

Toward a Measure of Appropriateness of User Interfaces Adaptations Solutions

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Abstract—The development of adaptive user interfaces (UI) presents for a long time an important research area in which researcher attempt to call upon the full resources and skills of several disciplines. The adaptive UI community holds a thorough knowledge regarding the adaptation of UIs with users and with contexts of use. Several solutions, models, formalisms, techniques and mechanisms were proposed to develop adaptive UI. In this paper, we propose an approach based on the fuzzy set theory for modeling the concept of the appropriateness of different solutions of UI adaptation with different situations for which interactive systems have to adapt their UIs.

Keywords—Adaptive user interfaces, adaptation solution's appropriateness, fuzzy sets.

I. INTRODUCTION

NOWADAYS interactive systems are developed to be used by an increasing information society characterized by a great diversity of users and to interact with users in several different situations. The future of such applications hinges upon capacities of proposed solutions and mechanisms to support reliably the adaptation of their user interfaces (UIs) with the current user and with the context of use. By context of use we mean the triplet (user, platform, and environment).

The development of interactive systems which are endowed with adaptive UIs presents for a long time an important research area in which researcher attempt to call upon the full resources and skills of several disciplines, chiefly, the psychology, the software engineering and the artificial intelligence. The adaptive user interfaces community holds a thorough knowledge regarding the adaptation of UIs with users and with contexts of use. Several solutions, models, formalisms, techniques and mechanisms were proposed to develop adaptive software interfaces. All in all, existing solutions propose on one hand different mechanisms to extract necessary information from the context to create and update implicit or explicit user's and environment's models. On the other hand, existing solutions propose mechanisms that perform modifications on the interface. These modifications may concern the content, the presentation and the exchange modalities between users and systems. The quality of the

adaptation depends on the pertinence of user's and environment's models and on the quality of capacities to perceive and to interpret available contextual information.

Although the existence of an important number of works and solutions regarding UIs adaptation, there is not accurate algorithmic solutions which fulfill wholly generic needs of adapting user interfaces. Each solution may be the most appropriate in some situations but not in all situations. An interactive system is considered as appropriately functional in the long term regarding the interactions with users, only if this one is endowed with mechanisms that allow to the system to discover by itself appropriate behaviors of its UI. We think that a Meta adaptation in which we blend different existing solutions may be a good solution. In other words, interactive systems have to be equipped with mechanisms which adapt mechanisms of adaptation of the interface by selecting from several available solutions, the most appropriate solution for a specific situation of use. In this paper, we present a Meta adaptation mechanism based on the fuzzy set theory [10]. The proposed mechanism selects for each situation needing adaptation the most appropriate solution of adaptation. For a situation needing adaptation, it is to define the set of appropriate solutions. It is therefore to categorize existing solutions into two categories: appropriate solutions and not appropriate solutions. However, we cannot confirm a threshold of solutions' appropriateness with situations. The fuzzy set theory appears as a good tool for modeling the vague concept of the appropriateness of UI adaptation solutions with a situation needing adaptation.

II. ADAPTIVE USER'S INTERFACES

According to the aim of the adaptation of UIs [5], [8], we distinguish two kinds of adaptation: adaptation of the UI to the profile of the current user and the adaptation of the UI to the context in which the interaction is situated. In this paper, we are interested to the second kind of adaptation despite the fact that the proposed solution may be applied for both adaptation kinds.

The term plasticity is often used to point at UIs that are adaptive to the context of use, while preserving usability [7]. The implementation of the plasticity concept aims to address problems caused by user's mobility and the pervasive computing [2]. The mobility drives users to use miscellaneous interactive devices as PDAs and smart phones which have exchange capacities that differ from classical work stations. The plasticity as a solution for adapting UIs to the context of use, concerns the adaptation of interaction modalities to the limited resources of different devices and to the constraints

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imposed by the mobility on user's perceptual and motor capacities. The plasticity of UIs is directed by means of two levers [3]: remolding and redistribution. The UI remolding consists in changing the form of this one by transforming all or parts of the UI by removing components that become irrelevant or by inserting new ones that allow acceding new services deemed relevant in the situation for which the UI is adapted. When remolding a UI, transformations may concern modalities of exchange between users and systems. The UI redistribution corresponds to the ability of re-allocation of all or parts of UI components to different interaction resources maintained in different nodes of a system.

