Adaptable and Adaptive User Interfaces for Disabled Users in the AVANTI project

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Abstract. This paper reports work carried out in the context of the ACTS AVANTI AC042 project, addressing the issue of providing accessibility and high quality interaction in Web-based multimedia applications and services, to people with disabilities. The work presented concerns the design and development of a user interface component, which employs adaptability and adaptivity techniques to tailor itself to the abilities, skills, requirements and preferences of individual users, the different contexts of use, and the changing characteristics of run-time interaction between the user and the system.

1. Introduction

The increasing use of Internet and the World Wide Web as a primary medium for communicating information is creating numerous opportunities and challenges for the population at large. The importance of providing mechanisms for delivering information to all potential users in the context of the forthcoming Information Age has, therefore, increased significantly. The EC ACTS AVANTI AC042 project aims to address the interaction requirements of disabled individuals using Web-based multimedia applications and services. Along these lines, one of the main objectives of the work undertaken within the AVANTI project was the design and development of a user interface that would provide equitable access and quality in use to all potential end users. This paper presents the user interface of the AVANTI system, which employs adaptability and adaptivity techniques, in order to provide accessibility and high-quality interaction to users with different abilities, skills, requirements and preferences.

Adaptable and adaptive systems have been considered in a wide range of recent research efforts (e.g. [5.], [11.]). The relevant literature offers numerous examples illustrating tools for constructing adaptive interaction (e.g. [7.], [13.], [21.]), and case studies in which adaptive interface technology has improved, or has the potential to improve, the usability of an interactive system (e.g. [8.], [3.], [4.]). This paper does not aim to reiterate the argumentation for adaptive interfaces, but instead to present the approach taken in the context of the AVANTI project towards the development of an adaptable and adaptive user interface to Web-based information systems.

The User Interface (UI) of the AVANTI information system is a component which provides interactive views of adaptive multimedia Web documents. The distinctive characteristic of the AVANTI UI is its capability to dynamically tailor itself to the abilities, skills, requirements and preferences of the users, to the different contexts of use, as well as to the changing characteristics of users, as they interact with the system. The AVANTI UI also features integrated support for various "special" input and output devices, along with a number of appropriate interaction techniques that facilitate the interaction of disabled end-users with the system. The categories of disabled users supported in the current version of the system are: people with light, or severe motor disabilities, and blind people. As the design of the UI has followed the principles of *design for all* (*user interfaces for all* [19.]), inclusion of additional target user groups is facilitated. When functioning as part of the AVANTI system, the UI is externally conceived by the user as a specialised front-end through which access to the information in the AVANTI multimedia databases is achieved. The UI is also capable of functioning as an independent Web browser, providing access to traditional Web documents to able, motor-impaired and blind people.

This paper, presents the architecture of the AVANTI UI and its place in the overall architecture of the AVANTI information system (Section 2). Then, it moves on to describe the special input / output devices supported and the method used for their integration into the system (Section 3). Subsequently, the methodology used to design the UI is outlined, and its correlation to the UI adaptation capabilities is discussed (Section 4). Following that, the adaptation mechanism developed is presented, and the distinctive characteristics of adaptability and adaptivity are analysed (Section 5). The paper concludes by presenting a synthetic view of the UI and outlining a number of enhanced navigation and interaction features developed in the context of the AVANTI project (Section 6).

2. Architecture of the User Interface component

The AVANTI information system comprises five main modules: (i) a collection of multimedia databases which are accessed through a common communication interface (Multimedia Database Interface - MDI) and provide mobility information for disabled people; (ii) the User Modelling Server (UMS), which maintains and updates individual user profiles, as well as user stereotypes; (iii) the Content Model (CM), which retains a meta-description of the information available in the system; (iv) the Hyper-Structure Adaptor (HSA), which adapts the information content, according to user characteristics; and, (v) the User Interface (UI) component, which is capable of tailoring itself to individual users.

