Enhancing Wearable Technologies for Dementia Care: A Cognitive Architecture Approach

Matija Franklin, David Lagnado[1], Chulhong Min, Akhil Mathur, Fahim Kawsar[2]

[1]Cuasal Cognition Lab, UCL
[2]Nokia Bell Labs

Abstract. Activities of Daily Living (ADLs) are often disrupted in patients suffering from dementia due to a well-known taxonomy of errors. Wearable technologies have increasingly been used to monitor, diagnose, and assist these patients. The present paper argues that the benefits current and future wearable devices provide to dementia patients could be enhanced with cognitive architectures. It proposes such an architecture, establishing connections between modalities within the architecture and common errors made by dementia patients while engaging in ADLs. The paper contends that such a model could offer continuous diagnostic monitoring for both patients and caregivers, while also facilitating a more transparent patient experience regarding their condition, potentially influencing their activities. Concurrently, such a system could predict patient errors, thus offering corrective guidance before an error occurs. This system could significantly improve the well-being of dementia patients.

Keywords: Cognitive Architecture · Wearable · Dementia

1 Introduction

Activities of Daily Living (ADL), everyday tasks such as making a cup of coffee or calling someone on the phone, are disrupted in patients suffering from dementia. Dementia, a condition affecting over 55 million people worldwide, produces an intention-action gap[1]. The intention-action gap occurs when someone is not able to successfully execute their intentions, often due to a decline in cognitive function. ADLs are good indicators of the level of dementia a person is experiencing. As dementia progresses, patients have increasing difficulty performing ADLs. This decline in function can be gradual or sudden, and its onset can be unpredictable.

Numerous assistive devices and technologies are available to aid people with dementia in performing their activities of daily living. These range from simple tools like pillboxes (small containers that remind people to take their medication), to more complex devices such as automated medication dispensers (devices

[1] Intention is the cognitive process by which people decide on and commit to an action. Action is the physical process of executing an intention.

that dispense medication at preset times). The development and utilization of such assistive devices and technologies have gained traction in part because dementia patients report that disruptions to ADLs cause the greatest loss of independence and wellbeing.

Multiple proposals have been put forward for the use of wearable technologies to aid dementia patients [8] [36]. In relation to ADLs, wearables equipped with adequate behavioural monitoring would be able to detect patient errors during these activities and provide them with *corrective guidance* - guidance that responds to the error. The present paper proposes an approach that utilizes wearables and cognitive models to create systems that provide patients with *directive guidance* - guidance that predicts errors and aims to prevent them from happening.

2 Dementia is Diverse and Dynamic

The reason why a one-size-fits-all corrective guidance is not viable for dementia patients lies in the diversity and dynamic nature of dementia. In other words, there are different types of dementia, and each patient's condition changes over time. Furthermore, even among patients with the same type of dementia, there are individual differences in the types of errors they exhibit.

Not all cognitive decline is the result of dementia. From early adulthood onwards, throughout a person's life, thinking speed, reasoning, working memory, and executive function all progressively decline [7]. This age-associated cognitive decline is non-pathological [16] and is an inevitable process of neurological aging. Dementia and mild cognitive impairment (MCI) are relatively rare conditions. Current estimates suggest that less than 20% of adults over the age of 80 have dementia [27].

Dementia is a syndrome characterized by a decline in memory and thinking abilities, as well as deterioration of cognitive abilities [20]. Symptoms of dementia include problems with planning and carrying out tasks, memory loss, mood and personality changes, and confusion. When these symptoms impair ADLs to a point where a person cannot live independently, they are said to have dementia.

Dementia is not a single disease, but an umbrella term for conditions that result in symptoms associated with memory loss, thinking, and communication problems. There are different types of dementia. First, dementia is not synonymous with MCI, although the two display similar symptoms and are thus often confused. MCI is a cognitive impairment that affects 5-20% of seniors [27]. Its symptoms are similar to those of regular brain aging - including decreased processing speed, working memory issues, and difficulties with reasoning and executive function - but more severe. People with MCI often forget names, numbers, and passwords, misplace items, struggle to remember conversations or decisions, and have trouble keeping track of their commitments and plans. As a result, MCI does not always prevent people from living independently, and some cases are even treatable. Approximately one in six people with MCI will develop dementia within a year.

There are many types of dementia, but Alzheimer's disease is the most common, accounting for 60-75% of all cases [27]. Other forms include vascular dementia, frontotemporal dementia, dementia with Lewy bodies, alcohol-related 'dementia', young-onset dementia, and Creutzfeldt-Jakob disease. A comprehensive review of all these conditions is outside the scope of this article. However, it is important to note that each type of dementia has its unique cognitive disruptions, patient errors, and treatment challenges. Additionally, mixed dementia is a condition in which more than one type of dementia occurs simultaneously [5], further complicating the establishment of a homogeneous approach to corrective guidance.

