A Framework for Individual Cognitive Performance Assessment in Real-time for Elderly Users

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Abstract

Changing cognitive performance in human elderly users requires a real-time assessment of current performance to provide appropriate, i.e. adaptive, assistance without bothering them. In the presented approach, the assessment of cognitive performance is done by simulating the user's cognitive functions through a computational cognitive model that is highly individualized for the specific user. The behavior of this model is evaluated with respect to the current cognitive performance by employing computerized psychological tests that allow a real-time assessment of cognitive performance with respect to a range of cognitive functions. By doing this, a real-time assessment is possible without involving the user in explicit performance tests.

Introduction

The cognitive performance of a person is an important indicator for the specific capabilities and needs one has in a certain situation. The level of cognitive performance is an individual characteristic for a human, which varies significantly in the course of a day caused by changes of the environment, the human affective state, fatigue or nutrition (Newell et al. 2003). For that reason, it is an important measure for determining the appropriate level of assistance for elderly people in their everyday life. Due to the continuous variability, it is important to measure cognitive performance constantly or any time the influencing factors change. As cognitive performance is a highly individual characteristic of a human, the measurement has to be tailored to the individual characteristics (Salthouse, Nesselroade, and Berish 2006).

As the success in interacting with an assistive system highly depends on the capabilities of the individual user, (Czaja and Lee 2003) such a system has to be adapted to the specific needs of the individual (Lindenberger et al. 2008). Therefore, the continuous measurement of cognitive performance, which allows a real-time adaptation to individual needs, increases the benefit of elderly users.

In this paper, we present an approach for a continuous assessment of cognitive performance that (i) takes the specific characteristics of an individual into account, (ii) is highly adaptive to those characteristics, and (iii) allows assessing performance with respect to the adaptation of an assistive system.

Cognitive Performance

In cognitive psychology, the term 'performance' refers to the measurement of several processes that can be represented both in cognitive and somatic functions of the brain. "The term performance denotes abilities and skills from the psychological functional ranges of perception, attention (concentration), learning and retention, thinking and intelligence, and psychomotor activity, all of which can be assessed by test' (The Committee for "Geriatric diseases and asthenias" at BGA 1986, p.49). So, cognitive performance is not defined by a single value like the intelligence quotient but rather as a combination of performance of several cognitive functions and processes.

For that reason, we define cognitive performance as a vector *cogPerf* $= (s_1, s_2, \cdots, s_n)$. Each dimension of this vector represents a certain function or process where each $s_i \in [0, 1]$ represents the test score with respect to the evaluation of the function; 1 represents perfect performance, 0 represents a deficit with respect to this function. As the definition of cognitive performance allows testing any function of human cognition which would result in a high-dimensional vector, the number of vector's dimensions is limited to the number of human factors that are necessary for describing human performance with respect to the domain for which performance is assessed. For instance, if cognitive performance is assessed in order to adapt a graphical user interface of an assistive system to the current capabilities of a user, the definition of human factors in human-computer interaction by (Wickens et al. 2004) can be used to define the dimension of cognitive performance that have to be evaluated. Following this, cognitive performance is described by the performance values for visual (*vis*) and motor (*mot*) capabilities, working memory (*wm*), long-term memory (*ltm*), attention (*att*), problem solving (*ps*), decision making (*dm*), reaction time (*rt*) and language abilities (*la*):

cogPerf = (vis, mot, wm, ltm, att, ps, dm, rt, la).

Influencing Factors

As cognitive performance is viewed as an update of a complex of cognitive abilities which is influenced by both the intellectual abilities and non-intellectual factors like fatigue or interest, the individual cognitive performance is not stable over the day but rather varies significantly. So, each person has an intraindividual level of cognitive performance whose level is affected by performance factors. These performance factors can be divided into three types: (i) situation-specific variables like noise or heat, (ii) task-specific variables like complexity or time-limit of a task, and (iii) individual-specific variables like health status, fatigue, affective state, motivation, interest, or nutrition. Some of these factors are likely to vary within short-time periods and completely differ in their impact on performance. They are termed reversible or flexible performance factors. Other factors will either never or only to some extend deregulate. Therefore, they are termed *irreversible* or *partial-irreversible* factors, respectively and represent static performance factors. As all these factors have an important and immediate impact on the cognitive performance, the assessment of cognitive performance has to be repeated anytime a performance factor changes in order to get the current level.

For assessing cognitive performance, the most important static performance factors are those that are specific for the individual, as such factors have a direct impact on cognitive functions and processes. With respect to elderly people who are often suffering from both age-related and disease-related impairments, the impact of the health status is the most critical one, as it directly influences cognitive performance. This status should represent the whole health status of the individual covering age-related changes, chronic conditions and diseases a patient is suffering from.

As flexible performance factors both individual-specific and situation-specific variables have to be considered. Important individual-specific variables are nutrition, fatigue, the individual affective state, the body temperature (e.g. fever has a strong impact on cognitive performance), and the impact of medications. Important situation-specific variables of cognitive performance are e.g. the environmental temperature, surrounding noise, and variability of the situation (e.g if the environment is crowded or if the person is surrounded by road traffic).

