Evaluation of User Cognitive Abilities for HCI

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Abstract: - New research results on Human Computer Interaction (HCI) methodologies are presented in this paper. An extension of cognitive model for HCI - (XUAN/t) based on decomposition of user dialogue into elementary actions (GOMS) is proposed. Using that model, descriptions of elementary actions performed by user and system are introduced sequentially. Based on the described model and psychometric concepts, we developed software tool for testing sensomotor abilities of a user in HCI. Software tool aranges tests into test groups for psychosensomotor and memory capabilities. User test results are persistently stored in a database and available for further statistical analyses.

Key-Words: - HCI, User interface, Software usability, Cognitive models, XUAN model .

1 Introduction

Recent research results in the area of human-computer interaction (HCI) indicate significant influence of HCI on computer system development, which, combined with technological development, enabled their application in almost every branch of human activity [1]. 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" [2].

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.

The 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.

Determining the degree of usability is a process in which systems are evaluated in order to determine product-success using methods available to the evaluator.

In this paper we considered extension of the XUAN interaction model [3] in order to evaluate user performance as realistically as possible.

The paper is organized as follows: after short introduction, in Section 2 and 3 we explained key concepts of user interfaces and HCI methodologies, while Section 4 deals with cognitive modeling of HCI. Section 5 describes our extension of existing XUAN interaction model. In Section 6 we introduce usability concept of UI. Testing results of cognitive characteristics, according to our extension of XUAN model, are discussed in Section 7. Finally, the main conclusions are reported in Section 8.

2 User Interface

User interface (UI) is the most important element in HCI. 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.

User interface, as an interaction medium of the system, represents "software component of the application which transforms user actions into one or more requests to the functional application component, and which provides the user with feedback about the results of its actions [4].

Key concepts of graphic interfaces were established in the early seventies. They were based on the WIMP metaphor, which includes key elements of the interface: Window, Icon, Menu and Pointer. Direct manipulation of graphic objects provides object manipulation on the computer screen via pointing devices as standard input devices of modern computer systems.

3 HCI Methodologies Classification

The importance of human-computer interactions was noticed in the late seventies. In 1982 this caused a development of an independent research group, which had, in 1992, formed HCI as a special discipline [2].

The subject of HCI research is a human being and everything related to a human being: work, environment and technology. Classification of HCI methodologies was made based on the method by which end-user is incorporated into system development [5]:

- *User centered development* - provides system development FOR the user based on feedback information from the user during the entire process of system development.
- *System development WITH users* – development of user participation which promotes system development in user environment (manufacturing facilities, offices, etc.) rather than within software companies.
- *System development based on taking into account the user* - this approach uses cognitive modeling of end users in order to understand user behavior in a certain situation and explain why one system is better than the other.

4 Cognitive 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.

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 [2]:

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

GOMS (*Goals, Operators, Methods and Selection*) [5] model consists of the following elements:

Goals – are results of user's task and they describe what the user is trying to accomplish.

Operators – are basic actions, which the user must make while working with a computer system. Operators can act on a system (pressing a key) or on the mental state of the user (reading a message). Detail level of the operators is flexible and it varies based on the task, on the user and on the designer.

Methods – are step sequences, which need to be performed in order to reach a given goal. A step in the method consists of operators.

Selection rules – provide prediction on which method will be used in reaching a given goal in case that there are different methods to reach the goal.

Models of the physical level relate to human motor skills and describe user's goals which are realizable in a short period. An example is KLM model (Keystroke-Level Model) [6] 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. In HCI practice there is no separate cognitive methodology; rather, some cognitive models and techniques are used within other methodologies, usually during evaluation. Cognitive models and techniques significantly contribute in determining (rationalizing) how acceptable is the designed solution.

Interaction models are descriptions of user inputs, application actions and result displays. 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 [2] which describes user inputs (from keyboard or mouse) and output to user (on a screen or a printer).

User Action Model (UAN) [7] 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 every 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 Extended User Action Notation (XUAN) model [3], 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. XUAN model's advantage is that it includes human mental action. Its drawback is excluding the state of the interface, which can lead to its inconsistency.

5 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.

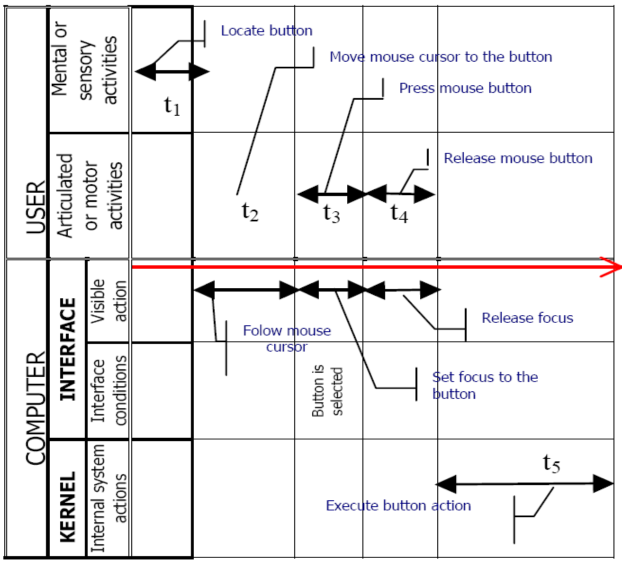

Fig.1. *XUAN/t model of a click-on-a-program-field of the interface*

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.