The requirements of the project dictated the development of a new experimental front-end, which would not be based on existing Web browser technology; the main reasons for that were: (i) although today's commercially available browsers support customisability through "add-on" components, etc, the level of adaptations planned within the project could not be effected using such approaches (e.g. integrating guidance in system dialogues), and (ii) the accessibility requirements posed by the disabled user categories addressed within the project could not be met, either by existing browsers in isolation, or through the use of third-party assistive products. To gain a better understanding of the issues involved, the reader is referred to section 3, which outlines some of the accessibility requirements of end users, in terms of input and output media and modalities, as well as to sections 4 and 5, which describe the type and range of adaptations employed within the AVANTI project.

The UI component is composed of six main software modules (see Fig. 1):

- The *HTTP communications* module; this is used to communicate with the HSA and the MDI, to retrieve the information content; the HTTP communications module can also be used to communicate with traditional HTTP servers, thus providing full standard browser functionality.
- The *KQML communications* module; this is a module that enables the UI to communicate with the UMS (using the Knowledge Querying and Manipulation Language [10.]), in order to exchange interaction monitoring information, and inferences about user states and interaction situations respectively.
- The *monitoring* module; the role of this module is to monitor user interaction and dispatch appropriate messages to the UMS. The information sent concerns both lexical and syntactic aspects of the interaction. The communication protocols between the UMS and the UI incorporate negotiation capabilities, so that, at any point in a session, the UMS is sent only information that is necessary for the inferences it attempts to make.
- The *adaptation mechanism* module; this module is responsible for retaining and applying adaptation rules that concern syntactic and lexical, adaptability and adap-

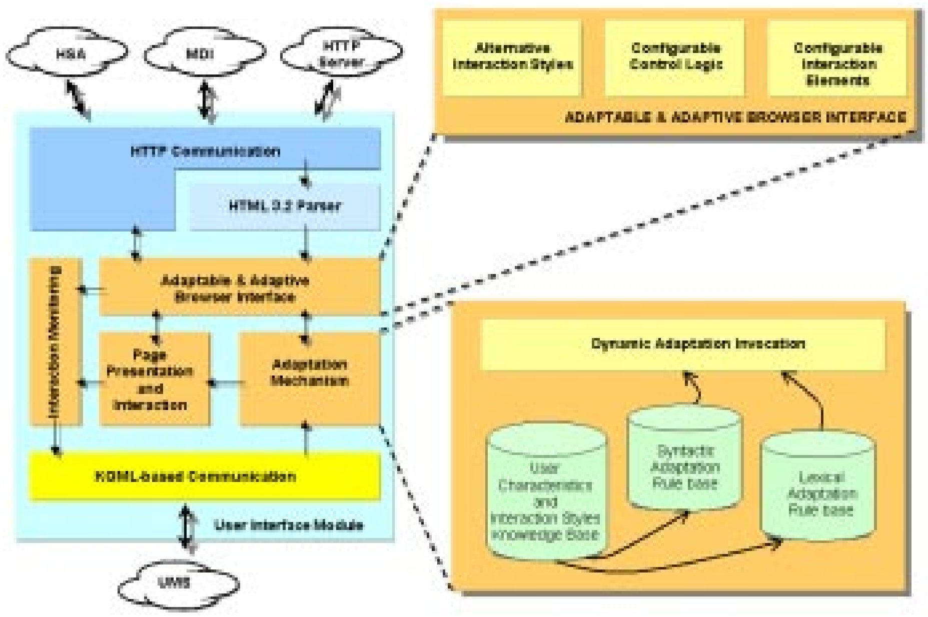

Fig. 1. Architecture of the AVANTI UI component

tivity at the level of the user interface, as well as for maintaining a knowledge space in which static user information and dynamically inferred (by the UMS) user states and interaction situations are held.

