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Adaptive Techniques for Universal Access

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Abstract. This paper discusses the contribution of adaptive techniques to Universal Access in Human–Computer Interaction. To this effect, the paper revisits the concept of Universal Access, briefly reviews relevant work on adaptive techniques, and follows their application in efforts to provide accessibility of interactive systems, from the early, product- and environment-level adaptation-based approaches, to more generic solutions oriented towards Universal Access. Finally, the paper highlights some of the research challenges ahead. The normative perspective of the paper is that adaptive techniques in the context of Universal Access have the potential to facilitate both accessibility and high quality interaction, for the broadest possible end-user population. This implies the design of systems that undertake context-sensitive processing so as to manifest their functional core in alternative interactive embodiments suitable for different users, usage patterns and contexts of use. Such a capability needs to be built into the system from the early phases of conception and design, and subsequently validated throughout its life cycle.

Key words: universal design in HCI, universal access, adaptive techniques, adaptability, adaptivity, User Interfaces for All, Unified User Interfaces, AVANTI browser

1. Introduction

The term *Universal Access* is associated with different connotations. Some consider it as a new, politically correct term, referring to the introduction of ''special features'' for ''special users'' in the design of a product. To others, Universal Access is a deeply meaningful and rich topic that elevates what designers call ''good user-based design'' to a more encompassing concept of addressing the needs of *all* potential users. Also, some believe that Universal Access has its historical roots in the US Communications Act of 1934, covering telephone, telegraph, and radio services, and aiming to ensure adequate facilities at reasonable charges, especially in rural areas, and prevent discrimination on the basis of race, color, religion, national origin, or sex (Shneiderman, 2000). To many others, the term is associated with the effort to provide and facilitate access to the built environment (e.g. buildings and landscapes) for people with functional disabilities (Mace et al., 1991). In the early period, accessibility problems were primarily considered as concerning only the field of Assistive Technology (AT), and consequently, access entailed meeting prescribed requirements for the use of a product by people with disabilities (Stephanidis et al., 1998c; Story, 1998; Vanderheiden, 1998). Due to its perceived small size, the AT field remained largely under-served by technological change. For example, in the case of the transistor, it took many decades since its invention, before it became embedded into hearing aids. With the advent of the digital computer, and its broad penetration in business activities, the accessibility issue re-appeared, as disabled and elderly people faced serious problems in accessing computer-based devices.

Today, Universal Access resurfaces as a critical quality target in the context of the emerging Information Society. This is not only due to the changing world view on disabled and elderly people*, but also due to the pace of technological change, which in many cases delivers products and services requiring particular skills and abilities on the part of the human user (e.g. experience in the use of advanced technologies). In other words, as a result of recent technological developments (e.g. proliferation of diverse interaction platforms, such as wireless computing, wearable equipment, kiosks), the range of the population, which may gradually be confronted with accessibility problems, extends beyond the population of disabled and elderly users to include *all* people. Thus, today, Universal Access refers to the global requirement of coping with diversity in: (i) the target user population (including people with disabilities) and their individual and cultural differences; (ii) the scope and nature of tasks; and (iii) the technological platforms and the effects of their proliferation into business and social endeavours.

In parallel to the above, in recent years, the field of Human–Computer Interaction (HCI) has attracted considerable attention by the academic and research communities, as well as by the Information Technology and Telecommunications (IT&T) industry. HCI is playing an increasingly important role in the accessibility of Information Society Technologies (IST), as citizens in the Information Society experience technology through their contact with the *user interface* of interactive products, applications and telematic services (Computer Science and Technology Board, 1997; Stephanidis, 1999).

In the context of HCI, Universal Access introduces a new perspective that recognises, respects, values and attempts to accommodate a very wide range of human abilities, skills, requirements and preferences in the design of computer-based products and operating environments. This eliminates the need for "special features", while, at the same time, fostering individualisation, and thus high quality of interaction and ultimately, end-user acceptability. Such a commitment should not be interpreted as a call for a single design solution suitable for all users, but, instead, as an effort to design products and services that can adapt themselves so as to suit the broadest possible end-user population. In doing this, the implication is that different solutions will be appropriate for different contexts of use.

Under this perspective, Universal Access is much more than direct access or access through assistive technologies, and it encapsulates issues related to the contents developed, to the functionality supported by different services, and to the physical, syntactic and conceptual (semantic) characteristics of interaction. Though there

* Such changes have been brought about as a result of demographic pressures, the human rights movement, and national and international legislation.

have been efforts in the direction of specifying the attributes of Universal Access, we are still far from an operational definition of the term. This means that designers and developers lack a comprehensive frame of reference, which would enable the evaluation and assessment of early and tentative design solutions against a set of well-defined and measurable yardsticks. As a result, Universal Access remains an abstract goal, rather than a well-articulated engineering target. With the exception of very few efforts, which will be briefly reviewed in the ensuing sections of this paper, Universal Access in HCI remains a new research field, rather loosely defined and sometimes open to interpretation.