Several works proposing different ways to implement plastic user interfaces may be found in the literature. Works of Szekely [9] were among oldest ones. In his works, Szekely had identified abstract levels to which the remolding is possible. Levels of abstraction are based on the general architecture of Models-Based Interface Design Environment (MB-IDE) [9] in which are distinguished: user tasks and domain concepts used to describe user-system interactions; abstract UI which gives some shape to the UI in terms of virtual spaces of activities; concrete UI in which interaction modalities are selected and the final UI which define programming languages and run-environments. These levels were extended in the project CAMELEON [1] with other preoccupations linked to the plasticity such as: identification of the context of use as well as changes in this one for which UI have to be adapted; degrees of usability to preserve; adaptations to apply and finally, the infrastructures that support the adaptation implementation.

Regarding UI distribution and redistribution, works contained in the state of the art established by [4] treat the UI distribution from different angle of view guided by the different dimensions mentioned in the definition: a distributed UI is a UI whose components are distributed across one or more of the dimensions input, output, platform, space, and time.

III. APPROPRIATENESS OF ADAPTATION SOLUTIONS

By recapping all invested efforts to develop plastic user interfaces, we can say that interactive systems endowed with plastic user interfaces, act when adapting their user interfaces according to the general process illustrated in Fig. 2. Several possible techniques and means may be mobilized in each step of the process shown in the Fig. 2. So, for a particular situation Sit_i for which an interactive system has to adapt its UI, a solution S_i consists in a set of chosen elements to carry out each step of the adaptation process. A situation Sit_i is defined by a set of parameters that form the situation signature Sit_Sig . the solution S_i may be described as $S_i = \langle cc_i, dcc_i, tda_i, \langle rma_{i1}, rma_{i2}, \dots, rma_{ij} \rangle \sim \langle rda_{i1}, rda_{i2}, \dots, rda_{il} \rangle \sim \langle ica_{i1}, ica_{i2}, \dots, ica_{ik} \rangle, tsr_i, \langle srma_{i1}, srma_{i2}, \dots, srma_{ih} \rangle \sim \langle s rda_{i1}, s rda_{i2}, \dots, s rda_{im} \rangle \sim \langle sica_{i1}, sica_{i2}, \dots, sica_{in} \rangle \rangle$. Where, cc_i denotes the chosen models and techniques to represent and capture the context of use. The element dcc_i denotes the partial solution used to identify changes in the context of use depending on cc_i . The element tda_i of the description is the

used solution to determine different possible adaptation alternatives described in the next element. The element $\langle rma_{i1}, rma_{i2}, \dots, rma_{ij} \rangle \sim \langle rda_{i1}, rda_{i2}, \dots, rda_{il} \rangle \sim \langle ica_{i1}, ica_{i2}, \dots, ica_{ik} \rangle$ regroups possible reactions whose execution can properly adapt UI. We distinguish three kinds of reactions: (i) reactions of remolding the UI like the removing of some icons with the maintaining of their textual descriptions instead of both at the same time when the system has less display surface or the change of a visual exchange modality with a vocal one; (ii) reactions of redistribution of the UI, for example, distributing the UI components of a web site between the screen of a classical work station and the screen of a PDA when a user is connected to the web site from both devices simultaneously; and reactions that are interventions on the context of use like for example, turning on the light when it gets dark. The element tsr_i of the description of le solution S_i expresses how the chosen reactions to apply are selected from the set of the possible reactions. The last element in the description of the solution S_i consists in the selected reactions to apply in order to perform the UI adaptation.

Faced with a situation Sit_i in which the UI have to be adapted, as shown in Fig. 1, there is a set $S = \{ S_1, S_2, S_3, \dots, S_n \}$ of possible solutions S_i to adapt the UI. The set $SA = \{ S_1, \dots, S_m \}$ is a subset from S , it contains solutions that are deemed appropriate with the situation Sit_i . It is therefore to categorize solutions S_i into two categories: appropriate and not inappropriate solutions. However, we cannot confirm a threshold of solutions' appropriateness with a situation Sit_i . The fuzzy set theory [10] appears as a good tool for modeling the vague concept of the appropriateness of solutions of UI adaptation with a situation needing adaptation. By admitting the existence of intermediate situations between everything and nothing, fuzzy sets allow expressing the partial membership in a category as well as the membership of elements in categories whose edges are imperfectly defined. The subset SA is a category for which we cannot define properly edges. We treat SA as being a fuzzy subset as shown in Fig. 1 for modeling the appropriateness of solutions of UI adaptation with different situations.

