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ORIGINAL PAPER

Modeling the progression of Alzheimer's disease for cognitive assistance in smart homes

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Abstract Smart homes provide support to cognitively impaired people (such as those suffering from Alzheimer's disease) so that they can remain at home in an autonomous and safe way. Models of this impaired population should benefit the cognitive assistance's efficiency and responsiveness. This paper presents a way to model and simulate the progression of dementia of the Alzheimer's type by evaluating performance in the execution of an activity of daily living (ADL). This model satisfies three objectives: first, it models an activity of daily living; second, it simulates the progression of the dementia and the errors potentially made by people suffering from it, and, finally, it simulates the support needed by the impaired person. To develop this model, we chose the ACT-R cognitive architecture, which uses symbolic and subsymbolic representations. The simulated results of 100 people suffering from Alzheimer's disease closely resemble the results obtained by 106 people on an occupational assessment (the Kitchen Task Assessment).

Keywords Cognitive assistance · Cognitive modeling · Error simulation · Cognitive architecture · Smart home · Alzheimer's disease

1 Introduction

One of the most difficult challenges our world faces is population ageing. More than 60 countries will have two million or more people aged 65 and over by the year 2030 (Kinsella and Velkoff 2001). A significant number of chronic diseases, especially of the

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Alzheimer's type, will accompany this population trend. According to the progress report on Alzheimer's disease, published in 2005 by the National Institute on Aging—part of the U.S. National Institutes of Health—4.5 million American people currently have the disease, and the prevalence doubles for every 5-year age group beyond age 65. As a result, research on maintaining these people at home, with the help of telemedicine and tele-assistance, has become a public health preoccupation.

Alzheimer's disease is a neurodegenerative illness that causes brain lesions. The disease is characterized by the progressive loss of memory and cognitive functions (Lezak 1995). Mental faculties such as language, judgment or decision-making are affected, causing the person's behavior to change. These disorders have an impact on daily life. Gradually, impaired people lose their autonomy in carrying out daily activities (Riddoch et al. 2002). They become dependant on family or professional caregivers.

It has become important to understand better the cognitive progression of Alzheimer's disease, especially if we consider the prevalence of the disease given by the National Institute on Aging. Cognitive modeling can help document the progression of the disease and predict autonomy at home. Moreover, technologies for maintaining disabled people at home will be required to develop further (Doughty et al. 1996; Tang and Venables 2000; Haigh and Yanco 2002; Rialle et al. 2002). These technologies should be based on a better understanding of the people they seek to assist. Cognitive modeling of the progression of Alzheimer's disease is a first step towards designing a new generation of assistive devices based on cognitive technology.

Thus, this project seeks to model and simulate the progression of Alzheimer's disease based on performance in an activity of daily living (ADL). The first two sections introduce smart homes, cognitive assistance, and challenges in modeling the progression of Alzheimer's disease, especially in respect to the successful completion of an ADL. We describe the ACT-R cognitive architecture upon which we chose to develop the model. The next sections are dedicated to the model itself: we present an overview of the model, and then we describe in detail the design and development of the model using ACT-R. Finally, we present the results of the simulation and we discuss the overall applications of the cognitive assistance model.

2 Smart homes and cognitive assistance

Smart homes seek to overcome the cognitive disorders of people to enhance their autonomy (Pigot et al. 2003; Rialle et al. 2002; Stip and Rialle 2005). Such systems are principally intended for people affected by Alzheimer's disease. These people are dependent on caregivers in their daily lives due to various cognitive deficits, such as planning, attention or memory disorders. For example, distraction or a lack of judgment can lead a person to leave the stove on for a long time, creating a risk of fire or burns. To reduce the burden on relatives and caregivers, smart environments must provide help for the autonomous completion of ADL.

Telemonitoring and cognitive assistance are the two main components of smart homes. Both are intended to detect and prevent abnormal situations: the former by informing caregivers or medical staff, and the latter by providing environmental cues to ensure that tasks are performed safely.

With considerable advances in new technologies, research on health smart homes has seen its perspectives broaden. The domestic environment of people with cognitive impairments can be upgraded using technological devices and then transformed into a smart environment. Information provided by smart sensors and localization tags is processed and analyzed to detect activity performance and hazardous behavior. This step of activity recognition involves properly representing the activity and its environment, including daily living objects, furniture, and all the actors involved in activity completion. The occupant's habits and behavior provide useful additional information for activity detection and recognition (Bauchet and Mayers 2005). When abnormal behavior is detected during ADL performance, impaired people are provided with cognitive assistance. By means of suitable cues from the smart environment, the system interacts with impaired people and helps them complete the problematic ADL (Vergnes et al. 2005). Since people with cognitive impairments are sensitive to changes and disruptions in their environment, cognitive assistance requires fine-tuning. The more the assistance is customized and suited to the deficits in question, the more it will be understood and followed by the resident (Pigot et al. 2005). Hence, cognitive assistance uses a two-step approach: the system first diagnoses the deficit involved in abnormal behavior, and then proposes appropriate assistance (Bauchet et al. 2006).

An essential step towards efficient cognitive assistance is therefore to describe the disorders that impaired people suffer and their impact on ADL performance. Cognitive modeling enables computer models of cognitive processes to be developed. These models can be used to simulate or predict human behavior (Cooper 2002). In other words, cognitive models contribute to a better understanding of the mechanisms of mental activity. In addition, with cognitive models it is possible to generate the behavior of impaired people. Applied to smart homes and cognitive assistance, they help understand and describe the cognitive processes involved in ADL execution, as well as the disorders affecting these cognitive processes.

Up till now, cognitive orthotics—computer-based assistive devices designed to help individuals with ADL tasks—offer various types of assistance, from pager to agenda-organizer. While some of these cognitive orthotics include context awareness, none of them include cognitive models (Lo Presti et al. 2004). Levinson (1997) has indicated the need to include cognitive models in assistive devices. PEAT (Levinson 1997) is a scheduling tool designed for people with brain injuries that assists them with ADL planning and execution. Levinson suggests including in this device a computer model of the mental functions involved in the successful completion of ADL. This computer model would simulate the impairment of these mental functions and provide compensatory support for impaired functions. Unfortunately, at this point only artificial intelligence planning has been implemented in PEAT.

In summary, cognitive assistance systems can be improved thanks to deep models of the cognitive mechanisms involved in ADL completion. Simulating typical behavior of impaired people serves to improve problem detection and supports the selection of appropriate forms of assistance by predicting the reactions of impaired people in particular situations.

3 Theoretical background

Cognitive modeling is a vast field involving a large research community. Different approaches are used in cognitive modeling, depending on how researchers choose to represent information. In this section we provide a brief overview of existing approaches and explain the framework we used to develop our model.

3.1 Cognitive modeling

The two principal approaches to cognitive modeling are connectionist models and cognitive architectures. In our context, we are interested in modeling the disorders of different processes of cognition. Cognitive architectures have been chosen over connectionist models due to their lack of transparency at the level of processes.

