Decision Making in Intelligent User Interfaces

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ABSTRACT
Intelligent user interfaces are characterised by their capability to adapt at run-time and make several *communication decisions* concerning 'what', 'when', 'why' and 'how' to communicate, through a certain *adaptation strategy*. In this paper, we present a methodological approach to assist this decision making process, which is based on a clear separation of the important attributes that characterise the adaptation strategy, namely the adaptation *determinants*, *constituents*, *goals* and *rules*. Based on this separation, we also present a methodological approach for the formulation of adaptation rules, which utilises techniques from the domain of multiple criteria decision making. It is argued that, following the proposed approach, the adaptation strategy can be easily customised to the requirements of different application domains and user groups, and can be re-used with minor modifications in different applications. As a result, developers of intelligent user interfaces can be significantly assisted, and users can be empowered to exploit the benefits of intelligent interfaces.

Keywords
run-time adaptation, adaptation strategy, decision making

INTRODUCTION
Intelligent user interfaces are expected to play a catalytic role towards the provision of accessible and high-quality interfaces for a wide range of users. Although several approaches have been reported in the related literature, e.g. [1], [2], currently there is no consensus about the characteristics, behaviour and essential components of intelligent user interfaces [3], [4]. In this paper we take the view proposed in [5], that the user interface has to make several *communication decisions* about the concepts it communicates. A user interface, in this context, is called intelligent in the measure to which it adapts itself, and makes these communication decisions dynamically, at run-time, conditioned on an analysis of information regarding the current context of the interaction, which is defined by the state of several fundamental aspects, such as the user profile, the task being performed, the application nature, etc. Thus, run-time adaptation, henceforth called *adaptivity*, is considered as a major aspect of intelligent user interfaces.

Adaptivity can be addressed from different perspectives [6], [7], [8]. At the highest level, two independent phases can be identified (Figure 1):

- deciding on the need for adaptations, based on some sort of assessment of user-computer interaction;
- performing adaptations through a certain 'adaptation strategy'.

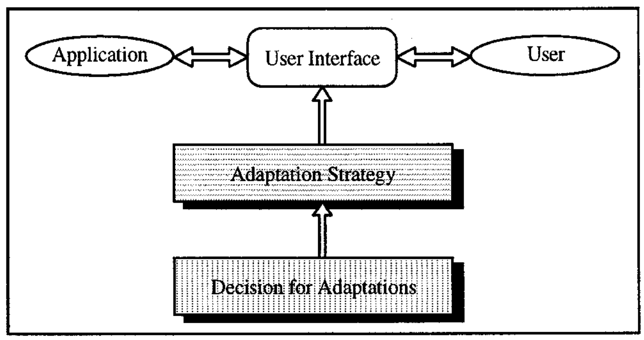

Figure 1. Adaptation at the highest level

In the context of this paper, we focus on the adaptation strategy as a decision making process, which can be characterised by the following attributes:

- *what to adapt*: the aspects of the user-computer interface that are subject to adaptations, henceforth called *adaptation constituents*; they may refer to either semantic (i.e. content of information), syntactic (i.e. sequencing of the interaction) or lexical aspects of interaction (i.e. interface objects, interaction techniques, media and modalities);

- *when to adapt*: run-time adaptation implies some sort of *monitoring* of the user-computer interface, in order to *assess* the state of certain aspects of the interaction, called *adaptation determinants* (e.g. user's sensory load, task's requirements), on which the adaptation decisions are conditioned;
- *why to adapt*: there may be several goals underlying the adaptation process (*adaptation goals*); certain goals may be conflicting with each other, thus trade-offs between them have to be decided by the designer;
- *how to adapt*: adaptations are driven by a set of rules (*adaptation rules*), that essentially assign certain adaptation constituents to specific adaptation determinants, for given adaptation goals.

