INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET EN AUTOMATIQUE

Project-Team MErLIn

Methods for Interactive Software Ergonomics

Lorraine - Rocquencourt

THEME COG

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2. Overall Objectives

2.1. Overall Objectives

Keywords: *3D interactive visualisations*, *User interface design and evaluation methods: Formal task description*, *adaptive user interfaces*, *ergonomic criteria*, *ergonomic quality of interactive software*, *gaze)*, *gestures*, *mixed reality*, *multimodal interaction (speech*, *standardization. New forms of human-computer interaction: Hypermedia*, *user assistance (online help)*, *user modelling*, *user testing*, *visual search.*

The goal of the MErLIn project is to contribute to the improvement of the Ergonomic Quality of Interactive Software. Two sub-goals contribute to this general goal:

- Study, through empirical studies[1], users' interactions with software-based systems in order to improve such systems. It is about increasing available knowledge about users' activities and cognitive characteristics as well as about the usability of software systems.
- Study and improve ergonomic design and evaluation methods, thereby contributing to the overall improvement of technical systems by providing software designers with sound methodological elements helping the incorporation of user-centered concerns within the design process life cycle. It is about increasing available knowledge on such processes, together with defining new methods or complementing existing ones.

Considering interactive computing systems for human use, i.e., ergonomic optimization of interactive software, requires to make progress both on fundamental knowledge and on methods in HCI (Human-Computer Interaction), and Ergonomics. The scientific contributions of the MErLIn project include scientific literature on users and task modelling, on empirical studies, on design and evaluation methods, on ergonomics recommendations, as well as software (e.g., mock-ups, test-prototypes, tools supporting design and evaluation methods). These various contributions are aimed at disseminating current ergonomic results, knowledge, and know-how to the national and international scientific community, but also to standards and to technology transfer through industrial contracts, collaborations and consulting activities.

Currently, the MErLIn project investigates two main research directions:

- The study, design, assessment, and set-up of ergonomic methods for designing and evaluating interactive software. This corresponds to the need for integrating available ergonomic results into the computer systems life cycle. The main current topics relate to task-based and criteria-based methods.
- The study of usability issues raised by "new" computer applications: new user populations, new application domains, new forms of interaction (often new technology raises new usability problems). This corresponds to the need for acquiring novel ergonomic results on innovative computer systems, and to further increase current knowledge on usability. The main current topics relate to multimodal interactions, and virtual reality.

3. Scientific Foundations

3.1. Scientific Foundations

The scientific domains characterizing the activities of the MErLIn project are essentially Ergonomics, especially Software Ergonomics, and HCI. Four definitions apply to the research activities of the MErLIn project:

Ergonomics or Human Factors[2] is the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data, and methods to design in order to optimize human well being and overall system performance. Ergonomics contributes to the design, and evaluation of tasks, jobs, products, environments, and systems in order to make them compatible with the needs, abilities, and limitations of people. Derived from the Greek *ergon* (work) and *nomos* (laws) to denote the science of work, ergonomics is a systems-oriented discipline which now extends across all aspects of human activity. Domains of specialization within the discipline of ergonomics are broadly the following:

- Physical ergonomics is concerned with human anatomical, anthropometric, physiological, and biomechanical characteristics as they relate to physical activity (relevant topics include working postures, materials handling, repetitive movements, work related musculoskeletal disorders, workplace layout, safety, and health).

[1] i.e., resulting from experience, through various methods, including controlled experiments.
[2] Definition from IEA (International Ergonomics Association) (http://www.iea.cc/ergonomics/)

- Cognitive ergonomics is concerned with mental processes, such as perception, memory, reasoning, and motor response, as they affect interactions among humans and other elements of a system (relevant topics include mental workload, decision-making, skilled performance, human-computer interaction, human reliability, work stress and training as these may relate to human-system design).

- Organizational ergonomics is concerned with the optimization of socio-technical systems, including their organizational structures, policies, and processes (relevant topics include communication, crew resource management, work design, design of working times, teamwork, participatory design, community ergonomics, cooperative work, new work paradigms, virtual organizations, telework, and quality management).

Software Ergonomics inherits from the main characteristics of ergonomics. It is a science that contributes to the knowledge necessary to software design, and more generally to computer-based environments, with the overall perspective of human security and well-being, but also with the perspective of effectiveness, efficiency and productivity, for instance by facilitating users' tasks, limiting learning time, reducing errors and the cost of errors. Software Ergonomics focuses on the improvement of human-computer interactions mainly in terms of cognition, as the main human activity involved with software interactions is mental. However, as novel interaction techniques (e.g., multimodality) and novel environments (e.g., Virtual Reality) arise, some aspects of physical ergonomics are starting to be considered as well.

Human-Computer Interaction (HCI)[3] is also at the center of the MErLIn project research activities: "Human-Computer Interaction can be defined as the set of hardware, software, human and environmental elements that influence the efficiency of systems and products, both from a technological and a human point of view".

In addition, the MErLIn project aiming at the optimization of Software Ergonomics, that is the *Ergonomic Quality of Interactive Software*, the following definition applies as well.

Ergonomic Quality of Interactive Software [49] covers all software aspects which have an influence on the user's task completion: it therefore covers usability in the widest sense, or ease of use, i.e., the extent to which the users can easily reach their interaction goals (presentation and dialogue aspects of the interaction) but also what is sometimes called utility, i.e., the extent to which the users can reach their task goals (functional aspects of the interaction such as functions, objects, data, etc.). From a software engineering perspective (e.g., architecture models), it could be said that *Ergonomic Quality* covers not only the classical presentation, dialogue control and application interface aspects, but also some application kernel aspects: those that have an influence on the users reaching their goals.

Approach: the MErLIn project uses methods from Ergonomics and Computer Science, with a strong background and orientation in experimental approaches and methods (in the sense of experimental sciences, with hypotheses testing and proving).

The project contributes to the rationalization of ergonomic methods, from experimental testing in the laboratory or field simulations, using performance data, analysis of verbal protocols, analysis of preferences. The modelling activities are also centered on the production of computer models.

The appropriateness and accuracy of such models compared to reality also goes through ergonomic evaluations.

Research work starts usually from the observation of real tasks, on selected fields of activity, often in parallel with particular practical problems to be solved. Data gathering is based on activity and interaction analyses, case studies, critical incidents, automatic logs, and records.