This paper will be concerned with the contribution of adaptive techniques to the universal accessibility of user interface software, with the intention to briefly review and critically assess recent progress, as well as elaborate on some of the challenges ahead. The treatment of these topics in this paper will mainly be grounded on work performed or supervised by the author in the context of a number of Research and Development (R&D) projects partially funded by the European Commission over the past decade. The paper is structured as follows. The next section provides a brief overview of adaptive techniques, and of the way in which they have been employed to facilitate a number of goals related to Universal Access. The emphasis is on early as well as more recent perspectives on adaptation, and on how it can be supported in user interface software. Having reviewed these efforts, the paper discusses the most important lessons learned from research work to date, and concludes with some of the research challenges ahead.

2. Adaptive Techniques and Universal Access: A Retrospective

Automatic system adaptation has long been a research theme in HCI. Significant progress has been made in recent years and many of the related research fields, such as user modelling, have delivered a wide collection of related techniques (for a review of user-modelling techniques see Kobsa, 1993). Until recently, however, and despite their sound theoretical and engineering background, adaptive techniques have had limited impact on the area of Universal Access. In fact, in many cases, adaptive techniques and assistive technologies have shared terminological references (the most prominent being the concept of “adaptation” itself), sometimes with fundamental differences in the interpretations of these terms. In particular, adaptation in the AT field has mainly referred to the introduction of accessibility facilities into previously inaccessible (to particular user categories) computer-based products and services, while the “traditional” lines of research in adaptive techniques have focused on facilitating and supporting user interaction with the system, in many cases on a domain-specific basis.

The first attempts to bring the two communities closer were initiated in the 1990s (e.g. the ACCESS Project, see Acknowledgements; see also Stephanidis and Emiliani, 1999) and were focused on user interface adaptations to support the requirements of disabled and elderly people. Subsequently, as the need for Universal Access became more evident in the context of the Information Society, a number of efforts emerged* aiming to investigate generic solutions based on a more comprehensive account of adaptive interaction. This paper will briefly review the recent history of adaptation-related research, as this has manifested itself in the field of adaptive technologies and in ''mainstream'' adaptive techniques in HCI, and will discuss some initial promising applications of adaptive techniques towards the goal of Universal Access.

2.1. Adaptive techniques and human–computer interaction

The notion of systems that can adapt according to various requirements and criteria, or even upon request, is not new. The relevant bibliography contains numerous cases in which adaptation techniques have been used to improve the performance of existing computing systems, or to enable the exploration of new dimensions in computing, in application domains such as networking, decision support, information retrieval and classification, etc. For a review, see Kobsa (1993).

In the broad domain of interactive software, adaptation has been identified as a characteristic of systems that can exhibit intelligent behaviour and possess the ability to support and co-operate with their users in the attainment of interaction goals (e.g. Benyon, 1997). Despite the high degree of attention that adaptation in interactive systems has drawn recently, the definition of what constitutes an adaptation-capable system remains broad and, in some cases, controversial. Thus, it is necessary to provide a contextual explanation of the terms before discussing how they can relate to accessibility as this has been defined earlier. For the purposes of this paper we will adopt a coarse classification of existing approaches to adaptation in interactive systems into two broad categories, namely user-invoked adaptation and automatic adaptation. Both categories have been extensively investigated and compared in the literature (see, e.g. Dieterich et al., 1993; Fischer, 1993, 2001; Kobsa and Pohl, 1995; Oppermann, 1994).

The first category of adaptation pertains to systems that offer their users the capability to select, or set between different alternative presentation and interaction characteristics, among the ones built into the system. Typical examples of such user-invoked adaptations include customisation of system behaviour through preference dialogs, modification of the position and size of interactive elements in Graphical User Interfaces, adjustment of domain-specific system functionality, etc. The main limitation associated with systems in this category is that they usually offer a limited set of adaptation facilities, which are most of the time pre-packaged. Moreover, making use of these facilities presupposes considerable familiarisation of the user with the system, which may limit, or render entirely void, the usefulness of the adaptation (since users have already adapted themselves to the system).

* Prominent examples of these efforts include: the AVANTI project (see Acknowledgements); the ERCIM Working Group ''User Interfaces for All'' (http://www.ics.forth.gr/proj/at-hci/UI4ALL/index.html); the International Scientific Forum ''Towards an Information Society for All'', (Stephanidis et al., 1998c, 1999); the Working Group ''Information Society for All'', a *Thematic Network* in the Information Society Technologies Programme of the European Commission.

The second approach to adaptation is based on the principle that the system should be capable of identifying those circumstances that necessitate adaptation, and accordingly, select and effect an appropriate course of action. This implies that the system possesses the capability to monitor user interaction, and use the monitoring data (possibly of more than one users) as the basis upon which it draws assumptions, continuously verifying, refining, revising, and, if necessary, withdrawing them from the set of assumptions known to be valid for a given user or group of users (Rich, 1989). Automatic adaptation is, in fact, the primary interpretation that is typically assigned to the notion of adaptive behaviour on the part of the system.