3.1.1 Cognitive architectures

Cognitive architectures are unified theories of human brain functioning. The term "cognitive architecture" refers to a particular set of structures, tools, techniques and methods that can support the design and construction of models of cognition (Newell 1990; Anderson 1993; Meyer and Kieras 1997; Gray 2007). This approach considers that cognition can be modeled as a set of functional subsystems that interact together. Cognitive architectures provide symbolic representations of cognitive processes, based on the production system paradigm. ACT-R (Anderson and Lebiere 1998) is one of the frameworks most frequently used to develop and simulate specific models. It has been successfully used to create models in fields such as memory research and problem solving (for example, the famous Tower of Hanoi). ACT-R is a complete computational architecture that embodies a general theory of cognition. The advantage of ACT-R for our work resides in the fact that errors characteristic of human performance can be modeled thanks to a subsymbolic system that is an extension of the production system (Lebiere et al. 1994).

3.1.2 Challenges in using cognitive modeling

The context of smart homes and cognitive assistance raises an interesting problem in regards to the modeling of cognition. Indeed, these new technologies need models that are able to simulate disorders in cognitive processes that lead to the generation of mistaken behavior during ADL completion. Traditionally, models designed using ACT-R have been oriented towards psychological behavior observed during the solving of logical or mathematical problems. These models have also focused on specific mechanisms of cognition, such as perception and attention, learning and memory, or language processing. Only a few models predict daily living behavior, such as the use of cellular phones while driving (Salvucci 2002). The first important challenge of this project is to build a model of cognitive processes that generates behavior involved in ADL completion. The second challenge is related to the fact that Alzheimer's disease affects cognitive processes, leading to hazardous behavior. Most existing models simulate the normal functioning of mechanisms, whereas our model aims to reproduce cognitive disorders.

3.2 The ACT-R cognitive architecture

ACT-R (Anderson and Lebiere 1998; Anderson et al. 2004) is a cognitive architecture derived from the ACT theory developed by John R. Anderson. This human cognition theory is strongly based on cognitive psychology experiments. It can be used to develop models for different cognitive tasks, such as problem solving and decision-making, or even learning. ACT-R generates predictive models for given tasks that can be tested by comparing their results with the results of people performing the same tasks. Comparisons are made on the basis of psychological criteria such as "accuracy of the task" or "time to perform the task."

ACT-R is based on multiple modules, each dedicated to a different type of information processing. The modules communicate by means of buffers, and coordination between the modules is managed by a unique production system. The latter detects information patterns and fires the most appropriate production rule. The buffers are updated as a result of performing an action, perceiving new elements, retrieving an element in memory, or modifying a goal. ACT-R can be seen as a hybrid system with symbolic aspects—such as knowledge representations and a production system—and subsymbolic aspects, represented by mathematical equations that control many of the symbolic processes.

The ACT-R theory distinguishes two sorts of knowledge: procedural knowledge (skills), and declarative knowledge (facts). This differentiation between two types of knowledge leads to two systems of long-term memory.

Procedural memory consists of a set of productions that coordinate information retrieval from declarative memory and from the environment in order to perform actions that will change the current goal state. Each production follows the pattern "IF <condition> THEN <action>," and is associated with a subsymbolic value called "utility." Utility is calculated based on the past use of a particular production and reflects its contribution value in terms of achieving the current goal. The current goal is stored in the goal module, which maintains relevant information in the focus of attention. The current goal operates like a filter that selects the productions relevant to the current task, or, in other words, those that match the condition pattern. When several rules match the condition pattern at the same time, a conflict situation arises. The conflict–resolution mechanism selects the production with the highest utility value. Phenomena such as choosing between different strategies can be modeled using this mechanism (Jongman and Taatgen 1999).

Information stored in declarative memory promotes personal and cultural coherence over the long term. In ACT-R, declarative memory includes both semantic and episodic memories. It is based on a network of interconnected nodes, or chunks. Each chunk is associated with a subsymbolic value called an "activation level," which controls its access in memory. In the pattern-matching phase, the system retrieves the element with the highest activation value. In other words, the capacity to recall information depends on the activation of this information in memory and on parameters that define this activation. Errors in recall are reproduced using a retrieval mechanism controlled by means of subsymbolic values (Lebiere et al. 1994).

Contrary to long-term memory, short-term memory is limited in time and capacity and is used to store temporary information. An extension to the short-term memory, the working memory, enables cognitive processing of elements that are temporarily stored in this memory. According to Baddeley (1990), working memory provides a system that can select, maintain and process information while a person is executing different cognitive tasks, such as comprehension, reasoning or problem solving. In ACT-R, working memory does not have a concrete representation like it usually does in other production systems. Rather, the concept of capacity limitations is supported by the concept of activation (Anderson et al. 1996). Working memory can be equated with the portion of declarative memory situated above the threshold of activation (Anderson et al. 1996).

4 Overview of the model

This paper aims to build a computational model of the cognitive processes involved in ADL. As described in the previous section, ACT-R has been chosen as the theoretical framework. To be as coherent as possible, the model must be based on psychological observations. We decided to build our model on observations made during a particular occupational therapy assessment. In this section, we specify the objectives and the characteristics of the model.

4.1 Objectives

This project aims to simulate the progression of Alzheimer's disease during ADL performance. As indicated in the previous section, most of the models developed with ACT-R focus on reproducing behavior observed in traditional psychological assessments. Our first objective is to identify the cognitive processes involved in the completion of daily living tasks, and then to simulate the completion of an ADL using the ACT-R cognitive architecture.

ADL performance is evaluated by assessing the errors committed by the elderly. Errors are characterized by their type and seriousness. With Alzheimer's disease, the type of error is essentially dependent on the type of cognitive disorder and can be defined in terms of the loss of memory and organizational abilities. The seriousness of an error can be measured by evaluating the level of support needed to overcome it. The second objective is therefore to represent errors in terms of both the type of cognitive disorder at the root of the error and the support needed when the error occurs.

When we decided to use the ACT-R cognitive architecture to develop the model, we chose to base our study on mistaken behavior during the Kitchen Task Assessment (KTA), an assessment developed by occupational therapists (Baum and Edwards 1993; Tyrrell and Couturier 2003). This functional test brings together the completion of a simple ADL, the detection of unusual behavior, and the assessment of the level of cognitive support required. The KTA was designed for people with senile dementia of the Alzheimer's type, to record their performance over the course of the disease.

Occupational therapists evaluate performance on a task based on motor or cognitive skills. For example, the Assessment of Motor and Process Skills (AMPS) (Fisher 1991) measures skills such as posture, mobility and coordination, as well as attentional, organizational and adaptive capabilities. In opposition, the KTA provides a functional measure based on the evaluation of cognitive processes that affect task performance. It differs from the AMPS in that it focuses its evaluation on processing the skills of initiation, organization, inclusion of all steps, sequencing, safety and judgment, and completion. These skills are assessed while the task is being performed.

