Supporting Adaptivity in Intelligent User Interfaces: The case of Media and Modalities Allocation

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Abstract

Adaptivity is widely recognised as a major characteristic of Intelligent User Interfaces for improving the usability of interactive systems, in order to meet the requirements of heterogeneous user categories. The process through which adaptivity takes place is characterised by several attributes. In this paper, we are concerned with adaptivity constituents, determinants, goals and rules, and identify the requirements that the adaptivity process has to meet, with respect to these attributes. We propose a methodology which addresses the adaptivity at the media and modalities level, and complies with these requirements. We also present the implications of the methodology for users and user interface developers. It is argued that the provision of methodologies and tools that comply with the identified requirements may significantly assist the design and development of intelligent user interfaces, and substantially promote the 'design for all' principle.

Keyword: Intelligent Multimedia User Interfaces

1. INTRODUCTION AND BACKGROUND

Intelligent User Interfaces (IUIs) constitute a major direction of current HCI research, towards the provision of high-quality user-computer interaction. Related literature acknowledges a series of different reasons that pose the requirement for IUIs, including the need for systems to be used by users with different requirements, a single user with changing requirements, in the context of changing or different environments [Kuehme 93].

In this respect, IUIs are considered especially important when the aim is towards supporting heterogeneous user groups with variable and diverse needs, abilities and preferences (including people with special needs), since they facilitate a more 'natural', i.e. effective and efficient user-computer interaction, attempting to imitate human-human communication.

Several efforts towards the development of IUIs have been reported in the literature, resulting in a number of prototyping systems, in several application domains (e.g. architecture, business, financial, tutoring and training, process control, project management, visualisation [Roth 93]).

However, there is still a lack of consensus concerning the characteristics, essential components and behaviour of IUIs.

In this paper, we take the view that a user interface has to make several communication decisions while interacting with the user. These decisions may concern several aspects of the interaction, such as *what* to communicate, *when* to communicate, and *how* to communicate. In this context, a user interface can be called intelligent to the measure that it adapts itself, and makes these communication decisions dynamically, at run-time, based on the requirements of the interaction [Szekely 91]. Thus, run-time adaptivity to the requirements of the interaction is considered the central part of an IUI.

The process of adaptivity is characterised by several attributes. In this paper we are concerned with the adaptivity constituents, determinants, goals and rules:

- *adaptivity constituents* - the aspects of the interaction that are adapted, e.g. information content, presentation primitives (interaction techniques, I/O devices, media or modalities);
- *adaptivity determinants* - the factors guide the adaptivity process, e.g. adaptivity based on user characteristics, task or application nature;
- *adaptivity goals* - the particular objectives that are to be served by the adaptivity process, e.g. minimise number of errors, optimise efficiency or effectiveness;
- *adaptivity rules* - 'drive' the instantiation of the adaptivity constituents, based on the state of the adaptivity determinants.

Our approach to support adaptivity also presumes the existence of a monitoring module that makes inferences about the state of user-computer interaction (Figure 1), and a high-level user interface development environment, that 'realises' the instantiations of the adaptivity constituents, as described in [Stephanidis].

In the following, we present a brief overview of current approaches to adaptivity, with respect to the above attributes. We identify a diversification of current approaches to adaptivity, which constitutes a major drawback to the development of IUIs. Consequently, we identify the requirements that the adaptivity attributes need to meet, in order to address the accessibility and usability requirements of a wide range of user categories. Also, we present a methodology, which addresses the media and modalities adaptivity, and complies with the identified requirements. The proposed approach has implications both at the development level, and at the interaction level. That is, it assists the designer to easily design the adaptivity process, tailored to the requirements of the specific application.

