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Towards an adaptable framework for mobility assistive technologies

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Abstract

This study approaches adaptability for mobility assistive technologies by proposing an adaptable framework for mobility assistive technologies, inspired by ACT-R, the desiderata for developing cognitive architectures as highlighted by R. Sun and Vernon et al. and human behaviour. This study proposes an adaptable framework for shared control and autonomous mobility as the first step towards the formation of a comprehensive adaptive framework. This study proposes a minimalist four-module adaptive framework consisting of the perception/motor module, the cognitive module, the memory module, and the action module. The minimum requirements for the implementation of this framework on an intelligent wheelchair for shared/collaborative control were highlighted. Although an overview of the proposed adaptive framework for mobility assistive technologies was presented, there are still numerous concerns to address. One of the main issues remains the most suitable connectionist and symbolic process to be used in the hybrid framework, which will be investigated in future work. In addition, it is still essential to resolve details of the adaptation/learning process in the framework, so it will be necessary to develop learning mechanisms in cooperation with reward systems as well as observation/inference systems for the framework.

Keywords: Cognitive Architectures; Adaptable Frameworks, Mobility Assistive Technologies

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1. Introduction

Humans as well as animals can naturally connect with their environment and others in a versatile way. They benefit from instruments that permit them to fine-tune their behaviour to the current (or recently experienced) parameters of an environment. This ability to learn and remember enables them to adaptively meet their varying ecological demands and environmental changes. Moreover, the learning and retention of information and experiences are goal-driven. Information relevant to its survival is regarded as most important. This phenomenon can be referred to as adaptability [1,2]. This is a trait that has been sought-after, for many years, by artificial intelligence (AI) researchers and cognitive scientists for total appropriation into intelligent systems.

In an attempt to develop intelligent systems, over the years, researchers have made efforts to outline a structured blueprint of human cognitive abilities. These structured blueprints (representations) have been used to propose cognitive architectures pertinent to varying areas of science and engineering. Cognitive architectures have demonstrated effectiveness in certain applications, but there seem to be recurring differences in terms of research objectives, structure, mode of operation and application [3–5]. This is understandable due to the differences in computational representations of human cognition (computationalist/symbolic representation, the connectionist/emergent/subsymbolic representation and the hybrid representation) [6,7].

Although some cognitive architectures are no longer in active development, existing cognitive architectures and their computational representations are still evolving and are yet to implement all the capabilities indicated in its theory. Originally, most cognitive architectures started as highly symbolic representations but recently some subsymbolic features have been incorporated making some architectures more mixed than symbolic. For instance, in the SOAR version 8 and subsequent versions, the learning assumption mechanism was revisited to include reinforcement learning, episodic learning and semantic learning [8]. Also from ACT-R 5, a major improvement was made to its theoretical framework. The perceptual-motor memory, which was inspired by the EPIC architecture, was added to reflect a more accurate simulation of human perceptual-motor interaction [7]. ACT-R 7 improved on the declarative memory chunk-types by allowing for multiple inheritances [9]. ACT-R is a hybrid cognitive architecture and its subsymbolic approach for decision making is based on a probabilistic process (i.e log odds to determine chunk activation) from a set of declarative memory called chunks and the intended set goal. This pattern of evolution is also similar to other popular cognitive architectures that are still in active development.

With symbolic and connectionist both having their strengths and drawbacks in implementation, it is becoming relatively clear that they are both necessary in modelling intelligent systems. As Marvin Minsky quoted, “To get around these constraints, we must develop systems that combine the expressiveness and procedural versatility of symbolic systems with the fuzziness and adaptiveness of connectionist representations”. The theoretical concepts and advancement of cognitive architecture make it a solid option for the representation and modelling of intelligent behaviours, but there is still the question of how precise existing representations are to correctly reflect human cognitive processes [10,11].

Other researchers approach intelligent systems on a task basis, not necessarily proposing a universal framework to mirror human intelligence at all levels. These kinds of intelligent systems loosely fall under the category of cognitive/intelligent/adaptive agents and are developed to mimic, automate or outperform humans in specific tasks or a set of goals. They are usually developed in attempts to solve real-world problems without paying so much attention to proposing “a unified theory for cognition”. This includes varying examples from specific task-based cognitive agents like AlphaGo (a computer program created to learn and improve in playing games) to intelligent robots designed to perform a set of tasks like assistive and service robots. The AphaGo has gone on to defeat some GO board champions, after learning the game over time [12]. This approach to intelligent systems has been successfully applied to many fields to solve real-world problems. It has been applied to factory automation, visual inspection, character recognition, natural language processing, companionship, human identification, intelligent transport, field and service robots, assistive robots, medical care and many other areas. Although much emphasis is not given to using a unified theory of cognition, this approach also follows a similar modular structure to cognitive architectures (i.e a structural approach towards cognitive abilities as highlighted by R. Sun [13] and D. Vernon *et al.* [14]). Major emphasis is placed on restricting its structure to achieving its intended objectives for its desired use case(s) and improving on its structure/features as development continues [15].