The KTA measure is based on the level of assistance required to successfully complete the target task. The subject's performance on a specific cooking activity is evaluated according to six criteria (cf. Table 1). For each criterion, the level of support provided by the test administrator is scored from 0 to 3 (0 for a subject who performs without any help, 1 for a subject who requires a verbal cue, 2 for a subject who requires physical assistance, and 3 for a subject totally unable to perform that section of the test). All subjects who completed the KTA were able to respond to verbal or physical assistance. The assessment is not administrated if a subject had verbal comprehension problems.

Alzheimer's disease is characterized by its irreversible deterioration of cognitive abilities. Depending on the evaluation scale, its progression is divided into either seven stages (Reisberg Scale (Reisberg et al. 1982)) or four stages (Clinical Dementia Rating (CDR) (Berg 1998). As the disease progresses, the person suffering from Alzheimer's disease commits errors more often and the support required becomes increasingly substantial. The KTA reveals a correlation between the score obtained on the test and the stage of the disease. The scores obtained during the study demonstrate that subjects with questionable dementia (CDR of 0.5) are quite independent, subjects in the mild stage of the disease (CDR of 1) require verbal cues to successfully complete the cooking task, whereas subjects suffering from moderate

Table 1 Definition of criteria for the KTA evaluation (Baum and Edwards 1993)

Criterion name	Definition
Initiation	Can the person begin the task?
Organization	Can the person gather the items necessary to perform the task?
Performance of all steps	Can the person perform all the steps necessary to complete the task?
Sequencing	Can the person sequence the activities that make it possible to complete the task?
Judgment and safety	Is the person safe in performing the task?
Completion	Does the person know when he or she is finished with the task?

Table 2 Normal progression of the cooking activity

1. Initiate the task	4. Cook
2. Measure	a) Turn on the stove
a) Take the milk out of the refrigerator	b) Place the saucepan on the stove
b) Pick up the measuring cup	c) Stir until the mixture is hot
c) Measure the right quantity of milk	d) Turn off the stove
3. Stir	5. Pour
a) Pour the measured milk into the saucepan	a) Pick up the saucepan
b) Pour the pudding mix into the saucepan	b) Pour the mixture into the four dishes
c) Pick up the wooden spoon	c) Pick up the spatula
d) Stir the ingredients	d) Scrape out the saucepan
	6. Clean up (end of task)

and severe dementia (CDR of 2 or 3) require physical assistance. The third objective of this study is to predict ADL performance based on the stage of Alzheimer's disease.

4.2 The cooking activity

The specific ADL selected for the KTA was the preparation of a pudding from a commercial package. The recipe has four major steps: measure the ingredients, stir them, cook the mixture on the stove and pour the hot mixture into four dishes. Each stage of the recipe was composed of several subtasks that had to be completed, as described in Table 2.

The methodology used to build the model follows the three objectives listed previously. First, we modeled a healthy person completing the cooking task. We focused our attention on the cognitive processes used to successfully complete the task. The KTA was designed to measure the cognitive aspects of performance. We therefore purposely chose not to model mechanisms linked to the perceptual and motor modules offered by ACT-R. Secondly, we incorporated into this model the type of errors observed during the KTA. The subsymbolic system included in ACT-R provides a means to model cognitive phenomena such as memory loss. Thirdly, we represented the progression of the dementia as the increase of the number of errors committed over the course of the disease's progression. Finally, we simulated the support provided by the test administrator to estimate the seriousness of these errors. ADL performance in the model was then evaluated in terms of the type and the seriousness of the errors.

5 Design and implementation of the model

In designing the model, we first represented the cooking activity by specifying both its declarative and procedural elements. We then coded the cognitive errors frequently observed during the KTA. Next, we explained how to simulate the drop in performance as a result of the progression of Alzheimer's disease. Finally, we provided an overview of how to model interaction between the subject and the test administrator.

5.1 Representation of the cooking activity

The hierarchical structure of the recipe lends itself to the use of a model where the different stages are represented as specific goals. This kind of model, called *goal-oriented*, is used to simulate problems where a goal may be suspended or set aside temporarily. According to Altmann and Trafton (2002), the different mechanisms related to interruptions, for example resuming a goal that has been suspended after an interruption, involve an important process of managing goals. Goal oriented systems are then best suited to model scenarios such as being interrupted in the middle of a task, or turning one's attention to some other. The goal-oriented structure of ACT-R enables the sequence of the stages to be modeled. Hence, the six subtasks in the recipe are represented by six specific goals in the model. The following two sections describe how declarative and procedural memories are used to model the activity.

5.1.1 Declarative memory and working memory

In the KTA, the task to perform is a cooking activity with which all the subjects are familiar. At the beginning of the experiment, declarative memory holds knowledge about ingredients and utensils already known by the subjects. For example, the milk and the pudding powder used in the recipe are classified as ingredients, while the wooden spoon and the pan are classified as utensils. New elements, such as the measured milk or the mixture, are added during the process by means of the working memory.

In ACT-R, instead of being represented as a separate module, working memory is composed of the portion of declarative knowledge that can be retrieved. Only information with an activation level superior to a particular threshold is accessible. Each element in declarative memory is associated with an activation value, defined according to its relevance to the current goal. A certain amount of activation, called source activation, flows from the current goal to related elements to maintain them in a more active state (Daily et al. 2001). This mechanism acts like a semantic network that retains the information needed to accomplish a specific task. With working memory modeled in this way, the clarity and accessibility of pertinent information depend directly on the complexity of the task. The hierarchical organization of goals that was chosen for this model, which sees the cooking activity divided into six subtasks, reduces task complexity since only a few elements are relevant to the current goal.

5.1.2 Procedural memory

Each of the recipe's basic actions has been coded as a production rule, stored in procedural memory. In this paper, only the two most important coding mechanisms have been detailed (cf. Table 3).

The first one refers to the retrieval of an element. During completion of an ADL, when subjects want to retrieve an ingredient or a utensil, they first access a representation of the object in their memory, and then search for its location in their environment, identify it and

Table 3 Rules in procedural memory

(a.1) RETRIEVE_MILK IF the goal is to measure and the state is "ready to proceed" THEN set the state to find the milk and retrieve the milk	(a.2) RETRIEVE_MEASURING_CUP IF the goal is to measure and the state is to find the milk and the milk is retrieved without failure THEN set the state to find the measuring cup and retrieve the measuring cup
(b) TRANSITION_0_1 IF the goal is to initiate and the state is complete THEN create a new goal to measure the milk using the measuring cup	

finally pick it up. In this model, the perceptual and motor parts of the action of retrieving have not been simulated. It is assumed that accessing the representation in memory automatically simulates the action of retrieving and the cognitive errors associated with that action. In ACT-R, this corresponds to a retrieval request in declarative memory (rules a.1 and a.2 in Table 3). If the retrieval request succeeds, the object is identified as having been retrieved cognitively and physically.