2. STUDY OF ADAPTIVITY PROPERTIES IN CURRENT SYSTEMS

The state of the art in Adaptive User Interfaces is exemplified by limited prototypes in narrow domains, that are able to interpret only a few kinds of input and generate limited forms of output [Maybury 93a], [Dieterich 93]. In particular, the adaptivity determinants and constituents, as well as the adaptivity goals and rules adopted differ substantially; they are usually predetermined at design time, hardcoded into the system, and cannot be easily modified by the designer, which constitutes a major drawback for the development of adaptive and intelligent user interfaces.

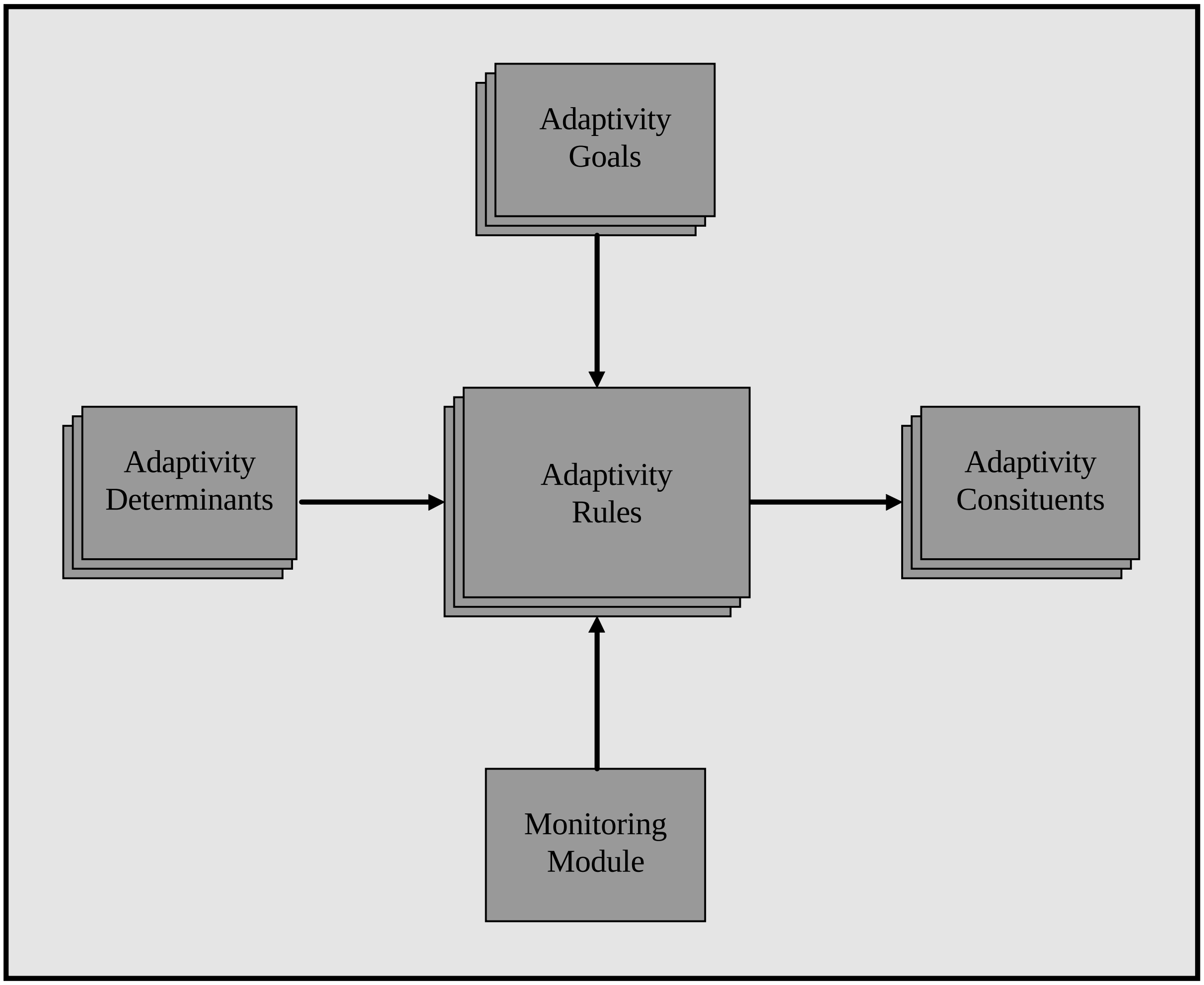

Figure 1: The attributes of the adaptivity process

2.1. Adaptivity Determinants

The set of Adaptivity Determinants adopted in currently implemented systems is diversified. In most approaches it seems that there is a common set of characteristics that are considered essential. This set includes:

- the user's characteristics (preferences, experience, etc);
- the tasks being performed (nature, urgency, etc);
- the information characteristics (nature, purpose, etc);
- 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 adaptivity determinants may be found:

- the *goals and characteristics of the producer of information* (e.g. affect perceiver's knowledge, opinion, emotional state), *and the receiver of information* (e.g. knowledge, interest, opinions) [Arens 93];
- *dialogue acts*, such as subject informative: enable - communicate actions to achieve a task subgoal, result - give information about the outcome of a task subgoal, cause - give information concerning the causality of a task subgoal, inform - display information as is; subject-organising: sequence - specify a succession of linked steps, summary - provide overview of task subgoals, condition - a particular subgoal is a precondition; and presentational: locate - draw attention to an information type, foreground - give further detail of an information type, background - give content information, emphasise - make an information type prominent [Sutcliffe 94];
- *expressiveness* (i.e. ability to present all the information using some techniques) *and effectiveness criteria* (i.e. amount of redundancy) [Mackinlay 86], [Gargan 88];