Although both types of adaptation have evident relation to, and can greatly contribute in achieving, Universal Access, it is automatic adaptation that holds the greatest promise in the context of constructing systems that are capable of catering for the needs of their users. The recent research literature has contributed a large number of adaptive techniques that have addressed the issue of rendering a system more appropriate for particular users. Some examples that demonstrate the implicit relation between these approaches and Universal Access include: content-based filtering of Web sites and email messages (Boone, 1998; Pazzani et al., 1996), collaborative filtering and recommendation systems (Basu et al., 1998; Billsus and Pazzani, 1998), adaptive interfaces that identify and undertake repetitive tasks (Hermens and Schlimmer, 1994; Schlimmer and Hermens, 1993), adaptive travel and scheduling assistants (Dent et al., 1992; Gervasio et al., in press; Linden et al., 1997; Rogers et al., 1999), intelligent tutoring systems (Baffes and Mooney, 1999; O'Shea, 1979), etc.

As already mentioned, in much of the existing work the notion of Universal Access is implicit in the very goals that adaptive techniques seek to address. For example, adaptively presenting system functionality in ways that support novice users of the system, as well as more experienced ones, increases the ''accessibility'' of that system and ensures higher degrees of usability for both user categories (Fischer, 2001). However, despite this obvious connection, adaptive techniques have hardly impacted on more traditional notions of accessibility involving different user (dis)abilities, and it was not until recently that the first successful cases in the latter category were reported.

2.2. Accessibility by Disabled and Elderly People

2.2.1. *Early Focus: Product- and Environment-level Adaptations*

Early attempts to employ adaptation techniques to facilitate the accessibility of interactive software were motivated by the intention to serve specific user communities, such as disabled and elderly people⋆. Blind or visually impaired users attracted most of the attention in these early attempts, due to the particular

⋆ Indicative projects addressing this research direction are the Mercator project in the USA (Mynatt and Edwards, 1992), and a number of collaborative R&D projects funded by the European Commission (see Stephanidis and Emiliani, 1999).

challenges faced by this user community, resulting from the emergence of Graphical User Interfaces that had severely limited their opportunities to access computers, in comparison to the previous command-based interfaces that could more easily be "verbalised".

Adaptations in these early efforts were reactive in nature, in the sense that they sought to "treat" the problem of inaccessibility once it had been introduced, rather than prevent it from occurring in the first place. The different approaches that emerged under this perspective can be broadly classified into two categories: product-level and environment-level adaptations. Product-level adaptations were manifested either as ad-hoc modifications in already developed, inaccessible interactive products, or as dedicated product (re-)developments for particular categories of disabled people. Irrespective of their intended purpose, these adaptations share a common characteristic: they are hard-coded into the application and are static, in the sense that they are implemented as one-off accessibility solutions. Updating or modifying them to accommodate the slightest user variation or preference entails re-engineering the user interface. Although an in-depth discussion of these shortcomings is beyond the scope of this paper (interested readers can refer, for example, to Savidis and Stephanidis, 1995a and Savidis and Stephanidis, 1998), it is important to note the following considerations. First of all, product-level adaptations introduce a programming-intensive approach towards accessibility, which increases the cost of implementing and maintaining accessible software. Secondly, technological progress may render such adaptations harder to implement; there may be restrictions imposed either by the target application or by the operating system. Thirdly, for practical and economic reasons, product-level adaptations always appear on the market with a considerably time-lag behind the products they adapt. Environment-level adaptations, on the other hand, moved away from the single-product level and addressed the "translation" of the visual, direct-manipulation dialogue realised by interactive software running within a software environment, to alternative modalities and media, accessible to disabled users. Several proposals emerged concerning the different types of tools that could be used to facilitate such adaptations. For example, in the case of blind users, the notions of "filtering" and "off-screen" models (Mynatt and Weber, 1994) were proposed as basic adaptation techniques facilitating access⋆. In a similar fashion, other types of software adaptation were developed for different categories of disabled users (e.g. motor impaired users, users with learning difficulties, etc). Indicative examples include interface scanning, "sticky keys" and word prediction⋆⋆. The major drawback of environment-level adaptations is rooted in the fact that they attempt to

⋆ Progressively, these techniques have found their way into commercial products, which are today available in the market (e.g. screen readers).

⋆⋆ Examples of Assistive Technology products for motor or cognitive impaired users can be found at the following URL addresses: http://www.olivetreesoftware.com/itmidx9.htm, http://www.donjohnston.com/, http://www.intellitools.com/, http://www.medizin.li/mt__index__az/__a/a__40034.htm, http://www.prentrom.com/speech/axs.html).

render accessible software that was designed for (and thus is inherently only appropriate for) "average", able-bodied users. No matter how advanced the methods and techniques used to effect the aforementioned "transformation" are, these types of adaptation are bound to far lower levels of interaction quality, when compared to interactive software specifically designed to cater for the particular needs and preferences of different categories of disabled users. These limitations become critically important when viewed in the context of the emerging Information Society, where accessibility can no longer be considered as a mere adaptation-based translation of interface manifestations to alternative modalities and media, but as a quality requirement demanding a more generic solution (Stephanidis et al., 1998c).