The second mechanism is used to model planning abilities. When a subject has completed a particular stage of the recipe, that person has to plan which sequence to execute next. In this model, this is represented by a transition system where the current goal is changed. The production rule leads to the creation of the following goal (rule b in Table 3).

5.2 Modeling cognitive errors

Alzheimer's disease is characterized by the impairment of cognitive functions and increasingly poorer ADL performance. Indeed, patients with senile dementia who are affected by these impairments commit errors while executing daily living tasks. In the KTA, these errors have to be classified and evaluated. To grade the subjects' performance, the assessment uses six criteria: initiation, organization, performance of all steps, sequencing, judgment and safety, and completion (cf. Table 1). Each criterion regroups various typical errors. The errors represented in our model are those described in the KTA.

In the ACT-R framework, these errors can be classified into three different groups: omission errors, commission errors and behavior errors. In the following sections, we present in detail how these three categories of errors have been modeled using ACT-R. As the disease progresses, the number of errors increases. The impact of the disease's progression will be outlined in Sect. 5.3.

5.2.1 Modeling omission and commission errors

Evaluation scales, such as the Reisberg scale or the CDR, highlight different types of abnormal behavior depending on the stage of the disease: both scales identify memory impairment as one such behavior that afflicts patients from the early stages of the disease. Working memory and primary memory (or recent-facts memory) are the most frequently impaired mechanisms (Lezak 1995). Working memory retains the information needed during the execution of cognitive tasks and it has a direct impact on task performance. During ADL completion, a deterioration of working memory leads to the loss of certain elements from the recipe. Indeed, in the KTA, subjects can forget ingredients or utensils. This is one type of error observed, called an omission error. A second sort of error is related to the use of utensils. Some subjects use tools incorrectly, confusing two utensils for example. This kind of error is called a commission error. These first two classes of errors are modeled in ACT-R by calculating the activation of elements contained in declarative memory. Thanks to its hybrid architecture, with symbolic and subsymbolic aspects, ACT-R can model human errors made while solving complex cognitive tasks (Lebiere et al. 1994). Difficulties in retrieving elements in memory are due to several factors that have been taken into account in the calculation of activation, using the following equation:

Total activation of a chunk in ACT-R:

$$\boldsymbol{A}_i = \boldsymbol{B}_i + \sum_{j=1}^{n} \frac{W}{n} \boldsymbol{S}_{ji} + \sum_{k} \boldsymbol{P}_k \boldsymbol{M}_{ki} + \boldsymbol{\varepsilon} \tag{1}$$

where A_i: total activation of chunk i, B_i: base-level activation (constant in this model), W: source activation, n: number of slots filled in the goal chunk, S_{ji}: strengths of association (constant in this model), k: slots of chunk i, P_k: partial matching scale, M_{ki}: partial matching similarity, ε: transitory noise, generated and added every time that there is a retrieval.

Each element, or *chunk*, has a base-level activation (B_i) that reflects the effect of practice and forgetting. The activation level increases when a node is accessed and decreases as time passes without further stimulation (Daily et al. 2001). This decay of base-level activation is computed by one of the ACT-R's global parameters. In this model, this parameter value has been let at its default value, which means that the value of term B_i is constant. The second term in Eq. 1 defines the semantic network, also called source activation spreading. The strengths of association remain constant throughout the model. The third term in Eq. 1 defines partial matching. The activation of elements is adjusted based on the similarity between the chunks i and the desired chunk k (M_{ki}). A matching scale (P_k) determines the weight given to the similarity between the two chunks. Finally, Gaussian noise (ε) is added to the chunk activation to render the system less deterministic.

Omission errors refer to the subjects' incapacity to recall certain elements. These errors are evaluated under the "organization" criterion, which deals with the retrieval of ingredients and the manipulation of utensils. Omission errors can be made throughout the task process, at each stage of the recipe. When subjects want to retrieve an ingredient or a utensil, they first access its representation in memory. If this element is not accessible, this is classified as an omission or "forgetting" error according to ACT-R theory. In ACT-R, a chunk can be retrieved only if its level of activation is over a parameterizable latency threshold. Omission errors occur when a chunk cannot gather enough activation to be retrieved above the fixed threshold value (Lebiere et al. 1994).

Confusion errors, also called *commission errors*, occur when a subject makes a mistake by picking up one utensil instead of another. As with omission errors, commission errors are evaluated under the "organization" criterion and are present throughout the task process, at each stage of the recipe. Within the ACT-R framework, allowing imperfect matching in the production system can account for errors of commission (Lebiere et al. 1994). This mechanism permits the retrieval of a chunk that only partially matches the current pattern (instead of the correct chunk). The similarity value (M_{ki}) in ACT-R makes it possible to specify elements that are likely to be confused.

5.2.2 Modeling behavior errors

Aside from errors due to memory problems, such as omission errors or commission errors, the KTA includes five criteria for evaluating certain behavior errors. Sometimes patients have difficulty initiating a task. The "initiation" criterion evaluates if the subject is able to correctly begin the task. The "performance of all steps" criterion evaluates the subject's capacity to perform all the different subtasks of the recipe. The "sequencing" criterion determines how the patient organizes the stages of the recipe. In Alzheimer's disease, disruption in planning is frequent, and can lead to patients having difficulty ordering the subtasks they must perform. The errors belonging to the "judgment and safety" criterion may occur in the "cook" subtask or in the "pour" subtask. The "judgment" aspect is verified in the "cook" stage when the subject uses the stove (especially when it comes to turning it off), whereas the "safety" aspect is verified when the subject handles the hot mixture. Finally, the "completion" criterion illustrates the problem of perseverance that affects people with dementia of the Alzheimer's type. These people will keep doing chores, without noticing that the task is over. Examples of perseverance errors include subjects continuing to scrape the pan or waiting for the mixture to heat up, when everything is already all set.

As with declarative memory, ACT-R provides a subsymbolic system that influences the selection of production rules in procedural memory. Each production is associated with a subsymbolic value, called "utility." The utility of a production is expressed by the following equation:

Utility of a production in ACT-R:

$$\boldsymbol{U}_i = \boldsymbol{P}_i \boldsymbol{G} - \boldsymbol{C}_i + \boldsymbol{\varepsilon} \tag{2}$$

where P_i: Expected probability that production i firing will lead to a successful completion of the current goal, G: Value of the goal, measured in time, C_i: Expected cost of achieving that goal, measured in time, ε: Transitory noise.

A conflict situation arises when several rules satisfy the same conditions. A conflict-resolution mechanism, based on these utility values, is used to choose between two rules satisfying the same conditions. The production rule with the highest utility is fired by the production system.

