Neerincx, M; Lindenberg, J; Grootjen, M "Accessibility on the Job: Cognitive Capacity Driven Personalization", proceedings HCII 2005.

# Accessibility on the Job: Cognitive Capacity Driven Personalization

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## Abstract

A major part of the current accessibility approaches focus on Internet or mobile services for the general public, and on assistive technology for user groups with specific visual, auditory, motor or cognitive limitations. This paper proposes to extend these approaches on two aspects. First, a focus on the accessibility of services and applications in the professional market could help to improve job participation. Second, "designing for personalized support" will extend the types of persons who can successfully participate, because the resulting user interfaces are attuned to diverse cognitive capacities and momentary work contexts. Several support functions are distinguished to complement five types of cognitive capacities: spatial ability, memory, processing speed, expertise & experience, and task-set switching capability. Based on a general framework for personalization of such functions, a prototype of a personalized user interface for a broad range of naval operators and operational contexts has been developed.

## 1 Introduction

Personal capacities differ on many dimensions that are relevant for computer usage. For specific dimensions, such as visual, auditory, motor or cognitive limitations, it is possible to define users with 'non-standard' characteristics causing problems to access 'standard' applications and services. For these users, guidelines, assistive devices and adaptive technology are being developed, such as the Web Content and User Agent Accessibility Guidelines of the World Wide Web Consortium (W3C) and the 'Design for All' guidelines of the European Telecommunications Standards Institute (ETSI). It is important to note that the 'non-standard' users are similar to the 'standard' users in the sense that they are both users who are trying to accomplish a certain task in a certain use context using a certain device, who may have their own personal requirements for support (cf. Cremers & Neerincx, 2004). These support requirements are determined by the combination of individual capacities, user tasks, system constraints and contextual settings. It is interesting to note that contextual factors, such as background noise, can provide similar constraints to the interaction as individual capacities, such as specific auditory limitations. Furthermore, context and capacities can interact in such a way that specific tasks may become difficult to perform for some persons. For example, some people may be hindered severely by distracting phone calls when fatigued (e.g. during night), whereas others can proceed with their work easily. Because person, task and context factors interact, we maintain that accessibility can be substantially improved by establishing individual user interface instances that are attuned to the specific user, task and usage characteristics in combination. Whereas the starting point is coming from current User-Centered Design (UCD) approaches stating that users should be offered support that meets their needs in an effective, efficient and satisfactory manner (Maguire, 2001), we propose to focus more on user and context diversity in UCD practices (i.e. to integrate "inclusive design" into UCD).

For a major part, current "inclusive design" approaches focus on Internet or mobile services for the general public or consumer market (Stephanidis, 2001; Stary & Stephanidis; 2004). It is interesting to extend such approaches to the professional market. When new Information and Communication Technology (ICT) is being developed and implemented, new tasks are created for the employees. Improvements of ICT-accessibility will result in increased amounts and types of people who can perform these tasks. The general question is "how to enhance job participation by attuning the user interface and its support functions to individual cognitive capacities and momentary use contexts". Section 2 distinguishes a number of cognitive capacities that affect the performance of computer-supported tasks. Section 3 presents cognitive support functions that can complement these capacities and section 4 presents a framework for personalization of these functions. As an example, section 5 describes a prototype of a personalized user interface for a broad range of naval operators and operational contexts. Section 6 contains the conclusions.

# 2 Cognitive capacity diversity

For attuning the user interface to the individual cognitive capacities, we need practical theories that include accepted features of cognition such as limited processing capacity, be validated in the context of a specific domain, and provide predictions of the task performance of the diverse employees within this domain. In this paper, we will focus on the features that have been identified in two research lines: the situation awareness model for information search & navigation (Neerincx et al., 1999; 2000; 2001) and the cognitive task load model for supervision & damage control (Neerincx, 2003).

## 2.1 Spatial Ability

The spatial ability of users proves to affect the Web-navigation performance. Users with poor spatial ability have more problems with navigation in Web-sites, requiring extra search and navigation support (Czaja, 1997). Höök et al. (1996) found that spatial ability is related to the time spent in completing a set of tasks in a large, hypermedia, information structure. Particularly, certain aspects of spatial ability were related to the ability to navigate in hypermedia, namely those related to solving spatial problems mentally rather than solving spatial problems in the physical world. An experiment by Vicente et al. (1987) demonstrated that psychometric tests of vocabulary and spatial visualization are the best predictors of task performance (searching in a hierarchical file system), accounting for 45% of the variance. The spatial predictor was found to be most influential. To address individual differences, hypermedia user interfaces should be attuned to the spatial ability of the individual user.

