Testing Cognitive Characteristics of Users in Interaction with Computer

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Abstract: - This paper presents some new research results on Human Computer Interaction (HCI) methodologies. We present an extension of cognitive model for HCI - (XUAN/t), based on decomposition of user dialogue into elementary actions (GOMS). Using this model, descriptions of elementary (sensor, cognitive and motor) actions performed by user and system are introduced sequentially, as they will happen. Based on the described model and psychometric concepts, we developed software CASE tool for testing cognitive as well as psychomotor abilities of a user in HCI. Software tool arranges tests into test groups for psychosensomotor and memory capabilities. User test results are persistently stored in a database and available for further statistical analysis. The main research goal was suitability verification of different HCI techniques for special user groups. Case study was performed and numerical results verifying the proposed model are presented in the paper.

Key-Words: - HCI, User interface, Cognitive models, HCI testing tool, User profile.

1 Introduction

Multidisciplinary nature of human-computer interaction requires contribution from different science disciplines; especially from computer science, cognitive psychology, social and organizational psychology, ergonomics and human factors, computer-aided design and engineering, artificial intelligence, linguistics, philosophy, sociology and anthropology. HCI can be defined as "a filed of study related to design, evaluation and implementation of interactive computer systems used by humans, which also includes research of the main phenomena that surround it" [1].

Main goal of HCI is to improve interaction between the user and the computer in order to make computers more user friendly and designed systems more usable. The most important element in HCI is user interface. User articulates his requests to the system via dialogue with the interface. Interface is the point at which human-computer interaction occurs. Physical interaction with end user is provided using hardware (input and output devices) and software interaction interface elements.

2 Modeling

Cognitive modeling provides a description of user in interaction with the computer system; it provides a model of user's knowledge, understanding, intentions and mental processing. Description level differs form technique to technique and ranges from high-level goals and results regarding thinking about a problem all the way to the level of motor activities of the user such as pressing a key on a keyboard or a mouse click. Research of these techniques is done by psychologists, as well as computer science specialists.

Alternative cognitive abilities model, based on cortical functions, is also known as "simultaneous and successive syntheses model" [2]. In both information processing ways, simultaneous as well as successive way, the memorizing processes are integration core enabling functioning of the whole integration (including perception and cognitive processes).

2.1 Cognitive Model of HCI

Classification of cognitive models is based on whether the focus is on the user and its task, or on transformation of the task into interaction language [1]:

- Hierarchical presentation of user's tasks and goals (GOMS model [3]);
- Linguistic and grammar levels;
- Models of physical level.

Models of the physical level relate to human motor skills and describe user's goals that are realizable in a short time period. An example is KLM model (*Keystroke-Level Model*) [4] used for determining user's performance with a given interface. In this mode, the task of accomplishing a goal is given in two stages:

- *Task acquisition*, during which user makes a mental picture of how to reach a given goal, and
- *Task performance* using the system.

Task acquisition closely connects KLM with GOMS level that gives an overview of the tasks for a given goal. KLM decomposes the phase of task performance into five different physical operators (pressing a key on a keyboard, pressing a mouse button, moving a cursor to a desired position, moving a hand from keyboard to mouse and reverse, and drawing lines using a mouse), one mental operator (mental preparation of user for physical action) and one system response operator (user can ignore this operator unless he is required to wait for system response). Each operator is given a time period for its action. By summing these time periods we get estimated time for completion of those tasks for a given goal. Precision of the KLM model depends on the experience of the designer, because he is required to make a realistic decision about the abilities of end user. Obviously, the development of high quality user interface is impossible without cognitive modeling and techniques.

2.2 Interaction Models

Interaction models are descriptions of user inputs, application actions and obtained outputs. Interaction models are based on formalisms, which ensure their implementation within interface development tools.

One of the oldest and most general interaction models is PIE model [1], which describes user inputs (from keyboard or mouse) and output to user (on a screen or a printer).