In this paper, we provide a methodological approach to this decision making process, which is based on a clear separation of the previously identified attributes. Based on this framework, we also present a methodology for the formulation of adaptation rules, utilising techniques from the domain of multiple criteria decision making. It is argued that, following this approach, the adaptation strategy can be easily customised to the requirements of different application domains and user groups, and can be reused with minor modifications to different applications. As a result, developers of intelligent user interfaces can be significantly assisted, by the provision of a design space that allows the expression of user- and application-related aspects, such as user needs, abilities, and preferences, nature of the application, context of use, etc.

BACKGROUND AND RELATED WORK

Despite their significance to the adaptivity process, the attributes identified above are not sufficiently addressed in existing systems. The adaptation determinants, constituents and goals, can substantially differ in existing systems, while, on the other hand, they are usually only implicitly taken into account in the formulation of adaptation rules. Moreover, they are often hard-coded into the system. This approach is inflexible, as the attributes of the adaptation strategy cannot be easily modified, customised to the requirements of different application domains and user groups, and re-used to different applications [9].

The set of Adaptation Determinants adopted in existing systems usually includes the user's characteristics (preferences, experience, etc), the tasks being performed (nature, urgency, etc), the information characteristics (nature, purpose, etc), and the state of discourse. These characteristics are captured in several models, such as task, user model, dialogue model, application model, etc. Additionally, depending on the requirements of the particular application, other adaptation determinants may be found, such as dialogue acts [10], expressiveness and effectiveness criteria [11], graphics design aspects, [12], etc. Even when researchers agree on the set of adaptation determinants, the characteristics of these determinants that are considered significant may differ substantially. For example, information content is characterised or classified as linguistic or non-linguistic, analogue or non-analogue, arbitrary or non-arbitrary, static or dynamic, etc [13], by the data types, properties of relational structure, arity, user information seeking goal, etc [14], by the intrinsic property, class property, set property, etc [9], etc. Also, the modelling of the knowledge regarding adaptation determinants may vary significantly; user models, for example, may be classified according to granularity, temporal extent and representation, etc [7].

The adaptation constituents, i.e. the aspects of the interaction that are adapted, also differ substantially in existing systems, and may address the semantic, syntactic or lexical level of interaction. In [7], a list of adaptation constituents that are usually employed in existing systems is provided. This set includes generic functions, e.g. error correction or active help, and interaction level functions, e.g. user presentation of input to the system, system presentation of information to the user, access to capabilities, task simplification. Other adaptation constituents can also be found in the related literature. For example, MMI^2 adapts the layout of network diagrams [12], UIDE focuses on the provision of context-sensitive help [15], AIMI adapts the presentation of text, maps and tables [16], etc.

The goals that the adaptivity process attempts to fulfil vary substantially in existing systems, according to the requirements of the application and the user groups. In [7], for example, a list of adaptation goals is provided, which includes easy, efficient, and effective use, make complex systems usable, present what the user wants to see, speed up use, simplify use, etc. Additionally, several other goals might be found, such as minimisation of user errors, maximisation of user satisfaction, reduction of computational resources, etc [6]. In several application domains, there is a major goal that the system has to reach. For example, in the case of an air-traffic control system, the overall goal is the error-free use; for a computer game, the overall goal might be the user's satisfaction. In several other cases, however, more than one (sometimes conflicting) goals may be significant.

Finally, the rules that guide the adaptations vary in existing systems, and address different levels (i.e. lexical, syntactic, semantic level) of user-computer interaction. Some indicative examples include: "If information is urgent, then choose a medium with low default detectability and a channel with no temporal variance" [9]; "If the task sub-goal requires spatial information - prefer visual media resource" [10]; "If what has to be displayed is a structural analysis of a complex abstract domain, then use network charts" [17]; "If the number of secondary values is strictly positive, then the selected abstract interaction object is listbox" [18].

These rules are usually 'hardcoded' in the user interface, and cannot be easily modified, or reused across several applications. Also, these rules only implicitly take into account the adaptation goals. This approach does not allow the easy incorporation of design decisions, i.e. trade-offs between different interface goals-'qualities', in the design procedure.