- The *adaptable and adaptive browser interface* module; this module is responsible for the presentation of the actual user interface of the AVANTI system. It instantiates the task decomposition and dialogue design, by implementing all the tasks and styles therein. The different dialogue alternatives are selected for execution dynamically, by consulting the adaptation mechanism and receiving appropriate decisions as a reply.
- The *page presentation and interaction* module; this module is responsible for presenting the user with an HTML document and allowing for interaction with the elements contained therein. The modality, as well as other aspects of the presentation are determined through user characteristics, with the assistance of the adaptation mechanism.
- The *HTML parser* module; this module implements an HTML 3.2 parser, specifically developed to cater for the requirements of the AVANTI system. Special meta-tag syntax has been introduced in the context of the AVANTI system, so that it is possible to affect the presentation of the user interface from within HTML documents (e.g. it is possible to enhance the command toolbar with new buttons and associated commands). Additionally, content tags have been introduced, in order to support the "inline" incorporation of multimedia content (audio and video) in HTML documents. The current implementation of the AVANTI user interface does not include support for scripting languages (e.g. Javascript), or extensions to HTML, commonly supported by commercial Web-browsing applications (e.g. frames).

3. Integration of Input / Output Devices

The problems that the target user categories face at the terminal level mainly concern: (i) the output devices and the compatibility of the presentation medium; (ii) the input devices and methods; and, (iii) the complex operational procedures required to control the terminal. In order to address these problems within the UI component, special software and hardware modules have been integrated in the terminal. Furthermore, alternative interaction techniques have been built into the user interface, to facilitate the process of controlling the resulting terminal configurations and interacting with the system.

The implementation of the terminal adaptations has adopted an architecture for the integration of special I/O devices, whereby an additional Device Software Layer (DSL) provides a way to uniformly control, and communicate with, special hardware and accompanying software. This software layer also allows the parallel operation of different I/O devices, resolving any potential conflict, and/or communication malfunction. A schematic representation of the adopted architecture (see [2.]) can be found in Fig. 2.

The above implementation has two advantages. First, many instances of the

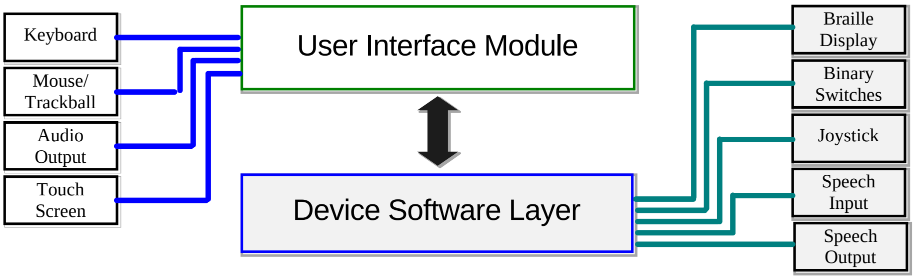

Fig. 2. Architecture for the integration of I/O devices

AVANTI UI can share the input and output devices consistently. Second new devices can be easily integrated by enhancing the DSL (e.g. by adding appropriate device structures) and without modifying the UI directly.

Standard I/O devices and systems that are supported by the AVANTI terminals include: keyboard (or any keyboard emulation device), mouse / trackball (or any mouse emulation device), non-speech audio output and touch screen. These are directly controlled by the UI component itself. The special I/O devices and systems supported (and controlled through the DSL) are: Braille display, touch tablet, binary switches, joystick, speech synthesis (output) and speech / command recognition (input).

To facilitate the use of the special devices by disabled users, specific interaction techniques have been developed. For example: switch interaction with the interface is achieved through (automatic, or user controlled) scanning and on-screen keyboards; touch tablets can be used by blind users through demarcated areas (raised edges, Braille labels, etc.), each of which corresponds to specific functionality; speech synthesis is used to present textual information to blind users and to signify attributes related to the possible hypermedia nature of the presented documents (e.g. links); speech recognition can be used to allow blind users to issue vocal commands to the system, through a special set of control and navigation commands; gesture recognition permits the use of a joystick by blind users, by coupling specific gestures to command sequences; tactile presentation of hypertext in Braille is augmented with special symbolic annotations, that facilitate the comprehension on the part of the user, of the exact type of item being presented.