Behavior errors can be seen as poor choices among different strategies (Jongman and Taatgen 1999). When faced with a particular situation, subjects adopt different types of behavior and each type of behavior can be seen as a strategy. These strategies are implemented in procedural memory by means of different rules that can be applied to a particular situation. The modeling of behavior errors in ACT-R is therefore done by creating a conflict situation between a rule controlling normal behavior and a rule controlling an incorrect action. If the system fires a production leading to the wrong action, the model reproduces this error. Table 4 presents two conflict situations, one concerning a problem of subtask sequencing and the other a problem of safety. The errors leading to a wrong action are respectively implemented by (a.2) and (b.2) rules. For example, if the (a.2) rule is fired instead of the (a.1) rule, a sequencing error occurs.

In this model, rules leading to wrong behavior have been elaborated based on typical errors observed during the KTA. For example, a frequently made error was to turn on the stove before starting. The (a.2) rule reproduces this sequencing error and is in direct conflict with the (a.1) rule leading to the first step of the recipe. Utility values associated with incorrect rules are linked to the probability of these rules being triggered. Assuming that people with Alzheimer's disease make behavior errors, the probability of triggering incorrect rules is higher than for healthy persons.

Table 4 Examples of conflict situations

(a.1) TRANSITION_0_1 IF the goal is to initiate and the state is complete THEN create a new goal to measure the milk using the measuring cup	(a.2) TRANSITION_0_1_ERROR1 IF the goal is to initiate and the state is complete THEN create a new goal to light the stove
(b.1) TURN_OFF_STOVE IF the goal is to cook and the state is to achieve the task THEN turn off the stove and set the state to complete	(b.2) COMPLETE_COOK_STAGE IF the goal is to cook and the state is to achieve the task THEN set the state to complete (without turning off the stove)

(a) Sequencing problem, (b) Safety problem

5.3 Progression of the disease

Cognitive deficits increase as Alzheimer's disease progresses. Hence, ADL performance decreases as the dementia develops. In other words, errors in ADL execution occur at a higher rate with severe dementia.

This progression of the disease is modeled in ACT-R through changes in the subsymbolic parameters that model the level of cognitive abilities.

5.3.1 Modeling omission errors

As outlined previously, Alzheimer patients suffer from a variety of memory problems, especially with regard to working memory and the retrieval of elements in memory (Lezak 1995). In ACT-R, omission errors are linked to the threshold value and source activation spreading (Lebiere et al. 1994). Source activation spreading constitutes the semantic network, which is related to the notion of working memory.

In ACT-R, there is a limitation on total source activation (W in Eq. 1) and this limitation represents the limited capacity of working memory (Anderson et al. 1996). This limit has been used to model individual differences in working memory capacity, represented by different values of W (Lovett et al. 1999). Thus, the increase in omission errors in Alzheimer's disease is modeled by the variation in the total source activation (W) value. The value of W directly influences the accessibility of elements in declarative memory through the spreading effect. Since the value of the threshold is constant for each subtask, the chunks that do not receive enough activation will not be retrieved, provoking omission errors. In other words, by decreasing the value of W, we increase the amount of errors. In our model, the value of the parameter controlling the total source activation (W) decreases from one CDR stage to the next, going from 1.0 (default value for ACT-R models) for a healthy subject to 0.6 for a subject with severe dementia.

5.3.2 Modeling commission errors

In addition to working memory problems, Alzheimer patients do not discriminate well between target items and distractors (Lezak 1995). As a result, in carrying out activities of daily living, patients may use inappropriate elements to complete a task. Such is the case in the KTA when subjects use inappropriate utensils to make the pudding.

As described in the previous section, commission errors are modeled in ACT-R through the partial matching system. A parameterizable scale, called the mismatch penalty, makes it possible to control the importance given to partial matching. The higher the mismatch penalty, the more the similarity or the difference between two chunks is emphasized. In such cases, the likelihood of elements being confused is heightened. We have therefore modeled the decrease in performance caused by Alzheimer's disease by increasing the value of the partial matching scale P_k. The number of commission errors increases as a result. Chunks that are relevant to the completion of a particular stage of the recipe receive source activation from elements currently in the focus of attention. The value of the partial matching scale has been computed to counterbalance the level of activation and permit the retrieval of a "distractor" element instead of the expected element. To compute the P_k value, the number of active slots in the current goal have to be taken into account (in a similar manner as for the spreading of source activation W/n). Thus, the value of the parameter controlling P_k increases from 2.0/n for healthy subjects, to 4.45/n for subjects with severe dementia, where "n" is the number of active slots in the goal.

5.3.3 Modeling behavior errors

Behavior errors are modeled through the resolution of conflict situations. A production leading to abnormal behavior (an inappropriate production (I:P.)) clashes with the production leading to the expected behavior (expected production (E.P.)). When modeling an error, if the inappropriate production is to be triggered by the production system, the probability that the inappropriate production will achieve the current goal (P_i term of Eq. 2) has to be greater than the probability that the expected production will do so. Hence, as the disease progresses, the probability of the inappropriate production (I.P.) achieving the goal increases while the probability of the expected production (E.P.) doing so decreases. The probability of E.P. achieving the goal versus the probability of I.P. doing so is set at 1.0 against 0 for healthy subjects, and 0.41 against 0.59 for subjects with severe dementia.

5.4 Assistance

When subjects make an error in the KTA, the test administrator intervenes to help them complete the task successfully. As subjects may require different levels of support depending on the stage of the disease, the KTA defines three levels of assistance. The test administrator first provides verbal cues to the subject. Subjects selected for the KTA do not present language comprehension problems; however if verbal support is not sufficient, physical assistance is offered. Finally, if the subject is unable to perform a section of the task even with physical assistance, the test administrator performs it so that the subject can carry on with the rest of the task. The KTA score is calculated based on the level of assistance required.

For each level of assistance, the model simulates the assistance provided by the test administrator on the one hand, and the effect on the subject's behavior on the other hand. The simulation of these two facets of assistance is clearly separated: the former uses the ACT-R environment and the latter uses the ACT-R model. By assisting the subject, the test administrator acts as an entity external to the subject. This is simulated in the ACT-R environment. This environment can be accessed via the Lisp functions available in the API of the ACT-R framework. These Lisp functions are used to simulate the intervention of the test administrator. The process is the same for each intervention: once the error is detected, the performance score is updated according to the criterion to which the error belongs and according to the nature of the assistance. The assistance is modeled in terms of its effect on the subject. Indeed, the interaction with the test administrator has an influence, more or less important, on the patient's behavior. For example, this interaction will help the patient remember the ingredient he or she is supposed to use, or the next correct step in the recipe. As we have mentioned previously, the accessibility of elements in both declarative and procedural memory in ACT-R is managed by subsymbolic activation. This mechanism is used to model erroneous behavior: when the level of activation of a chunk or a production is not great enough, it cannot be retrieved or fired, causing an error. Consequently, the effect of the intervention on the subject is modeled via the subsymbolic activation too. When the administrator talks or acts, this leads to a strengthening of the activation level of the targeted elements in either declarative or procedural memory.