2.2.2. *Towards More Generic Solutions*

In the light of the above, it became evident that the challenge of accessibility needs to be addressed through more proactive and generic approaches, which account for all dimensions and sources of variation. These dimensions range from the characteristics and abilities of users, to characteristics of technological platforms, and to relevant aspects of the context of use (Stephanidis et al., 1998c). The concept of Dual User Interfaces* (Savidis and Stephanidis, 1995a) constitutes a first step in this direction, as it defines a basis for "integrating" blind and sighted users in the same working environment.

A Dual User Interface is characterised by the following properties: (i) it is concurrently accessible by blind and sighted users; (ii) the visual and non-visual metaphors of interaction meet the specific needs of sighted and blind users respectively, which may differ considerably; (iii) the visual and non-visual syntactic and lexical structure meet the specific needs of sighted and blind users respectively; and (iv) at any point in time, the same functionality and the same semantic information is made accessible to both user groups through the corresponding visual and non-visual instances of the Dual User Interface.

The HOMER User Interface Management System (UIMS) (Savidis and Stephanidis, 1995a, 1998) has been developed in the context of the GUIB and GUIB-II projects (see Acknowledgements) to facilitate the design and implementation of dual interfaces. HOMER is based on a 4th generation user interface specification language (the HOMER language). To support non-visual interface development, the COMONKIT non-visual interface toolkit (Savidis and Stephanidis, 1995b, 1998) was also developed and integrated within the HOMER UIMS. The HOMER UIMS has been used for implementing various dual interactive applications such as a payroll management system, a personal organiser, and an electronic book with extensive graphical illustrations and descriptions (Savidis and Stephanidis, 1998).

* The concept of Dual User Interface, as well as the HOMER User Interface Management System have has been developed in the context of GUIB and GUIB II projects (see Acknowledgements).

Dual User Interfaces signified a radical departure from previous approaches to user interface accessibility, by proposing that accessibility is treated from the early design phases of interactive software development, and that the accessibility requirements of more than one user categories are taken into account. Thus, the concept of Dual User Interfaces and the HOMER UIMS were the first attempts in this direction and served as a catalyst towards proactive and more generic solutions to user interface accessibility, contributing new insights to the engineering of accessible user interface software.

2.3. Adaptive techniques and universal access: combining perspectives

Following the early work that resulted in the notion of Dual User Interface and the HOMER UIMS, the first systematic effort to address the issue of accessibility of computer-based systems by *''all''* different categories of users (including disabled and elderly people) through the application of concepts and principles, as well as concrete methods and techniques from the field of adaptive human-computer interaction, was the ACCESS Project (see Acknowledgements). This section will provide an overview of the concept of *User Interfaces for All*, which offered the theoretical grounds upon which the *Unified User Interface development* methodology is based, and explain how these relate to adaptive techniques and Universal Access. Furthermore, a successful case will be presented where adaptive techniques were used to render Web-based information systems accessible by diverse users in different contexts of use.

2.3.1. User Interfaces for All *and* Unified User Interface *Development*

The basic premise of Dual User Interfaces, namely that accessibility can be tackled in a generic manner, was subsequently extended and further generalised through the concept of *User Interfaces for All*, and led to the development of a technical framework for supporting such an approach, as well as to the application of such a framework for the realisation of accessible and usable interactive applications.

The concept of *User Interfaces for All* is rooted in the idea of applying *Design for All* (or *Universal Design*, the terms are used synonymously) in the field of HCI (Stephanidis, 1995, 2001b). The underlying principle is to ensure accessibility at design time, and to meet the individual requirements of the user population at large, including disabled and elderly people. To this end, it is important that the needs of the broadest possible end-user population are taken into account from the early design phases of new products and services. Such an approach, therefore, eliminates the need for *a posteriori* adaptations and delivers interactive products that can be tailored to the individual requirements of *all* users.

The *Unified User Interface development* methodology* (Akoumianakis et al., 2000; Akoumianakis and Stephanidis, 2001; Savidis et al., 2001; Savidis and

* The *Unified User Interface development* methodology and related tools were developed in the framework of the ACCESS Project (see Acknowledgements).