User Action Notification (UAN) model [5] was developed by system designers in order to understand the complexity of interactions with regard to the system, rather than the user. UAN model efficiently describes (and identifies) four elements of interaction in a way understandable to all participants in software development. Also, it does not differentiate between text and graphic interfaces, thus supporting each interaction technique. A drawback of this model is its approach to interactions by regarding the system only, without taking into account the other participant, the human being.

This problem was overcome in the XUAN (*Extended User Action Notification*) model [5], which equally treats both the system and the user. XUAN model treats the user and the system in terms of their visible, in case of the user articulated, internal actions.

The advantage of XUAN model is that it includes human mental action. Its drawback is excluding the state of the interface, which can lead to its inconsistency.

2.3. Extending XUAN Interaction Model

In order to evaluate user performance as realistically as possible, we extend the mentioned interaction models (UAN, XUAN). Extended model (XUAN/t – *Extended User Action Notification per Time*) treats equally the complexity of interactions, both from the system and from the user. This model is given in table form (Fig.1), which is divided into two parts.

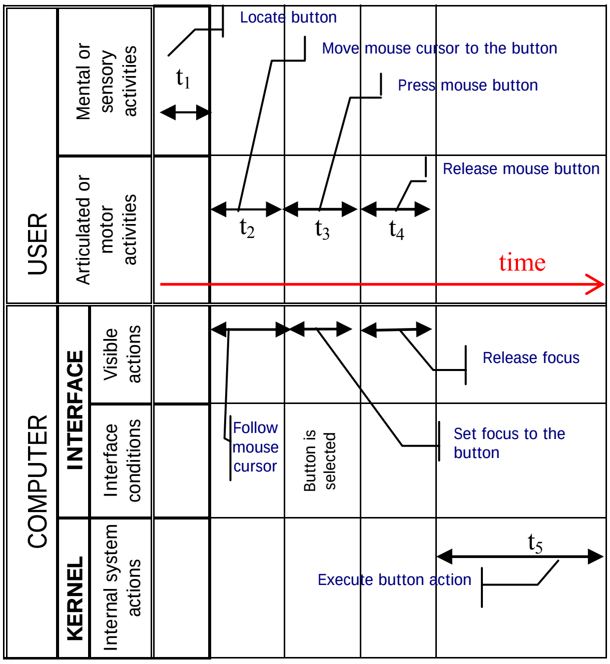

Fig.1. *XUAN/t model of a click-on-a-program-field of the interface*

First part contains two rows in which descriptions of mental or sensory and articulated or motor activities of the user are given. Second part contains three rows in which interface descriptions (visible actions and interface conditions) and internal system actions (core) are given. Separation line dividing these two parts is highlighted in red because it represents a point at which human-computer interaction occurs, and it also represents a time scale. In addition to giving descriptions, activities are presented graphically on the time scale in proportion to time duration. Graphic presentation also provides visual interpretation of position, order and duration of activities.

In order to efficiently estimate the number of actions and time duration of the entire task, a complex dialogue is decomposed into elementary actions using GOMS model. Descriptions of elementary actions by the user and by the system are entered sequentially in order of occurrence. Each activity is given the time needed for its completion. Estimated time is determined by summing the times required for individual activities. This way, proposed model provides interpretation of action descriptions with empirical variables, which can be evaluated. In this model time component is based on the duration of individual elementary actions; it is limited by given events as reference points. The user initiates these events, but they occur in the system. The system can register them precisely in order to determine the beginning and the end of activity. This model is intuitive and it can be easily supported with available software tools.

