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Companion-Technology for Cognitive Technical Systems

Susanne Biundo · Andreas Wendemuth

Abstract We introduce the Transregional Collaborative Research Centre "*Companion*-Technology for Cognitive Technical Systems" – a cross-disciplinary endeavor towards the development of an enabling technology for *Companion*-systems. These systems completely adjust their functionality and service to the individual user. They comply with his or her capabilities, preferences, requirements, and current needs and adapt to the individual's emotional state and ambient conditions. *Companion*-like behavior of technical systems is achieved through the investigation and implementation of cognitive abilities and their well-orchestrated interplay.

Keywords cognitive systems · Companion-characteristics · planning · reasoning · decision making · multimodal interaction · disposition recognition

1 Introduction

The technical systems we constantly use in our everyday lives – household appliances, entertainment electronics, smart phones, ticket machines, application systems and electronic services of all kinds – are becoming increasingly "intelligent" as innovation cycles continue to accelerate. Their functionality is changing, becoming more versatile and complex. Our desire or even our necessity to use these innovative products and services to their fullest potential is often diametrically opposed to their lack of user-friendliness and ease of operation. Voluminous instruction manuals, lengthy menu promptings and non-existent assistance are just a few of the obstacles that significantly hinder the barrier-free and truly easy use of these systems.

The Transregional Collaborative Research Centre SFB/TRR 62 "*Companion*-Technology for Cognitive Technical Systems" aims to develop a technology to complement the expanding functional intelligence of technical systems with an equivalent intelligence in interacting with the user and to integrate the two.

Our research follows the vision that technical systems of the future will be *Companion*-systems – cognitive technical systems, the functionality of which is completely adjusted to the individual user's capabilities, preferences, requirements and current needs; attuned to the user's personal situation and emotional state; always available, cooperative and reliable; and presenting itself to the respective user as a competent and trustworthy partner [5,21].

To realize this vision, the Centre undertakes an interdisciplinary investigation of the fundamental aspects required to create so-called *Companion-characteristics* of cognitive technical systems: competence, individuality, adaptability, availability, cooperativeness and trustworthiness. The goal is to develop a technology that enables the systematic construction of *Companion*-sys-

Susanne Biundo
Ulm University, Institute of Artificial Intelligence, D-89069 Ulm, Germany, Tel.: +49-731-50-24122
E-mail: susanne.biundo@uni-ulm.de

Andreas Wendemuth
Otto-von-Guericke University Magdeburg, Institute for Information and Communication Engineering, D-39016 Magdeburg, Tel.: +49-391-67-58448
and Center for Behavioral Brain Sciences, D-39118 Magdeburg. E-mail: andreas.wendemuth@ovgu.de

tems. To achieve this goal, the Centre investigates the central cognitive abilities of planning, reasoning and decision-making, interaction and dialogue management as well as perception and recognition, as the stated *Companion*-characteristics are to be realized through the interaction of cognitive system processes.

The relevant research questions are approached according to two complementary ways of looking at the interaction between user and system. The system view focuses on the construction and integration of cognitive functions and on using these to realize the *Companion*-characteristics. The user view looks at the effect of system behaviors on the user and investigates the *Companion*-characteristics by using psychological behavioral models and by analyzing brain activity during human-system interaction.

The Collaborative Research Centre establishes a link between synergistic interdisciplinary basic research and important societal concerns. As increasingly complex technical systems continue to find their way into ever more areas of our lives, the demands placed on individual users when interacting with these systems also increase. At the same time, developments in technology continue to open up new and unforeseen opportunities for technical support and digital assistance. In this field of tension – especially as concerns the aging society – *Companion*-technology is expected to make significant contributions. The areas of application range from new types of individualized operating assistance for technical devices to novel versatile digital assistants and electronic services and include innovative support systems, for instance, for persons with cognitive disabilities.

In recognition of its innovative developments [6] and their anticipated societal benefits, the Centre was awarded *Landmark in the Land of Ideas* by the *Germany – Land of Ideas* initiative in 2015 [1].

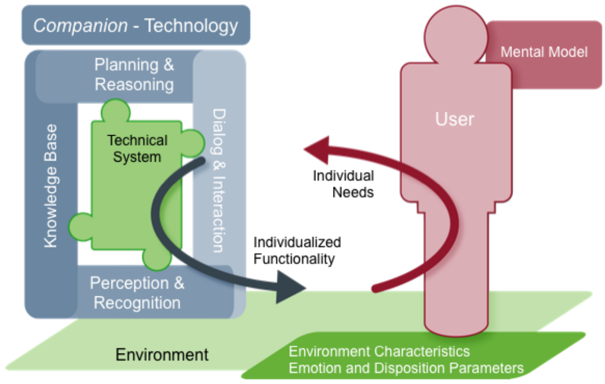

Fig. 1 *Companion*-Technology at a glance

2 Research Program

The development of a *Companion*-technology for cognitive technical systems involves cross-disciplinary methodological research in computer science and AI, the engineering sciences, and the life sciences. Figure 1 shows the key research issues addressed.