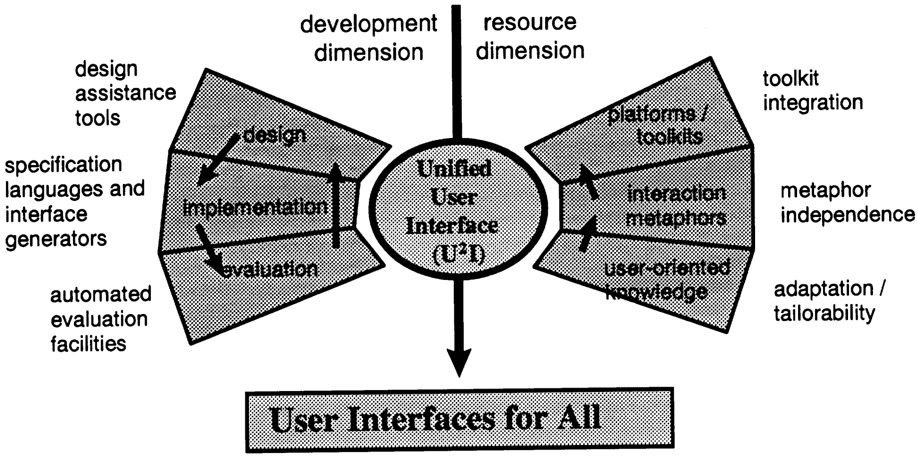

Figure 1. Elements of unified user interface development.

Stephanidis 2001a, 2001b, 2001c; Stephanidis 2001c; Stephanidis et al., 2001; Stephanidis et al., 1997a) is a new methodology seeking to convey a new perspective on the development of user interfaces, and to provide a principled and systematic approach towards coping with diversity in the target users groups, tasks and environments of use.

Unified User Interface (U^2I) development entails an engineering perspective on interactive software, and a collection of tools that allow the specification of a user interface as a composition of abstractions (see Figure 1). A U^2I comprises a single (unified) interface specification, targeted to potentially *all* user categories. In practice, a U^2I is defined as a hierarchical construction in which intermediate nodes represent abstract design patterns decoupled from the specific characteristics of the target user group and the underlying interface development toolkit, while the leaves depict concrete physical instantiations of the abstract design patterns. The U^2I development method comprises design- and implementation-oriented techniques. Design-oriented techniques (U^2I design) aim towards the development of rationalised design spaces, while implementation-oriented techniques (U^2I implementation) provide a specifications-based framework towards constructing interactive components and generating the run-time environment for a unified interface.

U^2I design (Savidis et al., 2001) aims at: (i) initially identifying and enumerating possible design alternatives, suitable for different users and contexts of use, employing techniques for analytical design (such as design scenarios, envisioning and ethnographic methods); (ii) identifying abstractions and fusing alternatives into abstract design patterns (i.e. abstract interface components that are de-coupled from platform-, modality-, or metaphor-specific attributes); and (iii) rationalising the design space by means of assigning criteria to alternatives and developing the relevant argumentation, so as to enable a context-sensitive mapping of an abstract design pattern onto a specific concrete instance.

The result of the design process is a unified user interface specification. Such a specification can be built using a dedicated, high-level programming language, and results in a single implemented artefact which can instantiate alternative patterns of behaviour, either at the physical, syntactic, or semantic level of interaction. The unified implementation, which is produced by processing the interface specification, employs adaptation techniques to effect the mapping of abstract interaction patterns and elements to their concrete/physical counterparts.

Adaptation in Unified User Interface development has a different meaning than that prevailing in earlier efforts. Specifically, adaptation is considered as both a design-time and a run-time feature (see Figure 2). The former type of adaptation is referred to as adaptability, and depicts the design efforts devoted to providing different accessible versions of an interface, prior to the initiation of interaction. The latter form, referred to as adaptivity, coincides with the reserved notion of adaptive behaviour in intelligent user interfaces and concerns the run-time enhancements of the dialogue to facilitate individualisation and usability.

It should be noted that the concept of adaptability in the context of the U^2I methodology does not coincide with the concept of tailorability (i.e. the provision of facilities to the users through which they can modify aspects of the system while interacting with it) as is often the case in the relevant literature. Instead, adaptability entails a conscious effort to identify, document and specify alternative interactive embodiments that suit different users or contexts of use. These interactive embodiments may use different interaction elements, which may embody radically different interaction metaphors. For the purposes of adaptability, designers and developers will need to instantiate such design options, and subsequently unify them into abstract compositions that can be interpreted at run-time and mapped to their appropriate physical counterparts.

The implementation of U^2Is is supported by a development environment that includes:

(a) The I-GET User Interface Management System (Savidis and Stephanidis, 1997, 2001c; Stephanidis et al., 1997a), which supports the high-level specification of U^2Is, as well as the automatic generation of user interface implementation from such specifications.
(b) The USE-IT Design Support Tool (Akoumianakis and Stephanidis, 1997a, 1997b, 2001), which provides the design-time support for achieving adaptability. Specifically, USE-IT decides upon the lexical aspects of the interaction dialogue based on knowledge about user characteristics, abilities and preferences, as well as on knowledge about the structure of lexical level characteristics of the interface with respect to the various target user groups.

The U^2Is that are developed using the above mentioned tools automatically inquire the generated adaptability decisions, and apply these decisions at run-time.