As it is evident from the above discussion, the critical attributes of the adaptivity process, namely determinants, constituents, goals and rules, differ substantially in existing systems. That is, existing systems adapt certain pre-determined constituents, based on a set of certain predetermined determinants, through the use of specific rules, in order to meet pre-specified goals. This approach has several drawbacks. The adaptivity process is not flexible, and thus cannot be easily transferred between applications: if only some of the adaptation constituents, determinants, goals, or rules need to be modified, then the adaptivity process may need substantial modifications.

If, for example, the user's abilities are not included in the set of adaptation determinants of a particular application, their subsequent incorporation in an alternative version of the application that aims to address the requirements of people with special needs is not straightforward. Also, the interface designer is given minimal support for the development of intelligent user interfaces, as the adaptivity process needs to be designed for each application almost from scratch.

In order to address the requirements of different application domains and user groups, and assist the reusability of the adaptivity process across different applications, a methodological approach is required, which enables:

- the customisation of the set of adaptation determinants and constituents;
- the incorporation of the adaptation goals as an integral part of the adaptivity process;
- the modification of adaptation rules, according to the goals of adaptivity.

In this paper, we present such an approach, which is based on a clear separation of the attributes of the adaptation process. In this respect, the attributes of the adaptation strategy, as these have been identified above, can be easily customised to the requirements of different application domains and user groups, and re-used with minor modifications in other applications.

THE PROPOSED APPROACH

In our approach, the sets of adaptation determinants, constituents, goals and rules are clearly separated. They are defined by the designer, so as to enable their customisation to the requirements of the application at hand. In particular, we adopt the following formalism.

Adaptation Determinants

Let D = { $<ad_1>, <ad_2>, ..., <ad_N>$ }, be the aspects of the interaction that are considered significant in the adaptation process. Then, we define the Adaptation Determinants space as follows:

$$AD = <ad_1> \times <ad_2> \times ... \times <ad_N>$$

Each of the elements of D can be viewed as a vector that is subject to further decompositions into other vectors or scalars. For example, one of them might refer to the user's requirements, abilities, preferences, etc, which could be further decomposed into visual or motor abilities, etc. The granularity of these elements depends on the intentions of the designer.

Adaptation Constituents

Let C = { $<ac_1>, <ac_2>, ..., <ac_M>$ } be the aspects of the user-computer interface that are subject to adaptations for a particular system. Each of the elements of C may have several attributes. For example, the constituent 'visual text' may have attributes such as font, size, colour, position, etc, while the constituent 'auditory text' may have attributes such as volume, speed, etc.

Let also O = { $o_1, o_2, ..., o_K$ } be the available operations that can take place between the adaptation constituents. If, for example, constituents refer to the different media employed, then O might include temporal operators. Then, we define the Adaptation Constituents space as the space containing all the elements of C, together with all the valid combinations of them, by means of the operators of O.

Adaptation Goals

Let G = { $g_1, g_2, ..., g_L$ } be the set of goals that a specific interface seeks to meet. Then, we define the Adaptation Goals space as follows:

$$AG = \{\Sigma \lambda_i \cdot g_i \,/\, g_i \in G,\ \lambda_i \in [0, 1],\ \Sigma \lambda_i = 1,\ i = 1, 2, ..., L\}$$

where the constraints regarding the weights λ_i have been introduced for normalisation purposes.

The set of goals can be seen as a set of performance criteria, and may be derived from an initial requirements analysis space. Each goal is connected with a factor λ_i, i.e. a weighting factor that can be bound to a specific value, through several techniques that assign importance to performance criteria, such as *pair comparison* or *simultaneous comparison* [19], [20]. Though factors λ_i are in general technique-dependent, it is also essential to choose for each goal an appropriate unit of measurement; e.g. in the case of setting efficiency as a goal, it may be expressed in many ways, one of them being the ratio of an 'ideal' time to perform a task, to the actual time taken.