Focus: research work at MErLIn has also three additional characteristics. The focus is on methods dedicated to designers who are not necessarily skilled in ergonomics, even though such methods can also improve the activity of the ergonomists themselves. More specifically, the project deals with the integration of ergonomics approaches within the computer system life cycle through sets of recommendations, methods, software support tools, and involvement in standardization, teaching, and consulting.

[3] Definition from AFIHM (Association Francophone d'Interaction Homme-Machine) (http://www.afihm.org)

The focus is on users who are not computer specialists. This user population is the major target of current software developments, whether it is the general public (e.g., interactive booths, electronic commerce, mobile systems) or professional experts in various domains (e.g., nuclear power plants, railways systems, textile design). A particular focus is on accessibility which promotes increased effectiveness, efficiency, and satisfaction for people who have a wide variety of capabilities and preferences.

The focus is not only on “classical” work situations, but also on new computers uses, not yet all well defined, such as: consumer products (e.g., electronic commerce), information retrieval (e.g., tourism), mobility, etc.

4. Application Domains

4.1. Application Domains

This year, the main application domains have been: 3D virtual and mixed reality environments; task modelling; interaction with visualizations of large sets of multimedia information; personal information management systems, text and picture visual search, 3D interactive visualization metaphors, picture browsers; online help; Embodied Conversational Agents (ECAs); gaze-contingent displays.

See section 5.1 for specific scientific results with the industrial and academic partners involved.

5. New Results

5.1. Introduction

The research work carried out this year is presented along three main topics: ergonomics methods for the evaluation and design of software interactions; ergonomics of multimodal interactions; implementation and ergonomic evaluation of gaze as a designation modality; interaction with visualizations of large sets of pictures or complex images; contextual and adaptive online help; utility and usability of Embodied Conversational Agents.

5.2. Ergonomic methods for the evaluation and design of software interactions

5.2.1. Generic issues in ergonomics methods for HCI

Participant: D. L. Scapin.

An invited conference paper [32] aimed at stressing the human aspects in the design and evaluation of software systems, from the point of view of engineering ergonomics. It does not aim at exhaustiveness, but rather at providing a broad overview of the main issues. After a few definitions and statements on the needs for a user-centered approach, the paper describes the main ergonomic requirements to be taken into account. Then, after a survey on usability methods and standards, the choice of ergonomic methods is discussed within the software lifecycle steps and other parameters of the context. The paper concludes with an outline of the major issues to be retained.

The European project COST294-MAUSE "Towards the MAturation of IT USability Evaluation" (see http://www.cost294.org), comprises four working groups (WGs). Our participation has mainly concerned WG1 (Leader: D. L. Scapin) whose goal is to build a refined, substantiated and consolidated knowledge-pool about usability evaluation. WG1 has extended the coverage of its initial method descriptions. Using its "UM Generic Description" template and its "Case Study Description" template, WG1 has been able to describe nineteen methods (including one methodology consisting of several methods), and three applications of a method/ "case studies". The second interim report based on the above analyses is accessible via the MAUSE Digital Library [40]. Further WG1 work will concern: enlarging the coverage of a variety of UMs, particularly for "Collaborative Methods"; extending coverage to more computer-based methods; (coordination with WG4 in progress); exploring new peer-review mechanisms in order to disseminate further the results obtained. A specific WG1 workshop (with a call for contributions) has been organized for the spring of 2007.

5.2.2. K-MADE development and delivery

Participants: M. Baron, D. L. Scapin.

KMAD (Kernel of Modal for Activity Description), recently modified from the initial MAD task model, led to the design of a new task modelling tool (KMADe Tool), which provides support for the design and evaluation of user interfaces. That tool and the associated services have been further improved.

The first step has been the improvement of the KMAD model semantics. The grammar for the expressions of preconditions, postconditions and iterations have been modified to allow the complex management of constraints as well as a better feedback on error control. Also, new task characteristics have been added, such as associating tasks to multimedia files (video and sound). Finally, a new simulation algorithm has been implemented; that algorithm is much faster and requires less processing resources. It has been tested on large size examples. The new version of the model will be described in a journal paper [17].

The second step has been the improvement of the tool. In addition to the implementation of the new grammar and the simulation, some efforts have concerned further functionalities of the tool and usability aspects. These efforts include the graphic representation of the task model which was enriched by incorporating an existing library, already tested for this type of representation (graph visualization and layout). The JGraph library is written in Java; it is based on a model/view pattern and it offers several functionalities, for instance: simple or grouped selection tasks; in/out zooming of the task model; quick overview; copy/cut/paste and undo/redo; structured printing of related parts of the task model on several pages. A new XML-based data format has also been implemented which will allow better comunication with other tools, particularly in terms of software integration. Also, with these new features, the tool was tested on various cases studies (e.g. car renting procedures, fire emergency procedures) and the tool has been adapted to be used both in French and English. The KMADe tool was presented at a conference [24].

The last step has been the deployment of the model and tool: the tool is available on line (http://kmade.sourceforge.net), together with a user manuel (150 pages) both in French and English.

In conjunction with the above activities, a study has been carried out (student internship) on the topic of task tree visualization. This research led to three solutions : the multi-views visualization, the MagicLens and the interactive search. Each vertex in the task tree represents a task in the activity. The multi-views technique enables to show additional information. The magicLens is based on the same principle but has the advantage of being independent of the basic view of the tree. If those two first techniques are especially useful to discover the activity, the last one enables the user to analyse it: it provides an interactive tool to find tasks that correspond to some criteria. The prototypes of those solutions have been implemented, but these are not yet integrated in KMADE [34], [39].

Further work is being done on various aspects of validation and use in various contexts (dialogue design, mixed systems, etc.) through various collaborations (e.g., Universities of Poitiers, Toulouse, Lille, Melbourne).

A first evaluation of the model and tool has been carried out with groups of students at Poitiers University. A number of suggestions on usability improvements have been gathered. Further, more formal evaluations are being considered to validate the model and tool on real activities, with real users. The goal is twofold: verify the level of accuracy of the model semantic (power of expression), and assess the level of support provided to the analyst to enter actual data from interviews into the tool (usability).

Another major research issue being followed concerns the potential scope of queries on the model in order to identify useful additions to the service capabilities of the KMADe tool. The approach is to identify sets of query requirements, initially based on the literature on task-based recommendations. The expected outcome is to provide a set of queries supporting a task-based design and evaluation process (e.g. comparison of tasks models, identification of common tasks, of tree depth, of common objets used by certain tasks).