3 Testing Cognitive Characteristics

The classical methods of experimental psychology are under the constant development in order to cope with complicated cognitive tasks, specific to human interaction, on one side, and to computers on the other. The reliable and valid results of the interface performance rating can be achieved by observing the user efficiency through the repetitive assignment of similar tasks in similar environment conditions. The most important prerequisite to design an efficient interactive system is understanding cognitive and perceptual abilities of the user [6-8]. Modern computer systems are based on human ability to fast interpret affection of sense organs and respond with a sequence of complex actions. In the short time intervals, measured in milliseconds, users perceive changes on their screens and react adequately. A lot of working duties is tightly bound to perception, so designers should be aware of the boundaries of human perception [9]. The eyesight is especially important because the speed of human reaction depends on various visual stimuli, such as the time to accommodate to a very bright or very dim light, ability to recognize the appropriate part of a context, determine the speed or route of the moving point, etc. Visual sense reacts differently to different colors depending on spectral boundaries and color sensibility. The other senses, like these of hearing and touch, are also important. Ability tests represent measure tools for special HCI characteristics. These tests are standardized procedures for special HCI activities. These activities are measured for each user in order to compare to other users results achieved under similar conditions. There are several steps during user-computer dialogue, which we grouped into sensory, cognitive and motor activities. Test construction is based on recognition of activities in user-computer interaction, prominent user characteristics and the measurement method of individual production results. Classification into sensory, cognitive and motor activities is provisional, because they intermix during task performance. Based on the described model and psychometric concepts, we developed software CASE tool for evaluation of human cognitive characteristics in interaction with the computer.

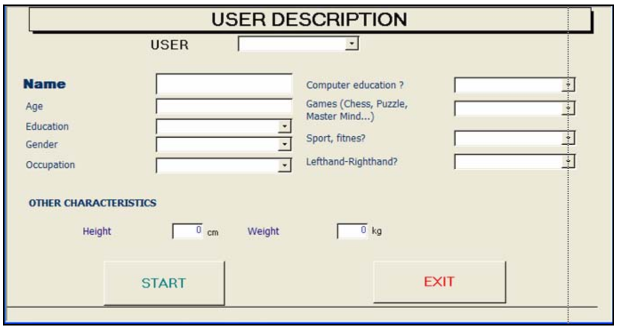

Fig.2. *User description input form*

The software tool provides user identification data input and user characteristics (Fig.2), determining a test list, and defining general and particular test conditions. In order to test all subjects under the same conditions it is necessary to define general conditions (screen resolution, mouse speed, etc.) and determine particular conditions of the micro surrounding (noise, light, temperature, etc.). A test task is given to users at the beginning of each test. During testing, tests are given in predetermined order and in designed time limits. Testing depends on the choice of tests given on the list. Test groups related to perceiving, information processing and motor activities include tests of memory, sensory and psychomotor abilities.

3.1. Sensory Ability Tests

Cognitive processes, which represent response to specific stimulation, are represented using visual-information processing model [10].

Available information comes to special sensory register and remains in it about one second. Physical characteristics of the stimulation are determined at this level. After that, information is erased from the register (has been forgotten) or transferred into the short-time memory. At this level, some information has been lost, while the rest (along with information from long-time memory) has influence on user response. The goal of sensory ability tests (perception) is to determine reaction times of users to visual (TP1) and audio (TP2) stimuli. User's abilities in domains of seeing, hearing and kinesthetic senses are tested. The test lasts 20 seconds, during which time user is stimulated with series of stochastic visual and auditory stimuli. User's task is to react as quickly as possible by pressing a certain key (LIGHT-OFF, RINGER-OFF), confirming registration of the tested stimuli. System registers time lapse between giving the stimuli and user's response, as an evaluation parameter.

3.2. Psychomotor Tests

In order to articulate his demands, user utilizes certain interaction elements of user interface (hardware and software), which enable his physical interaction with the computer. In physical interaction with hardware device, user makes a voluntary activity, which is coordinated with visual senses (from the primary sensory zone) and kinesthetic senses (from the motor cortex). Kinesthetic senses provide muscle coordination and development of skills for performing different complex movements while working. The goal of psychomotor tests is to determine the precision in coordination, object manipulation, psychomotor orientation, reaction time, manipulation aptness and the ability of making visual-motor guesses. First group of tests (PM), so called "CLICK-A-FIELD", is aimed to probing psychomotor orientation, visual-motor guessing ability and coordinated manipulation of user-computer interaction tools, coordination of individual senses and body parts. Tests last 20 seconds, and user's task is to click a field (1×1 cm), which cyclically, using random coordinate generator, appears on the screen. During the test, the system on-line continually registers times related to certain events (PRESS-MOUSE-BUTTON, RELEASE-MOUSE-BUTTON) and connects them in database with the user and the test. After the event, RELEASE-MOUSE-BUTTON field is erased form the screen and it appears at a new randomly generated coordinates.