A patient's dementia symptoms also change over time. Dementia is dynamic in that a patient's symptoms worsen over time [24]. The rate at which it progresses and the cognitive functions it impairs will differ even among patients with the same type of dementia [34]. As a result, there are individual differences in the types of errors they display, even within the same type of dementia.

In conclusion, dementia takes different forms, with cases existing where a single patient manifests more than one form. It changes over time, typically worsening by affecting a cognitive modality with greater intensity. However, its progression differs among patients, and different patients exhibit different errors even if they have the same type of dementia. A technology capable of detecting these errors and tracking their changes over time would indeed be beneficial.

3 Wearables: Monitoring, Augmentation, and Guidance

Wearable technology provides a unique advantage for helping dementia patients by monitoring their behavior, identifying errors as they occur, and aiding patients in correcting these errors after they occur - corrective guidance - or even before they occur - directive guidance. Through the use of various sensors and the capacity to communicate with other smart devices, wearable technologies can be context-aware. Multiple examples exist of wearable systems being used for augmented memory, including the wearable remembrance agent [28], which monitors information retrieved from computers; SenseCam [13], a camera that serves as a memory aid; and DejaView [6], a healthcare system comprised of multiple sensors that assist patients in recalling daily activities. Despite potential perceptions of these technologies as intrusive, research suggests that patients support their development [12] [31].

There have been proposals for utilizing more minimal setups, using just one wearable device, to monitor user behavior and augment a patient's memory [8] [22] [36]. Such wearables are made feasible with the aid of tailored machine learning algorithms that can identify dementia type and patient error based on data gathered from wearable technology [17] [19]. A systematic implementation incorporating the seven most popular wearables at the time examined whether these devices could serve as suitable dementia patient monitoring devices [26]. The study found that the devices enabled real-time monitoring of dementia patients, but also identified major technological gaps, such as the need for devices with lower power consumption.

Wearables can also serve as diagnostic tools for dementia patients. A recent systematic review assessing wearable technology in dementia found that these devices could effectively monitor patient behavior, highlighting that adults with dementia were less active, had a more fragmented sleep-wake cycle, and exhibited a less varied circadian rhythm [4]. Inertial wearables have been proposed as pragmatic tools for monitoring control and gait, which serve as useful biomarkers in dementia [11]. A more recent paper determined that gait impairment monitoring by wearable technologies combined with machine learning algorithms could differentiate between different types of dementia [21].

Furthermore, wearable technology can provide patients with guidance for ADLs by assisting them through activities, thereby reducing or correcting errors [8] [30]. For example, CueMinder reminds patients to perform ADLs using image and vocal cues, aiming to promote patient independence [14]. Other systems are more single-task oriented, such as AWash, which uses a smartwatch to monitor and segment hand-washing actions and prompts users to remind them to wash their hands [2].

We posit that the benefits wearable devices provide to dementia patients could be further enhanced with the use of cognitive architectures in two key ways. First, such models could provide an explanatory layer by identifying the cognitive modality that has been disrupted given the error patterns displayed by a patient. This has implications for the early detection of disruption to cognitive modalities. Apart from the diagnostic benefit, this would also increase transparency with patients. Second, by understanding what cognitive modalities are getting disrupted, wearables could predict the likelihood of future errors, thereby serving as a tool for tailored directive assistance that can enhance a patient's independence and well-being.

4 Cognitive Architectures

A cognitive model is a representation of the mental processes in the mind [1]. It offers an understanding of how the mind takes in, processes, and stores information. Some cognitive models provide a comprehensive description of the mind's operations, while others focus on specific elements such as memory, attention, or decision-making. The goal of cognitive modeling is to emulate human cognition in a way that aligns with observable data, like reaction times or functional magnetic resonance imaging results.

When a cognitive model is constructed to serve as the basis for artificial intelligence, it is referred to as a cognitive architecture [18]. Typically, cognitive architectures consist of various modules, each dedicated to a specific task or set of tasks. For example, one module may be responsible for attention, another for working memory, and another for long-term memory. Each module has its own set of processes and data structures that it uses to fulfill its function. These modules are interconnected, allowing information to flow between them so that

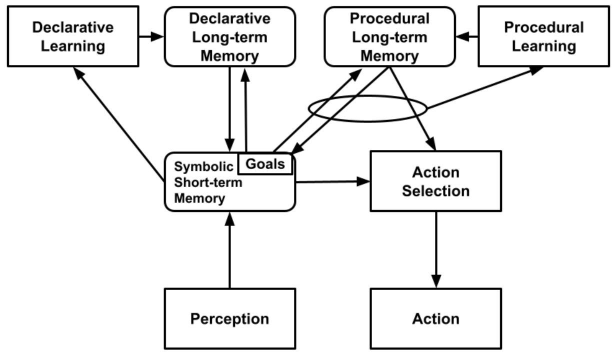

Fig. 1. A Prototypical Cognitive Architecture

the outputs of one module can become the inputs of another. The specific array of modules and their interconnections may vary between different cognitive architectures. Some architectures aim to emulate the operation of the human mind as closely as possible, while others may be more simplified or abstract.