In addition papers [15], [23], [22] have been published following research work on another project (University of Poitiers) on formal validation of user interfaces.

5.2.3. Personal Information Management : an investigation of user's practice

Participant: D. L. Scapin.

Following a 2005 Post-Doc by T. Blanc-Brude on PIMs (Personal Information Management systems) further analysis of a study led to two conference papers [25], [26] and a journal article [18].

This study aimed at finding out which attributes people actually recall about their own documents (electronic and paper), and what are the characteristics of their recall, in order to provide recommendations on how to improve tools allowing users to retrieve their electronic files more effectively and more easily. An experiment was carried out with fourteen participants at their workplace. They were asked first to recall features about one (or several) of their own work documents, and secondly to retrieve these documents. The difficulties encountered by the participants in retrieving their electronic documents support the need for better retrieval tools. More specifically, results of the recall task indicate which attributes are candidates for facilitating file retrieval and how search tools should use these attributes.

In summary, when participants were asked to find their own document(s), they only used a small subset of the attributes they were able to recall, and often they had difficulties in finding their document(s), with current available tools. This shows the need for better tools for retrieval. In addition, the results indicate which document attributes are more often recalled (e.g., keywords) but also which ones are best recalled, that is with less errors (e.g., type). Thus, results indicate which attributes are candidate for facilitating file retrieval. The results also show how the various attributes that the users are able to recall should be exploited to be usable. Systems should allow users to formulate the document attributes with the expressions and the degree of accuracy that characterize their recall. In addition, systems should take into account the approximate but foreseeable nature of the recall in the returned results by including a margin of error or allowing users to easily modify the parameters of the attributes. The results also provide ideas to exploit the fact that the recall of certain attributes can depend, on the one hand, on the type of user and, on the other hand, on the "recency" and/or frequency of use of the documents. Lastly, they encourage the tracking by the system of the attributes which relate to the interactions between the document and its environment (i.e., usage context events, links between documents and actions performed on the document) and they suggest which precise types of interactions are relevant to monitor and retain.

Providing further analyses are conducted, together with additional controlled experiments, the recommendations provided in this paper can be viewed as a contribution to the design of improved retrieval tools. Obviously implementing these recommendations in actual PIM tools will need further development, ecological testing of their usability and utility, as well as comparisons with current systems, with a user-centered perspective.

5.2.4. Comparing methods for the evaluation of HVEIs (Human-Virtual Environments Interactions)

Participant: D. L. Scapin.

Following a 2004 Ph.D. dissertation that dealt mainly with the design and evaluation of the Ergonomic Criteria (E.C.) applied to HVEIs, a collaboration with C. Bach (IRIT / Metapages) concerned the detailed analysis of the data obtained in past experiments in order to compare Ergonomic Criteria (and regular inspection) with User Testing, the goal being to identify quantitative differences in evaluation performance, but also qualitative differences in terms of type of problems diagnosed. A paper is being submitted to an international journal [16]. In short, the study measured the effectiveness of the (E.C.) as an inspection method, compared with two other methods: Users Tests and free Inspection. This comparison, carried out on two different Virtual Environments, attempted to evaluate the following points: the overall evaluation performance; the distribution of the problems found with the different methods; within-methods problem similarity; between-methods problem similarity vs specificity. Some of the results show that:

- There is no significant difference between E.C. and User Testing overall evaluation performance, but a significant difference between E.C. and Control group.
- The participants' group using the E.C. identify a larger diversity of problems than User Testing and Control; whatever the method used, the most concerned E.C. are the same.
- Concerning problem coverage, that there is a quite similar distribution of problem flaws on both application types (educational 3D and map 3D).

- The Control group, and further more, the User Testing group seem to be more influenced by the type of application than the E. C. group. Globally, the E.C. seem to lead to more consistency in problem diagnosis.

A detailed analysis of the types of problems diagnosed is also being described.

5.2.5. User centred design and evaluation of mixed systems

Participants: S. Charfi, D. L. Scapin.

This research work is based on a collaboration with IRIT (E. Dubois, R. Bastide). Mixed systems are interactive systems based on the fusion of physical and digital worlds. The specificity of such systems includes the very large amount of objects of different types involved in the users' activity. Such a characteristics represents new challenges for design.

In this research, the orientation is to merge a task-based approach, classical in ergonomics and a complementary approach to model mixed systems, that describes specificities of this new form of interactive system. More specifically, the goal is to contribute to the coordination of task models and mixed systems models in order to support theoretically and technically the mixed systems design process. To illustrate and validate the approach, a real software application for the Toulouse Museum of Natural History has been selected and is being developed.

First, a state-of-the-art review, still on going, has been carried out, covering mixed systems definitions and models, task models, and domain models. A first attempt at associating mixed systems models and task models has been investigated using two models (and tools): K-MAD (K-MADe) and ASUR (GuideMe), both theoretically in terms of generic concepts, and practically on the museum software. For merging purposes, elements expressed in both models (involved entities, sub-task decomposition, task properties such as goal and stakeholders) and complementary elements of each model (task pre/post conditions, device characteristics, description of the media used to convey information) have been pointed out.

A paper has been presented about the initial results obtained [29]. The research now attempts to fully describe the museum software and potential design solutions of a mixed system type (e.g. using physical objects rather that graphical objects), and to generalize the approach, both from the modelling point of view, and from the design process point of view. A second use case will be investigated to validate this generalization. This use case is the one used as a reference in the GT CESAME of the GDR I3 (CNRS - STIC).

Specific issues will concern: the correspondence between K-MAD sub-trees and ASUR diagrams, particularly in terms of entities and modes/ levels of description; the support for selecting one particular ASUR model among others to be related to one specific task identified in the task model; the study of the suitability of the selected ASUR model in a task sequence described by the task model (in these last two perspectives, the main issue is to identify macro elements in the task model that may influence the choice of one or another design solution selected for a "micro" interactive sub-task or sequence of sub-tasks); the simulation of the interweaving of the two models.

5.2.6. Formal design and validation of the dialogue in interactive software

Participants: S. Caffiau, D. L. Scapin.