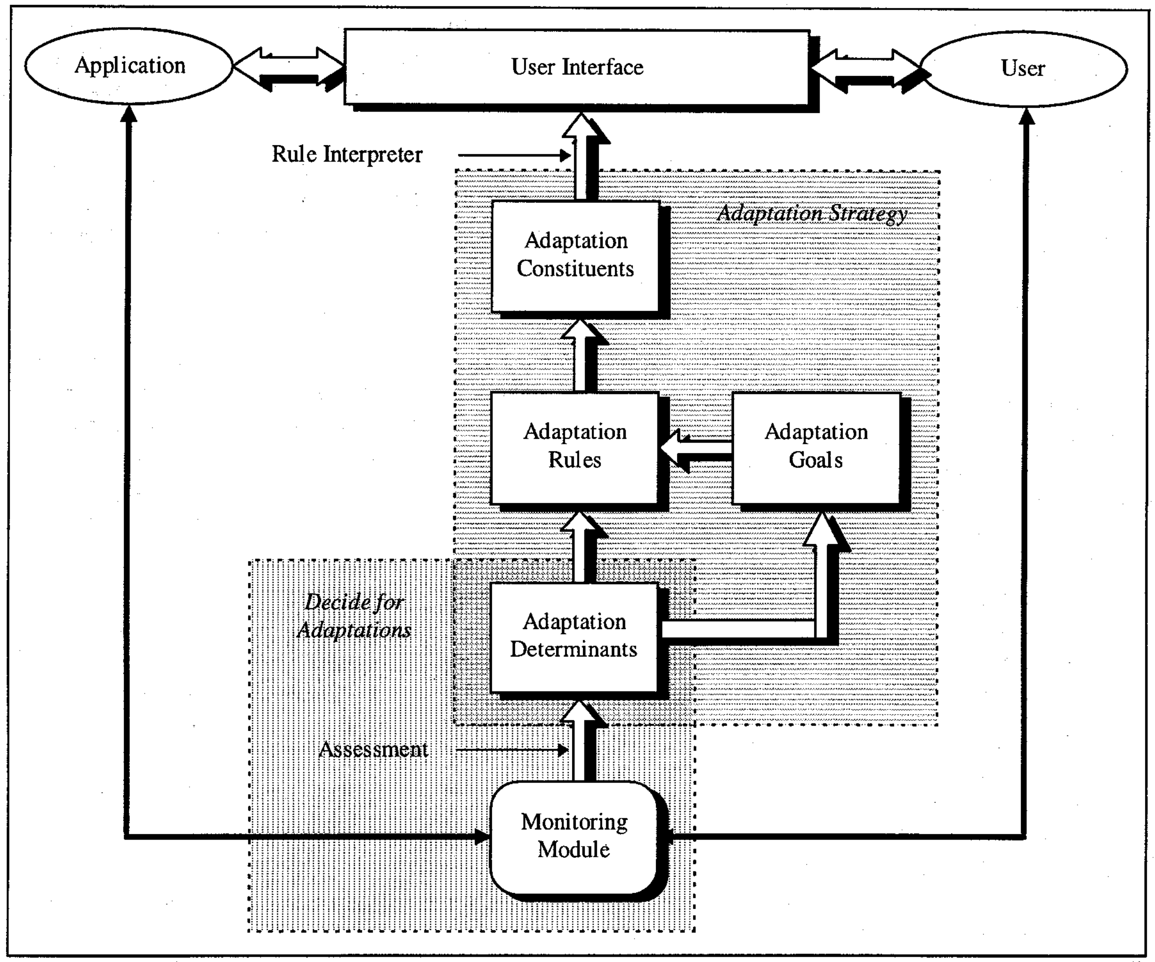

Figure 2. Decision making in intelligent user interfaces

Adaptation Design Space

Following the above notation, the design space for adaptations in intelligent user interfaces, called Adaptation Design Space (ADS), can be defined as:

$$ADS = ad \times AC, \text{ where } ad \in AD$$

This set includes all the possible 'design instances', in the sense that its elements are pairs assigning the whole AC space to each instance of the AD space.