The following two sections describe the simulated assistance provided to remedy omission, commission and behavior errors.

5.4.1 Assistance for omission and commission errors

In the KTA model, omission and commission errors occur and are detected when a retrieval request fails or when an unexpected element is retrieved. As these errors are directly linked to declarative memory, assistance focuses on chunk activation. Both verbal and physical help lead to a new retrieval request in declarative memory via a production rule. In addition, the preeminence of physical assistance is modeled by a strengthening of the activation of the desired chunk to make it easier to access this chunk in declarative memory. This is done thanks to a Lisp function that allows the modification of the base-level activation value for a particular chunk. The effect of physical assistance is simulated by the increase of the base-level activation of the target chunk. If the subject is not able to retrieve the chunk anymore, the state of the current goal is changed, with the assumption that the test administrator will retrieve the element instead of the subject.

5.4.2 Assistance for behavior errors

The KTA evaluates five kinds of behavior errors corresponding to those that have been modeled in ACT-R and explained above. Inappropriate behavior is linked to the conflict-resolution system, which is based on the utility of productions. Errors are detected based on the state of the environment ("judgment and safety" errors), the nature of subsequent action ("sequencing" and "performance of all steps" errors) or the time elapsed doing the same action ("initiation" and "completion" errors). Intervention in these cases has similar effects: verbal help and physical assistance are modeled by increasing the utility of the production leading to the expected behavior. The utility value is set up via its probability to lead to the current goal. The probability (P_i) of a particular production's utility is estimated according to its experienced successes and failures (Eq. 3). A Lisp function allows the modification of the successes value for a particular production rule. In the model, the successes value is increased to simulate the strengthening of the probability that the right production achieve the goal (toward the bad one).

Probability of success equation in ACT-R (Anderson 1993):

$$\mathtt{P}_i = \frac{\mathtt{Successes}}{\mathtt{Successes} + \mathtt{Failures}} \tag{3}$$

If the subject is not able to choose the right production, the state of the current goal is changed, simulating the test administrator completing the action instead of the subject.

6 Simulation and results

This model simulates people with senile dementia of the Alzheimer's type following a pudding recipe. The system is able to simulate the behavior of a single subject. Each step involved in ADL execution is observed and potential problems are located (cf. Tables 5,6). The model is parameterized according to the different stages of the disease. By selecting the CDR level corresponding to a person's cognitive level, the system makes it possible to study the progression of the disease. For instance, the functional abilities of a person with CDR 0.5 (cf. Table 5) can be compared with those of a person with CDR 3 (cf. Table 6). We can see that a person with questionable dementia (CDR 0.5) makes only one error, burning herself while managing the hot saucepan, whereas a person with severe dementia (CDR 3) makes errors under each criterion. Table 6 provides an example of the error made by a simulated subject who is unable to initiate the task.

The system is also able to simulate the behavior of 100 subjects, giving the overall average score obtained and the distribution of the subjects' results under each criterion (cf. Tables 7,8). For example, in Table 8, which lists the results of a simulation of 100 people with severe dementia, 24 people are able to initiate the activity on their own, 17 require verbal cues, 16 require physical assistance and 43 are incapable of initiating the task.

The results demonstrate that the cognitive assistance provided is clearly related to the stage of the disease. Variance analysis examined the differences in the model's results across the stages of dementia. A significant F-ratio ($F(4{,}495) = 1158.8$; $p < 0.0001$) demonstrates that performance on the task is affected by the progression of the disease. For each criterion, the score increases as the disease worsens. Healthy subjects (CDR 0) are independent: they almost never require assistance. Subjects with questionable or mild dementia (CDR 0.5 and

Table 5 Extract from a sequence and results of the simulation of a person with CDR 0.5

**** Stage 4: Pour ****	
[. . .]	
	The subject takes an empty dish: Dish 2
	The subject does not manipulate the saucepan correctly
	The subject burns himself: Safety problem → VERBAL HELP
	The subject correctly pours the mixture into the dish
[. . .]	
Results of the simulation	
Initiation:	0
Organization:	0
All steps:	0
Sequencing:	0
Judgment–safety:	1
Completion:	0
Score:	1

Table 6 Extract from a sequence and results of the simulation of a person with CDR 3

**** Stage 0: Task initiation ****

....

....

The subject does not begin: Initiation problem → VERBAL HELP

....

The subject does not begin: Initiation problem → PHYSICAL HELP

....

The subject is not capable of beginning the task: Initiation problem → NOT CAPABLE

The test administrator tells him that he has to measure the milk

[. . .]

Results of the simulation

Initiation:	3
Organization:	2
All steps:	3
Sequencing:	2
Judgment–safety:	2
Completion:	2
Score:	14

Table 7 Simulation results for 100 runs of the model (CDR 0.5)

Criterion	Independent	Verbal help	Physical help	Not capable
Initiation	99	1	0	0
Organization	61	37	2	0
All steps	52	38	10	0
Sequencing	62	34	4	0
Judgment–safety	77	21	2	0
Completion	98	2	0	0
Average score: 1.69				

Table 8 Simulation results for 100 runs of the model (CDR 3)

Criterion	Independent	Verbal help	Physical help	Not capable
Initiation	24	17	16	43
Organization	7	35	33	25
All steps	0	2	5	93
Sequencing	0	4	9	87
Judgment–safety	1	25	29	45
Completion	7	9	0	61
Average score: 13.84				

Table 9 Mean values and standard deviation of scores obtained on the KTA (for real subjects and for simulated subjects) by stage of dementia

Stage of the disease		KTA results	SD for KTA results	Model results, running 100 times	SD for model results
CDR 0	Without dementia	–	–	0.01	0.099
CDR 0.5	Questionable dementia	1.75	2.21	1.69	1.119
CDR 1	Mild dementia	4.65	3.73	4.52	1.723
CDR 2	Moderate dementia	9.81	4.57	9.87	2.339
CDR 3	Severe dementia	13.88	4.61	13.84	2.419

CDR 1) encounter some difficulty in performing the task. Thanks to verbal cues, however, they can continue the task and complete it successfully. A greater number of subjects with mild dementia make errors, and they sometimes need more extensive cognitive assistance than subjects with questionable dementia. Most subjects with moderate dementia (CDR 2) have difficulty under nearly every criterion. They require physical assistance to complete the task. Finally, subjects with severe dementia (CDR 3) make errors under all criteria. Verbal cues and physical assistance are almost always insufficient. More than half of the subjects with CDR 3 are considered incapable under at least one criterion.

To validate our model, a comparison has to be made between simulated results obtained using the model and results obtained by real subjects on the KTA. The KTA results communicated only present the mean score obtained by 106 subjects depending on the stage of dementia. It therefore remains impossible to detail and compare the types of error made under each criterion according to the progression of Alzheimer's disease.