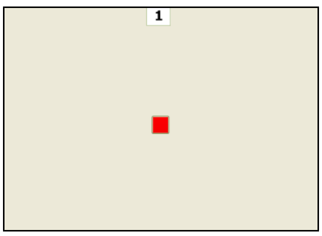

Fig.3. *Tests PM2 - field is highlighted red on the interface*

In order to determine the influence of different factors on user's psychomotor characteristics we developed four different tests. The goals of these tests are the same, however: PM1 field on the interface is darker shade of gray than the background; PM2 field is highlighted red on the interface (Fig.3); in PM3 test the field is 1×3 cm on the interface; in PM4 test after RELEASE-MOUSE-BUTTON event a beep sound is given in order to provide audio stimuli.

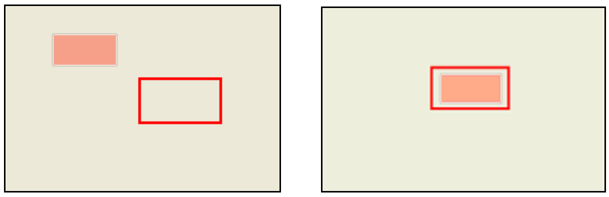

Fig.4. *Test PM5 - "DRAG-ME" test*

For determining precision and ability of fast, easy, correct and coordinated manipulation of visual objects with interaction technique of dragging objects on the screen, we developed PM5 test (called "DRAG-ME") (Fig.4). Test lasts 20 seconds, and user's task is to click on a red rectangular object on the screen and drag it into a rectangular window with red borders. After each attempt the object on the screen appears at a different randomly generated coordinate. System on-line registers successful attempts.

3.3. Memory Tests

Memory is information-process structure composed from three components: sensory, short-time and long-time memory [11]. All memory components are necessary for successful information memorizing. Memory subsystem for sensory information deals with sensory representation of visual or audio event, which stimulates user sense during very short period. Short-time memory represents activity center in information processing system with limited capacity. In this zone, information comes from both sensory as well as long-time memory subsystem [11]. Information in long-time memory is persistent with potentially unlimited capacity. Crucial characteristic of long-time memory is that information, which is memorized, may differ from the original information because of the experience as well as other information influence.

The main goal of memory tests (TM1) is to investigate memory span through the ability of immediate reproduction of a series of elements after only one viewing of the series. This test is not time limited; it lasts until the first unsuccessful reproduction is made. User can see, in a certain time interval, series of randomly generated numerical signs of given length. Presentation time of the series is proportional to the length of series. User's task is to reproduce the entire series successfully. This step is repeated with each series one sign longer.

We also developed two more tests with the same scenario as TM1, with a certain difference: TM2 generated series are made of letter signs, and in TM3 the series are made with alphanumeric signs.

System registers the longest length of successfully reproduced series as a memory span parameter.

4 Case Study

In order to acquire HCI ability information from different user groups, we performed special tests on group of 234 users. The group includes n1=116 male and n2=118 female users. We performed statistical analysis on obtained results in average reaction time on visual as well as audio stimuli in order to discover statistically significant difference between different user groups. For statistically significant difference estimation we used Student's t-test [12], which is based on average reaction time difference between two independent user groups (with limitation that n1+n2 should be greater than 60). Hypothesis acceptance condition was that average reaction time difference between two independent user groups is significantly greater than standard average response time difference error. The standard average response time difference error for our test was 0.089419 sec. Obtained Student's t-value can be interpreted using Student's tables for limit t-values for chosen level of freedom n1+n2-2 (=232 in our case) and significant level (p=0.01, which means 99% of confidence).