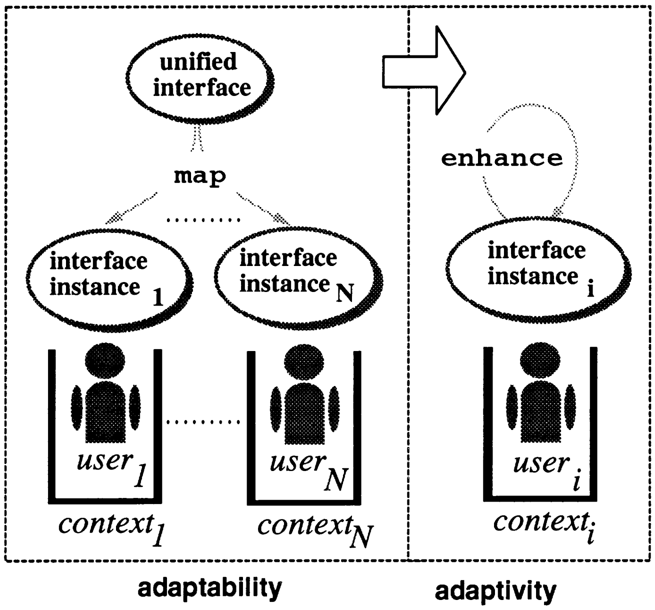

Figure 2. The complementary roles of adaptability (left) and adaptivity (right) in Unified User Interfaces encapsulating automatically adapted behaviours.

The primary emphasis in U^2Is is to ensure that adaptability is employed to arrive at an instance of an interactive system that is sufficiently accessible for a particular user to start interacting with. Further modifications in the interaction process can be introduced through adaptivity and user tailoring, to achieve even higher quality of interaction and system performance that better suits the abilities, requirements and preferences of the end-users.

2.3.2. *Adaptive Techniques and Universal Access in AVANTI*

The AVANTI project (see Acknowledgements) aimed to address the interaction requirements of individuals with diverse abilities, skills, requirements and preferences, using Web-based multimedia applications and services. To the author's knowledge, the AVANTI system was the first system to employ adaptive techniques in order to ensure accessibility and high-quality interaction for *all* potential users*.

The basis for adaptivity in the AVANTI framework is its user modelling component, the User Modelling Server (UMS) (Schreck and Nill, 1998), which was developed within the project, and is the evolution of the BGP-MS user modelling shell system (Kobsa and Pohl, 1995). The UMS is utilised in AVANTI to provide the required support for user-oriented adaptations. It offers location-independent access

*The project demonstrator addressed concurrently the requirements of able-bodied, blind and motor-impaired users.

to user-related information to any interested component. In the AVANTI system, the UMS inter-operates with the user interface and content adaptation components, which monitor users and report their actions back to the UMS.

Content adaptations are supported in AVANTI through the Hyperstructure Adaptor (HSA) (Fink et al., 1998; Schreck and Nill, 1998) which dynamically constructs adapted hypermedia documents for each particular user. The degree of support for, and the type of, content-level adaptations in the three information systems developed in the context of AVANTI are presented in (Stephanidis et al., 1998a) and (Fink et al., 1998). It is interesting to note that the user characteristics that trigger appropriate adaptation types at the content level mainly concern the type of disability, the expertise and the interests of the user. The resulting adaptations mostly concern: (i) alternative presentation using different media (e.g. text vs. graphics, alternative colour schemes); (ii) additional functionality (e.g. "shortcuts", adaptive links to frequently visited portions of the system); (iii) conditional presentation of technical details; (iv) conditional presentation of details that are of interest to users with specific disabilities only; and (v) "role-taking" facilities allowing users to identify themselves as having a particular disability, active interest, etc. Knowledge about the user and the interaction session is mostly based on information acquired dynamically during run-time (e.g. navigation monitoring, user selections, explicit user invocation), with the exception of the initial profile of the user, which is either retrieved from the UMS, acquired through a questionnaire during the initiation of the interaction, or retrieved from a smart card.

The User Interface component of the AVANTI system is functionally equivalent to a Web browser and is intended to provide accessible interactive views of the adaptive multimedia Web documents. The AVANTI browser was developed following the U^2I development approach, and served as a case study in the application of the related methods and techniques. Adhering to U^2I, adaptability and adaptivity at the user interface level are applied to tailor the browser to the end-user abilities, requirements and preferences, both during the initiation of a new session and throughout interaction with the system (Stephanidis et al., 1997b). The distinctive characteristic of the AVANTI Web browser is its capability to dynamically tailor itself to the abilities, skills, requirements and preferences of the end-users, to the different contexts of use, as well as to the changing characteristics of users, as they interact with the system (Stephanidis et al., 2001).