Assessing Cognitive Performance

In psychology, each dimension of cognitive performance as defined above is measured by standardized questionnaires and tests. There are several types of psychological testing, each of them evaluating a specific characteristic of human behavior, e.g. intelligence, ability, aptitude, attainment, personality, interest, or motivation. In addition, there are tests that measure deficits in cognitive functions, such as sensory capabilities, memory, attention, executive functioning, and motor capabilities. Utilizing such tests allows for an assessment of any single dimension of cognitive performance, yielding a final description. Psychological tests all have in common that the user is always requested to answer questions or perform tasks. After performing these tasks, the performance is classified by relating the results to standardized scales.

Computational Assessment of Cognitive Performance

Due to the fact that it is not possible to directly test an individual who is occupied with tasks of everyday life, the idea is to develop a computational approach that does not directly include the user into the assessment process. Because of the heterogeneous characteristic of the group of elderly people, approaches in which performance is measured by mapping certain user characteristics to a certain level of performance can hardly be developed. As there is no unique relation between user characteristics and the level of cognitive performance, rules to directly infer the current performance cannot be generated. In addition, the impacts of different performance factors cannot be viewed independently from each other, but rather have an effect on other dimensions of performance (Salthouse and Ferrer-Caja 2003). So, rule-based approaches to determine the level of cognitive performance as proposed by (Rumetshofer and Wöß 2003) and (Gavrolova and Vasilyeva 2003) cannot be developed.

For that reason, we pursue an approach which allows assessing cognitive performance based on a cognitive model that is specific for any individual user, as proposed by (Gray, Schoelles, and Myers 2005) and (Jipp et al. 2005). Such models allow for (i) checking the assumption about implications of cognitive capabilities with respect to their consistency, redundancy and completeness, (ii) detecting implicit assumptions, and (iii) precise predictions (Wallach 1998). Thus, the level of cognitive performance can be determined without involving user interactions in any test. Rather the cognitive model interacts with the particular test to assess the current cognitive performance. The model is built up by using a cognitive architecture which can be viewed as a computational representation of the function of the human mind (Anderson et al. 2004). Due to the heterogeneity of the group of elderly and the varying performance factors, the model flexibly adapts to the individual.

Cognitive Model

Due to the two different characteristics of the performance factors, their impacts on cognitive performance have to be differently integrated into the model. Whereas static performance factors can be initially incorporated into the model, the integration of flexible ones results in continuous modification of the model. In addition, there are influences of static performance factors that are common for elderly people like usual age-related characteristics. For this reason, the development of the cognitive model is divided into two parts (see fig. 1 on the following page).

1. A basic model is created that represents the cognitive abilities that are common for elderly people. This model is individualized by modifying it in a way that it represents all influences of the static performance factors specific for the individual.
2. The influences of flexible performance factors are represented by integrating their influence anytime they change. So, this second step is repeated when any of the flexible performance factors change.

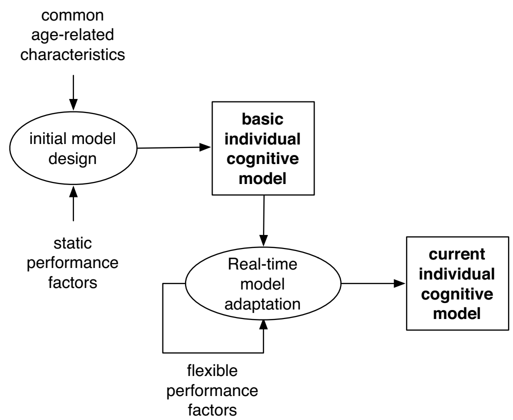

Figure 1: The initial creation of the model and its dynamic adaptation.

Cognitive performance is measured by assessing the model using certain psychological tests, each of them testing the abilities with respect to one dimension of the cognitive performance vector. For instance, the problem solving capabilities are tested by evaluating the model behavior in solving the Tower of Hanoi task (Simon 1975). Before the testing is started, flexible performance factors, e.g. biometric based inferences about the current affective state, are integrated into the model by adapting its processing parameters. Afterwards the model performs the task. It results a certain score which is afterwards normalized to fit the value range (see fig. 2).

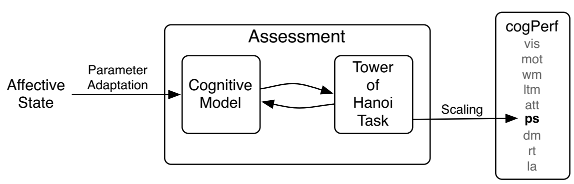

Figure 2: The adaptation process of the model with respect to the affective state and the testing process of problem solving capabilities.

Conclusion

Real-time assessment of cognitive performance is important to determine the specific abilities of an individual during the course of a day. As it cannot be done by directly involving a person in psychological tests, we propose to use a computational cognitive model for assessment. As several factors constantly influence the level of cognitive performance, their real-time influences are integrated into the model. The result is an up-to-date representation of the person's cognitive functions that can be used to determine the current cognitive performance.

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