SOLO: A COGNITIVE ORTHOSIS

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Abstract

Solo is a cognitive assistive device which provides support in remembering when to perform tasks, executing the steps in a task, and recovering from unexpected events. The system includes an interface for clients to receive reminders, an interface for caregivers to enter information about the client's scheduled tasks, and a Cognition Manager which provides reminders and task guidance at appropriate times.

Introduction

A number of reports suggest that external cueing systems which call themselves to the user's attention can assist people with cognitive impairments in the performance of activities of daily living (ADLs) [1-7]. One drawback to most external memory aids is that they are designed to present scheduled, one-step activities (e.g. "At 5:00, cook dinner"). However, many activities are not limited to one step. For example, cooking dinner will typically involve a number of steps related to preparing kitchen utensils and following a recipe. Persons with cognitive impairments may experience difficulty with multi-step activities for a variety of reasons. Many activities require sequential processing (e.g., add flour and butter before adding water; heat the oven before putting in the chicken) or prospective memory (e.g., take the chicken out of the oven on time) [8]. In order to facilitate performance of such complex activities, a system is required that is able to provide messages in sequence, can respond to client feedback about the status of each step, and can provide branching to alternate steps based on that feedback.

We are developing a cognitive orthosis, called Solo, to aid cognitively impaired clients and their caregivers in managing their daily activities. Solo will allow a caregiver to organize a client's activities into a daily schedule and will instruct the client in how to perform activities in the schedule. Solo has four components:

- An **Activity Assistant** that runs on a hand-held device with wireless communication capabilities (e.g., web-enabled PDA, cell phone, two-way pager, ultralight PC). The Activity Assistant will lead a client through his or her daily schedule and will assist the client in following detailed instructions to accomplish activities on this schedule.
- A **Design Assistant** that allows a caregiver to define the steps within an activity and to create a schedule consisting of multiple activities.
- A **Cognition Manager** that is responsible for (1) building a client schedule based on information supplied by the caregiver and for (2) monitoring and updating the instructions presented to the client (via the Activity Assistant) based on the schedule provided by the caregiver and the feedback provided by the client during activity execution. An *Activity Planner,* based on the Adversarial Planner [9], will manage the client's schedule, while an *Instruction Sequencer,* based on RAPS [10], will manage the sequence of steps within a task.
- An **Information Server** that hosts a database containing all the information about the client's schedule and activity instructions, and that runs the software necessary to interact with the Activity Assistant and the Design Assistant.

Solo provides a number of innovative features not offered by commercially-available scheduling or wireless cueing systems. First, it provides for management and monitoring of client performance by the caregiver. Second, the system provides two-way interaction between the client and the system, allowing the client to provide feedback about whether or not an activity step has been completed, or whether additional time or instructions are needed. Third, instruction sets designed with the Design Assistant can include branching from one instruction to another, based on client responses, in addition to simple sequential presentation of instructions. Using this feature, a caregiver who is familiar with a client's clinically observed difficulties will be able to incorporate contingency planning in the instruction set so that clients can avoid (or recover more effectively from) errors.

Related Research

There are several systems under development that seek to provide support with planning and problem solving as well as prospective memory. The Planning and Execution Assistant and Training System (PEAT, Attention Control Systems Inc, Mountain View, CA) is a commercially-available system that uses artificial intelligence to automatically generate daily plans and re-plans in response to unexpected events. Using manually entered appointments in conjunction with a library of ADL scripts, PEAT generates the best plan to complete all of the required steps, and assists with plan execution by using visual and auditory cues. The user provides input to the device when a step has been completed, or if more time is required to complete the step [11].

Devices like PEAT require input from the user to provide feedback to the device (e.g. pushing a button after the cued tasks have been completed). However, a person with a cognitive disability may not remember what step they had just been asked to perform and/or the need to indicate that the step had been completed. Even for those people capable of providing this input, the additional requirement increases the cognitive load on a person, and can result in the user becoming further frustrated and agitated. In addition, users who lack initiation and planning skills may not be able to actively retrieve the messages or information stored in these devices [12].