The results for 100 simulated subjects have been compared to the results presented in the KTA paper for 106 subjects (Table 9). The correlation between the KTA results and the model results has been calculated. The two sets of mean values for each stage of the disease are highly correlated (corr = 0.999). The model reproduces reliably the mean score obtained by subjects depending on the stage of dementia. The standard deviations for the KTA are visibly higher than the ones for the model. However, the proportional increase of the standard deviation value during the disease is reproduced.

7 Discussion

The model we have developed using ACT-R makes it possible to simulate Alzheimer patients performing a cooking task. Results show that typical errors due to Alzheimer's disease can be modeled using the ACT-R cognitive architecture. The model's limitations, as well as proposed improvements with respect to modeling choices, will be presented in the following section.

7.1 Discussion of the results of the model

Based on the results, the goals set for the model have been reached. The model enables the simulation of ADL performance according to the stage of the disease. Simulation results for a single person make it possible to observe the step-by-step completion of the cooking activity, and the simulation results for 100 people provide average scores that can be compared with the KTA results communicated by Baum and Edwards (1993). The results obtained by running the model and the results outlined in the KTA are similar (comparison in Table 9). This model provides an overall score for each subject and details the distribution of errors for each criterion and for each stage of the recipe.

Each KTA criterion has been modeled. To model the subjects' behavior, we used two mechanisms offered by ACT-R: the first one is related to access to elements in declarative memory, leading to omission or commission errors; and the second one deals with a conflict–resolution system that chooses a particular piece of procedural knowledge at a given time, leading to initiation, completion, sequencing or judgment errors. The simulated errors correspond to the typical errors observed during the evaluation of real subjects using the KTA. For example, some human subjects tried to cook in the measuring cup. This error is evaluated under the "organization" criterion and corresponds to the inappropriate use of tools or equipment. In the model, this error is modeled by a commission error. In other words, the error is simulated via declarative memory as the confusion between two memory units, the measuring cup and the saucepan. In the same way, some of the real subjects showed initiation disorders. They were not able to begin the task without assistance. This error is simulated in the model via procedural memory. Table 6 showed a sequence for a subject with an initiation disorder. Moreover, simulated errors by stage of dementia correspond to what was observed on the KTA for real patients in terms of the level of assistance required to perform the task. Subjects in the mild stage of the disease required mainly verbal cues to perform the task while subjects in the moderate and severe stages of the disease required physical assistance (Baum and Edwards 1993).

The hybrid architecture provided by ACT-R makes it possible to model both an ADL and the progression of the dementia. Indeed, the different errors observed during the cooking task are modeled by using the subsymbolic systems in declarative and procedural memory, and the ACT-R parameters are adjusted to simulate each stage of the dementia. As a consequence, despite the fact that ACT-R was initially designed to model psychological tests, this model demonstrates that the cognitive architecture can be used to model ADL performance.

7.2 Shortcomings and limitations of the model

The work presented in this paper constitutes a first attempt to model an ADL performed by Alzheimer patients using the ACT-R cognitive architecture. A model is a representation of an aspect of reality and therefore includes, by definition, some limitations. We chose to disregard certain aspects of Alzheimer's disease in designing this model. First of all, we did not model perceptual and motor mechanisms. Indeed, unlike other assessments, which are focused on motor skills, the KTA evaluates the cognitive aspects of a task. Secondly, we chose to disregard language skills since subjects that complete the KTA are expected to understand verbal instructions. This section points out the shortcomings of this model, as well as some possible improvements for a subsequent iteration of the model.

7.2.1 Validation of the model

A major limitation of this model lies at the level of the validation of simulation results. Overall scores obtained using the model match the overall scores obtained by human subjects. However, this validation is limited since the KTA authors only present overall scores for each level of dementia, without providing a distribution of the errors made under each criterion and for each stage of the recipe. Verification of the data's coherence with respect to the distribution of errors is therefore limited. Correlations between different kinds of errors cannot be carried out. For example, will subjects that make initiation errors also make completion errors? Do subjects commit more errors in particular stages of the recipe? Are some errors made more frequently than others? To simplify the model, we worked with the hypothesis that the percentage of errors is the same for each stage of the recipe, and that all the errors have the same chance of being committed. Alternatively, we could have assumed that errors are made more frequently in complex stages of the recipe. This assumption would have been coherent with the ACT-R framework since the complexity of a task is represented by the number of elements relevant to the goal. The more the task is complex, the less the information is clear and accessible. Whatever the hypothesis chosen, future work should include observation of Alzheimer patients to make empirical comparisons and confirm the consistency of the model or make changes to it.

7.2.2 Improvements to the model

Other limitations result from decisions made during implementation. Future work could improve the quality of the model by introducing generic error modeling, improving the interaction between subjects and the test administrator or integrating perceptual and motor aspects.

In its current version, the model generates a set of typical errors described in the KTA. The errors modeled are specifically related to the task being performed. Errors are encoded explicitly using a mechanism that presents a conflict situation between correct and incorrect rules (cf. Table 4). It is important to make abstraction of the context when representing errors to render the model reusable and adaptable to the simulation of various activities. We are currently working to develop generic error modeling within the ACT-R framework. The sequencing mechanism coded as rules (a.1) and (a.2) in Table 4 will be replaced by a mechanism linked to activation values. Indeed, goals can be seen as particular chunks in declarative memory that have corresponding activation values (Altmann and Trafton 2002). Sequencing errors occur when an inappropriate goal is retrieved instead of the expected one.

The test administrator is presently represented via the model's environment. A new release of ACT-R is now available that allows several models to be loaded at the same time. In a future version of our model it would be interesting to explore the possible interactions between two models. The test administrator would be modeled as a real cognitive entity interacting with the model.

We purposely did not use the perceptual and motor modules provided by ACT-R in this model. We preferred to focus on the cognitive processes observed in the KTA. However, it would be interesting to integrate these aspects of cognition in the next version. These modules would be useful for a possible fine-tuning of the quality of the modeling. Indeed, people with Alzheimer's disease can suffer from visuoperceptual deficits. This has an impact when visual analysis and perceptual organization are required (Lezak 1993). Attentional deficits are also common in Alzheimer's disease. By modeling visual attention in our ACT-R model, we would be able to introduce distractors that lead to objects being overlooked or mistaken.

7.3 Applications of the model

Modeling and simulating the progression of Alzheimer's disease based on ADL execution present interesting applications for smart homes and cognitive assistance. In this paper, we have presented a way to model the impairments resulting from Alzheimer's disease by using the ACT-R cognitive architecture. For each stage of the disease—expressed in terms of CDR—the model predicts the most frequently made errors for a specific cooking task. The examiner's assistance is modeled and its impact on the subject's performance of the activity is simulated. This cognitive simulation is part of a larger project that aims to foster autonomy at home among people with cognitive impairments. To assist people in an efficient way, cognitive assistance systems have to understand the abnormal behavior induced by the disease.