4. Unified Design and Rule-Based Adaptation

The design of the user interface component of the AVANTI system has followed the Unified User Interface Design methodology (UUID), which has been proposed as an efficient and effective method for achieving the goal of user interfaces for all (see [19.], [18.]), including disabled and elderly users. Following UUID, only a single unified user interface is designed and developed, which comprises alternative interaction components, appropriate for different target user categories. This single design artefact may have multiple instantiations during initiation of interaction (adaptability), in order to ensure accessibility for a wide range of users. Moreover, each interface instance is continuously enhanced at run-time (adaptivity), in order to provide high-quality of interaction to all potential users (see [20.]).

Two dimensions of adaptations are addressed within the user interface of the AVANTI system, in relation to: (i) the *time* that adaptations take place, i.e. whether adaptations take place during the initiation of interaction (adaptability), or at run-time (adaptivity); and, (ii) the *level of interaction* at which adaptations are applied, i.e. syntactic and lexical level adaptations. Thus, four types of adaptations can be distinguished: lexical adaptability, syntactic adaptability, lexical adaptivity and syntactic adaptivity.

In the present context, *adaptability* refers to the process of selecting / modifying (aspects of) the user interface during initiation of each interaction session, according to user characteristics that are known prior to interaction (e.g. user abilities) and are assumed to remain unchanged within a single session (e.g. particular user expertise). *Adaptivity*, on the other hand, refers to the process of selecting / modifying (aspects of) the user interface dynamically, according to *dynamic user characteristics* and *situations* that are detected at run-time (e.g. high error rate, inability to complete a task, etc.)

Syntactic level adaptations concern the selection of different *styles* for each abstract interaction task. In particular, following the UUID methodology, the user tasks that can be performed through the user interface of the AVANTI system have been hierarchically structured and incrementally decomposed in a polymorphic fashion, defining alternative styles and task hierarchies, according to requirements and preferences of different user categories. In other words, different styles define alternative ways in which a specific task can be realised. Styles can be either compatible or incompatible to each other (depending on whether they can be simultaneously active), and are synthesised through the operators `BEFORE`, `OR`, `XOR`, `*` (simple repetition) and `+` (absolute repetition) (see [15.]). En example decomposition for the task "Go to Previous Document" is presented in Fig. 3.

During the design stage of the browser, it was found that certain styles exist that need to be included in the decomposition of most of the tasks. These styles are not specific to browsers and can be expected to be equally common in other types of applications. Styles in this category include: (i) *explicit feedback*, either during task performance (interim feedback) or after task completion (completion feedback); (ii) *confirmation*, which may belong to one of two types: either a brief request for explicit approval before the system carries out an action, or a more elaborate explanation of the possible consequences / side effects of the action, in conjunction with the request for approval; (iii) *guidance*, which provides help for the completion of a task (e.g. the sequencing of actions, the types of data required in each field, etc.), when, for example, there is evidence that the user is unable to complete this task; (iv) *prompting*, which provides information concerning the initiation and completion of a specific task, when, for example, there is evidence that the user is unable to initiate this task.

Lexical level adaptations concern the selection of interaction object attributes for each task, or style. In particular, the lexical level interface objects of each style can be instantiated with multiple attributes. The attributes of the interaction objects that are subject to adaptations in the present implementation include scanning (for severely motor-impaired users), font, colour and size parameters for the case of visual interac-