6 Usability of User Interface

The term usability refers to a measure of the product success. The usability estimation is a system validation process that uses any of the method available to the estimator. One of the problems of system usability estimation is a lack of quantitative method to express different aspects of the usability.

According to the International Organization for Standards definition (ISO 9241-11), "System usability comprises the learnability, effectiveness, efficiency and satisfaction with which specified users can achieve specified goals in a particular environment", where:

- ***Learnability*** measures the time taken to get accustomed to the system and its operation and how easy it is to remember operational details;
- ***Effectiveness*** measures the accuracy and completeness of the goals achieved;
- ***Efficiency*** measures the accuracy and completeness of goals achieved relative to the resources (e.g. human time and effort) used to achieve the specified goals;

- ***Satisfaction*** measures the comfort and acceptability of the system to its users and other people affected by its use.

Understanding physical, intellectual and personal differences between potential users defines the level of understanding and fulfilling user needs. Regarding different human perceptual, cognitive and motorical 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.

A lot of working duties is tightly bound to perception, so designers should be aware of the boundaries of human perception [8]. The eyesight is specially important because the speed of human reaction depends on various visual stimuli, 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 senses of hearing and touch, are also important.

The working environment can neither be ignored. Well-designed working environment increases user satisfaction, increases the speed of achieving the goal, and reduces the number of errors. There are a plenty of aspect of working environment that should be taken into account, like: luminance level, albedo reduction, balance of light and glint, noise and vibrations, temperature, air flow and humidity, and the equipment temperature. Even the most elegant screen design loses its preference in noisy, dark and conglomerate environment. Such environment does not only reduce the working speed and increases errors, but also discourages even the most motivated users.

The classical methods of experimental psychology are under the constant development in order to cope with complicate 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 the similar environment conditions. Every experimental result is just a piece of a mosaic in the human performance in interaction with information systems based on computers.

The most important prerequisite to design an efficient interactive system is understanding cognitive and perceptual abilities of the user [9-11]. 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. The Ergonomics Abstracts journal has published the classification of human cognitive process [12]: short and working memory; long and semantic memory; problem resolution and reflection; decision and risk estimation; linguistic communication and understanding; search, pictures, and sensor memory and learning, skill development, knowledge acquisition and concept creation.

This journal specifies a set of factors, which qualify perceptual and motoric performance: awaking and vigilance; weariness and the lack of sleep; sensor load (mentally); awareness of the results and loopback information; monotony and boredom; sense limits; healthy food and diet; fear, nervousness, mood, emotion; drugs, smoking and alcohol and physical rhythms.

7 Testing Cognitive Characteristics

Evaluation of user's cognitive characteristics is done by tests designed for evaluation of certain characteristics and obtaining the user profile. Test construction is based on recognition of activities in user-computer interaction, prominent user characteristics and the method of measurement of individual production results. There are several steps during user-computer dialogue, which we grouped into sensory, intellectual and articulatory activities. Within sensory activities, we isolated the processes in which human being is gaining knowledge about phenomena and events around him such as:

- Impact of physical and chemical processes from the environment on human senses;
- Initiation of certain physiological processes in nerve cells of the sensory organs;
- Transmission of nerve excitation by neurons to the primary sensor zone in cortex,
- Initiation of a psychological response, which enables the human to become aware of the stimuli, which acted on the sensory organ.

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. Classification into sensory, intellectual and motor activities is provisional, because they intermix during task performance. In order to investigate senso-motor abilities, based on the described model and psychometric concepts, we developed software tool for evaluation of human cognitive characteristics in interaction with the computer.