Following previous collaborations with University of Poitiers (and ENSMA), a thesis just started following the work on K-MADe and SUIDT, on the topic of merging task-based approaches and dialogue-based approaches. Indeed, task modelling has become very important in HCI (Human-Computer Interaction), and it is being used extensively as means of human activity modelling and requirements production, both important parts of software systems analysis and design. However, current models, methods, and tools are quite cumbersome to use, and their cost/benefit ratio, not always satisfactory, leads to usage mainly in large projects, which have the appropriate time and ressources (often in critical systems environments). Improving that relationship and speeding the process would be a major contribution to the field of HCI. The research work starting in this thesis aims at investigation such a challenge: the link between task models and dialogue models. The first step of this research will focus on the potential correspondence between these two categories of models; and

should offer contributions for enriching task models with the required dialogue model attributes. This will include the examination of the nature of design decisions, their characteristics, logic, and stages, in order to define an initial basis for a design methodology integrating all these requirements. A second step will be to attempt backtracking design from software designed with different interaction styles, which will support meta-modelling of the interaction. The third step should establish formal links between task models and dialogue models, using the previous meta-modelling. This should result in the definition of software validation using "usage scenarios" as a basis for evaluation. Analysis and development tools will be developped following the research findings, and using existing software developped in Poitiers and Rocquencourt (e.g., SUIDT, K-MADe). The aim will be to improve existing tools, in a multidisciplinary way, i.e., with the integration of both ergonomics aspects and software engineering aspects. The initial steps of the research work have been presented at RJC 2006 (Rencontres Jeunes Chercheurs en IHM) [28].

5.2.7. Towards effective online help to current software applications

Participants: J. Simonin, M. Hategan, N. Carbonell.

To improve the effectiveness of online help, we are currently investigating two research directions: adaptivity and multimodality.

User modelling is an active, fast developing research area. Recent scientific advances make it possible to consider the implementation of effective adaptive user interfaces. However, specific usability issues are yet to be investigated. To react predictably is viewed as a major usability requirement for interactive software. Hence, how will users react to, and accept, user interfaces the behaviour of which evolves autonomously in the course of time? What amount of control over the interface evolution users should be given?

As for multimodality, we have shown that multimodal contextual help that combines oral messages with graphics is well accepted by novice users, stimulates help consultation, and improves its effectiveness [19], mainly because oral help messages disrupt novices' interactions with new software much less than textual messages, and enable users to apply instructions and recommendations while these are delivered.

Besides, embodying advanced online help systems endowed with speech capabilities may further increase the effectiveness of these systems. Using an Embodied Conversational Agent (ECA), especially a talking head, for assisting novice users, has the potential to enhance their motivation to consult online help systems more frequently, hence to facilitate and improve the learning of how to control new software.

This year, efforts have been focused on the development and use of an operational generic software platform for assessing the utility, usability and acceptance of adaptive user interfaces or embodied multimodal user support, in realistic human-computer interaction situations.

5.2.7.1. Design and implementation of a Wizard of Oz software platform

We have developed a generic Wizard of Oz platform which enables the simulation of novel user interfaces implementing a variety of new interaction modalities (e.g., input and output speech) and interaction strategies (e.g., adaptability and adaptivity). Integration and animation of ECAs (e.g., talking heads) is also possible.

Functionalities of this platform include (i) real time transfer of the user's screen displays to the wizard's workstation over a local network, and transmission of the wizard's actions/commands to the user's workstation; (ii) efficient support of the wizard's simulation activities; (iii) recording and replay of the user's interactions with any Windows application (i.e., user and system events, together with screen copies of the application displays); (iv) efficient integration of any ECA whose animation is described in a Control ActiveX. If need be, the synchronised replay of interactions may include speech utterances from the user and gaze fixations synchronised with, and superimposed on the displays. The platform also provides annotation facilities, that is software tools for segmenting and labelling/commenting digital interaction traces, or for defining (semi-automatically) areas on the displays to analyse the evolution of the user's focus of visual attention. This platform has been presented and demonstrated at WACA'06 [33].

5.2.7.2. Assessment of the efficiency and user acceptance of adaptive online help

Up to now, research on adaptive user interfaces has been mainly focused on the design of efficient user models and adaptation strategies [47]. Effects of dynamic system adaptation to the current user's profile on interaction efficiency and user satisfaction have motivated only a few published studies. We have completed a comprehensive survey of published research on adaptive user interfaces which has been accepted for publication [21]. We are currently preparing an experimental study with a view to gaining meaningful information on ergonomic issues pertaining to the utility and usability of adaptive online help. This study is focused on the utility and usability of dynamic adaptation to the evolution of the current user's knowledge and skills while discovering new software and learning how to use it. The chosen application is online help to the use of Flash, a standard software tool for creating animations. Advanced adaptive help strategies will be simulated using the Wizard of Oz platform described in the paragraph: "Design and implementation of a Wizard of Oz software platform". Twenty volunteer participants (Bac + 2 students who have never used Flash) will experiment this simulated adaptive help system during one hour or so, with a view to getting familiar with basic Flash tools for creating animations. Individual experimentation sessions are scheduled to start in January 2007.

5.2.7.3. Contribution of ECAs to the effectiveness and appeal of online user support

Research on the design and implementation of ECAs is developing rapidly. Numerous prototypes with human-like appearance and behaviour are now available in research laboratories. However, the benefit that may be expected from their integration into user interfaces has motivated only a few studies according to [48]; see for instance [43].

This year, we have performed, in collaboration with France Télécom R&D (CRE, 04/15/05-04/15/06), an experimental study meant to assess the actual contribution of a human-like ECA (a realistic woman face with talking capabilities and facial expressiveness provided by France Télécom) to the efficiency and usability of human-computer interaction. Twenty participants (Bac + 2 and Bac +3 students who had never used Flash) interacted with Flash during one hour or so. They had to create two pre-defined animation scenarios using a multimodal (speech + graphics) online help system as they liked. The absence or presence of the ECA as an embodiment of the help system which was the free variable, defined two situations which were experienced by each participant in counterbalanced order. Analyses of interaction traces, verbal and non verbal questionnaires, post-tests and debriefing interviews were focused on the investigation of the effects of the ECA's aspect, communicative and expressive behaviour, on users' performances, motivations and subjective judgements. Traces included eye tracking recordings (ASL-501 head-mounted eye tracker). Moments when participants looked at the ECA were examined in detail and interpreted as objective cues of participants' attitude towards the ECA; interpretations took into account of the nature of the participants' concomitant interactions and activities/tasks.

Main conclusions indicate that a majority of participants appreciated the presence of the ECA. In particular, they judged the presence of a humanoid animated agent useful, especially during the first interactions of novices with new software. In addition, results contribute to validating the method used to design the expressions, behaviour and "personality" of the ECA. They also suggest the appropriateness of the methodology we designed and implemented for evaluating the contribution of ECAs to Human-Computer Interaction, especially the use of eye-tracking data and non verbal questionnaires.