In healthcare, assistive robots and medical care has attracted the attention of many researchers. This is because of the current and projected population of the elderly and individuals with some form of disability. A significant number of these disabled individuals falls into the category of mobility impairment [16,17]. Many prototypes have been proposed or developed to address different challenges related to mobility impairment. The common objective has always been to partially or completely restore mobility independence to impaired users and/or monitor the state of their health. This is achieved by developing or improving on a kind of automated and/or adaptive system to address a specific problem or set of problems common to a certain group of impaired individuals. The challenges addressed generally falls under one or more of these categories; shared control, autonomous navigation in unknown environments, personalization of mobility aids, monitoring for diagnostics or adaptation, rehabilitation training, and so on. Some examples include the NavChair, which was one of the early works towards shared control and autonomous navigation for mobility-impaired individuals [18], the i-Walk assistive robot designed to offer assistance to individuals with light to moderate impairment [19], the internet of things framework for assistive mobility devices that was proposed to address autonomous navigation of assistive mobility devices in an ad-hoc network setting [20], a learning-based hierarchical control scheme for an exoskeleton robot that uses learning by demonstration and an admittance control scheme for shared control [21], and an Active Leg Exoskeleton (ALEX) that was designed to help motor-impaired patients by using a force-field controller for “assist-as-needed” gait rehabilitation [22]. Many of these prototypes, over the years, has focused more on functionality rather than adaptability to its users. Moreover, human satisfaction has been (on many occasions) considered secondary in the design but it is of equal importance towards the acceptability and usability of these devices. It is, therefore, necessary for the design structure of mobility aids in healthcare to take into consideration the important role adaptability plays in the development of an intelligent system [23].

Motivated by the desiderata for developing cognitive architectures by R. Sun [13], that of Vernon *et al.*[24], and by the desire to develop a framework specifically focused on mobility assistive technologies, this paper seeks to propose a reference adaptive framework for mobility assistive technologies applicable to healthcare. The proposed adaptive framework is a minimalist four-module framework that consists of the perception/motor module, the cognitive module, the memory module, and the action module. This framework takes into account the connectionist and symbolic representation to achieve certain objectives (like shared/collaborative control, and autonomous navigation). This framework would be implemented, in the coming months on a wheelchair to validate its proof of concept.

The rest of the paper is organized as follows. First, the minimum requirements for the adaptive framework for mobility assistive technologies are presented. Then an overview of the adaptive framework and the adaptive framework concept is briefly explained. Given the limited space, only the most crucial attributes of each module in the framework would be considered. Finally, a concluding statement is presented.

2. Desiderata (Minimum requirements) for the adaptive framework.

Using the intelligent wheelchair, some assumptions in achieving autonomous navigation and shared/collaborative control are presented. Although there is no standard definition of shared control accepted by the research community, based on its varying applications and existing literature, most researchers agree on two main modalities; haptic guidance systems and input-mixing systems [25]. This study would be focused on shared control in terms of input-mixing [26]. The intelligent wheelchair is expected to receive commands from its user and complement these commands with some level of automated control when required. Future works can modify these requirements following its specific design objectives for varying applications and these requirements would be met by the different modules present in the adaptive framework. Therefore the following minimum requirements are presented in the proposed adaptive framework in terms of shared control (input-mixing).

2.1. Maximize user’s involvement

As much as autonomy is important for assistive robots, users must remain in the loop for many reasons. These include enriching users’ experience, engaging/exercise users’ cognitive ability, minimizing the loss of users’ residual skills, improving users’ fondness of his/her device and many more. Feedback should also be considered in enriching users' experience as well as users' safety in the case of command error or uncertainties [27]. There is a need for the adaptive framework to be intelligent enough to strike a balance between users' input and decision-making.

2.2. Autonomous navigation.

These include; accurate balance between users' input and expected goals, its ability to perform its primary function with limited user input when required, autonomous navigation in an unknown environment, and consideration of users' safety in decision-making.

2.3. Seamless collaboration

It is also important for the intelligent wheelchair to be able to seamlessly collaborate with the user without its user noticing any switch between controls. Also, accurate feedback and execution of desired inputs in line with expected outcomes or goals are essential.

2.4. User's profiling, monitoring for user's safety, and privacy policy.

Users' of assistive mobility technologies always have some form of disability, the ability of a device to adapt should include user personalization. This means a rich user profiling for better adaptation and to alert relevant stakeholders if or when the case arises. Also, users' information must be very secured and safe.