Adaptation Rules

In this context, developing the rules that 'drive' the adaptations, is a task of selecting sub-sets of the AC space, for each instance of the AD space (instead of the whole AC, as in the case of the ADS), given a specific element of the AG space. Thus,

$$AR_g = ad \times ac, \text{ where } ad \in AD,\ ac \in AC,\ g \in AG$$

The suggestions provided by the adaptation rules provide input to a rule interpreter (e.g. high-level user interface development environment), which instantiates the resulting user interface. Thus, our view of decision making for adapting the interface to the requirements of the user-computer interaction is shown in Figure 2.

As it is evident from this figure, the adaptation process is directly affected by the:

- *monitoring module*: the data provided by this module are assessed, and the output is passed to the adaptation strategy; thus the sets of adaptation determinants and goals need to be 'compatible' with the capabilities of the monitoring module;
- *rule interpreter*: the output of the adaptation rules is the selection of specific adaptation constituents; thus, the form of adaptation constituents has to be 'compatible' with the rule interpreter.

The separation of the attributes of the adaptation strategy enables its customisation to the requirements of different application domains and user groups, by enabling the designer to take into account the aspects that are considered significant to the ADS space. Also, the adaptation strategy can be easily re-used with minor modifications to other applications.

In order to illustrate this argument, let us consider as an example, the case of a user interface which takes user's expertise as the only aspect of the user's profile affecting the adaptation strategy. If the same application is to be accessible by people with special needs, then user's abilities (adaptation determinants), and the possible alternative presentation techniques (adaptation constituents) need also to be taken into account in the adaptation strategy. In existing systems, where the attributes of the adaptation strategy are not clearly separated, and usually hard-coded into the system, the interface developer would be required to review the whole set of adaptation rules, and modify some of them accordingly. In contrast, following the proposed approach, the adaptation strategy can be easily modified: the user's abilities are inserted in the set of adaptation determinants, and the alternative presentation techniques in the set of adaptation constituents. Additionally, only adaptation rules concerning these aspects need to be defined. As the above sets (AD, AC and AR) are clearly separated, the task of modifying them is simplified.

DEVELOPING ADAPTATION RULES

Although the development of the ADS is relatively simple, the development of the AR space is not straightforward. Some of the rules may be particularly complex, and thus may be difficult for the designer to explicitly define. For this reason, we have also developed a methodology for the development of adaptation rules, which is based on the combination of Partial Adaptation Rules (PARs). PARs are partial decisions concerning adaptations, which are based on sub-sets of the ADS. They can be easily introduced by the designer, or derived from the literature, e.g. human factors and ergonomics handbooks. The combination of PARs into Adaptation Rules is driven by a set of weighting factors attached to each partial rule, which reflect the significance of each suggestion to the satisfaction of each adaptation goal.

In particular, the steps of the proposed methodology are as follows:

Step 1. Definition of the Adaptations Design Space

The designer defines the AC, AD, and AG spaces, according to the requirements of the application at hand. For each element of the AC space, the respective attributes are also defined. For example, the designer might define the following sets:

Determinants

D = { <no_of_errors>, <no_of_help_requests>, <task_completion_time> }

where

<no_of_errors> = { low, high }
<no_of_help_requests> = { low, medium, high }
<task_completion_time> = { low, high }

The elements of the above sets, as well as their granularity, depend on the intentions of the designer.