- information about *generally shared world knowledge* applicable across different task domains [Neal 91], e.g. common sense about the business world, office work, human communication [Thomas 87];
- *graphics design aspects*, e.g. empirical studies on graphics tools usage, theoretical distinctions between tools [Chappel 93];
- *teaching strategies* (particularly in intelligent tutoring systems) [Dannenberg 92].

Even when researchers agree on the set of adaptivity 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 [Bernsen 93];
- by the data types, properties of relational structure, arity, user information seeking goal, etc [Roth 93];
- by the intrinsic property, class property, set property, etc [Arens 93];
- as descriptive, spatial, operational-action or operational-procedural, temporal, etc [Sutcliffe 94]

Also, the modelling of the knowledge regarding adaptivity determinants is variable; user models, for example, may be classified according to granularity, temporal extent and representation.

2.2. Adaptivity Constituents

The adaptivity constituents, i.e. the aspects of the interaction that are adapted, also differ substantially in currently implemented systems, and may address the semantic, syntactic or lexical level of interaction. [Dieterich 93], provides a list of the adaptivity constituents that are usually employed in existing systems. This set includes:

- generic functions: error correction or active help

- interaction level: user presentation of input to the system, system presentation of information to the user, access to capabilities, task simplification

Other adaptivity constituents can be found in the related literature. For example:

- UIDE [Sukaviriya 93] and PUSH [Hook 95] focus on the provision of context-sensitive help;
- WIP [Arens 93] is concerned with the provision of 3D instructions for technical devices;
- TEXTPLAN [Maybury 93b] provides narrated animations;
- AIMI [Burger 93] adapts the presentation of text, maps and tables;
- ANDD [Marks 90] and MMI^2 [Chappel 93] adapt the layout of network diagrams;
- BLAH [Weiner 80] and GRAFLOG [Santana 95] provide graphical explanations of expert system's conclusions and drafting tasks, respectively;
- ALFresco [Stock 93] provides customised images of Fourteenth Century frescoes, while APT [Mackinlay 86] provides customised graphical presentations of relational data.