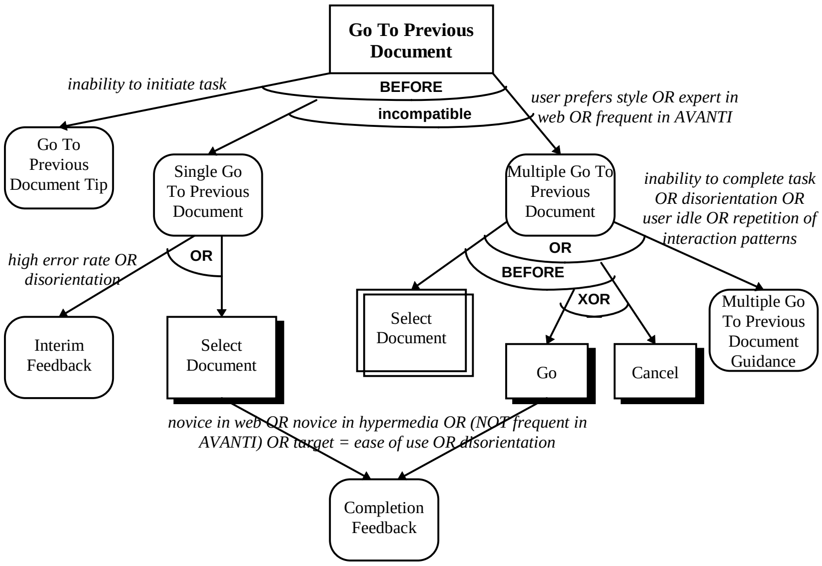

Fig. 3. Example of a polymorphic task decomposition

tion, and speech, sound and presentation parameters for the case of non-visual interaction. Lexical level adaptations also concern the selection of the appropriate overall metaphor of interaction. Two metaphors have been designed and developed for the needs of the AVANTI project, namely a "Public Information System" and a "Web-Browser" metaphor.

"Static" user characteristics (i.e. characteristics for which knowledge exists prior to interaction), have been selected, after an initial requirements analysis phase, to serve as the basis for adaptability. These include: (i) *physical abilities*, i.e. whether the user is able-bodied, blind or motor-impaired; (ii) the *language* of the user (the system supports English, Italian and Finnish); (iii) *familiarity* of the user with: *computing*, *networking*, *hypermedia* applications, the *Web* and the *AVANTI* system itself; (iv) the overall *interaction target*: speed, ease, accuracy, error tolerance; and, (v) *user preferences* regarding specific aspects of the application and the interaction; e.g. whether the user prefers a specific style for a given task; or the preferred speech volume when links are read; etc.

The selection of the above characteristics was made so as to ensure that adequate knowledge exists for the system to cater for a wide range of users, taking into account not only possible disabilities, but also characteristics that differentiate individual users -that may in general belong to the same broad category- between each other. In the current version of the system, these characteristics are acquired through an initial "questionnaire" session; more automated solutions are foreseen for future versions (e.g. smart-cards). It should be noted, that although these characteristics are uniformly termed "static", they are not all assumed to remain unchanged "permanently". In fact, it is foreseen that future versions of the system will detect and record changes in these characteristics over time, thus causing different adaptations to be effected in the user interface, in terms of adaptability. The *dynamic "user states"* and "*interaction situa-*

tions" that are taken into account in adaptivity (also selected during the initial requirements analysis phase) concern: (i) *user familiarity with specific tasks* (capability to successfully initiate and complete certain tasks); (ii) *ability to navigate* (move from one document to another in a consistent way); (iii) *error rate*; (iv) *disorientation* (inability to cope with the current state of the system); (v) *user idle time*; and (vi) *repetition of interaction patterns* (commonly encountered sequences of interaction steps).

```
                              Adaptability Rules
IF novice in hypermedia                          THEN   LinkType = Button
IF novice in computing AND motor impaired        THEN   ScanRate = Slow
IF novice in computing AND motor impaired        THEN   Font = Large AND Size = Large
FOR THE TASK  review bookmarks  {
    IF   user unable to complete task  THEN
         ACTIVATE STYLE  review bookmarks with guidance
}
                              Adaptivity Rules
IF high error rate OR inability to navigate      THEN   ScanRate = Slow
IF disoriented OR user idle                      THEN   SpeechVolume = High
FOR THE TASK  review bookmarks  {
    IF   user unable to initiate task  THEN
         ACTIVATE STYLE  awareness notification for review bookmarks facility
}
```

Fig. 4. Examples of adaptability and adaptivity rules

A set of syntactic adaptability and adaptivity rules has been defined and associated with each user task, providing the mechanism for the selection of appropriate interaction styles. Lexical level adaptations are also effected through respective rules, that assign different values to the attributes of the realised interaction objects. Fig. 3 presents an example task decomposition for a task, namely "Go To Previous Document", together with the syntactic adaptability and adaptivity rules that specify the conditions under which each style is being activated, while Fig. 4 presents simplified examples of lexical adaptability and adaptivity rules (the whole set of rules has been defined in [1.]).