Constituents

C = { <automatic_prompt>, <help_detail>, <navigation_type> }
O = { × }

where

<automatic_prompt> = { enabled, disabled }
<help_type> = { hyperlinks, auditory_message, help_bar }
<navigation_type> = { hierarchical, unstructured }

Then, the ADS is defined as:

ADS = { (low, low, low, AC), (low, low, high, AC), ..., (high, high, high, AC) }

where

AC = { (enabled, hyperlinks, hierarchical), (enabled, hyperlinks, unstructured), ..., (disabled, help_bar, unstructured) }

Also, the designer defines the following Goals space:

G = { effectiveness, simplicity }

Step 2. Definition of Partial Adaptations Rules

Partial Adaptation Rules are introduced, which 'match' instances of the AD space to instances of the AC space. Each rule is attached with a set of *weights*, which reflect its significance with respect to each adaptation goal, i.e. the contribution of each selection to the satisfaction of each goal. These weights are introduced by the designer, and can be either derived or adapted from data of the relevant literature, identified through experiments and usage trials, or estimated through several methods, such as pair comparison or simultaneous comparison [19], [20]. Although in the present work weights are real numbers, alternatively, one can also use rough sets [21], fuzzy sets [22], etc.

Example adaptation rules that may be defined for the example of this paper are shown in Figure 3. PAR_1, for example, can be read as: "if no_of_errors is low, then the constituent (disabled, hyperlinks, unstructured) is selected with weights 0.7 and 0.6 regarding the effectiveness and simplicity goals respectively". Note that for the same determinant, as in the case of no_of_errors for this example, more than one suggestions can be defined.

Step 3. Define Constraints

Depending on the requirements of the application, specific constraints are introduced. The constraints have the form of elements that should not appear in the final rules. If, for example, the designer considered the element (enabled, hyperlinks, structured) not appropriate, then this element should be defined in the set of constraints. For this specific example, we assume no constraints in the combination of PARs.

	Adaptation Determinants			Adaptation Constituents			Adaptation Goals	
	errors	help	time	prompt	help	dialogue	effectiveness	simplicity
PAR_1	low	*	*	disabled	hyperlinks	unstructured	0.7	0.6
PAR_2	high	*	*	enabled	auditory	structured	0.5	0.8
PAR_3	high	*	*	enabled	help_bar	unstructured	0.5	0.3
PAR_4	*	low	*	disabled	hyperlinks	unstructured	0.6	0.7
PAR_5	*	medium	*	-	hyperlinks	unstructured	0.6	0.4
PAR_6	*	high	*	enabled	help_bar	structured	0.8	0.5
PAR_7	*	*	low	enabled	-	structured	0.2	0.7
PAR_8	*	*	high	disabled	-	unstructured	0.7	0.1

Figure 3. Example Partial Adaptation Rules

Step 4. Combine Partial Adaptation Rules

The partial adaptation rules defined previously are combined to form the Adaptation Rules. This combination can be seen as a problem of multiple criteria decision making, in the sense that different alternatives are 'suggested', which are attached a set of relative weights according to some criteria-goals. In fact, one of the main advantages of the proposed approach, is that it enables the utilisation of techniques from the field of multiple criteria decision making in the domain of intelligent user interfaces.

In particular, in the context of this paper, we employ a weighted additive utility model [20], [23], in order to assess the 'appropriateness' of each suggested constituent. The weighting factors of this model take into account two factors:

- one reflecting the designer's view on the significance of each adaptation goal in the adaptivity process;
- and another one reflecting the average intrinsic information conveyed by the weights concerning each goal, as this is reflected in the concept of entropy of information [23], [24].

This approach is also similar to the concept of *immediate probabilities* [25], introduced in the domain of decision making under doubt, as it takes into account both the significance of each alternative to the satisfaction of each goal, as well as the interface designer's (decision maker) consideration on the significance of each goal in the development process.

In the following section, we provide a simple example scenario, in order to illustrate the proposed approach.

AN EXAMPLE SCENARIO

We consider a simple example scenario, where the monitoring module 'reports' that, while in a specific task context:

- the user has made four mistakes,
- the user has made one help request, and
- the time spent by the user in order to complete an operation is greater than the expected one.

Also, we assume that this raw data is assessed, and the following conclusions are drawn:

- *no_of_errors* is high,
- *no_of_help_requests* is low, and
- *task_completion_time* is high.