This could be remedied if a device was able to recognize the user's context; that is, his or her physical and social environment. If the device was aware of the user's location, for example, it could give reminders relevant to that location. Information about the user's environment might also provide cues to the device on what reminders might be important (handwashing if the person is in the washroom) or unnecessary (a reminder to go to the cafeteria if the person is already there). Social cues might allow the device to know when a reminder would be inappropriate; such as when the user is talking with another person and might not want to be interrupted.

Context-sensitive reminding requires monitoring a person's environment and activities. Several researchers have used sensors and switches attached to various objects in the user's environment to detect which task the person is completing. If these devices detect an unanticipated change in the person's normal routine, then external assistance is called. Trials with several subjects indicate that this method of tracking a person's actions is a good way of monitoring the state of a person's health and independence (e.g., [13]).

An example of a system that provides context-sensitive assistance is the COACH (Cognitive Orthosis for Assisting aCtivities in the Home) [14], an adaptable device to help people with dementia complete handwashing with less dependence on a caregiver. The COACH used artificial neural networks, plan recognition, and a single video camera connected to a computer to automatically monitor progress and provide pre-recorded verbal prompts. It was able to automatically adapt its cueing strategies according to a user's preferences and past performance of the ADL, and play multiple levels of cue detail [14].

Another system that uses sensors and cues to reason about when to provide reminders is Autominder. Like Solo, Autominder uses an automated planner to schedule and track reminders [15]. Autominder manages single step tasks such as taking medicine, however, while Solo can manage multi-step tasks. This introduces issues not addressed by Autominder, such as allocating adequate time to complete tasks, checking whether required resources (e.g., tools) are available, and rescheduling tasks when circumstances change such that insufficient time is available to complete a task. Additionally, Solo integrates the client's schedule with instructional assistance on how to perform a task, which is not a part of Autominder.

Project ACCESS includes multiple projects related to developing context-aware assisted cognition devices. One system, Opportunity Knocks, uses multiple technologies (cell phone, GPS receiver and wireless modem) to learn a user's typical daily routines (including locations of activities), monitor for variations in the individual's typical day-to-day activities and then decide whether a prompt is necessary if the routine is unexpectedly changed [16]. Related work at Intel [17] seeks to infer a person's intended tasks based on interaction with everyday objects. The objects in the person's environment are outfitted with radio frequency identification (rfID) tags to support this process. The system can then offer reminders appropriate to the user's desired tasks.

Persistent Assistance

Solo is designed to provide persistent daily assistance to cognitively impaired clients. The Cognition Manager and Information Server will execute continuously, serving instructions to the client on demand and reminding the client of scheduled activities. The Design Assistant will execute upon user demand. The Activity Assistant will execute at scheduled times, as tasks become active. For most clients we expect this to result in multiple interaction sessions with the Activity Assistant per day. Due to the unique interaction needs resulting from differing injuries and impairments, this ongoing interaction will necessarily be personalized for each user. We expect most caregivers and clinicians to interact with the Design Assistant at least once a day to update the client's schedule, with occasional additional interaction to add or alter instructions. Key questions that motivated the design of the Solo architecture and are of interest to this workshop include the following:

- How will Solo support both nominal and contingency interaction among the distributed group consisting of client, caregiver, and clinician?
- How can personalized, intelligent assistance support evolution over time? In the case of the

cognitively impaired, these changes can result not only from altered preferences but from altered medical condition.
- How effective do clinicians find the Design Assistant at letting them describe and update tasks for use by clients? This interface for non-programmers results in tasks that are automatically translated into a reactive planning language.

Nominal and Contingency Interaction

During nominal interaction, Solo will support the client by providing a portable view of his or her daily schedule. When it is time for a scheduled activity to be performed, the Cognition Manager will alert the client using a signal customized for the client (e.g., alarm tone or audio file of client speaking) and will display the appropriate instructions for performing the activity. Once the client begins to perform the task, he will be prompted for each step of the task and asked to give feedback when he completes the step. He also can ask for help if an instruction is unclear.