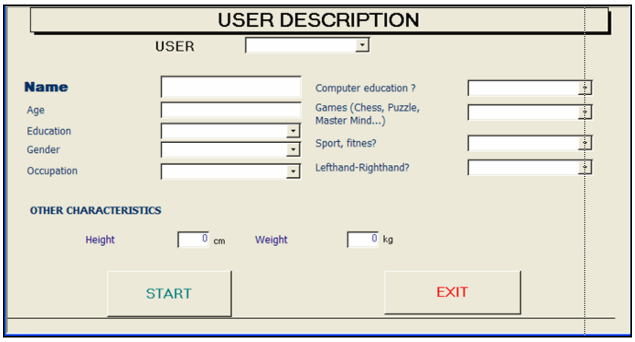

Fig.2. *User description input form*

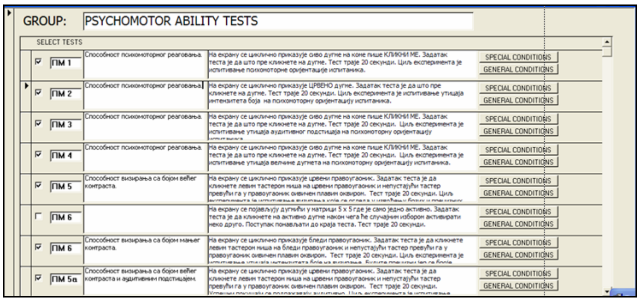

Fig.3. *Form for determining the list of tests and defining general and particular test conditions*

Software tool provides user identification data input and user characteristics (Fig.2), determining a test list, and defining general and particular test conditions (Fig.3).

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.). At the beginning of each test subject is given a test task. 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 receiving, information processing and motor activities include tests of memory, sensory and psychomotor abilities.

The goal of sensory ability tests (perception) is to determine reaction times of subjects to visual (TP 1) and auditory (TP 2) stimuli. Subject's abilities in domains of seeing, hearing and kinesthetic senses are tested. Test lasts 20 seconds, during which time subject is presented with series of stochastic visual and auditory stimuli. Subject's task is to react as quickly as possible by pressing a certain key (LIGHT-OFF, RINGER-OFF), with which he confirms registration of the tested stimulus. System registers time lapse between giving the stimulus and subject' response, as an evaluation parameter.

The goal of psychomotor tests is to determine the precision in object manipulation, psychomotor orientation, reaction time, manipulation aptness and the ability of making visual-motor guesses. First group of tests, so called "CLICK-A-FIELD", is aimed at 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 subject'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.

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: PM 1 field on the interface is darker shade of gray than the background; PM 2 field is highlighted red on the interface; in PM 3 test the field is 1×3 cm on the interface; in PM 4 test after RELEASE-MOUSE-BUTTON event a beep sound is given in order to provide auditory stimulus.

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 PM 5 test (so called "DRAG-ME"). Test lasts 20 seconds, and subject's task is to click on a red rectangular object on the screen and drag it into a rectangular window with blue borders. After each attempt the object on the screen appears at a different randomly generated coordinate. System on-line registers successful attempts.

The main goal of memory tests (TM 1) 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. Subject is presented, in a certain time interval, with a series of randomly generated numerical signs of given length. Presentation time of the series is inversely proportional to the length of series. Subject'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 TM 1, with a difference: TM 2 generated series are made of letter signs, and in TM 3 the series are made with alphanumeric signs.

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

8 Conclusion

In order to evaluate user performance in interaction with user 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-guided testing of the intent-group and precisely quantifies user performance.

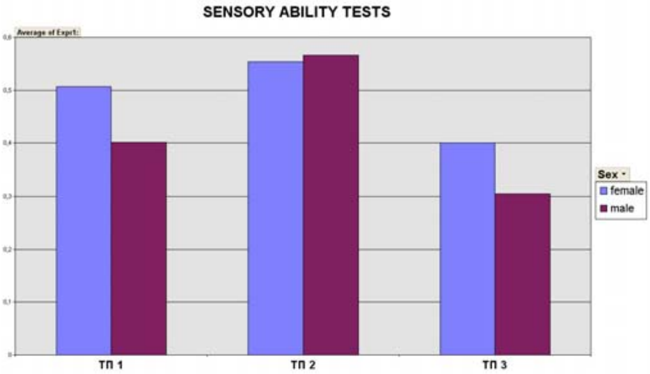

Fig. 4. *Comparative overview of sensory ability tests for men and women*

In this study we obtained an efficient tool for making user profiles. The software tool enables graphical interpretation of the results, visual analyses of the tested groups averaged results (Figs 4 and 5), and easy creation of the user profiles.

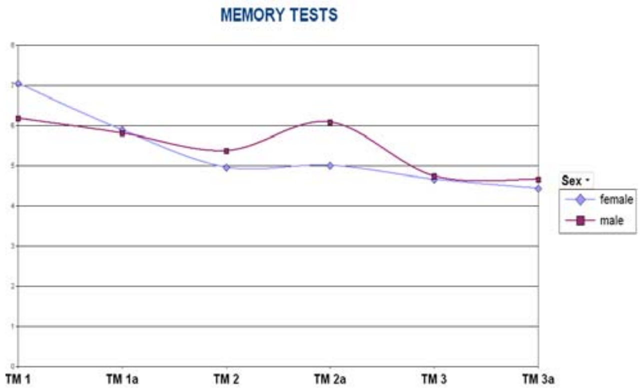

Fig. 5. *Comparative overview of memory tests for men and women*

Differentiation of test 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.

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