2.3 Adaptivity Goals

The goals that the adaptivity process attempts to fulfill vary substantially in current systems, according to the requirements of the application and user group. [Dieterich 93], for example, provides the following list of adaptivity goals:

- easy, efficient, effective use
- make complex systems usable
- present what the user wants to see
- speed up use
- simplify use
- a UI that fits heterogeneous user groups
- a UI that considers increasing experience

Additionally, one might state several other goals, such as:

- minimise number errors
- maximise user satisfaction
- minimise cost, in terms of computational resources

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 effective and error-free use; for a computer game, the overall objective might be the user's satisfaction. In several other cases, however, more than one (sometimes conflicting) goals is significant. For a public interface, for example, the efficiency and effectiveness might be both desired.

2.4. Adaptivity Rules

The rules that guide the adaptivity vary in currently implemented systems. MacIDA, [Petoud 90], for example, uses a set of selection rules of the form: “a window is selected for each entity, a simple edit box is selected for each attribute of an entity, a table is selected for each repetitive aggregate of attributes, and a push button is designated for each function”. IBIS, [Seligmann 91], uses design rules that map intent to stylistic choice and style rules that map stylistic choices to visual effects. [Stephanidis 93] addresses the adaptivity for people with special needs, using rules of the form: “If user task = X (X ∈ {selection, position, quantification, command input}), and user load = Y (where user load refers to cognitive, perceptual and motor load, and Y ∈ {low, medium, high}), and ..., then use Z (where Z ∈ {direct screen selection, direct selection on a tactile surface, ...}).

On the other hand, many adaptivity rules may be found in the literature concerning the assignment of adaptivity constituents to adaptivity determinants, such as:

- “If what has to be displayed is a structural analysis of a complex abstract domain, then use network charts” [Bernsen 92];
- “If the task sub-goal requires spatial information - prefer visual media resource” [Sutcliffe 94];
- “Condition: composition of whole into parts of types, Chart Reference: pie chart” [Chappel 93];
- “Condition: judging accurate values; Chart reference: table” [Roth 90];
- “If information is urgent, then choose a medium with low default detectability and a channel with no temporal variance” [Arens 93];
- “If the data type is alphanumeric or numeric, and discrete, and the range of values is greater than 6, then use a list box” [Janssen 93];
- “If the number of secondary values is strictly positive, then the selected abstract interaction object is listbox” [Bodart 94].

These rules are usually hardcoded in the user interface, and cannot be easily modified, or reused across several applications (except for some cases, such as the UIDE system [Sukaviriya 93], where the rules are stored in a file that is modifiable by the designer). Also, these rules are monolithic, in the sense that the selection of adaptivity constituents is not depending on adaptivity goals, but only to the adaptivity determinants. This approach does not allow the easy inncorporation of design decisions, i.e. trade-offs between different interface qualities, in the design procedure.

2.5. Conclusions on Current Approaches to Adaptivity

As it is evident from the above discussion, the critical attributes of the adaptivity process, namely determinants, constituents, goals and rules, differ substantially in currently adopted approaches. That is, current systems adapt certain pre-determined constituents, based on a set of certain predetermined determinants, through the use of specific rules, in order to meet prespecified 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 adaptivity constituents, determinants, goals, or rules need to be modified, then the adaptivity process has to be redesigned. If, for example, the user's abilities are not included in the set of adaptivity 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 IUIs, as the adaptivity process needs to be designed for each application almost from scratch. The overall result is that the requirements of several user categories, and especially of people with special needs, are not met.

In order to assist the development of IUIs that address the requirements of several application domains and user categories, new methodologies and tools need to be developed, which comply with the following key requirements:

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

The existence of such tools will assist the development of adaptive interfaces, thus address the accessibility and usability problems of the population at large, including people with special needs. Such a methodology is proposed in the following, which addresses the adaptivity of media and modalities to the requirements of the interaction, and complies with the above requirements.

3. A METHODOLOGY FOR THE ADAPTIVITY OF MEDIA AND MODALITIES

In the following, a methodology is presented, which addresses adaptivity at the media or modalities level. A more elaborated presentation of the proposed methodology can be found in [Karagiannidis 95a].