If a step takes significantly longer than expected, the user will be prompted again with an alternative step (i.e., the same step presented differently or an alternative way of performing the same step). If the user still does not indicate he has completed the step, the caregiver can be notified to provide further assistance or the task can be abandoned. All such interaction will be logged for use by the caregiver and clinician in adjusting instructional sequences.

If tasks are abandoned before completion or if a task takes significantly longer than expected, the planner will adjust the client's schedule. When a task is abandoned, it frees up time to do other tasks on the schedule early if constraints permit. When a task runs late, it requires making choices about what planned tasks to delay to another day based on priority information provided by the caregiver or clinician when the schedule is built. When the caregiver or clinician builds the client's next schedule, tasks that were abandoned during the day will be reconsidered for scheduling the next day.

To provide contingency support, Solo integrates deliberative planning with plan repair for activity scheduling with reactive planning for situated instructional assistance with alternative steps. It models tasks as goal states to be achieved. Task failure occurs when a goal state is not achieved by executing the associated instruction. Schedule repair is needed when tasks fail or are delayed.

The architecture of Solo's Cognition Manager resembles the integration between deliberative and reactive planning in 3T [18], a control architecture for mobile robots and crew space systems [19, 20]. In both cases, the deliberative planner passes a goal to the reactive planner. The reactive planner adds a task to its agenda that should accomplish that goal. When the task is removed from the agenda, the reactive planner passes back status information to the deliberative planner indicating whether the task was successful or not. This corresponds to whether the RAP associated with the goal from the planner completed successfully or not. While the 3T approach has been used to track humans performing tasks, specifically astronauts performing procedures [21], the Cognition Manager represents the first use of this approach to provide instructional assistance to humans integrated with task tracking.

It is expected that instructional sequences, including contingency response steps, will be customized to specific clients. This customization results from the variations in the client's environment (e.g., gas or electric stove) as well as personalization to address how a client's impairment manifests itself. Thus, similar to the way it is done today, instructions will be developed for individual clients. We believe, however, there is potential for reuse of instructions by starting with a standard instruction and adjusting it to meet a particular client's needs (e.g., adjust the audio message used to notify the client).

To date we have implemented both the nominal and contingency instructional support using RAPS and are preparing to evaluate it with candidate clients. We have just begun implementation of the software for task scheduling in AP.

Evolution Over Time

We expect the knowledge used to build instructions and schedules to evolve for a particular client in a variety of ways. One type of knowledge evolution occurs when the steps of the instruction must be revised to accommodate changes in the client's environment, such as acquiring a new appliance. Another type of evolution occurs if the client's medical condition changes, requiring adjustment of both how steps are conducted as well as how instructions are presented to the user. Changes in medical condition may also require adding new tasks and eliminating others, which affects the scheduling activity. Additionally, adjustment of instructions can occur as the caregiver or clinician learns more about what techniques are effective for a particular client.

Solo was designed to accommodate such knowledge evolution. The Design Assistant provides an editor for viewing and adjusting both the steps of an instruction as well as the presentation of instructional steps. The Design Assistant can also be used to manage the set of instructions available for a client, including adding and removing tasks.

In addition to allowing a caregiver to edit tasks as needed over time, Solo has features that help the caregiver to know what changes might be necessary. First, Solo logs the client's interaction during daily tasks. This information can be used to determine what tasks were difficult for the client, and which were performed with ease and perhaps did not require reminders. The caregiver or clinician can also identify and revise instructional steps that are not effective for the client. Second, Solo provides a means to call for assistance from a caregiver or clinician. By moving from automated instruction to human assistance, Solo supports learning how to adjust instructions to better support the client.

Initially, Solo will rely on feedback from the user to determine the user's progress through his or her tasks. However, the Solo architecture supports integration of sensor modules which could provide additional information about the user's environment. This sensor data could allow for context-sensitive reminding. In addition to providing immediate information about the status of the user's environment (and therefore whether a reminder is necessary), collecting sensor data could allow the system to learn about the user's tasks. This could support evolution over time in two ways. First, a user may need more reminders as his disability progresses; or may need fewer reminders as he recovers or acquires cognitive skills. Awareness of the user's environment will allow the system to offer reminders intelligently, providing more reminders when avoiding unnecessary and potentially frustrating extra reminders. Second, the addition of sensors could allow for task inference. If the system is able to recognize the user's desired tasks, it will be able to automatically provide appropriate reminders to the current situation. Such an adaptive system could potentially also learn what reminders are most effective based on the user's past performance.