Various approaches have been taken to construct cognitive architectures. However, as John Laird [18] argues, many cognitive architectures share similarities. He proposes a prototypical cognitive architecture consisting of memories and processing units common to other renowned cognitive architectures like SOAR, ACT-R [29], Icarus [3], LIDA [9], Clarion [32], and EPIC [15]. The block diagram of this prototypical cognitive architecture is shown in Figure 1. This prototypical cognitive architecture will be used in this paper, as it consists of most elements present in other widely-used cognitive architectures.

In this architecture, sensory information is initially processed by perception and then transferred to short-term memory. From here, cues from long-term declarative memory can be retrieved to access facts relevant to the current situation. Declarative memory has an associated learning module that uses activity from short-term memory to add new facts to this memory type. Similarly, procedural memory stores knowledge about what actions should be executed and when. Like declarative memory, procedural memory can be cued by activity in short-term memory, and it also includes a learning component. Data from both procedural memory and working memory are used by the action-selection component to determine the most suitable next action. This could involve physical actions in the external environment or deliberate changes in short-term memory. Thus, behavior is generated through a sequence of decisions over potential internal and/or external actions. Complex behavior, including internal planning, arises from actions that create and interpret internally generated structures and respond to the dynamics of the external environment. The architecture of this model supports both reactive behavior in dynamic environments and more deliberate, knowledge-mediated behavior. Lastly, learning mechanisms can be incremental - adding small units of knowledge one at a time - and/or online - learning occurring during performance. As new knowledge is experienced and acquired, it is immediately available. Learning does not require extensive analysis of past behavior or previously acquired knowledge.

5 Implementing a Cognitive Architecture for Dementia

A successful cognitive architecture provides a fixed infrastructure for understanding and developing agents that require only task-specific knowledge to be added, in addition to general knowledge [18]. This allows cognitive modeling to build upon pre-existing theories by using an existing architecture, thereby saving the time and effort spent starting from scratch. For modeling human behavioral data of dementia patients performing ADLs, the proposed cognitive architecture in Figure 1 can be used to understand how patients observe changes in the environment, interpret them, retrieve other precepts from memory, convert them into actions, and so forth.

[35] have researched and categorized the four most common errors that dementia patients exhibit while performing ADLs. First, *Sequencing errors*, which can be further categorized into: *Intrusion* - the performance of an inappropriate action from a different activity that prevents the completion of the intended activity; *Omission* - the omission of an action required for completing the intended activity; *Repetition* - the repetition of an action that prevents the completion of the intended activity. Second, errors related to finding things; further divided into errors in finding items that are out of view and identifying items that are in view. Third, errors related to the operation of household appliances. Finally, *Incoherence errors*, which can be further divided into *toying* - performing random gestures with no apparent goal - and *inactivity* - not performing any action at all.

With this required task-specific knowledge, the prototypical cognitive architecture can be used to model dementia patients performing ADLs. Sequencing errors thus emerge from disruptions to the action selection or action performance modalities. More specifically, intrusion and repetition are action selection errors while omission could be due to either action selection or action performance. Errors in finding things that are out of view, as well as identifying things that are in view, can result from errors in short-term memory, declarative long-term memory, or declarative learning. Errors in the operation of appliances can emerge from errors in procedural long-term memory and procedural learning. Finally, incoherence errors may be due to disruptions to short-term memory, specifically the ability to hold a goal in mind, or due to errors in action selection and action execution. The block diagram of how patients' errors relate to the cognitive modalities is available in Figure 2.