## 2.2 Memory capacity

A second cognitive factor that plays an important role in computer-supported tasks is memory capacity. Especially working memory can influence task performance. The working memory resources determine our ability to retain and manipulate the limited amount of material that falls within our focus of attention. Differences are small or nonexistent for tasks that simply require people to retain a small amount of information for short periods (digit-span task, cf. Kausler, 1994), but are larger when people must simultaneously process, or manipulate, the material (reading span task). For language, elderly experience relatively large limitations in overall working memory capacity at times of high demand (Just & Carpenter, 1992).

## 2.3 Cognitive processing speed

Cognitive processing speed is the speed of executing relatively over-learned or automatized elementary cognitive processes, especially when high mental efficiency (i.e., attention and focused concentration) is required (cf. Carroll, 1993). Cognitive processing speed is usually measured by tasks that require rapid cognitive processing, but little thinking. It contains elements such as perceptual speed (the ability to rapidly search for and compare known visual symbols or patterns), rate-of-test-taking (the ability to rapidly perform tests which are relatively easy or that require very simple decisions) and number facility (the ability to rapidly and accurately manipulate and deal with numbers). Possible solutions for these physical and social aspects come from recent technological developments. By integrating computers around the body and into clothes, designated by the term "wearable computing", the physical aspects of the human-system interaction can be addressed (Abowd, Dey, Orr, & Brotherton, 1997b). To have meaningful automatic adaptation based on context is not enough. Questions on why the user exhibits his behaviour as he does, have to be answered (Abowd et al., 2002). This is an important step towards predicting user behaviour (Isbell, Omojokun, & Pierce, 2004).

## 2.4 Expertise and experience

The individual levels of subject matter expertise and experience with the current tasks have substantial effect on the user performance and the amount of cognitive resources required for this performance. They affect the level of information processing as indicated by the Skill-Rule-Knowledge framework of Rasmussen (1996): higher expertise and experience results into more efficient, less-demanding deployment of the resources (cf. Anderson, 1993). At the skill-based level, information is processed automatically resulting into actions that are hardly cognitively demanding. At the rule-based level, input information triggers routine solutions (i.e. procedures with rules of the type 'if <event/state> then <action>') resulting into efficient problem solving in terms of required cognitive capacities. At the knowledge-based level, the problem is analyzed and solution(s) are planned, in particular to deal with new situations. Accurate knowledge-based behavior requires substantial information processing capacity and knowledge (e.g. mental models).

## 2.5 Task-set switching capability

Switching between task-sets and dealing with task interruptions is often required for optimal task management and interleaving. However, users are inclined to concentrate on one task-set and neglect another task-set ("cognitive lockup", Kerstholt, 1997). Furthermore, switching can be a major mental load factor in itself and elderly seem to have generally less capacity for switching (Kramer et al., 1999; Sit & Fisk, 1999). Kramer et al. (1999) found large age-related differences in switch-costs early in practice (i.e. the costs in reaction time and errors due to switching between two tasks). After relatively modest amounts of practice the switch costs for old and young adults became equivalent and maintained equivalent across a two-month retention period. However, under high memory loads older adults were unable to capitalize on practice and the switch costs remained higher for them. To address task demands and individual capacities, user interfaces must be designed to accommodate people's memory limitations relative to task-set switching and to being interrupted (McFarlane, 1999).

# 3 Cognitive support

Section 2 distinguished five cognitive capacities that affect individual task performance. The following subsections will discuss two sets of support functions that can complement these capacities for two types of activities: navigation & search, and supervision & damage control.

## 3.1 Navigation and search

Neerincx et al. (1999; 2000; 2001) developed a practical theory according to which user's spatial ability and memory capacity have a substantial effect on the user's situation awareness during navigation and search in hypermedia environments (cf. Endsley, 1995). This theory distinguishes three support functions that improve individual situation awareness, in particular for users with less spatial and/or memory capacity (see table 1). First, the categorizing landmarks are cues that are added to the interface to support the users in recognizing their presence in a certain part of a web-site (i.e. it arranges information into categories that are meaningful for the user's task). This should help the users to perceive the information in meaningful clusters and prevents the user from getting lost. Second, the basis for the history map is a sitemap: a representation of the structure of a web site. It shows a marker to indicate the location of the page currently being viewed in the overall structure. The previously visited pages are marked as well. The history map is clickable, which means that pages can be selected from there. This memory aid should improve users' comprehension of the service's structure in relation to their task and provide information about the status of their various sub-goals. Third, the navigation assistant has knowledge of the domain (the content of the web-based service) and current user (such as interests, profession, education, age and transport constraints). By means of this knowledge the assistant is able to dynamically provide advice to the individual user. This support function should help the user to focus on parts of the web-site that might provide relevant information (i.e. a prediction that a visit is useful; e.g. see figure 1).