Knowledge Transfer/Task Analysis

As described above, we expect that instructional sequences, including contingency response steps, will be customized for each client. The responsibility for identifying tasks the client wants/needs to do, analyzing each task, and creating instruction sets for each task, is expected to fall on clinicians and caregivers, who may have no programming experience. Hence, the "language" the Design Assistant uses to describe tasks is a critical component of the system. We have developed an XML representation of a client's schedule and tasks. The Design Assistant creates an XML document based on information provided by the clinician or caregiver, and provides the XML document to the Cognition Manager. The Cognition Manager, in turn, interprets the XML document in order to translate it into Lisp code consistent with the Activity Planner and Instruction Sequencer.

Initially, we are using a custom XML structure as our task representation language. However, we expect that the proposed AbleLink Instructional Media Standard (AIMS) [22] will be compatible with Solo. AIMS is under development by AbleLink Technologies, a manufacturer of task guidance software for people with intellectual disabilities. AIMS is intended as a standard task representation language for cognitive assistive technologies and, potentially, mainstream scheduling software. We will be tracking the progress of AIMS and, if appropriate, using it as the task representation language for future versions of Solo.

Current Status

Our current efforts are focused on developing and evaluating the Design Assistant. A major challenge in developing the Design Assistant is providing a simple approach for caregivers to follow to define the steps of an activity. Essentially, breaking an activity into steps for a client is an exercise in task analysis, where the caregiver must identify each individual step of the activity and develop unambiguous instructions that can guide the client through each step. Rather than provide a programming-style interface, we are developing a more graphical approach that allows caregivers to specify each step and the relationship between steps from a display of options.

Concurrent with development of the Design Assistant, we are developing the Cognition Manager's Instruction Sequencer in conjunction with the Activity Assistant. Together, these components will present a series of prompts to a user, corresponding to the steps in a task. These prompts will be presented as dynamically generated HTML. The user can respond to the prompts using the Activity Assistant to indicate progress or difficulty. The Instruction Sequencer will present subsequent steps as the user progresses through the task, or alter the sequence of steps in response to problems.

Usability trials by clinicians familiar with instructional requirements are planned to assess the extent to which the Design Assistant is both functional and usable. Additional trials will assess the effectiveness of the Cognition Manager and Activity Assistant in guiding clients through sample tasks. Results will be used to inform system revisions and guide subsequent enhancements. In addition to formal usability studies, informal usability testing will occur continuously throughout the project. This will include activities such as talking with caregivers and consumers about their needs, getting feedback on screen mock-ups and design ideas, and asking clinicians to use and evaluate the system.

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References

[1] M. Broek, J. Downes, Z. Johnson, B. Dayus, and N. Hilton, "Evaluation of an electronic memory aid in the neuropsychological rehabilitation of prospective memory deficits.," *Brain Injury*, vol. 14, pp. 455-462, 2000.

[2] N. Hersh and L. Treadgold, "Neuropage: The rehabilitation of memory dysfunction by prosthetic memory and cueing," *Neurorehabilitation*, vol. 4, pp. 187-197, 1994.

[3] H. Kim, D. Burke, M. Dowds, and J. George, "Utility of a microcomputer as an external memory aid for a memory-impaired head injury patient during in-patient rehabilitation," *Brain Injury*, vol. 13, pp. 147-150, 1999.

[4] H. Kim, D. Burke, M. Dowds, and G. Parks, "Electronic memory aids for outpatient brain injury: Follow-up findings," *Brain Injury*, vol. 14, pp. 187-196, 2000.

[5] S. Kime, D. Lamb, and H. Wilson, "Use of a comprehensive program of external cueing to enhance procedural memory in a patient with dense amnesia," *Brain Injury*, vol. 10, pp. 17-25, 1995.