A fuzzy set is characterized by its membership function. This function associates with each element of the fuzzy set a degree of membership. In fact, it is to establish a membership function for the fuzzy subset SA which at its edges, SA includes or excludes solutions firmly. But between the extreme values, the membership degree varies in proportion to the proximity of the set. The membership function of SA has to express for each solution S_i a degree of appropriateness with a situation Sit_i . So, the subset SA is defined as the set of pairs: $SA = \{ (S_i, \mu_{SA}(S_i)) \}$, S_i is a solution for adapting the UI in the situation Sit_i with $\mu_{SA}(S_i) \rightarrow [0,1]$.

The establishment of the membership function μ_{SA} amounts to propose how to measure degrees of appropriateness of solutions of UI adaptation with different situations. We propose a measure based on a set of specified indexes of appropriateness. Each index reflects a particular aspect of the appropriateness of a solution to adapt UI in some situation. Several indexes have to be defined for the appropriateness

measure. For each index, it is to define different possible modalities or numerical interval values as well as how to obtain index values. The set of indexes defined for the measure of the solution appropriateness must cover the maximum of aspects. For example, we can define a set of indexes that reflect ergonomic aspects, functional aspects, extra functional aspects; indexes that express the users' appreciations of adaptations, indexes for expressing risks that way accompany the application of solutions and indexes that express Feedbacks of the use of solutions in different situations. These indexes express the pheromone tracks of the application of solutions. Every time the solution's performance is evaluated in a particular situation, an action of adding or evaporating pheromone is done. Evaporating pheromone means that the solution does not show adequate performance in a particular situation. Adding pheromone will produce positive feedback and means that the solution shows adequate performance in a particular solution. Several pheromone indexes may be used, reflecting tracks of applications of a solution in different situations. The choice of indexes to be used for the measure of the appropriateness of solutions has to be carefully made. Table I contains some possible indexes.

TABLE I
EXAMPLES OF APPROPRIATENESS INDEXES

Index	Appropriateness Aspect	Type And Modalities
Ind_A	Is UI after adaptation allows users to know system' states	Ergonomic, (Yes, No)
Ind_B	UI components represent users tasks	Ergonomic, [0,100], percentage
Ind_C	Help language	Extra functional, (English, Spanish, French...)
Ind_D	How context is represented	Functional,
Ind_E	Equivalence between exchange modalities	Functional, [0,100], percentage
Ind_F	Display density	Functional, [0,100], percentage
Ind_G	...	...
Ind_H	...	...

IV. A FORMULA FOR THE MEASURE OF SOLUTIONS' APPROPRIATENESS

The chosen indexes for the measure of solutions' appropriateness are to be classified into three classes: binary indexes which take values from only two modalities. For example, the evaluation of the indicator (Is the solution mobilizes vocal exchange modalities) produces (yes or no); the second class corresponds to indexes which values are taken from more than two modalities. For example, the index (help language) takes values from (English, Spanish, French...etc); the third class corresponds to indexes which take values from a continuous numerical interval. For example, the extra functional index (The duration of time required to detect the changes in the context) takes values from a continuous numerical interval.

In the case of indexes of the first class, let consider the set of n solutions S_i ($i=1,2,...,n$) for adapting a UI face to a situation Sit and k indexes of appropriateness I_j ($j=1,2,...,k$).

The value A_{ij} expresses the degree of adequacy of the solution S_i face to the situation Sit regarding the index j . The function $\mu_{SA}(S_i)$ is formulated as:

$$\mu_{SA}(S_i) = \begin{cases} 0 & \text{if } (A_{ij} = 0) \\ 1 & \text{if } (A_{ij} = 1) \end{cases} \quad (1)$$

For indexes of the second class, let consider the sub set O_j of solutions that are in a situation of appropriateness regarding to the index j . The variable γ_j with ($\gamma_j = \gamma_{1j}, \gamma_{2j}, \dots, \gamma_{nj}$) allows evaluation appropriateness of solutions S_i of O_j regarding to the index j . let be a variable $\mathcal{Q}_j^{(m)} = \mathcal{Q}_j^{(1)}, \mathcal{Q}_j^{(2)}, \dots, \mathcal{Q}_j^{(z)}$ used to denote the z modalities for the variable γ_j ordered in ascending order to express reinforcement in terms of appropriateness regarding to the index j . we associate with each $\mathcal{Q}_j^{(m)}$ a score $\mathcal{Q}_{jm}$ with ($\mathcal{Q}_{j1} < \mathcal{Q}_{j2} < \mathcal{Q}_{j3} < \dots < \mathcal{Q}_{jz}$) and equidistance between scores. The score $\mathcal{Q}_{jmin}$ is the score associated with the modality under which the solution S_i is not appropriate. The score $\mathcal{Q}_{jmax}$ is the score associated with the modality above which the solution S_i is appropriate. The membership function in this case may be expressed as:

$$\mu_{Oj}(S_i) = \begin{cases} 0 & \text{if } \vartheta_{ji} \leq \vartheta_{jmin} \\ \frac{\vartheta_{ji} - \vartheta_{jmin}}{\vartheta_{jmax} - \vartheta_{jmin}} & \text{if } \vartheta_{jmin} < \vartheta_{ji} < \vartheta_{jmax} \\ 1 & \text{if } \vartheta_{ji} \geq \vartheta_{jmax} \end{cases} \quad (2)$$

In the case of indexes for which values are taken from a continuous numerical interval (quantitative continuous indexes), we have to square up to the incertitude about the appropriateness line. In order to circumvent this problem, we use two appropriateness lines SC_{min} and SC_{max} . The first one presents the value below which a solution S_i is deemed inappropriate. The last one presents the value above which a solution S_i is deemed appropriate. Let consider the sub set O_j of solutions which are in a situation of appropriateness regarding to the index j . The continuous variable ϑ_{ij} allows evaluation appropriateness of solutions S_i of O_j regarding to the index j . The membership function may be formulated under the hypothesis that the appropriateness of solutions vary with a linear manner as:

$$\mu_{Oj}(S_i) = \begin{cases} 0 & \text{if } 0 \leq \vartheta_{ij} \leq SC_{min} \\ \frac{\varphi_{ji} - \varphi_{jmin}}{\varphi_{jmax} - \varphi_{jmin}} & \text{if } SC_{min} \leq \vartheta_{ij} \leq SC_{max} \\ 1 & \text{if } \vartheta_{ij} \geq SC_{max} \end{cases} \quad (3)$$

The overall appropriateness of a solution of UI adaptation S_i when adapting the user interface face to a situation needing adaptation is considered as an accumulation of possessions of appropriateness according to all indexes specified for measuring solution's appropriateness. Thus, we have to reduce into one dimension all membership degrees obtained according to various indexes. We propose the use an aggregation function $h: [0, 1]^j$ for $j \geq 2$, as:

$$\mu_{SA}(S_i) = h(\mu_{SA1}(S_i), \mu_{SA2}(S_i), \dots, \mu_{SAk}(S_i)) \quad (4)$$

The sets SA_j are the j fuzzy subsets of UI adaptation solutions determined on j appropriateness indexes. Several ways are available to determine the function h . We propose to use a formula of generalized average membership degrees:

$$\mu_{SA}(S_i) = h_{\beta}(\mu_{SA1}(S_i), \mu_{SA2}(S_i), \dots, \mu_{SAj}(S_i)) = [\sum_{l=1}^j w_l (\mu_{SA_l}(S_i))^{\beta}]^{1/\beta}, \beta \neq 0 \quad (5)$$

The parameter β determines the type of average. In the case where $\beta = 1$, $\mu_{SA}(S_i)$ produce an arithmetical average; if $\beta = -1$, the membership function $\mu_{SA}(S_i)$ produce a harmonic average. The values w_l represent the weights specifying the relative importance accorded to each index of appropriateness.

Membership degrees of solutions in the fuzzy set of appropriate UI adaptation solutions increase when solutions accumulate possession of appropriateness. Thus, weights assigned to two indexes A and B for example, must be greater than the weight assigned to A alone. The use of a system of weighting to obtain different w_l is recommended; a weighting system must allow also according low importance for indexes reflecting less frequent appropriateness aspects and to not over represent some particular aspects. We propose to use the system:

$$w_l = \frac{\ln(1/\mu_{\psi}(C_l))}{\sum_{l=1}^j \ln(1/\mu_{\psi}(C_l))}, \overline{\mu_{\psi}(C_l)} = 1 - \mu_{\psi}(C_l) \quad (6)$$

V. TOWARD A DISTRIBUTED IMPLEMENTATION

The proposed measure may be implemented in a distributed way. To determine appropriate solutions of UI adaptation, several software entities may be involved to participate in the construction of the fuzzy set of appropriate solutions. Agents present potential candidates for playing the role of these entities. Agents [6] are autonomous software entities that act rationally based on their intentions in accordance with their goals, knowledge, interactions with other agents and perceptions of their environments. Agents may be involved to explore simultaneously several candidate solutions, extract needed information from solution's descriptions, evaluate values of all indexes and calculate the membership degrees of candidate solutions to the fuzzy set of appropriate solutions. Agents act in coordination and share tasks when evaluating indexes and membership degrees. After applying a solution for UI adaptation, if an evaluation of its performance in a particular situation or context was done based on some evaluation factors and if among indexes, pheromone indexes are used, the description of the solution have to be updated by adding or evaporating pheromone with certain coefficients.