**Table 1:** The cognitive factors with accompanying support concepts and functions that complement user limitations.

| Cognitive factor | Support concept | Support function |
|---|---|---|
| Spatial Ability/Memory | Set focus on relevant parts of the web-site. | Navigation Assistant |
| Spatial Ability | Support the users in recognizing their presence in a certain part of a web-site. | Categorizing Landmarks |
| | Provide an overview of the overall structure of a website. | History Map |
| Memory | Aid users' comprehension of the service's structure in relation to their task and provide information about the status of their various sub-goals | History Map |


**Figure 1:** Personal navigation assistant for hypermedia environments (Neerincx et al., 2001).

## 3.2 Supervision and damage control

In order to address operator limitations for processing speed, expertise & experience and task-set switching capability, four functions of cognitive support were developed to improve supervision and damage control (Neerincx, 2003). An overview of the cognitive factors, support concepts and support functions is given in Table 2 (section 5 will provide an example of these support functions).

First, the *information handler* filters and combines information to improve task performance time and situation awareness, i.e. knowledge of the state of the system and its environment. Due to the increasing availability of information and speed of information changes, situation awareness can deteriorate without support. Sensor information should therefore be combined into alarms that are structured according to their function, such as fire control, propulsion and energy supply. Furthermore, information handling can support the operators in keeping overview by making the structure of the complete system explicit at a global level and by indicating functional relationships between system components. Relevant information should be presented at the right time, at the right abstraction level, and compatible with the human cognitive processing capacity.

Second, the *rule provider* gives the normative procedure for solving (a part of) the current problem, complementing user's procedural knowledge. Due to training and experience, people develop and retain procedures for efficient task performance. Performance deficiencies may arise when the task is performed rarely so that procedures will not be learned or will be forgotten, or when the information does not trigger the corresponding procedure in human memory.

Third, the *diagnosis guide* complements user expertise and experience. The level of information processing increases when no complete (executable) procedure is available to deal with the current alarms and

situation. This support function guides the operator during the diagnosis resulting in an adequate problem-solving strategy for a specific task.
Fourth, the *task scheduler* affects the task-set switches by providing an overall work plan for emergency handling. Task priorities are dynamically set and shown in a task-overview to the operator resulting in effective and efficient switches.

**Table 2:** The cognitive factors with accompanying support concepts and functions that complement operator limitations.

| **Cognitive factor** | **Support concept** | **Support function** |
|---|---|---|
| Processing speed | Combining and structuring information | Information Handler |
| Expertise & experience | Providing normative procedures | Rule Provider |
| | Guidance of diagnostic processes | Diagnosis Guide |
| Task-set switching | Providing an overall work plan | Task Scheduler |