Adaptation in the AVANTI browser follows a rule-based approach. Specifically, adaptation rules have been defined and associated with each user task, providing the mechanism for the selection and configuration, of alternative user interface components. Rules and corresponding decisions are based on a number of 'static' and 'dynamic' user characteristics, which were selected during the user requirements analysis phase of the project. The selected static user characteristics (already known at design time) include: (a) physical abilities; (b) the language of the user (the demonstration system supports English, Finnish, Greek and Italian); (c) familiarity of the user with: computing, networking, hypermedia applications, the Web and the AVANTI system itself; (d) the overall usage target: speed, ease of use, accuracy, error tolerance; and (e) user preferences regarding specific aspects of the application and the interaction. The dynamic user characteristics (changing during interaction) and interaction states that are taken into account concern: (a) familiarity with specific tasks (i.e. the user's ability to successfully initiate and complete certain tasks); (b) ability to navigate using the documents' navigation elements; (c) error rate; (d) disorientation; (e) user idle time; and (f) repetition of interaction patterns (Stephanidis et al., 1998b).

The primary target for adaptability in the AVANTI browser is to ensure that each of the system's potential users is presented with an instance of the user interface that has been tailored to offer the highest degree of accessibility possible (limited, of course, by the system's knowledge about the user). Adaptivity is subsequently employed to further tailor the system to the user's inferred needs or preferences, so as to achieve the desired levels of interaction quality. It should be noted, of course, that the user retains overall control of the system and can override the system's decisions at any time, or even disallow adaptations entirely.

The AVANTI system has served as a successful testbed for the application and validation of the U^2I development methodology. Furthermore, it has proven that more ''traditional'' adaptive techniques (in this case from the field of Adaptive Hypermedia Systems) have much to contribute in the direction of accessibility by a wide range of users, including disabled people. Thus, the results of the AVANTI project have demonstrated the feasibility of bringing together methods and techniques from interface adaptation and content adaptation in order to make concrete steps towards the goal of Universal Access. As it will be elaborated in the next section, this constitutes simply a first step in the long path that lies ahead; nevertheless, the validity of the approach has been established and the potential can be exploited in the context of new challenges for Universal Access in the Information Society.

3. Discussion and Conclusions

In the course of the past few years, the interest on Universal Access has grown in the academic and research communities, industry and policy making bodies at national and supra-national levels. This has been the result of some solid R&D efforts, as well as of the increasing awareness of the critical impact of Universal Access on the accessibility, and, ultimately, on the acceptability of the Information Society. In this section we attempt to generalise from the experiences outlined in the previous section, and to provide an account of some of the lessons learned, as well as the relevant issues which should be taken up in future R&D efforts.

3.1. Lessons learned

Recent R&D activities have revealed valuable insights to the study of Universal Access in HCI, and several lessons have been learned concerning the contribution of adaptive techniques. For the purposes of the present paper, they are tentatively categorised into design- and development-oriented lessons.

The first important design lesson is that adaptation needs to be "designed into" the system rather than decided upon and implemented a posteriori. To this end, designers need analytical instruments, which unfold and incrementally capture diverse requirements and contexts of use. In the recent past, HCI has delivered several analytical design methods, which are of particular interest from the point of view of adaptation. For instance, design rationale (Carroll and Moran, 1996) and scenario-based design (Carroll, 1995) can provide informative frames of reference regarding the conduct of design.

Secondly, at the level of design methods or techniques, it is important to note that Universal Access requires an understanding of the global execution context of a task. This entails design techniques that can capture alternative design options and design representations that can be incrementally extended (i.e. design pluralism) to encapsulate evolving or new artefacts. The U^2I design method provides an instrument orthogonal to the above mentioned analytical frames of reference, which can be used to structure, capture and organise design alternatives in a manner that can be appropriated by suitable user interface development techniques.

A third design lesson that has been learned through practice and experience is that Universal Access means breaking away from the traditional perspective of "typical" users interacting with a desktop machine in a business environment. A more likely scenario is that of *environments of use* accessible at anytime, anywhere and by anyone. This entails that future systems should embody the capability for context-sensitive processing so as to present their users with a suitable computational embodiment or metaphor depending on user, situational and context-specific attributes (Akoumianakis et al., 2000). However, the architectural abstractions of such systems and their quality attributes remain a challenge.

The first development oriented lesson concerns the fact that prevailing graphical toolkits do not suffice to facilitate the broad range of alternative interactive embodiments needed to empower and facilitate Universal Access. Moreover, traditional user interface architectural models may need to be revised and extended to inform and guide developments in this direction. An example of such extension can be found in the Java Swing development platform*, which follows the MVC model of Smalltalk (Goldberg and Robson, 1983). However, if multiple platform environments, such as Java, are the cornerstones of today's distributed and collaborative computing, equally important for Universal Access is the notion of multiple toolkit platforms (Myers, 1995; Savidis et al., 1997). Such platforms provide the hooks and mechanisms to integrate alternative interactive embodiments for an application, so as for the latter to be accessible by anyone, at anytime and from anywhere.

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* http://www.ora.com/catalog/jswing/desc.html.