Detailed results are reported in the final deliverable of the contract [41]; they have also been summarized in a multimedia document [38] which was used to present results to France Télécom research groups involved in the design, development and ergonomic assessment of ECAs.

5.3. Interactive visualizations

The design of interactive visualizations of large collections of pictures (e.g., photographs) has not yet raised much interest in the HCI research community. This lack of interest seems to be mainly based on the implicit assumption that visualization techniques designed for large data sets can be used for visualizing large collections of pictures. For instance, [44] resorted to tree-maps for displaying pictures taken at CHI 2001,

while browser designers usually present picture collections in the form of 2D arrays of zoomable thumbnails which users navigate through using scroll bars.

However, specific visualization techniques need to be developed for the presentation of collections of digital photographs, especially personal, hence more or less familiar, photographs. User motivations for browsing picture collections are indeed different from those of users who explore digital or textual data sets. Search for a familiar photograph or for a few photographs that match a set of criteria is one of the most frequent activities that motivate browsing through a picture collection, especially a personal one; in addition, this type of task involves intensive visual search and target identification activities.

On the one hand, our contribution to the Micromégas project on multiscale visualization of, and interaction with, familiar information sets [4] has been focused on the design, implementation and ergonomic evaluation of 2D and 3D interactive visualizations of picture collections. Interaction has been implemented using standard devices and modalities (i.e. mouse or joystick).

On the other hand, gaze may prove to be more appropriate than standard mouse for designating objects and positions on the screen in contexts where the user interacts with very large displays, such as electronic walls, reality centres and caves. We have been working on the implementation of gaze as a pointing modality in multimodal interaction environments where commands/actions can be expressed using speech or, in some application contexts, gestures (e.g., use of a joystick).

2006 activities and results are presented in the following subsections.

5.3.1. 3D representations of, and interaction with, large collections of pictures

Participants: O. Christmann, N. Carbonell.

Entertainement and commercial Web-sites, information kiosks and public terminals tend to display an increasing number of pictures simultaneously: video and movie snapshots, CD sleeves, book covers, etc. Personal electronic archives and file directories are increasingly cluttered with unstructured collections of photographs, scanned drawings, videos. The only option offered to users by current software (e.g., ACDSee, PhotoSuite or ThumbsPlus) for searching large sets of pictures amounts to scrolling 2D arrays of zoomable thumbnails.

We have designed and implemented two 3D metaphors for visualizing and browsing large collections of photographs (e.g., landscapes, portraits, complex objects). Both metaphors visualize a collection of pictures or multimedia documents in the form of a vertical 3D cylinder. However, in the context of one metaphor, the representation is an object that users manipulate while, in the context of the other one, the user is surrounded by a cylindrical wall (immersive virtual reality). In the case of the immersive metaphor, move commands are ambiguous: users may feel as if they were moving in front of the "wall" (locomotion[5]), or they may have the impression that the wall itself is moving around them.

These metaphors have been compared regarding their respective efficiency (i.e., task execution times, success and failure rates, spatial orientation effectiveness) and usability (user subjective satisfaction especially). This study involved 20 participants who carried out two types of realistic visual search tasks: looking for a visually familiar picture, and searching for one or several pictures matching predefined criteria specified verbally. Each collection included over 1000 photographs, 150 of them (or so) being simultaneously displayed on the screen. Actions on the cylinder included left and right rotations, forward/backward adjustment moves and zooms.

Contrary to our expectations, participants' subjective judgements were less influenced by the implications of the two metaphors, immersion versus manipulation, than by picture distortions which varied from one 3D view to the other. Thus, participants' preferences were mostly influenced by their visual acuity (assessed through the Bioptor kit). Performances varied from one view to the other for each participant; however, comparisons between global averaged performances for each view did not show any significant difference. Results were presented at the ACM AVI Conference [30]. Demonstrations of the software prototype were carried out at the

[4] Micromégas is a 3 year national project (July 2003 - July 2006) in collaboration with the In Situ team at INRIA-Futurs and LRI (Orsay), and the LPM Laboratory in Marseille; it was selected for support by the ACI 'Masses de données'

[5] They may feel as if they were turning round on themselves, or as if they were "walking" along the virtual wall.

AVI and PaRISTIC Conferences[6]. We are currently preparing another experimental study which focuses on the comparison between the two 3D visualizations we have designed and standard 2D array displays. Tasks and experimental protocol will be similar to those implemented in the previous study. Traces of participants' interactions only will differ: their eye movements will be recorded in order to increase the number of objective measurements used to assess the comfort and efficiency of visual search activities using each of the three representations. Eye tracking data will also provide useful qualitative information on the visual exploration strategies induced by each representation.

In parallel, we are preparing a large scale usability study of the two 3D representations we have experimented, in collaboration with the CVCE[7] in Luxembourg. Both representations will be used to present multimedia documents on the history of European Union construction, at international scientific events (e.g., international scientific forums). Participants to these events will have the opportunity to interact with them using very large touch screens; interaction traces will be recorded.

5.3.2. Oral assistance to visual search on displays of small picture collections

Participants: S. Kieffer, N. Carbonell.

Regarding 2D visualizations of small collections of pictures, efforts have been focused, this year, on completing the analysis of data from a previous experimental study meant to assess the effectiveness of oral support to visual search, and motivated by the following observation mainly. Speech+gesture-based multimodality has been extensively studied, both from a software and an ergonomic point of view. However, speech+graphics as an output form of multimodality has raised fewer research studies, especially as regards the utility and usability of voice synthesis as a supplementary modality to graphics.

This study, which involved 24 participants, aimed at determining the influence of oral help messages on the speed and accuracy of visual target detection activities; targets were visually familiar to participants. Oral messages just specified the position of the target in one out of nine pre-defined areas on the screen. The effectiveness of this form of oral assistance was assessed for various display spatial layouts. 3600 photographs of real landscapes, people and objects, were selected from a database including over 6000 items, then formatted and divided up into 120 thematically homogeneous collections (30 photographs per collection). These collections were displayed using four spatial layouts (40 collections/scenes per spatial layout): elliptical, radial, matrix-like, random. The free variable was the presence/absence of spatial information voice messages, and bound variables were the display spatial layout in addition to performance measures and subjective judgements elicited through verbal questionnaires and debriefing interviews. Each participant performed the 120 target detection tasks twice, with and without the help of oral messages, in counterbalanced order.