Cognitive modeling plays various roles in assistive systems. Namely, it helps describe both the cognitive processes involved in ADL completion, and the consequences of the impairment of these cognitive processes on human behavior. Moreover, cognitive models generate the behavior of healthy or cognitively-impaired people performing activities. This simulation aspect can be applied in the learning phase or in the assistance phase.

7.3.1 Learning phase

Assistive systems require activity recognition to discriminate between normal and abnormal behavior. A preliminary step in recognition consists of a learning phase during which the assistive system automatically learns various ways of performing an activity, including the incorrect ones. Some assistive systems use Markov chains, for instance, to learn and classify these activities. In the case of Alzheimer's disease, the different disorders and the progression of the disease, along with the number of activities that can be carried out inside a house, lead to a variety of scenarios, including scenarios containing errors or hazardous behavior. Building up a collection of all these potential scenarios would be highly time-consuming and heavy in human cost. The use of deep models of impaired people can reduce these costs by generating normal and abnormal behavior that can be validated by cognitive theory. The automatic generation and classification of behavior can be done in huge numbers at a relatively low cost. The learning phase is thus optimized by the scenarios generated using cognitive models.

7.3.2 Assistance phase

Once the system has detected the current activity performed by the resident, the next step is to assist that person. The system interacts with the occupant through the environment in order to provide relevant assistance in the event of difficulty. To analyze the accuracy of the occupant's behavior, the system must detect errors or problems, and then identify cognitive disorders that are at the origin of these errors.

Flight simulation can use user modeling to detect errors (Callantine 2002). In the Crew Activity Tracking System (CATS), an operator model is used to predict operator activities and interpret the actions of a real operator. Drawing on contextual information, CATS builds the current operational context and generates predictions of operator activities based on its model. CATS then compares the actions detected in the real world to the activities it predicted to provide a diagnosis.

A dynamic diagnosis based on a cognitive model is also useful in assistive systems to provide the appropriate cue to help the subject. The pervasive cognitive assistance developed at DOMUS Laboratory is therefore based on the nature of the occupant's deficit. Based on the diagnosis, the assistive system selects the most appropriate support to help the resident. Four main cognitive deficits have been identified by caregivers: initiation, planning, attention and memory deficits. At this point, each deficit is diagnosed based on information provided by sensors and knowledge of the occupant's habits (Bauchet et al. 2006). An initiation deficit is characterized by a long period of inaction. To overcome this deficit, the assistive system urges the person to begin the activity by keeping the activity objectives on screen. A planning deficit, characterized by an inappropriate sequence of actions, is overcome by reminding the person of the next step to perform in the current activity. A step-by-step approach is offered to the occupant during the activity's completion, for example by lighting up the next object to be used. An attention deficit is diagnosed when the occupant demonstrates difficulty focusing on the current activity and when the actions performed are not relevant to the activity. In the case of this deficit, the goal of the activity is recalled so that the occupant can keep focusing on it. Finally, a memory deficit is only diagnosed when the person asks for specific assistance. The system will then provide the forgotten information.

The cognitive model we have developed can be used to improve the diagnosis of a deficit. The simulated activity, generated dynamically during the recognition phase, is compared with the one performed. Indeed, the model's output makes it possible to track the activity's step-by-step progression. The cognitive model simulates different errors specific to Alzheimer's disease, including signs of initiation, planning and memory deficits corresponding respectively to the "initiation", "sequencing" and "organization" criteria. If abnormal behavior occurs during the simulation, the mechanism responsible for the error is reported so that a specific behavior can be attributed to a specific deficit. This expertise is useful for the diagnosis phase.

During further development by the DOMUS Laboratory, the scenarios generated by the model will be compared to the sequence of actions performed by residents in order to identify the cognitive deficit associated with each behavior. Based on the diagnosis, appropriate assistance will be identified and provided to the occupant (cf. Table 10). The assistance provided must be personalized, simple, easily accepted and suited to the context (Pigot et al. 2005). Interventions can thus be carried out in various ways, taking into account the occupant's

Table 10 Response of the cognitive assistance system to the diagnosis made by the model

Diagnosis made by the model	Support provided by the cognitive assistance system	Means of interaction in Smart Homes
Initiation problem: The occupant does not begin the task	Recall the goal of the task	Send voice or text message
Omission error: The occupant does not remember the element to use	Recall the element to be retrieved	Highlight the target element in the environment or show a picture of the element
Commission error: The occupant does not use the tools appropriately	Help the occupant use or select the appropriate element	Show a video or send a text message
Omission of a step and sequencing problem: The occupant does not perform one of the task's steps or executes another step	Recall the next step to perform	Send voice or text message show a video if necessary
Lack of judgment and safety: The occupant does not manage dangerous elements properly (such as the stove)	Warn the occupant or help him or her to use the tool in an appropriate way	Send voice message or show a video
Completion problem: The occupant does not assess that he or she has completed the task	Indicate that the task is over	Send voice or text message

capacities or preferences. For example, if the occupant uses a tool that is inadequate for the task (commission error), the cognitive assistance system must help the occupant use or select the appropriate tool. It will send a text message indicating which tool to use or show a video explaining how to use the tool appropriately.

8 Conclusion

This paper presents a means for modeling and simulating the progression of dementia of the Alzheimer's type through the evaluation of performance during ADL execution.[1] To develop this model, three objectives were established: model an ADL, simulate the effects of dementia on ADL execution, and simulate the cognitive help required. We chose to develop the model using the ACT-R theory. Our work has been based on the KTA since this occupational therapy test provides us with an evaluation of subject behavior on a cooking task. The model simulates subjects performing the cooking task and making errors according to the stage of the disease. The model provides a tracedescribing how the task was completed and the score obtained based on the amount of required help.

The simulation results obtained when using the model are very similar to the clinical results presented for the KTA. In this regard, we can say that the objectives have been reached. Unlike most existing cognitive models that simulate mathematical or logical problem solving, we have developed a model of an ADL. Thanks to its hybrid architecture, ACT-R allows the disorders induced by dementia to be simulated, particularly those that are linked to memory mechanisms.

Cognitive models are used to improve the quality of interface design by applying what is known from psychology to the design of interfaces (Ritter and Young 2001). In the same way, cognitive models can be used to improve the design of 'smart' homes and cognitive assistance systems. Indeed, this model has been developed as part of a project on home support for people suffering from cognitive disorders. To provide them with the autonomy required, a 'smart' home must be able to look after their security and to accompany them in the performance of activities of daily living. In this context, the development of a cognitive model that would simulate the behavior of subjects with Alzheimer's disease appears very interesting. Such a model would be useful in smart home systems for the detection of dangerous situations and the simulation of the assistance required. This model is a first step toward a generation of cognitive models for pervasive assistance.

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