[6] N. Kirsch, S. P. Levine, M. Fallon-Krueger, and L. A. Jaros, "The microcomputer as an 'orthotic' device for patients with cognitive deficits," *Journal of Head Trauma Rehabilitation*, vol. 2, pp. 77-86, 1987.

[7] N. L. Kirsch, S. P. Levine, R. Lajiness-O'Neill, and M. Schnyder, "Computer-assisted interactive task guidance: Facilitating the performance of a simulated vocational task," *Journal of Head Trauma Rehabilitation*, vol. 7, pp. 13-25, 1992.

[8] N. Kirsch, M. Shenton, E. Spirl, J. Rowan, R. C. Simpson, D. Schreckenghost, and E. F. LoPresti, "Web-based assistive technology interventions for cognitive impairments after traumatic brain injury: A selective review and two case studies," *Rehabilitation Psychology*, vol. 49, pp. 200-212, 2004.

[9] C. Elsaesser and T. R. MacMillan, "Representation and algorithms for multiagent adversarial planning," MITRE Corporation, Washington, DC, Technical Report MTR-91W000207, 1991.

[10] R. J. Firby, *The RAPS Language Manual*. Chicago, IL: I/Net, Inc., 1999.

[11] R. Levinson, "The planning and execution assistant and trainer (PEAT)," *Journal of Head Trauma Rehabilitation*, vol. 12, pp. 85-91, 1997.

[12] M. B. Friedman, J. Kostraba, K. Henry, and J. Coltallaro, "Hardware description of a portable electronic device," presented at International Conference on Assistive Technology for People with Disabilities (RESNA), 1991.

[13] M. Ogawa, S. Ochiai, K. Shoji, M. Nishihara, and T. Togawa, "An attempt of monitoring daily activities at home," presented at World Congress on Medical Physics and Biomedical Engineering, Chicago, IL, 2000.

[14] A. Mihailidis, G. Fernie, and J. C. Barbenel, "The use of artificial intelligence in the design of an intelligent cognitive orthotic for people with dementia," *Assistive Technology*, vol. 13, pp. 23-39, 2001.

[15] M. E. Pollack, L. Brown, D. Colbry, C. E. McCarthy, C. Orosz, B. Peintner, S. Ramakrishnan, and I. Tsamardinos, "Autominder: An intelligent cognitive orthotic system for people with memory impairment," *Robotics and Autonomous Systems*, vol. 44, pp. 273-282, 2003.

[16] D. J. Patterson, L. Liao, K. Gajos, M. Collier, N. Livic, K. Olson, S. Wang, D. Fox, and H. Kautz, "Opportunity Knocks: A system to provide cognitive assistance with transportation services," presented at International Conference on Ubiquitous Computing, Nottingham, England, 2004.

[17] M. Philipose, K. P. Fishkin, M. Perkowitz, D. J. Patterson, D. Fox, H. Kautz, and D. Hahnel, "Inferring activities from interactions with objects," *Pervasive Computing*, vol. 3, pp. 50-57, 2004.

[18] R. P. Bonasso, R. J. Firby, E. Gat, D. Kortenkamp, D. P. Miller, and M. G. Slack, "Experiences with an architecture for intelligent reactive agents," *Journal of Experimental and Theoretical Artificial Intelligence*, vol. 9, pp. 237-256, 1997.

[19] R. P. Bonasso, D. Kortenkamp, and C. Thronesbery, "Intelligent control of a water recovery system: Three years in the trenches," *AI Magazine*, vol. 24, pp. 19-44, 2003.

[20] D. Schreckenghost, D. Ryan, C. Thronesbery, R. P. Bonasso, and D. Poirot, "Intelligent control of life support systems for space habitats," presented at Conference on Innovative Applications of Artificial Intelligence (IAAI), Madison, WI, 1998.

[21] R. P. Bonasso, D. Kortenkamp, and T. Whitney, "Using a robot control architecture to automate space shuttle operations," presented at Innovative Applications of Artificial Intelligence (IAAI), Providence, Rhode Island, 1997.

[22] A. Technologies, "AbleLink Instructional Media Standard," vol. 2005: AbleLink Technologies, 2004.