Oral indications on target positions which were well accepted by participants divided search times by three and significantly reduced error rates. The influence of oral messages was greatest for radial and random display layouts. These results which were presented at AVI'06 [31] may induce user interface designers to assist users in visual search tasks on cluttered displays with short oral messages including coarse information on target positions on the screen.

5.3.3. Gaze as a pointing modality in multimodal interaction environments

Participants: D. Gepner, M. Divjak, N. Carbonell.

For the last two years efforts have been focused on the investigation of two complementary research directions: (i) the implementation of gaze-contingent displays, (ii) the design and implementation of multimodal, speech- and gaze-based, command languages.

Prior to addressing these two research themes we had to develop a real time algorithm for computing fixations; this algorithm in C++ takes head movements into account[8]. This year's progress is presented in the next two paragraphs after a brief summary of the research issues addressed.

[6] Panorama des Recherches Incitatives en STIC, Nancy, November 22-24, 2005.
[7] CVCE means 'Centre virtuel pour la Connaissance de l'Europe', a research centre supported by the Luxembourg state.
[8] We use the ASL-501 head-mounted eye tracker.

5.3.3.1. Gaze-contingent displays

By definition, the resolution of gaze-contingent displays varies according to the user's current point of gaze, information density being higher around the current point of gaze than elsewhere on the display. The size of the high resolution area includes the foveal and para-foveal visual fields. To be effective and acceptable, gaze-contingent display algorithms should change display resolution as fast as the natural pace of human visual exploration scenes. Research on gaze-contingent displays is developing rapidly. See [45], pages 211-217 for a review of current research in this area. Potential application areas include: (i) interaction with complex distant visualizations or animations whenever image compression techniques (without loss of information) prove insufficient for achieving satisfactory display speed and reactivity; (ii) interaction with virtual reality environments such as Reality Centres or Caves where viewpoint changes often entail time-consuming computations which reduce interactivity.

This year, we designed and developed a gaze-contingent prototype using the ASL-501 eye tracker for tracing users' eye movements (60 Hz sampling rate). The prototype is operational and has been experimented on blurred images displayed on a standard 21" screen. However, the delay necessary for detecting fixations is too high (about 90 ms) for ensuring smooth scan paths; users perceive it and resent to be slowed down in their exploration of the progressively de-blurred image.

We are currently investigating several strategies for getting round this difficulty. In particular, we are considering guiding gaze during scene exploration, since predicting the landing position of the next fixation from the speed and direction of eye movements during the current saccade yields unreliable results [46]. We have experimented with a prototype that generates stimuli in the peripheral visual field, and observed that gaze is actually attracted by the stimuli. We are currently refining the implementation of this strategy in two ways. Firstly, we are testing peripheral stimuli of various sizes and visual properties, and in different positions in the user's visual field. Secondly, we are analysing a corpus of scan paths (240 Hz sampling rate, 8 participants) collected during unconstrained visual exploration of realistic scenes (130 photographs), with a view to identifying inter-individual similarities. Results of this analysis will be used to place peripheral stimuli in potential areas of interest in the displayed scene, and to activate them in an order compatible with human scan paths, based on the assumption that gaze guidance will be most effective and acceptable if it induces scan paths that fit in with human spontaneous visual exploration strategies as well as possible. The scope of this research is a priori limited to realistic scene exploration activities. Observation of scan paths during other activities, such as visual search, is necessary to determine the influence of the nature of the visual activity on scan paths and visual strategies.

To test the robustness of our real time fixation computation algorithm, we have also developed a demonstrator for an innovative electronic surveillance application, in collaboration with researchers at the Centre de Recherche en Automatique de Nancy (Francis Lepage and Bruno Buttice): gaze control of the shooting angle of a distant camera (with 2 DOF) mounted on a mobile robot. This demonstrator has been presented last spring at the EEA Club annual meeting [27]. The moves of the robot are controlled through dedicated keys on the local workstation keyboard; however, we are considering using speech commands for controlling the robot.

5.3.3.2. Multimodal speech- and gaze-based interaction

Spoken natural language may appeal to users in the general public, since it is the main modality used, together with pointing gestures or gaze, in face-to-face human communication. Our work on multimodal human-computer interaction is based on the following observation. Pointing hand gestures have the same expressive power as gaze in some contexts of use, namely, the selection of objects in very large displays (e.g., electronic walls, reality centres or caves, etc.), or in "Ambient Intelligence" environments [20]. In these interaction environments, both modalities can only specify directions, if used spontaneously as in real life. Our current work on multimodality addresses the main following issue: how to design multimodal command languages that use information on spontaneous or controlled gaze movements to disambiguate oral commands, especially those including deictic phrases and ambiguous nominal references to the current virtual or real scene? During this year, we have been carrying on with the analysis of a corpus collected earlier, with

a view to gaining an insight into users' gaze strategies during oral and multimodal interaction with 3D virtual environments. This corpus includes realistic data on spontaneous and controlled eye movements. 5 participants interacted during half an hour with various 3D applications, using first speech, then multimodal (speech+gaze) commands. Applications were created using the ORIS virtual reality development tool, and the user interface was simulated using an advanced implementation of the Wizard of Oz technique (i.e., the human wizard benefited from appropriate software assistance). The recorded multimodal interactions are being analysed using a specific software tool which we developed (under Linux). This tool records and "replays" interactions with any ORIS application in two separate windows. One window displays the user's points of gaze superimposed on the successive displays from the application. The other window displays graphical representations of the temporal evolution of pupil diameter and speech signal. It also displays the names of the graphical application objects looked at by the user (automatic labelling), as well as speech recognition results in both orthographic and phonetic forms. Users' oral commands and utterances can also be listened to simultaneously. All these data are carefully time-synchronized.
Phonetic and orthographic transcripts of participants' spontaneous speech utterances are now completed. We are currently designing a real time algorithm that can robustly and accurately: (i) interpret fixations which occur simultaneously (loose concomitance) with speech commands as designation gestures towards the displayed graphical objects involved in these commands; (ii) use this information for solving ambiguous references and deictic phrases included in oral commands (multimodal fusion). The next step will be to integrate this algorithm into a software demonstrator with a view to assessing its actual efficiency (accuracy and run time speed) in realistic situations where multimodal speech+gaze commands are used for interacting with various virtual reality applications. This demonstrator will also be experimented with extensively, in order to test the acceptability of the necessary constraints forced upon users' spontaneous gaze movements for achieving robust interpretation of gaze fixations. Later, the demonstrator will also be experimented in ambient intelligence environments [20].