3.1. Definitions and Notations - The Adaptivity Design Space

As already stated, the adaptivity process is achieved through the selection of instances of the adaptivity constituents, based on the state of adaptivity determinants, through the use of adaptivity rules. As the methodology addresses the adaptivity of media and modalities, the set of Adaptivity constituents is defined as

$M = \{ m_1, m_2, ..., m_n \}$ the set of available combinations of media and modalities, according to the configuration of the system

The set of adaptivity determinants is divided in the set comprising the characteristics of the information content, and the set comprising all the other aspects of the user-computer interaction that are considered significant for a particular application:

$I = \{ i_1, i_2, ..., i_j \}$ the set of adaptivity determinants that are considered significant for the particular application and are related to the Information content

$IC = \{ ic_1, ic_2, ..., ic_i \}$ is the set of adaptivity determinants that are considered significant for the particular application and are not related to the Information content

Thus, the adaptivity process is abstracted as shown in Figure 2.

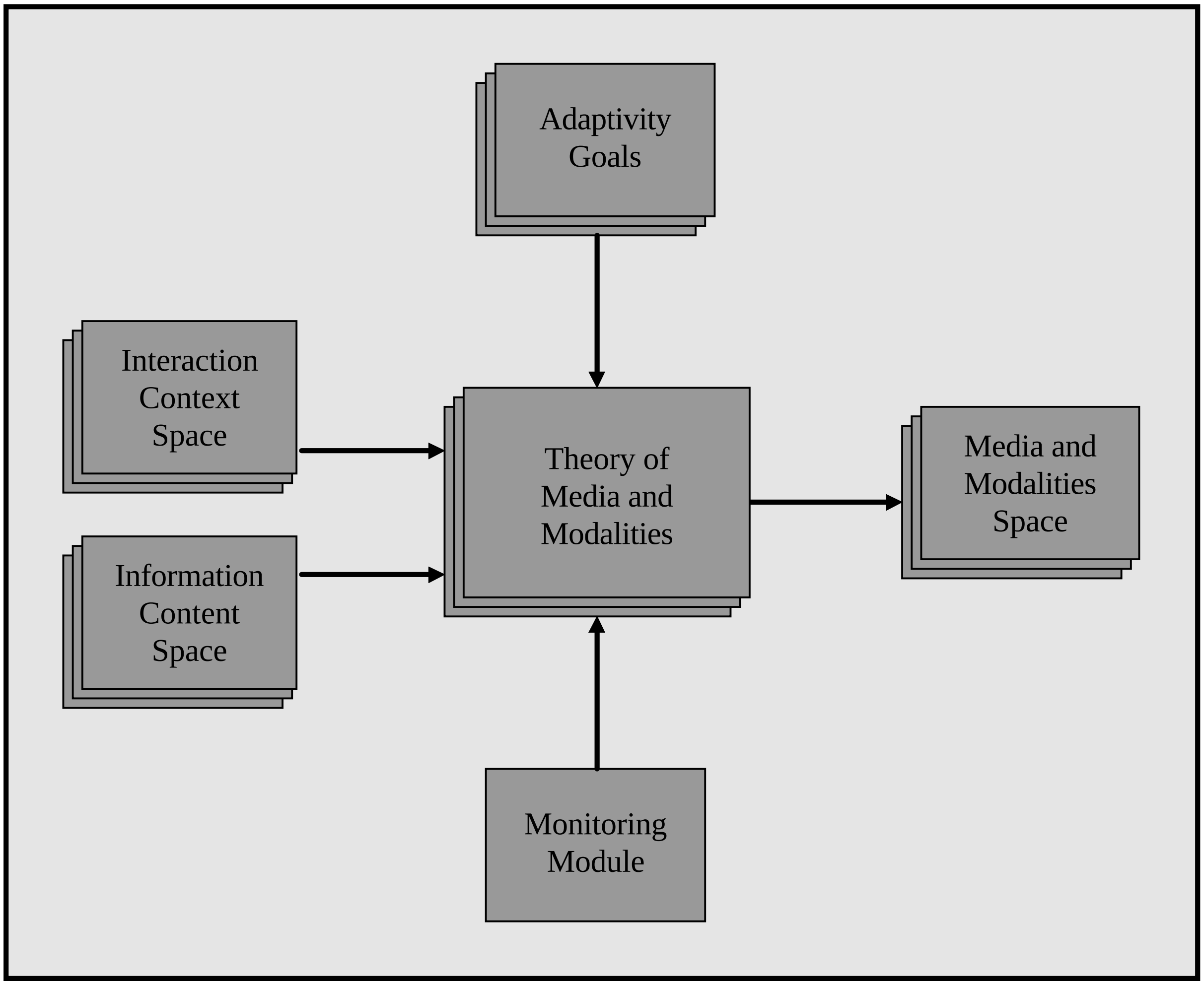

Figure 2: The Adaptivity Process following the notation of our approach.

The triple (IC, I, M) constitutes the Adaptivity Design Space (ADS), and is defined according to the requirements of a the particular application and user group. Consequently, the set of adaptivity rules must be developed, which relates instances of the IC and I spaces to instances of the M space, and is depended to the goals of the adaptivity. A methodology for the development of this set, which is called a *Theory of Media and Modalities* in the context of this paper, is proposed in the following.

3.2. Theory of Media and Modalities

Following the above notation, a Theory of Media and Modalities (TMM), would be a subset of the Adaptivity Design space, that is a set of triples, selecting adaptivity constituents instances (M space), based on the characteristics of the adaptivity determinants (IC and I space):