Consequently, a decision needs to be made, concerning *how* to adapt the interface, that is, to determine the adaptation rule, which selects the appropriate adaptation constituents, based on the state of the above adaptation determinants, and the goals that need to be satisfied.

This rule is derived by the partial adaptation rules that have been introduced by the interface developer, and are shown in Figure 3. In this specific case, rules PAR_2, PAR_3, PAR_4, and PAR_8 are triggered:

enabled	auditory	structured	0.5	0.8
enabled	help_bar	unstructured	0.5	0.3
disabled	hyperlinks	unstructured	0.6	0.7
disabled	-	unstructured	0.7	0.1

Each of the above rules 'suggests' a different constituent for each of the three elements of the AC space. In order to illustrate our approach, consider for example, the first constituent, namely the 'automatic_prompt'. Two of the PARs suggest that it is enabled, while the other two suggest the opposite. Each of these suggestions has a set of weights, according to their significance for each adaptation goal. Taking their average, the weights are:

	effectiveness	simplicity
enabled	0.5	0.55
disabled	0.65	0.4

The above weights are multiplied by a weighting factor that is assigned by the designer to each goal. In this way, the designer is enabled to incorporate different design decisions concerning the trade-offs between different (conflicting) goals. For example, if the designer considered efficiency to be more significant than simplicity for this specific application, then a greater weighting factor could be assigned to that goal. In this case, we assume that the weighting factors introduced by the designer are equal (i.e. 0.5 and 0.5 respectively).

Also, another weighting factor is used, reflecting the average uncertainty conveyed by the weights of each goal, as this is reflected in the concept of the entropy of information. For this specific example, the entropies of the weights of the goals are 0.987692 and 0.981941 for the effectiveness and simplicity goals respectively. Multiplying the weights of each alternative with the above weighting factors, we find that the constituent 'enabled' is the most appropriate for this specific case, under the assumptions stated above.

Following the same process, the most appropriate constituent for this specific case is

(enabled, auditory, unstructured)

The same process results in the development of the whole set of adaptation rules for this specific example.

CONCLUSIONS AND FUTURE WORK

Intelligent user interfaces need to make several communication decisions at run-time, through a specific adaptation strategy. This decision making process is characterised by the adaptation determinants, constituents, goals, and rules. Current efforts for the design and development of intelligent user interfaces do not explicitly separate these attributes of the adopted adaptation strategy, and, as a result, the adaptation strategy cannot be easily re-used in different applications.

This paper proposes a methodological approach which is based on the clear separation of the important attributes of the adaptation strategy. Also, based on this separation, we have provided a methodological framework for the development of adaptation rules, utilising techniques form the domain of multiple criteria decision making. In particular, we have utilised a weighted additive utility model, which takes into account the significance of each constituent to the satisfaction of each goal, as well as the designer's consideration of the significance of each goal. In this respect, the user interface designer's intentions regarding the satisfaction of each adaptation goal, as well as the trade-offs between different goals are incorporated. We have argued that, following this approach, the adaptation strategy can be easily customised to the requirements of different application domains and target user groups. In this respect, the development of intelligent user interfaces can be significantly assisted, and, as a result, users can be empowered to exploit the full benefits of intelligent interfaces.

One issue to be further elaborated is the identification of weights in the process of combining partial adaptation rules. In this paper, we have assumed that for each partial adaptation rule a set of weights is defined, and also that for each goal a weighting factor is determined, reflecting its significance to the design process. These weights are assumed to be real numbers, and are introduced by the user interface designer. Related literature, e.g. [20], [23], reports several ways of identifying these weights, e.g. pair comparison or simultaneous comparison, but also, one can find several critics regarding the application of these methods, as opposed to other techniques, such as preference-based decision making [26].

Work in progress also involves the development of a tool that assists the definition and manipulation of the attributes of the adaptation strategy and the automatic development of adaptation rules, customised to the requirements of different application domains and user groups.

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