6. Other Grants and Activities

6.1. National projects

- Participation to the Working Group CESAME (Conception et Exécution de Systèmes interactifs Adaptables et/ou Mixtes en Évolution) GDR I3 (D. L. Scapin).
- Participation to the "Micromégas" project, supported by the ACI "Masses de Données" until July 2006 (N. Carbonell, O. Christmann, D. L. Scapin).
- Collaboration with France Télécom R&D (Contrat de recherche externalisée LORIA-CNRS, until May 2006): Evaluation of the contribution of Embodied Conversational Agents (ECAs) to human-computer interaction: the case of online help (N. Carbonell, M. Hategan, J. Simonin).
- Participation to the "Pôle Intelligence Logicielle" of the "Contrat de plan État-Région Lorraine", theme "Télé-opérations et Assistants Intelligents (TOAI)": participation to two projects, "Multimodal tele-operation of a mobile robot equipped with a rotating camera" and "Visual attention modelling" (N. Carbonell, D. Gepner).

6.2. Networks and international working groups

- WWCS (Work With Computer Systems conference) Group (D. L. Scapin).
- Standards in ergonomics and HCI[9]
  - AFNOR X3SE (Ergonomie des Logiciels Interactifs); (Chair: D. L. Scapin).
  - ISO/TC 159/SC4/WG5 (Software ergonomics and human-computer dialogues) (D. L. Scapin expert).

[9] see also article (29/08/06: http://www.inria.fr/valorisation/standardisation/ergonomie/index.fr.html

  - ISO/TC 159/SC4/WG6 (Human-centred design processes for interactive systems) (D. L. Scapin expert).
  - CEN/TC 122/WG 5 (Software ergonomics and human-computer dialogues) (D. L. Scapin expert).

- Participation to the CNPq/INRIA project EDGE (Evaluation methods, Design Guidelines and Environments for Virtual Reality and Information Visualization Techniques) (D. L. Scapin).
- Participation to the project COST294-MAUSE "Towards the Maturation of IT Usability Evaluation" 2005-2009 (D. L. Scapin).
- ERCIM Working Group "UI4ALL" (N. Carbonell member of the Steering Committee).
- ERCIM Working Group "SESAMI" created in September 2006 (N. Carbonell, member).
- ACM Special Interest Group SIGACCESS (N. Carbonell, Board member).
- Scientific Committee of the CVCE Research Centre, Luxembourg (N. Carbonell, member).

7. Dissemination

7.1. Animation of the scientific community

7.1.1. Editorial Boards of Journals

- Behaviour and Information Technology. (Member of the Editorial Board: D. L. Scapin).
- International Journal of HCI. (Member of the Editorial Committee: D. L. Scapin).
- International Journal of Human-Computer Studies. (Member of the Editorial Committee: D. L. Scapin).
- Interacting with Computers. (Member of the Editorial Committee: D. L. Scapin; Reviews: N. Carbonell).
- ACM Transactions on Accessibility.(Members of the Editorial Board: N. Carbonell).
- International Journal of Universal Access in the Information Society. (Members of the Editorial Board: N. Carbonell, D. L. Scapin).
- Revue d'Interaction Homme-Machine. (Membre du Comité de Rédaction: D. L. Scapin).
- International Journal of Computational Intelligence. (Member of the Editorial Board of a Special Issue on Recommender Agents and Adaptive Techniques, Vol. 3, issue 2, 2006: N. Carbonell)
- Revue Information, Interaction, Intelligence. (Membre du Comité de Rédaction: N. Carbonell).
- Le Travail Humain (Membres du Comité de Consultants: N. Carbonell, D. L. Scapin).
- Journal of Virtual Reality and Broadcasting. (Reviews: N. Carbonell)

7.1.2. Conference Programme Committees

- HCII'07, Human-Computer Interactions International Conference, July 22-27, Bejing, China. (Program Committee Members, N. Carbonell, D. L. Scapin)
- WWCS'07, Working With Computer Computers Conference, May 21-24, Stockholm, Sweden. (Program Committee Member, D. L. Scapin)
- ACM International Conference on Multimodal Interfaces (ICMI 2006), Banff, November 2-4, 2006, Canada. (N. Carbonell)
- 3rd Cambridge Workshop on Universal Access and Assistive Technology (CWUAAT'06), 10-12 April, 2006, Cambridge, UK. (N. Carbonell)

- 9th ERCIM Workshop on User Interfaces for All (UI4ALL 2006), 27-28 September 2006, Königswinter (Bonn), Germany. (N. Carbonell)
- Advanced International Conference on Telecommunications (AICT 2006) - Track E-learning and Mobile Learning on Telecommunications (ELETE), Guadeloupe, February 22-26, 2006. (N. Carbonell)
- International Conference on Multimedia and Network Information Systems (MNIS'06), June 2006, Wroclaw, Poland. (N. Carbonell)
- International Conference on Networks and Systems Communications (ICNCS 2006) - Track Pervasive Education Systems (PESYS), November 2-4, 2006, Tahiti. (N. Carbonell)
- 10th International Conference on Knowledge-Based & Intelligent Information & Engineering Systems (KES 2006) - Invited Session on Recommender Agents and Adaptive Web-based Systems (RAAWS 06), 10-11 October 2006, Bournemouth, UK. (N. Carbonell)
- IHM'06, Conférence Francophone sur l'Interaction Homme-Machine, Montréal, Canada, April 18-24, 2006 (Program Committee Member, D. L. Scapin; Meta-reviewers, N. Carbonell, D. L. Scapin; Co-Chair Tutorials and Workshops : D. L. Scapin)
- 10ème Conférence Francophone Ergo'IA 2006, 11-13 octobre 2006, Biarritz. (Program Committee Members, N. Carbonell, D. L. Scapin)

7.1.3. Others

- ANR, RNTL 2006 Call: review of one project (N. Carbonell)
- Advisory Board of the LEA "The Universal Access Handbook", (Members, N. Carbonell, D. L. Scapin)
- Expertise for European Project: Network of Excellence (Expert: D. L. Scapin)