$$ADS \supseteq TMM = \{ (ic, i, m) / ic \in IC, i \in I, m \in M \}$$

The development of a TMM tailored to the requirements of a particular application may be a demanding task. Consulting the guidelines from the relevant literature is not sufficient, as the requirements of the specific application are not taken into account. Also, as TMM may contain several elements, it is reasonable to assist the designer in its development. For this reason, we break the problem of developing a TMM into smaller ones, by the introduction of the concept of Partial Theory of Media and Modalities.

3.2.1 Partial Theory of Media and Modalities

A Partial Theory of Media and Modalities (PTMM) is a subset of TMM, based on subsets of the Adaptivity Design Space. Thus, if the ADS is the one of the previous chapter, we may have PTMMs of the form $PTMM_{ICabilities,Iurgency}$, $PTMM_{ICload,Inature}$, etc. Developing PTMMs is easier that developing TMM. Thus, the problem of developing a TMM is transformed into the problem of combining PTMMs into a consistent TMM. This problem may be thought of as a problem of combining multiple knowledge bases, or as a multiple criteria decision making problem. Based on the relative literature ([Baral 91], [Zeleny 82]), we have developed such a methodology, which is presented in the following. The methodology has formed the basis for a tool, currently under development, which assist designers in adapting media and modalities.

3.3. The Proposed Methodology

The steps of the methodology are briefly presented in the following. A more comprehensive discussion can be found in [Karagiannidis 95b].

In the first step, the designer specifies the Adaptivity Design Space, that is spaces IC, I and M, according to the requirements of the specific application and user group. Additionally, the designer provides the attributes for each element of the M space (e.g. (text, visual) has attributes such as font, size, background and foreground color, etc, while (text, auditory) has attributes such as volume, speed, pitch, etc). In this way, the adaptivity determinants and adaptivity constituents are tailored to the requirements of the specific application.