They are based on two key observations. First, a user always has an individual mental model of the technical system he or she is using. From this model *explicit* as well as *implicit* function requests emerge. The former relate to the product or service requested: the user wants to buy a ticket from a ticket machine or wants to get navigation support while driving to a certain destination, for example. The implicit function requests claim *how* the system should provide this functionality and how it should interact with this particular user. It is the ability to address also these implicit requests that distinguishes conventional technical systems from *Companion*-systems. The second key observation is that both the system and the user are embedded in the environment. Thus, the system is able to perceive information about the user's whole ambience: the environment including objects, persons, and conditions as well as user parameters that provide information regarding his or her disposition and emotional state.

Companion-systems are knowledge-based systems. A multifaceted knowledge base stores the entire knowledge the system needs to exploit. As shown in Figure 2, there are two main components. The *knowledge model* comprises static knowledge, namely a declarative model of the application domain, the planning model to represent the various ways of acting in this domain, and the user model required to provide individualized functionality [2]. It includes profiles representing a user's expertise w.r.t. the system's technical functionality, his or her preferences regarding ways of acting and interacting, and an individual emotion pattern. The *dynamic world model* reflects the current state of the world and its development over time. It serves to connect the sub-symbolic processing of audio-visual sensor streams or biosignals taken from respective sensors with the inference-based information processing on the sym-

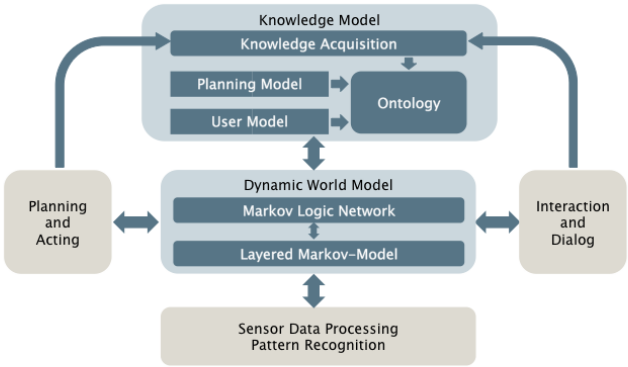

Fig. 2 Knowledge Processing in *Companion*-Systems

bolic level, thereby enabling the system to immediately react to changes of the situation or the user state [8].

The Collaborative Research Centre is structured along three main research areas.

Research Area A is concerned with planning and decision making, where these cognitive abilities are investigated from the user and system perspectives. Users of a technical system are pursuing a goal: they want to get a service or solve a problem and therefore place certain requirements on the functionality of the system. This means, the user's mental model has individual preconceptions and expectations on how the system should function in a particular situation and these determine the behavioral strategy the user will follow to achieve the goal [16]. On the *Companion*-system side, objectives and tasks are represented in the form of formal specifications. Based on these specifications, plans of action are automatically generated. Depending on the application at hand, these plans either control the system, i.e. they are automatically executed, or they are used to suggest and explain courses of action to the user [4]. In particular in the latter case the generated plans respect the individual user's preferences as filed in the user model of the knowledge base. However, external events or unexpected user behavior can invalidate a plan at execution time. One way to cope with those failures is to simply restart planning based on the current situation. This procedure might end up with a completely different action strategy, even though some unexecuted parts of the original plan might not be affected by the failure. In order to prevent the user from getting confused and dissatisfied with the way the system acts, failed plans are carefully repaired: invalidated parts are replaced without touching the unaffected ones [3]. But still, even having to follow a repaired plan in most cases implies a change of the action strategy.

As a change of strategy, in general, is an unavoidable element of the dialog between a *Companion*-system and its user, we investigate its neurophysiological foundations in biological systems. We use a suitably designed animal model, which is sufficiently complex to include relevant aspects of strategy change during subject-computer interactions and at the same time sufficiently simple to allow detailed neurophysiological analyses. Experiments showed how reinforcement-evaluating brain structures contribute to a change of the behavioral strategy [12]. These neurobiological findings entered into a declarative model that serves to estimate how difficult the management of a particular strategy change would be for a certain individual [17].

Research Area B investigates the cognitive abilities that determine the design of the dialog and the interaction between a human user and a technical system. Humans interact with their environment in many various ways and, in doing so, they use almost all of the senses, cognitive abilities, and motor skills available to them. Accordingly, a *Companion*-system, as a peer communication and interaction partner to the human, is able to interact with its users through different modalities and a variety of input and output devices [9,11]. Modalities and media are selected according to the current situation and the individual user model that indicates the user's interaction preferences, thereby addressing the *Companion*-characteristics of individuality and adaptability. In order to show in addition availability as well as cooperativeness it is to be guaranteed, among others, that the system reacts quickly to the user's input. In a functional imaging study, we observed that an unexpected delay of feedback by only 500 ms has an equally strong effect on brain activation as a complete omission of feedback. This suggests that additional neural resources are needed in such potentially irritating situations, which therefore should be avoided [14].