# 4 Personalized cognitive support

Section 3 presented two sets of support functions that complement the cognitive capacities indicated in section 2. Prototypes that contain such functions have been developed and tested in specific application domains; in general the support proves to have a beneficial effect on task performance (e.g., Neerincx & de Greef, 1998; Neerincx, 2003). The next step is to personalize the support functions: first, to determine which support functions a specific user needs at a specific moment and, second, to establish the specific support-mode and mode-control conditions. This section provides the general personalization framework for realizing such personalized cognitive support.
Personalization concerns the use of information about general and momentary user needs, to deliver appropriate services and content, in a format tailor-made to the user and to the user context (e.g. Alpert et al., 2003; Cremers et al., 2004; Stephanidis, 2001). Our aim is to provide personalized support by accommodating individual user characteristics, tasks and contexts in order to establish human-computer collaboration in which the computer momentary cognitive resources of the user (cf. Fischer, 2001).
A first requisite for providing cognitive support functions tuned to the momentary or predicted future capacities of the user is the ability to make real-time assessments and/or predictions of these capacities. In section two we described different cognitive capacities influencing performance in human-computer tasks. The basic capacities of a user can be measured and contained in a *user model* (experience, expertise, spatial ability, etc.). As was argued in the introduction, context can be of major influence on cognitive capacities. Therefore, information about the current context should be placed in a *context model*. In section three a number of support concepts were described; if available, such support concepts can be put in the *system model* accompanied by other information about the overall system (i.e. component status). Further, users are trying to accomplish certain goals by performing tasks and interaction with the system. The *task model* should therefore contain the relevant user tasks and specify which tasks are active currently. Based on the information contained in the four models personalized support can be provided (Figure 2). A personalized support module determines the momentary capacities of a specific user, based on his or her "default capacities" from the user model and the information from the context model. Combining the user's momentary capacity with information about the tasks that are to be performed and the available support modules, this personalization module can select and activate the appropriate support function. For example, based on the information that a user has limited spatial abilities and his task is to find information in a large Web-site he hasn't visited before, the personalized support module might activate a history map. A more advanced personalization mechanism will also determine the specific support mode (e.g. a navigation assistant in a critiquing mode or an automatic mode). Section 5 will provide an example that explains this notion of support modes in more detail.

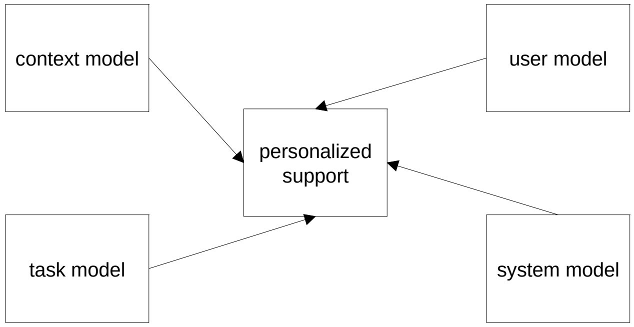


**Figure 2:** Realizing personalized support.

## 5 An example from the Navy

The Royal Netherlands Navy is maintaining and developing various classes of frigates. In future ships, a higher level of automation will be implemented with new crew support functions. The challenge is to improve the operational performance with an optimal job participation by attuning the user interface and its support functions to individual cognitive capacities of naval operators and the extremes in operational contexts. The focus is on the supervision of platform systems, and the planning and coordination of damage control activities. The number of activities will be small when the systems function well and damage is absent. When damage or disturbances appear, the—possibly cumulating—problems have to be solved as fast as possible by the available personnel. Figure 2 presents a "modern" user interface to perform the supervision & damage control activities by "standard" operators.