In the second step, the designer specifies the set of Partial Theories of Media and Modalities. Each suggestion provided by PTMMs refers both to media and modalities, as well as to their attributes, and may be related to the current state of the dialogue (i.e. not current medium). Each suggestion provided by a PTMM is attached a set of weighting factors $W = \{ w_1, w_2, ..., w_w / w_1, w_2, ..., w_w \in (0, 1] \}$, which represent its relative importance, according to several interface qualities. That is, w_i may indicate the significance of a suggestion with respect to the efficiency of the system, while w_j may indicate the ease-of-learning. In this way, the adaptivity goals are incorporated into the adaptivity process. It should be noted that, if the methodology is to be realised into a design assistant tool, default values could be provided for the weighting factors, as well as for the elements of the adaptivity design space; in this case, the designer need only modify them according to the requirements of the application.

Consequently, the designer orders the set of PTMMs, in order to resolve any ambiguity or conflict that may arise between two suggestions that have the same weighting factor. The ordering is, of course, related to the relative importance of each PTMM, according to the requirements of the application.

In the fourth step, constraints on the composition of media and modalities are introduced, according to the requirements of the application. Each constraint is attached with a set of weighting factors, similar to the ones attached to the suggestions of PTMMs.

Finally, the suggestions given by each PTMM are combined for each instance of the Adaptivity Design Space. The combination depends on the weighting factor of each suggestion. As each suggestion has attached a whole set of weighting factors, however, the combination may be realised in several ways, such as lexicographic combination (according to the value of a specific weighting factor, e.g. efficiency), mean value combination (according to the mean value of the weighting factors), variance combination (according to the variance of the weighting factors for each suggestion), etc. In this way, the designer may incorporate the trade-off of adaptivity goals that is desired in the particular application. Consequently, the combinations that are included in the set of constraints are removed, and the final TMM is produced.

3.4. An Example Scenario of Use

Let us consider the case of a multimedia browser application that supports accessibility to three user categories, namely the ‘average’ able bodied user, slightly cognitive impaired users and blind users. The adaptivity determinants, as treated by our methodology, are classified under the Interaction Context and the Information Content spaces (IC and I respectively).

More specifically, the IC space is constructed from the following determinants:

- cognitive user load (set under the generic class of user load)
- perceptual user load (set under the generic class of user load)
- motor user load (set under the generic class of user load)
- motor movement (set under the generic class of user input / output channels)
- speech articulation (set under the generic class of user input / output channels)
- conception of visually presented information
- error proneness

For this specific example, the sets are considered discrete. The granularity of the sets depends on the intentions of the designer; if two- or three-value scales are used, the computation of the methodology is much simpler, while, on the other hand, the adaptivity rules to be derived may be ‘apospasmatic’ or odd.
The I space under consideration is assumed to be the following:

- urgency of information conveyed
- media related nature of information conveyed (e.g. temporal, spatial)
- criticality of information conveyed

The set of adaptivity constituents M considered for this example is:

- text presented in tactile, auditory or visual form, where the latter may be either in plain visual form, or in enhanced visual, i.e. graphical form; graphically formatted text may be accompanied with auditory effects such as cues, special sounds, etc, or visual effects e.g. blinking frames; also, text may be presented in full extent, shortened or annotated with embedded hypertext links;
- graphics presented in non-temporal form (e.g. images), or temporal format, e.g. animation or video.

The next step in the application of the methodology is the construction of PTMMs, with respect to the particular adaptivity goals posed by the designer. The abstract adaptivity goals, e.g. ease-of-use or efficiency, are mapped into tangible suggestions for the use of media and modalities, through the use of weighting factors that refer directly to the goals. For instance, suggestion to use auditory text in the case of an abstract information type may be attached with a large value for the weighting factor that refers to perceptability.

The combination of the different suggestions provided by PTMMs for each instance of the Design Space is based on these weighting factors. As each suggestion is attached with a set of weighting factors, each one referring to a specific interface ‘quality’, the designer is enabled to incorporate design trade-offs. The designer may, for example, maximise the efficiency of the system, by selecting the suggestions for which the relevant weighting factor is strong, or find a particular trade-off between efficiency and user satisfaction.