Used agents may be intelligent agents or simple as ant agents. In the case of simple agent, all indexes, their possible modalities and values, their degrees of importance and how evaluating each one are provided to agents explicitly. Otherwise, agents themselves must extract information and decide which indexes to use and how to use them. In this case, agents must be equipped with reasoning capacities and cooperating mechanisms to cooperate with other agents. The

development of such agents is beyond the scope of this paper.

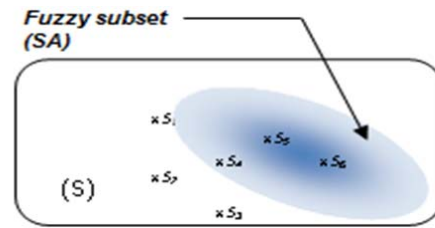


Fig. 1 Fuzzy subset with fuzzy contour

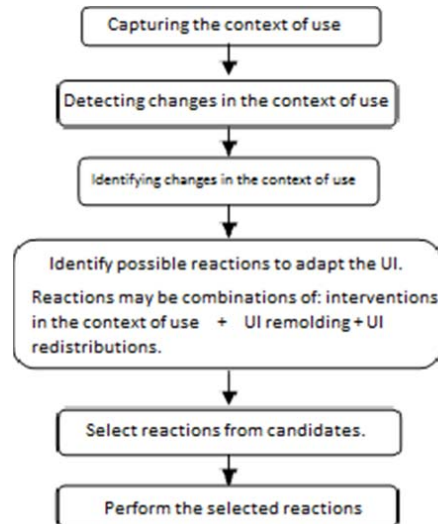


Fig. 2 General process of UI adaptation

VI. A BRIEF REVIEW

The work proposed in this paper presents an attempt to model the concept of appropriateness of different proposed solutions for UI adaptation without modeling solutions themselves. The proposed approach allows selecting the most appropriate UI adaptation solution in situations for which interactive systems have to adapt their UIs from several available alternatives. The proposed approach is sufficiently general and may be applied whatever used solutions to adapt UI. In addition to this aspect, the proposed approach shows other favorable characteristics as:

- 1) Modeling UI adaptation appropriateness using fuzzy sets allows softening the dichotomous vision of a solution for adapting UI is appropriate or not appropriate with and making gradual passage from the situation of inappropriateness to the situation of appropriateness.
- 2) Employed agents used to evaluate indexes of appropriateness are not obligatory identical. These agents may be built differently based on different architectures and models. Thus, the indexes processing benefits from the powers of several techniques and methods in the same time which may increase the quality of produced results.
- 3) The proposed fuzzy measure of the appropriateness of solutions of UI adaptation is multidimensional. The diversity of aspects reflected by selected appropriateness

indexes allows taking up and using all existing proposed solutions for measure appropriateness of adaptation UI. That is to say, we can use any existing solution by incorporating it with its importance degree into indexes of appropriateness. Thus, the degree of appropriateness produced by this approach is very expressive and meaningful.

- 4) The considering of the feedbacks of use of solutions among indexes increases the credibility of obtained appropriateness degrees because the feedbacks are captured from real exploitations and experimentations of UI adaptation solutions.
- 5) The proposed multidimensional fuzzy measure of the UI adaptation solutions appropriateness is decomposable. Thus, it is possible to analyze causes of inappropriateness of solutions.

VII. CONCLUSION

In this paper, an approach for modeling the concept of appropriateness of different proposed solutions for user interfaces adaptation. We used the concept of fuzzy sets to model solution's appropriateness in order to softening the dichotomous vision of appropriateness or inappropriateness of a solution and making the passage from the situation of inappropriateness to the situation of appropriateness gradually. The proposed approach consists in creating a fuzzy set of user interface adaptation solutions in which each solution is associated with a degree of membership. The degree of membership of a solution to the fuzzy set presents at what degree the solution is appropriate. The proposed approach may be use as a base to built Meta UI adaptation systems which the main role is to adapt the UI adaptation. Finally, we underline the need to enrich this approach particularly with a method that guides developers to study and select adequate indexes of appropriateness.

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