3. Overview of the adaptive framework for mobility assistive technologies.

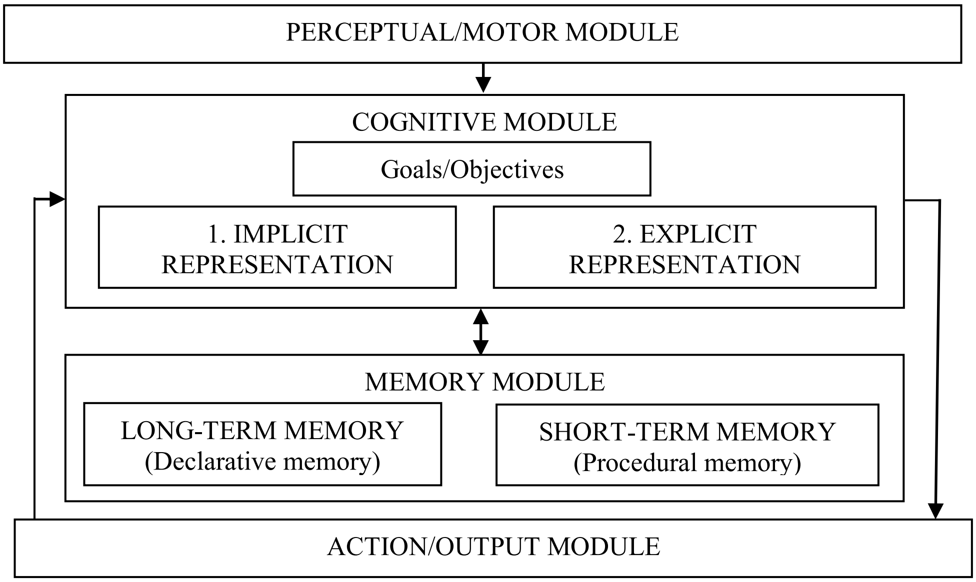

Fig. 1. Schematic diagram of the adaptive framework for mobility assistive technologies.

The design of the adaptive framework is guided by the desiderata for developing cognitive architectures as highlighted by R. Sun [13] and Vernon *et al.*[24]. It is divided into 4 modules; the perception/motor module, the cognitive module, the memory module and the action module. Every module has a different role and responsibility towards building an intelligent system. Fig. 1 above shows the schematic diagram of the adaptive framework for mobility assistive technologies.

3.1. Perceptual and motor module

The perceptual and motor interface preprocesses signals from the real world. This module handles multiple inputs which are subdivided into two, direct cues and nonverbal cues. The direct cues are signals that are needed for a direct command like visual, auditory, tactile and brain-computer interface (BCI) signals. The nonverbal cues include signals that do not serve as a direct command but as observation and monitoring cues like the heart rate variability (HRV) and signals from peer devices (when connected to an ad hoc network).

3.2. Cognitive module

The cognitive module consists of a set of goals and the implicit/explicit representation sub-modules of signals received from the perceptual/motor module. Using the bottom-up learning approach (implicit first and explicit latter [13]), input signals are processed. The cognitive module is the brain and heart of the framework and is responsible for assigning what information is stored where and what action is to be taken and when. The role of the cognitive module is twofold: Process signals, and Generate actions.

- Process signals: Signals are processed into two representations (implicit and explicit representation), the implicit representation takes precedence in determining the action related to knowledge (procedural memory) and the explicit representation takes precedence in determining factual knowledge (declarative memory). The explicit representation is influenced by the user's feedback and the result of performed actions.
- Generate actions: Actions are generated based on information retrieved from the declarative memory, procedural memory and the set of goals. For instance, in shared control, actions generated takes into account users input, real-time environmental perception, knowledge from previous experience (this includes user's responses to feedback, prior knowledge and previous success registered in the declarative memory).

3.3. Memory module

The information processed in the cognitive module as explained above is pre-categorized into long term declarative memory and short term procedural memory. This module as well as the cognitive module are influenced by the ACT-R [7,28], desiderata for developing cognitive architectures as highlighted by R. Sun [13] and Vernon *et al.*[24] and human behaviour.

3.4. Action/Output module

The action module performs actions and sends feedback (success or failure) to the cognitive module.

4. Conclusion

In this paper, this study proposes an adaptive framework for mobility assistive technologies inspired by the ACT-R [7,28], desiderata for developing cognitive architectures as highlighted by R. Sun [13] and Vernon *et al.*[24]. The authors take advantage of the symbolic and connectionist representation to present a hybrid framework capable of learning and adapting over time. Although an overview of the proposed adaptive framework for mobility assistive technologies was presented, there are still numerous concerns to address. One of the main issues remains the most suitable connectionist and symbolic process to be implemented in the hybrid framework, which will be investigated in future works. In addition, it is still essential to resolve details of the adaptation/learning process in the framework, so it will be necessary to develop learning mechanisms in cooperation with reward systems as well as observation/inference systems for the framework.

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