5. Adaptation mechanism

The adaptation mechanism of the AVANTI user interface component comprises subcomponents which collectively allow for rule-based adaptation decisions to be made. It is based on a two-fold approach, which is briefly discussed below:

1. Implementation of the user interface must be carried out in a task-, and style-aware manner, i.e. the design knowledge and alternatives of the task decomposition and dialogue design must be clearly represented in the actual interface.
2. There must exist a decision mechanism, which will undertake the task of maintaining, evaluating and administering adaptation rules. The decision mechanism should: firstly, provide ways in which it can be *consulted* for the provision of decisions for

the syntactic and lexical levels of adaptations; secondly, be capable of *propagating* adaptation decisions (thus *triggering adaptations*) at either level of the interaction.

The UI decision mechanism adheres to the above description and comprises the following sub-components (Fig. 5 and Fig. 6): (i) the *syntactic adaptability rule base*, which retains the task- and style-related rules, referring to “static” user characteristics and preferences; (ii) the *syntactic adaptivity rule base*, which retains the task- and style-related rules, referring to dynamic user characteristics and situations; (iii) the *lexical adaptability rule base*, which retains the lexical element-related rules, referring to “static” user characteristics and preferences; (iv) the *lexical adaptivity rule base*, which retains the lexical element-related rules, referring to dynamic user characteristics and situations; and, (v) the *knowledge space*, which maintains knowledge on “static” and dynamic user characteristics and preferences.

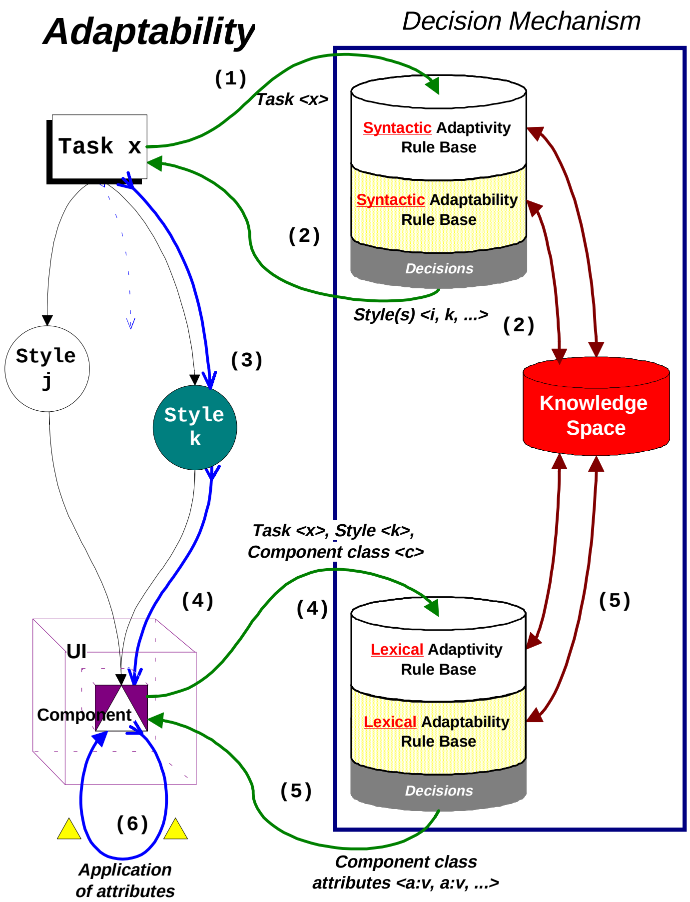

Fig. 5. Adaptability Mechanism

5.1 Adaptability

Adaptability is based on user characteristics and preferences that are known prior to interaction and are, in any case, assumed to remain static throughout a single interaction session. As a consequence, the corresponding rules can be evaluated during the initiation of the system and the resulting decisions can be directly applied for the instantiation of the interaction dialogues. The procedure followed is depicted in Fig. 5:

- A task *x* is triggered, either automatically (e.g. during system start-up), or as a response to a user action. The embedded communication facilities of the task structure consult the decision mechanism for the appropriate style(s) to be instantiated. The parameter passed is the identification of the task itself. (Fig. 5: (1))
- The syntactic adaptability rule base consults the knowledge space for the "current" user characteristics and preferences and evaluates its rules. The result returned is a (list of) style(s) that should be instantiated. (Fig. 5: (2))
- The task structure invokes the styles specified in the previous step, passing them any required application-specific parameters. (Fig. 5: (3))
- Any instantiated style creates / modifies specific "portions" of the user interface, comprising individual interactive components that are at some point created for presentation to the user. The communication facilities embedded to the *proxy adaptation object* attached to each such component, consult the decision mechanism for the appropriate attributes to be implemented (e.g. size, colour, volume). The parameters passed to the decision mechanism in this case are the task and style to which the component belongs, as well as the class / category of the component. (Fig. 5: (4))
- The lexical adaptability rule base consults the knowledge space for the "current" user characteristics and preferences, and evaluates its rules. The result returned is a list of attribute-value pairs that represent specific attributes of the component class and the respective values for the object that initiated the consultation. (Fig. 5: (5))
- The interface component applies the attributes to itself and proceeds to complete the steps required for its initialisation and presentation to the user. (Fig. 5: (6))

A main characteristic of the way in which adaptability is achieved (as opposed to adaptivity), is that communication between the decision mechanism and the user interface is initiated by the user interface constituents.

5.2 Adaptivity

Adaptivity is applicable at run-time and cannot be initiated by the interface constituents, as they do not have knowledge of changing user characteristics and situations. Thus, it is necessary that the decision mechanism triggers the adaptations itself. The procedure followed in the case of adaptivity, is depicted in Fig. 6:

- The UMS utilises monitoring data sent continuously by the user interface, and makes inferences on dynamic user characteristic(s) or situation(s) and informs accordingly the user interface decision mechanism (more specifically, it communi-

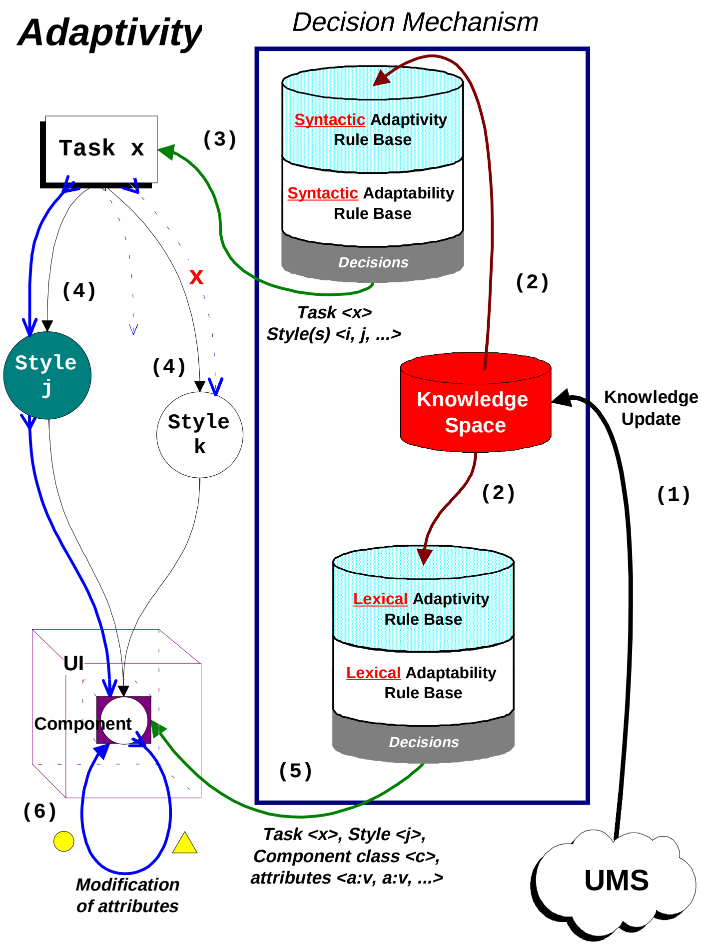

Fig. 6. Adaptivity Mechanism

cates new situations to the user interface knowledge space through a standard communication module [1.]). (Fig. 6: (1))

