge base is the research result.

In a *fourth step* case studies for different use scenarios will be used to validate the proposal and evaluate its applicability. Proper evaluation methods will be defined and applied to identify usability issues according to end-users. Possible evaluation methods are *Cognitive Walkthrough*, *Heuristics*, *Questionnaires* and *Interviews*. The case studies will consider different scenarios e.g.: visually impaired users, mobile phones, noisy environments. Varied dimension levels will be combined, for: devices (a mobile phone, an extra-screen), user profiles (children, color-blind users) and environments (driving a car, watching television). Users will also be involved in early stages of the project, in order to obtain their feedback iteratively.

In this project, reference models and meta-models that define different abstraction layers for UI will be considered. Model-Driven Engineering (MDE) techniques may support the definition of transformation rules and the different models. The organization of the design phase in models may help to reduce the gap between the requirements and the implementation. Besides, it may help to coordinate the project efforts, by dividing it in models of different abstraction levels and by mapping the transformation of them [14].

Hevner [8] suggests the use of cycles for understanding, executing and evaluating IS research. In this sense, three activities cycles are considered (Figure 5): *relevance*, *rigor* and *design*. These cycles structure the methodology of the project in (i) *environment*, (ii) *design*, (iii) *knowledge base*.

FINAL REMARKS

It is a challenge to identify all context information relevant for multi-dimensional adaptation. For instance, optimizing adaptation with respect to one dimension may deteriorate the quality with respect to another dimension. Sometimes, the final result is not necessarily better than the initial user interface. Consequently, it is even more challenging to consider this information providing a high usability level and transparency. The excess of adaptation can confuse users, get them lost during the interaction and cause cognitive overloading [13]. During this thesis, iterative evaluations with end-users are planned to handle these issues. The adoption of a scientific and systematic methodology will aid the fulfillment of the requirements identified with the analysis of shortcomings in the domain of context-aware adaptation. Previous works are limited to specific adaptation dimensions. This proposal represents an attempt to unify in a solution all possible contexts of information, as well as adaptation dimensions and levels, by identifying techniques and applying adaptation for different scenarios.

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