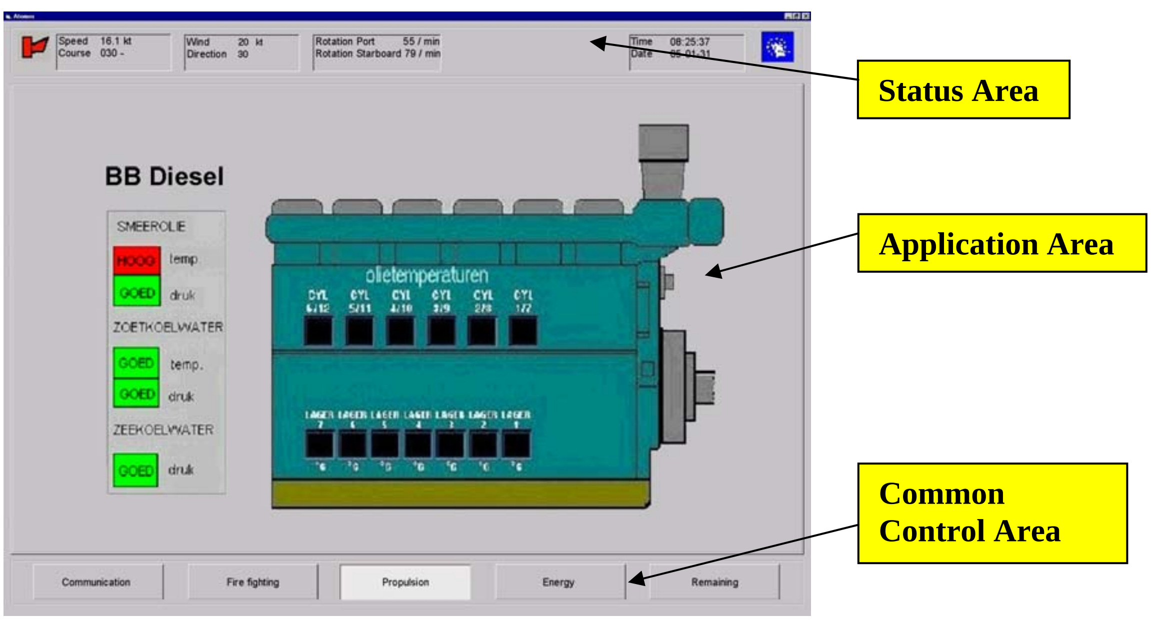


**Figure 3:** User interface for "standard" operators.

An operator with less experience might need additional support (*Rule Provider*). When the number of alarms increases, support might be needed for combining and structuring information to reduce the load the operators processing capacity (*Information Handler*). Furthermore, the increased number of alarms triggers an overall scheduling task and burdens the task-set switching capacity, thus leading to a need for scheduling support (*Task Scheduler).*

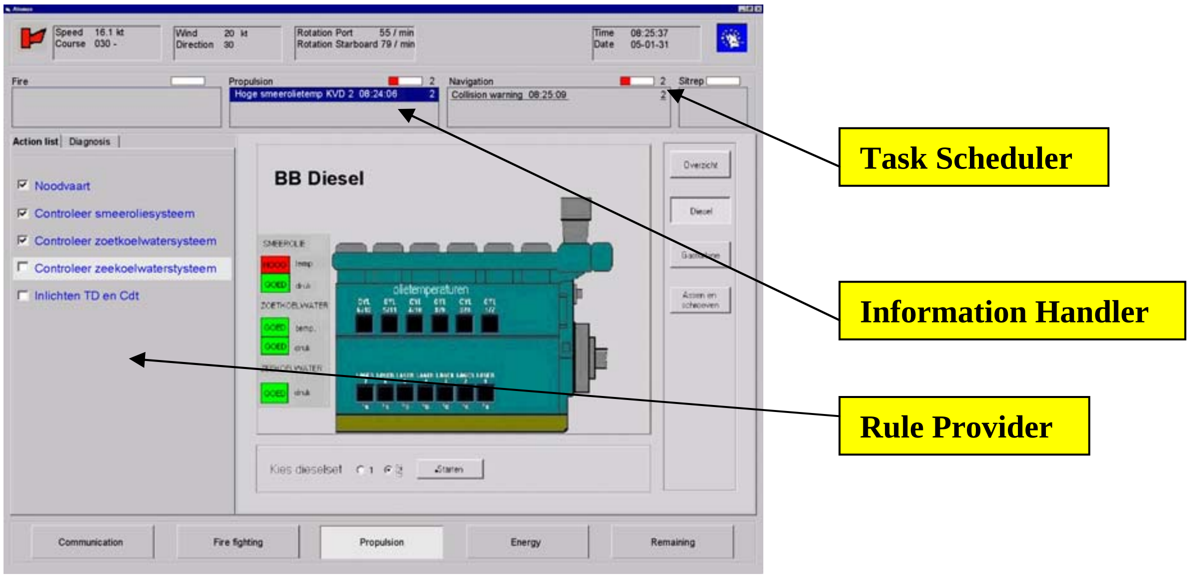


**Figure 4:** User interface providing cognitive support functions.

The four functions of cognitive support (table 2 in section 3.2) were developed for static support and used as a basis for the development of dynamic, personalized support mechanisms. Following the personalization framework of section four, a new dynamic support interface was developed, shown in Figure 5. Support modules can be switched on or off based on the momentary operator capacities. Reducing support at certain times can be useful to prevent underload and reduction of skills. In addition, alarms (or clusters of alarms) can be set in certain modes (determined by operator, system or both). This provides an extra opportunity to fine-tune the support to the available capacities.

There are 5 support levels for each event:
1. *Manual.* All procedure steps have to be performed individually.
2. *Critiqued.* All procedure steps have to be performed by the operator. However, the system looks over the shoulder of the operator and critiques the operator when necessary.
3. *Supervised.* All procedure steps are performed by the operator. However, another human operator is supervising.
4. *Concur.* The system performs all procedure steps it can. The operator steps in to supervise difficult (or sensitive) steps or to perform steps in the procedure which cannot be performed by the system.
5. *Automatic.* All steps are performed by the system autonomously.