A second development-oriented lesson, which relates to the previous one, concerns the type of tools needed to facilitate the development of universally accessible and usable systems. In particular, the suitability of such tools to the design of such systems depends on their independence from specific development platform. Tools considered appropriate are those which, instead of directly calling a platform, can link to it and make use of the available interaction resources. As a derivative of the previous argument, it follows that user interface development should progressively be supported through specification-based rather than programming-oriented techniques.

3.2. The challenge ahead

Despite the recent rise of interest in the topic of Universal Access, and the indisputable progress in R&D, many challenges still lie ahead. The intention of this section is to provide a brief and non-exhaustive account of some of the elements that can be considered as future R&D targets. To this effect, our primary interest is to highlight the thematic topics that can advance the existing wisdom on adaptive techniques for Universal Access in the context of HCI.

The first and by far the most important research challenge is how to design virtualities (Winograd, 1996) which are universally accessible and usable. In other words, there is a compelling need to advance a design-oriented understanding, both in terms of scientific method and empirical ground, of Universal Access in HCI. This calls for a concentrated effort to build upon existing frames of reference and codes of practice developed within the field of HCI, by integrating, refining and extending theories, methodologies and concepts (e.g. metaphors) from the social sciences and, in particular, those disciplines with an explicit developmental flavour. Such inputs are needed to facilitate a more informative ground for the study of context, which, as pointed out in previous sections, is critical for the quality of a system's adaptable and adaptive behaviour. One important aspect in this perspective is the investigation of the interrelationships and constraints between lexical, syntactic and semantic characteristics of interaction in context, and of how such context-related interrelationships and constraints can be captured and exploited in the design of new virtualities. The author strongly believes that a sound methodological basis for the study of context is the turning point in establishing effective operational definitions for Universal Access in the context of the emerging Information Society (Stephanidis et al., 1999).

The above remark introduces the second research challenge to be addressed, namely the compelling need to assess the implications of Universal Access on digital contents, functionality and interaction. This entails, amongst other things, a renewed account of the property of adaptation and how it can be embodied by digital contents, functionality and the user interface. Clearly, the traditional view that adaptable and adaptive behaviour is a characteristic property of the interactive software may no longer suffice given the trends towards ubiquitous access, mobile computing and Internet appliances. Additional research is needed to focus on techniques for representing semantics in such manners that are modality-independent, scalable and extensible.

A third research target relates to the development of methods and tools capable of making Universal Access not only technically feasible, but also economically viable in the long term. In the past, the availability of tools was an indication of maturity of a sector and a critical factor for technological diffusion. As an example, graphical user interfaces became popular once tools for constructing them became available, either as libraries of reusable elements (e.g. toolkits), or as higher-level systems (e.g. user interface builders and user interface management systems). In the area of Universal Access, methods and tools for building interactive systems exhibiting the required properties are still at the infancy stage. Until now, systematic attempts that have been reported are the Agency Model developed by the FRIEND21 project (Institute for Personalised Information Environment, 1995), the Unified User Interface development platform outlined earlier in this paper, and described in details in Stephanidis (2001a), as well as, more recently, Java Accessibility by Sun Microsystems⋆ and Active Accessibility by Microsoft⋆⋆. Nevertheless, additional research is needed to define novel user interface architectural frameworks to facilitate context-sensitive processing, and provide alternative interactive embodiments of computational systems.

Finally, theoretical work has to be supported by large-scale case studies, which can provide the instruments for experimentation, thus ultimately improving the empirical basis of the field. Such case studies should not only aim to demonstrate technical feasibility of R&D propositions, but also to assess the economic efficiency and efficacy of competing technological options in the longer term.

3.3. Concluding remarks

A retrospective of the past decade indicates that Universal Access in the emerging Information Society is more of a challenge rather than a utopia. Today, researchers from different backgrounds or scientific communities identify Universal Access as a visionary research topic, and as a promising new interdisciplinary field, as well as a desirable social target in the context of an Information Society acceptable by its citizens. Such progress, though slow, has been steady and, in many cases, has lead to novel research concepts and prototypes. Work conducted so far has demonstrated that the adoption of adaptive techniques constitutes a viable and promising direction towards systematic and generic solutions to user interface accessibility, by facilitating the development of interactive systems that can adapt their characteristics and behaviour to the requirements of *all* users. In view of such developments, and given the breadth of the accumulated knowledge and experience,

⋆ http://java.sun.com/products/jfc/jaccess-1.2/doc/guide.html
⋆⋆ http://www.microsoft.com/enable/msaa/default.htm

it is becoming increasingly evident that there is a compelling need for new interdisciplinary research efforts that take a long term view of the issues underpinning Universal Access. Such efforts should necessarily develop their own body of theoretical and practical instruments to bring about the expected outcomes. There are many themes which may constitute core research topics, and many of those have been elaborated in recent R&D agendas (see, for example, Stephanidis et al., 1998c, 1999). In all those efforts, adaptation features emerges as a central research item that can play a catalytic role to the advancement of several desirable properties of emerging systems and services (e.g. individualisation, ubiquitous access). The study of adaptive techniques is an essential direction of future research work towards achieving Universal Access.

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