In the context of the selected application, adaptivity scenarios affect the presentation of information as well as the interaction means provided to the users. The final result of the methodology might be a set of rules that imply:

- if the user should be alerted, then the selected media and modalities should be different that the most recently used ones;
- textual information should be provided, if possible, in shortened i.e. not extended form, when considering efficiency as the prominent aspect;
- hypertext links should not span in depth of more than one level, i.e. there should be avoided the presentation of hypertext links at a level more than the initial;
- simplification i.e. flattening of 3D and stereo audio should promoted;
- if a blind user is exploring information in tactile form, new incoming information should be introduced in auditory form and vice versa;
- blind user’s alert should be provided with use of auditory cues;
- subsequent user alerts should be distinguished with use of different sounds;

- if for an error prone blind user his / her motor channel is currently busy e.g. the user reads tactile information, then any auditory message should concurrently disable any input by the user for preventing errors;
- if the user's perceptual load is considered low and has moderate to low motor movement ability, then use of the auditory modality is preferred

The result of the application of the methodology is the provision of a set of adaptivity rules, which are based on the particular sets of adaptivity determinants, constituents and goals. These rules might subsequently be used by a high-level user interface development environment, in order to provide a user interface that dynamically adapts to the requirements of the interaction.

As it is evident from the above discussion, the proposed methodology complies with the requirements identified. It enables the designer to specify the adaptivity determinants and constituents that are significant for the particular application. For instance, in the case of an air-traffic control application, the user's expertise need not to be modelled in the set of adaptivity determinants, as the user is expected to be expert; on the other hand, the user's expertise is of significant importance when considering an information system that is to be used by the general public. In this case, the designer may model this aspect in the set of determinants. Additionally, the media and modalities to be employed, which are the adaptivity constituents in the methodology, may also be specified by the designer, for each particular application.

Also, the adaptivity rules can be tailored according to the goals that the designer wishes to incorporate. Following the proposed methodology, the designer may optimise several 'qualities' of interaction, such as efficiency, number of errors, or user satisfaction, or any combination of them.

In this way, one may design a user interface that adapts its behaviour in order to, for example, maximise the efficiency of user for an expert user, minimise the number of errors for a novice user, etc. As a result, the adaptivity process is tailored to the requirements of the application domain and user category, thus significantly promotes the 'design for all' principle.

4. DISCUSSION AND CONCLUSIONS

Adaptive behaviour constitutes the central characteristic of Intelligent User Interfaces. In this paper we have been concerned with certain attributes of the adaptivity process, namely adaptivity determinants, constituents, goals, and rules. We have identified the requirements that have to be met by the attributes of the adaptivity process, in order to address the requirements of several application domains and user groups. Also, we have presented a new approach to the adaptivity at the media and modalities level, which complies with the above requirements.

It has been argued, that the provision of methodologies and tools that assist the design of the adaptivity process and comply with the identified requirements, may substantially promote the development of Intelligent User Interfaces, thus promote the 'design for all' principle.
The proposed methodology has formed the basis for a tool, currently under development, which assists the designer in the allocation of media and modalities, in the context of intelligent

user interfaces. Since the methodology has not been developed for the purposes of a specific user interface development environment such as a specific UIMS, its implementation into the above mentioned tool may be integrated within a development environment with the addition of the necessary communication protocols and interpretation modules.

As far as the communication protocols are concerned, issues related to the timing of the adaptivity need to be identified, i.e. whether the adaptivity modules communicate directly with the UI part of the applications, or a shared space a.k.a. blackboard exists where updates of the adaptivity constituents are placed. As far as the interpretation modules are concerned, the application of the methodology requires explicit identification of the interface components to be adapted i.e. the adaptivity constituents should either reflect original entities of the particular interface technology platform or be mapped to a series of entities of it.

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