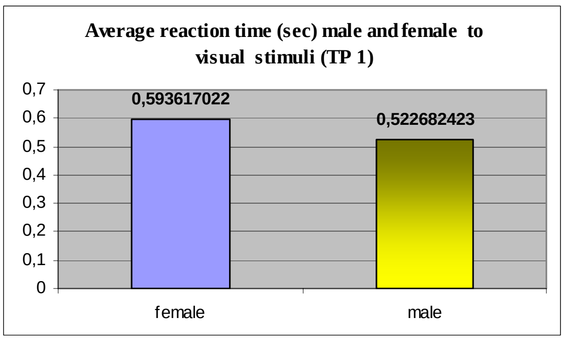

Fig.5. *Average reaction time in sensory ability tests (visual stimuli)*

In case of visual stimuli (TP1), obtained Student's t-value t=0.79 is less then limit value t=2.58, which means that there is no statistically significant difference between male and female users (Fig.5). The difference is effect of random variance, the samples belongs to the same basic set.

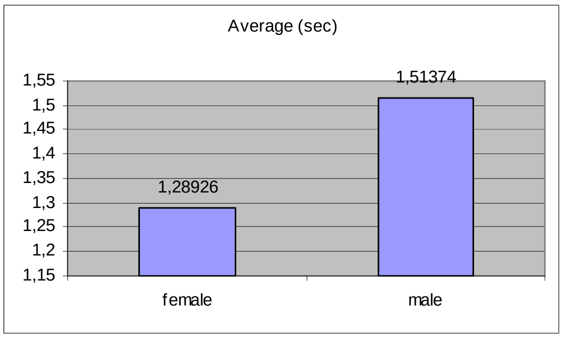

Fig.6. *Average reaction time in sensory ability tests (psychomotor orientation)*

But, in case of psychomotor orientation tests (PM), average response time was 1.51374 sec for male and 1.28926 sec for female users. Obtained t-value t=2.06 is greater than limit value t=1.96, which means (with 95% confidence, $p<0,05$) that there is statistically significant difference between male and female users (Fig.6). Nevertheless, in case of psychomotor orientation tests with small (PM1) as well as significant (PM2) contrast difference in button color, average response time for entire testing population (both male and female users) was 1.39104 for PM1 and 1.061 sec for PM2. Obtained t-value t=3.9567 is greater than limit value t=2.58, which means (with 99% confidence) that there is statistically significant difference in response time between cases with small and significant contrast difference in button color (Fig.7).

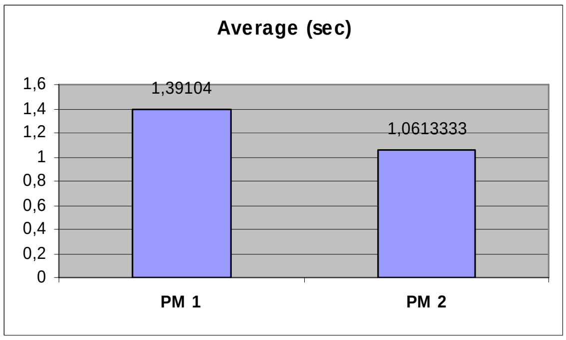

Fig.7. Average time in psychomotor tests with small and significant contrast difference in button color

For the memory tests we used randomly generated numbers with average length of 7.322 numerical signs (for TM1 test) and randomly generated signs with average length of 5.88 letter signs (for TM2 test). Obtained t-value t=4.79 is greater than limit value t=2.58, which means (with 99% confidence) that there is statistically significant difference in average length of repeated sequence for numbers and letter signs.

5 Conclusions

Understanding physical, intellectual and personal differences between potential users defines the level of understanding and fulfilling user needs. Regarding different human perceptual, cognitive and motor abilities can lead to universally usable interface development. Taking into account different aspects of user profiles confronts us with the challenges of physical, cognitive, perceptual, personal and cultural differences between users. In order to evaluate user performance in interaction with interface, we extend the concepts of existing interaction models. Based on the described model and psychometric concepts we developed software tool for testing sensomotor abilities of user in human-computer interaction. Test concept allows program-led testing of the intent-group and precisely quantifies user performance.