Not all support levels are available all the time. For example, the are procedures the cannot be (are are not allowed to be) performed automatically. In that case concur would be the highest level of automation.

Figure 5 shows the interface in which the alarm ‘oil temperature high’ is set in the concur mode. The Rule Provider component shows the steps that have been performed by the system. The current step in the procedure is performed jointly by operator and system.

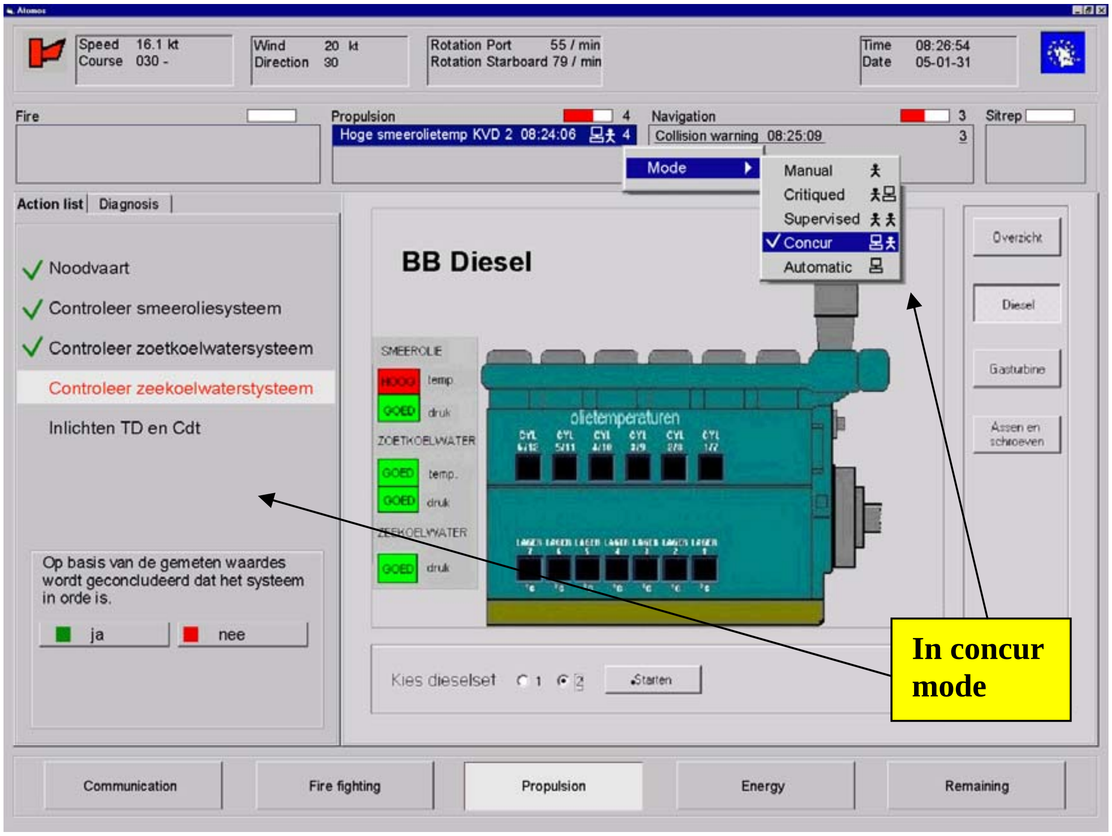


**Figure 5:** User interface providing dynamic support.

## 6 Conclusions and discussion

To improve the overall awareness of the "design for all" approach, 'classical' accessibility approaches separated "universal accessibility" guidelines from general user-centred design approaches (see for example Stephanidis, 2001). The resulting question is how to integrate them into the design practices. We presented a design approach, in which accessibility is not a separate, additional aspect or objective of development processes, but integrated into the design and test of personalization mechanisms for the user interfaces. In particular, we focussed on the accessibility of services and applications in the professional market to improve job participation. The proposed "designing for personalized support" approach will extend the types of persons who can successfully participate, because the resulting user interfaces are attuned to diverse cognitive capacities and momentary work contexts. Several support functions were distinguished to complement five types of cognitive capacities: spatial ability, memory, processing speed, expertise & experience, and task-set switching capability. Based on a general framework for personalization of such functions, a prototype of a personalized user interface for a broad range of naval operators and operational contexts has been developed. Currently, this personalized user interface is being evaluated to see if it really enables a diversity of operators to perform the required tasks in diverse operational contexts adequately.

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