6 Evaluating the Cognitive Architecture

Validating a cognitive architecture of patient error would be feasible to conduct at scale with wearables and cognitive assessment batteries. As previously discussed, wearables can be used to detect different types of dementia [21], as well

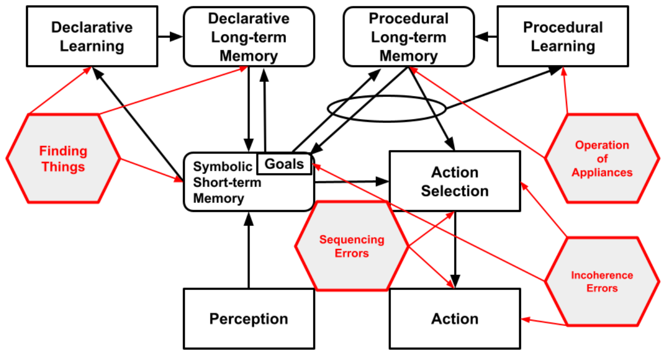

Fig. 2. Cognitive architecture of patient errors

as varying patient behaviors [22], and thus, will be able to discern individual differences in the frequency of patient errors. To identify whether the observed patient errors stem from disruptions to the modalities proposed in Figure 2, they can be tested against results from cognitive assessments. A cognitive assessment is a set of tests that are administered to evaluate an individual's cognitive abilities. These tests are often used to diagnose cognitive impairments.

The Cognitive Assessment Battery (CAB) is one such test [23]. CAB is capable of clearly distinguishing between normal cognitive aging, Mild Cognitive Impairment (MCI), and dementia. It consists of six assessments covering different cognitive domains, namely, language, executive functions, speed, attention, episodic memory, and visuospatial functions. The Mini-Mental State Exam (MMSE), also used to screen for dementia, assesses attention, language, recall, and orientation [10]. These two tests are complimentary and have both been modified and validated using different methodologies. For example, the MMSE has been updated in the Modified MMSE, which includes verbal fluency [33]. Furthermore, there is evidence that such tests can be reliably administered over the phone [25], boding well for the possibility of these tests being administered through wearable technologies. Additionally, when a new type of error appears, patients could be administered new cognitive assessments.

The result of validating the model would be a cognitive architecture that provides an explanatory, causal layer behind patient error; specifically, how different disruptions produce varying distributions of patient error. Aside from being explanatory, such a model would also be predictive of the likelihood of future distributions of error for a patient, as different frequencies of error would result from distinct disruptions to cognition. The functionality of such a model will now be discussed.

7 Functionality

The functionality of a cognitive architecture for wearables assisting dementia patients with ADLs is twofold. First, the architecture would enable such technologies to be diagnostic and transparent with patients. The wearables could continuously track the frequency of patient error, understanding how alterations to these patterns might relate to changes in cognitive modalities. The system would provide a real-time assessment of an individual's performance over time. This information could be used to evaluate an individual's performance, which would be essential for understanding the efficacy of rehabilitation programs.

Provided consent is given, the wearable could also directly send updates to the patient's caregivers or close friends and relatives. This would inform the treatment and care the patient needs to receive. For instance, if a person is going about their daily activities and is not making some of the errors that are typically made, but is making new kinds of errors, this would indicate a deterioration in function. By supplying this information to the caregiver, the caregiver could provide guidance to help prevent further deterioration.

The cognitive architecture would offer a number of advantages for patients with dementia. First, it would provide them with greater transparency over their condition. Second, it would offer a level of support that could assist them in making decisions about their care. Third, it would be highly customized, allowing patients to receive the specific level of support they need. Lastly, it would be non-intrusive, meaning patients could wear the device without feeling as though they are being monitored.

Secondly, the architecture could be used to predict future errors in dementia patients. As the distribution of error will cluster around disruptions to certain cognitive modalities, a wearable with such a cognitive architecture could anticipate patient behavior. This predictive capability could, in turn, be used to provide patients with directive guidance, offering advice on performing ADLs before the predicted error occurs. Arguably, this would be more beneficial than corrective guidance that responds to patient error after it happens.

There are many potential applications for a cognitive architecture, and the specific applications will depend on the unique needs of the dementia patient population. However, the potential benefits of such an architecture are clear. By predicting when errors are likely to occur, a cognitive architecture could provide patients with guidance to help them avoid making errors. In turn, this could help patients stay safe and enhance their quality of life. Future research could explore the communication methods used for talking to patients about changes to their condition, as well as ways of gaining their attention and giving them precise directive guidance.

8 Conclusion

This paper contends that the benefits wearable devices currently offer to dementia patients, and those they could provide in the future, can be amplified by integrating cognitive architectures. It puts forth such an architecture, delineating the connections between modalities within the architecture and patient errors commonly manifested by dementia patients during ADLs. The paper asserts that this model could enable continuous diagnostic monitoring for both patients and caregivers, while also affording patients a more transparent understanding of their condition, which may inform their actions. Furthermore, such a system would have the capacity to predict patient errors, thus offering them corrective guidance before an error occurs. Such a system could greatly enhance the well-being of dementia patients.

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