– The knowledge space triggers the re-evaluation of rules in the syntactic and lexical adaptivity rule bases. (Fig. 6: (2))
– Once the evaluation mechanism of the syntactic adaptivity rule base is triggered by the knowledge space, all rules that (partially, or entirely) depend on the modified knowledge are evaluated. This may result in new decisions regarding the styles that should be used to instantiate specific tasks, and notification is sent to the affected task structures accordingly. (Fig. 6: (3))
– When a task structure receives notification from the decision mechanism that a different set of styles should be used for its instantiation, it performs two distinct steps: (i) it stores this piece of information for use in future invocations, and (ii) it checks whether it is currently active (i.e. if the corresponding task is being carried

out by the user); if so, it may be necessary to dynamically deactivate certain styles and possibly also activate alternative ones in their place. (Fig. 6: (4))
– In parallel, the evaluation mechanism of the lexical adaptivity rule base is triggered by the knowledge space, and all rules that (partially, or entirely) depend on the modified knowledge are evaluated. This may result in new decisions regarding the values of the attributes that certain interface objects (participating in specific tasks and styles) should have, and notification is sent to the affected objects accordingly. (Fig. 6: (5))
– When an affected object receives notification from the decision mechanism that a different set of attributes should be exhibited, it applies the new attributes to itself, possibly after retracting any other conflicting attributes set in the past. (Fig. 6: (6))

Central to the overall adaptivity mechanism is the communication with the UMS, which actually triggers the modifications in the user interface, by dynamically providing inferences drawn from knowledge provided through monitoring, as well as through user group stereotypes and static user-specific characteristics (see [9.]).

6. Discussion and Future Work

This paper has presented the user interface component of the AVANTI information system. The design and development have followed the Unified User Interface Development methodology, rendering the resulting unified interface capable of adapting itself to suit the requirements of three user categories: able-bodied, blind and motor impaired. Adaptability and adaptivity are used extensively to tailor and enhance the interface respectively, in order to effectively and efficiently meet the target of interface individualisation for end users. Furthermore, to support interaction by disabled users, special I/O devices and respective interaction techniques have been integrated into the system.

In addition to the above, the AVANTI user interface offers a number of features that are aimed at assisting and enhancing user interaction with the system, as well as improving the accessibility of the resulting interface by specific user categories (see for example [12.], [23.], [16.]). Such features include: (i) enhanced history control for blind users, as well as linear and non-linear (graph) history visualisation for sighted users; (ii) resident pages that enable users to review different pieces of information in parallel; (iii) link review and selection acceleration facilities; (iv) document review and navigation acceleration facilities; (v) enhanced mechanisms for document annotation and classification; and, (vi) enhanced intra-document searching facilities. These features are described in detail in [17.]. Their design and development has been based on techniques used to support user navigation and orientation in large hypermedia systems (e.g. [14.]) and are not available in commercial browsers, as well as on existing empirical studies of user interaction patterns on the Web (e.g. [6.], [22.]).

The AVANTI UI is currently under evaluation by end users at three trial sites, in the context of the AVANTI system. The results of the evaluation will be used to refine the individual styles that comprise the interface, the interaction techniques developed specifically for disabled users, based on the supported special devices, as well as the adaptation rules used in the current version of the system. Future plans for the enhancement of the UI component include the integration of additional, non rule-based decision mechanisms, and the application of research results in the development of semantic level adaptation capabilities into the adaptation mechanism.

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