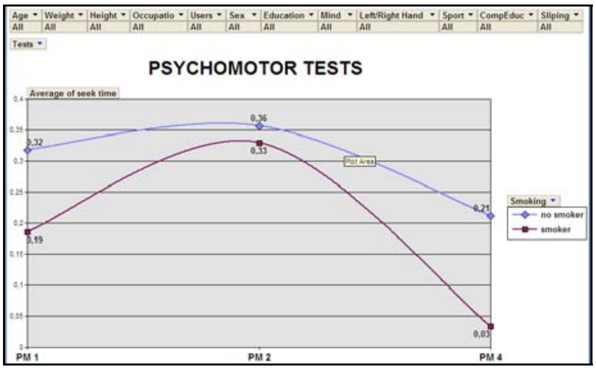

Fig. 8. *Graphical interpretation of user profile for smokers and nonsmokers*

In this study we obtained an efficient tool for making user profiles (Fig.8). The software tool enables graphical interpretation of the results, more on the statistical capabilities (Fig.9), visual analyses of the tested groups averaged results, and easy creation of the user profiles.

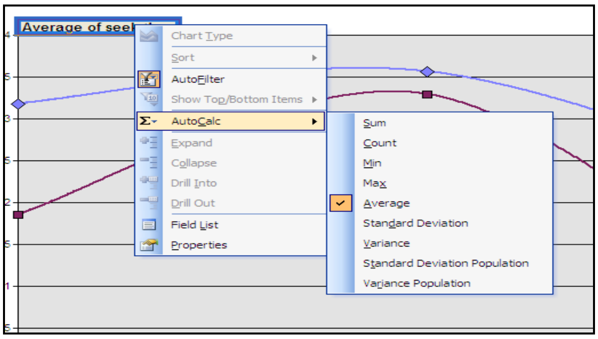

Fig. 9. *Representation of the CASE Tool statistical capabilities*

Differentiation of tested users is utilized to determine compatibility of individual interaction models with given intent-groups. Qualitative result analysis provides recommendations for design of individual interface parts, which are useful for the intent-group for which it is designed.

A future works can be based on extending a set of user characteristics which qualify perceptual and motoric performance, extending a set of tests using different interaction techniques.

References:

[1] Dix, A., Finlay, J., Abowd, G., Beale, R., *Human-Computer Interaction*, 2nd ed. Prentice Hall Europe, 1998.

[2] Das, J. P., Kirbi, J., Jarman, R. F., Simultaneous and successive syntheses: An alternative model for cognitive abilities, *Psychological Bulletin*, 82, 1, 1975, pp. 87-103.

[3] Kieras, D. E, Arbor, A., Towards a Practical GOMS Model Methodology for User Interface Design, In M. Helander*: Handbook of Human-Computer Interaction*, Elsevier Science Publishers B. V. (North Holland), 1988, pp. 135-202.

[4] Card, S. K., Moran, T. P., Newell, A., The Keystroke-Level Model for user performance with interactive systems, *Communications of the ACM*, vol. 23, 1980, pp. 396-410.

[5] Harrison, M. D., Duke, D. J., A review of formalisms for describing interactive behavior, *In the Software Engineering and Human-Computer Interaction – Notes in Computer Science*, vol. (896), Springer-Verlag, 1995, pp. 49-75.

[6] Wickens, D., Hollands, G., *Engineering Psychology and Human Performance*, Prentice-Hall, Englewood Cliffs, NJ, 2004.

[7] Ashcraft, M. H., *Cognition*, Third Edition, Prentice-Hall, Englewood Cliffs, NJ, 2001.

[8] Goldstein, E. B., *Sensation and Perception: 6th* Edition, Wadsworth Publishing, Pacific Grove, CA, 2002.

[9] Ware, C., *Information Visualization: Perception for Design*, 2nd edition, Morgan Kaufmann Publishers, San Francisco, CA, 2004.

[10] Atkinson R. C., Shiffrin, R. M., Human Memory: a proposed system and its control processes, In: K. W. Spence and J. T. Spence (eds.): *The Psychology of Learning and Motivation*, vol. 2, New York, Academic Press, 1968, pp. 89-195.

[11] Sperling, G. A.: A model for visual memory tasks, *Human Factors*, 5, 1963, pp. 19-31.

[12] Spiegel, M. R., *Theory and Problems of Probability and Statistics*, New York: McGraw-Hill, 1992.