In general, the interaction between a user and a *Companion*-system can be understood as a dialogue, as it is made up of a sequence of consecutive interaction steps. This cumulative interaction structure forms the basis for the determination of user intentions by the *Companion*-system. In order to enable an effective and constructive dialog, the system is not only able to recognize the current dialog situation, but can choose among various strategies to keep the dialog going. In this context, the *Companion*-characteristic of trustworthiness is of particular importance. One means to show trustworthiness is the ability to conduct explanation dialogs, i.e., a *Companion*-system is able to explain its own behavior and the circumstances that can be considered as a cause [15].

Research Area C deals with the cognitive abilities of perception and recognition. To ensure that the functionality of *Companion*-systems is customized to the individual user, and thus is able to adapt to his or her emotional state and current behavioral disposition, the technology must be able to recognize and appropriately interpret any relevant changes in the environmental conditions as well as the user's state on a continuous basis. Since changes in behavioral disposition and emotion may manifest themselves in various ways, a wide range of parameters are used to recognize them. They comprise prosodic and linguistic characteristics, head and body positioning, facial expressions, gestures and psychobiological data, requiring altogether a concise multimodal interpretation [18]. The environmental conditions of the user and the specific user parameters are captured dynamically, interpreted and subsequently transferred to a total state description in a cascade of recognition and fusion processes. It is essential that the recognition processes include location and time components, take into account the operational context and be based on background information. The latter includes, among other things, typical behaviors and emotional patterns of the individual users. The inclusion of history, background information and operational context allows the processes to be controlled for recognition of the situation, emotional state and disposition, thus producing reliable recognition results.

The conceptualizing of *Companion*-systems must be based on real-world situational aspects and emotional processes in dialogues between humans and computers, and it must make available system elements for realization of these effects. This is achieved through investigation and provision of decision-relevant and actionable corpora within the Centre covering non-linguistic, human behaviors, which are induced by a natural language dialog with delay of the commands, non-execution of the command, incorrect speech recognition, offer of technical assistance, lack of technical assistance, and request for termination and positive feedback [20]. The experiments are designed in a way that many aspects of user companion interaction that are relevant in mundane situations of planning, re-planning and strategy change (e.g. conflicting goals, time pressure, ...) are experienced by the subjects, with huge number and quality of recorded channels, additional data from psychological questionnaires and semi-structured interviews [7]. Wizard of Oz techniques as well as fully or semi-automated interactions have been employed, leading to general insights in the design and annotation of emotional corpora for real-world human-computer-interaction [13].

3 Application Perspectives

The SFB/TRR 62 has taken to apply the investigated principles of *Companion*-technology to various applications. *Companion*-technology-based assistive systems with mobile augmented reality have been realized in an automotive setting. Here touch-free hand gesture recognition [10] is used for the acknowledgement and selection of workflow processes in automobile production, leaving the worker undisturbed in the assembly process. A situation-specific representation of information is achieved by head mounted displays, which represent causalities using a state machine with complex restrictions. Worker preferences for interaction were surveyed to improve manageability.

In another scenario, emotion-detection-controlled support of high-qualitative dialogues in call centers were investigated on a large scale and under real-world conditions with inbound telephone conversations of a large energy supplier. The aim here is early detection of adverse dialogue progress from emotional cues, and counteracting by real-time notification of the call center agent. A total of 93 hours of telephone dialogues was recorded, annotated and analyzed, enabling development and rollout of a prototype software for agent support [19].

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Susanne Biundo is a professor of Computer Science at Ulm University and the Director of the DFG-funded Transregional Collaborative Research Centre *Companion-Technology for Cognitive Technical Systems* SFB/TRR 62. She led the *European Network of Excellence in AI Planning* and acted as the Co-chair of various international AI conferences including the most recent *1st International Symposium on Companion-Technology* (ISCT 2015). Her research interests are in AI Planning, Automated Reasoning, Knowledge Modeling, and Cognitive Systems.

Andreas Wendemuth is a professor for Cognitive Systems at the Otto-von-Guericke-University Magdeburg. As Deputy Director of the SFB/TRR 62 he coordinates the activities at the site Magdeburg and the overall technical activities of the SFB. His research interests lie in the areas of automatic language processing, situated emotion detection, automated classifications, and cognitive technical systems. He is founding member and on the Board of Directors of the Center for Behavioral Brain Sciences, Magdeburg.