7.1.4. Ph.Ds and Habilitations examining boards

- Sébastien Carbini: Interaction multimodale oro-gestuelle personne libre : application à l'interaction multi-utilisateur avec de grands écrans. Doctorat de l'Institut Polytechnique de Grenoble, spécialité "Signal, Image, Parole, Télécoms", 20/09/06, N. Carbonell, rapporteur.
- Mounia Ziat: Conception et implementation d'une function zoom haptique sur PDAs - Expérimentation et usages. Doctorat de l'Université de Technologique de Compiègne, spécialité "Technologies et Sciences de la Cognition et de la Coopération", N. Carbonell rapporteur.
- Arnaud Lewandowski: "Vers de meilleurs supports aux activités coopératives en accord avec la co-évolution - Application au développement logiciel coopératif". Doctorat de l'Université du Littoral, spécialité Informatique, 06/12/06, D. L. Scapin examinateur.
- Jean-Claude Martin: Multimodal Human-Computer Interfaces and Individual Differences: Perception, representation and generation of situated multimodal behaviours. Habilitation à Diriger les Recherches, Université Paris XI Orsay, 06/12/06, N. Carbonell, rapporteur.
- Bertrand Tornil : "Adaptation et interaction gestuelle et haptique, ciblées utilisateurs vers plus d'utilisabilité et d'accessibilité". Doctorat de l'Université Toulouse 3, spécialité informatique, 08/12/06, N. Carbonell rapporteur.

7.2. Teaching

- Institut Supérieur de Technologie et de Management (ISTM), Module IHM: M. Baron (12h).
- Université de Poitiers, Master Professionnel mention Sciences et Technologies de l'Information et de la Communication (STIC): M. Baron (8h).

- Université de Poitiers, Master 2 Génie Physiologique, développement sous J2SE et J2EE: M. Baron (27h).
- Université de Poitiers, Master 1 Génie Physiologique, ingénierie des systèmes Web avec Java EE: M. Baron (9h).
- Master Informatique, Universités de Nancy, M1: U.E. d'ossature "Modèles de perception et raisonnement": N. Carbonell (24h).
- Master Informatique, Universités de Nancy, M1: U.E. de différenciation "Conception et évaluation dínterfaces utilisateur": N. Carbonell (30h).
- Master Informatique, Universités de Nancy, M2 spécialité recherche "Perception, Raisonnement, Interactions Multimodales", U.E. de différenciation "Modélisation de l'utilisateur et flexibilité des interfaces": N. Carbonell (15h).
- Master Informatique, Universités de Nancy, Responsabilité de la spécialité recherche "Perception, Raisonnement, Interactions Multimodales": N. Carbonell.
- Master Informatique, Universités de Nancy, Membre de l'Equipe de formation du Master et membre permanent du jury de soutenance des stages, pour les spécialités recherche : N. Carbonell.

7.3. Participation to conferences, workshop, invited talks

- MAUSE (COST Action 294: Towards the Maturation of Information Technology Usability Evaluation) Workshop, University of Konstanz, March 19-21 2006, Germany. (D. L. Scapin)
- RoCHI2006, September 21-22 2006, Bucharest, Romania. (D. L. Scapin)
- ACM International Conference on Multimodal Interfaces (ICMI 2006), Banff, November 2-4, 2006, Canada. (N. Carbonell)
- ACM Working Conference on Advanced Visual Interfaces (AVI'06), May 23-26, Venice, Italy. (N. Carbonell, O. Christmann; Demonstration)
- 9^{th} ERCIM Workshop on User Interfaces for All (UI4ALL 2006), 27-28 September 2006, Königswinter (Bonn), Germany. (N. Carbonell)
- $10^{ème}$ Conférence Francophone Ergo'IA 2006, 11-13 octobre 2006, Biarritz. (N. Carbonell, D. L. Scapin)
- Annual Meeting of the Scientific Committee of the Centre Virtuel de la Connaissance sur l'Europe (CVCE), October 20-21, 2006. (N. Carbonell)
- $2^{ème}$ Workshop sur les Agents Conversationnels Animés, 26-27 octobre 2006, Toulouse. (J. Simonin)
- IHM'06, Conférence Francophone sur l'Interaction Homme-Machine, April 18-24, 2006, Montréal, Canada. (M. Baron, D. L. Scapin; Demonstration)
- Invited talk "Apparition, expression, utilisation d'un clone humain assistant d'aide en ligne", France Télécom, Rennes, November 16, 2006 (N. Carbonell, J. Simonin)
- Panorama des Recherches Incitatives en STIC (PaRISTIC), November 22-24, 2006, Nancy, (N. Carbonell, O. Christmann; Demonstrations)

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Major publications by the team in recent years

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[13] S. SEBILLOTTE. *Décrire des tâches selon les objectifs des opérateurs. De l'interview à la formalisation*, in "Le Travail Humain,", vol. 54, 1991, p. 193-223.

[14] J. SIMONIN, S. KIEFFER, N. CARBONELL. *Effects of display layout on gaze activity during visual search*, in "Proceedings of 10th IFIP TC13 International Conference on Human-Computer Interaction (INTERACT'05), LNCS Series num: 3585, Rome, Italy", M.-F. COSTABILE, F. PATERNO (editors). , Springer, September 12-16, 2005, p. 1054-1058.

Year Publications

Articles in refereed journals and book chapters

[15] Y. AÏT-AMEUR, M. BARON, N. KAMEL. *Encoding a process algebra using the Event B Method. Application to the validation of user interfaces*, in "Software Tools for Technology Transfer Special Section", Submitted for publication, 2006.

[16] C. BACH, D. L. SCAPIN. *Comparing usability methods in the evaluation of Virtual Environments: Inspection using Ergonomic Criteria vs. User testing*, Submitted for publication.

[17] M. BARON, F. JAMBON, P. GIRARD, D. L. SCAPIN. *Formal multi-level Task modelling: the K-MADe model and tool*, Submitted for publication.

[18] T. BLANC-BRUDE, D. SCAPIN. *Etude de la mémoire des documents chez l'utilisateur pour la conception de systèmes d'aide à leur récupération*, in "Revue d'Interaction Homme-Machine (RIHM)", To appear, 2007.

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[22] Y. AÏT-AMEUR, I. AÏT-SADOUNE, M. BARON. *Etude et comparaison de scénarios de développements formels d'interfaces multi-modales fondés sur la preuve et le raffinement*, in "Actes de MOSIM 2006, Rabat, Maroc", 6ème Conférence Francophone de Modélisation et Simulation. "Modélisation, Optimisation et Simulation des Systèmes : Défis et Opportunités", Avril 2006.

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