Agent-Based Modeling for Developing Pervasive Persuasive Systems

Budhitama Subagdja
Joint NTU-UBC Research Centre of Excellence in Active Living for the Elderly (LILY)
Nanyang Technological University, Singapore
Email: budhitama@ntu.edu.sg

***Abstract*—Building a cyber-physical system consisting of many reactive elements that continually interact with each other may require considerable efforts to ensure that it behaves as desired. The scale of the issues to tackle is much expanded when it comprises human-factors to analyze and change (e.g persuasion). In this paper, a development methodology is proposed for building the kind of system that developer interacts and communicates directly with the components in the domain. The developer interacts with them in simulated or runtime context in order to instruct and shape the whole system. As a technique of Agent-Based Modeling, the entire system is considered to consist of interacting (semi-) autonomous agents that can reason, adapt, and learn at runtime. This approach of development requires a particular agent architecture that can reason and learn about human activity and social conditions comprising spatial, temporal, and hierarchical structure of information. In this paper, the teachable approach is exemplified using a simulated persuasive multi-agent system for elderly care in ageing-in-place domain.**

I. Introduction

Recent improvement in ICT and the field of Artificial Intelligence have fundamentally changed the way people interact and engage with technology. Fields like Ubiquitous Computing, Ambient Intelligence (AmI), or the Internet of Things (IoT) have looked at embedding and interacting computational devices within an environment to enable them perceiving and responding to the presence of people and their activities. Substantial advancement in perceptual input products and widespread adoption of low-cost but sensing-rich mobile devices (e.g smartphones, tablets, small embedded computers) have made the technology of realtime human activity tracking and analysis cost-effective and broadly affordable in the market.

This technological advancement requires distinct theory and methodology of development compared with the traditional model which mainly focuses on single computational entity with efficient algorithms to solve the problem. Instead of a single entity, the problem is approached as distributed components concurrently sharing the same environment and exchanging information with one another to achieve the desired goal [1]. Conventional ways of tackling this issue usually approach it by extending the abstraction of the problem and solution to cover additional aspects in the domain environment like spatial, temporal, or organizational structure. An example of that kind of abstraction is multiagent systems [2], [3] in which the system is regarded as multiple autonomous agents, each with its own purpose, working together to accomplish the overall objectives. Although most abstractions are used to hide the intricate details of the problem and letting the developer focuses more on higher level description, the same assumption as the classical one is still adopted that the development process is conducted through coding programmatic representation detached from the deployed runtime context.

Currently, the technology is no longer just for supporting tasks accomplishment or solve one's problem, but also to non-coercively change a person's behavior or habits. Fogg has suggested that the technology can be used to persuade people [4]. Examples of the domain of persuasive technology include education, healthcare, or ageing-in-place (elderly care). The complexity of the issue to tackle in persuasive system is increased especially when no complete model of the human target is available with a large variations of personality traits and possible behavior change (adaptation) of the target person. The issue may also include handling the interdependency between components of the system when they are built and designed independently from one another.

A radical approach is proposed in this paper that instead of relying on the initial abstraction, developing a persuasive system with pervasive components can be simplified by letting the developer interact and communicate directly with the components at runtime. The developer may give instructions to the components in the system to do the tasks they supposed to do while the components learn their relevant context to apply in the future. As an agent, a component may ask the instructor for clarification or raise question if there is still missing information. In this case, the components must be able to learn and understand the intricate structure of interactions between them and the instructor, together with understanding the target users. This requires a particular cognitive architecture for the agent to learn, adapt, and infer the complex structure of the world and activities within.

Parallel to Agent-Based Modeling (ABM) [5], the proposal suggests a view of the target domain as a set of (semi-) autonomous agents interacting within the same environment. In ABM, the user investigates the complex domain by running the model as a multiagent system to simulate the phenomena. Some practical tools (e.g [6], [7]) allows the investigator to perform exploratory studies by monitoring and modifying internal and external conditions of the agents at both individual and group levels at runtime. On the other hand, the proposed model put ABM and teachable approach together in the context of system or software development for which the agents are taught and shaped to make up the whole product. The exploratory process is conducted to capture the requirement, specification, design, and deployment release within the same runtime context. The mechanism of learning must be able to handle different representational structure like sequences, contexts, social relationships, hierarchies (nested) which are necessary to learn and infer human activities and their contexts. Using a custom-built simulation of ageing-in-place with a multi-agent persuasion system for elderly-care, the new approach of development is exemplified.

This paper is organized as follows. Section II discusses other related existing works. Section III describes the case and issues of multiagent persuasion system for elderly-care as background examples. Section IV describe the proposed teachable agent-based model for the domain. Section V exemplifies the implemented models.

II. Related Work

Means of simplifying abstraction and building process to let end users develop the systems have been around for decades. End user programming environments (e.g [8]) have been used by many to compose programmatic abstraction using graphical or direct manipulation user interface. Some have adopted the systems that can be taught or demonstrated by a lay person to accomplish tasks at runtime (e.g [9], [10]). A simple demonstrable system may simply just record the user actions. More sophisticated versions may perform generalization of the user intentions based on the user interaction history and can generate explanations explicitly (e.g as in [11]).

The teachable approach has been adopted in the field of robotic as well. In contrast to teachable software or applications, the aim of a demonstrable robot is mostly to aid the development of the robotbehavior rather than to help the end user to accomplish the tasks. A robot may have a complex intertwining set of operations which is too complex to describe or specify except when it is demonstrated directly in multi-modal interactions at runtime [12].

A robot may give some feedback when a demonstration is given to help the instructor understand the internal state of the robot. Social or emotive cues can be displayed by the robot to indicate the condition of learning [13] (e.g thinking, confused, excited) allowing the instructor to adapt the teaching strategy when needed. The robot may also ask questions at the right context to obtain the necessary information as parts of its Active Learning (AL) strategy [14]. The question can be asking for confirmation or demonstration from the user about particular skills or features to learn. Robotic programming by demonstration has also been applied to multiple robots that are taught simultaneously but in coordinated fashion [15], [16]. The proposed approach in this paper is a teachable framework that adopts a similar objective to most demonstrable robotics approaches in which the goal of the instruction is to simplify and ease the development process. However, it is rather applied to software or applications. Each component can be a piece software or application that runs autonomously and functions independently. The instructor can choose a particular individual component or a group to teach. A group of components share each other information and may work together as taught.

III. The Case of Multiagent Persuasion for Ageing-in-Place

In this section, issues in applying technologies for Ageing-in-Place are discussed. Ageing-in-Place (AIP) can be considered as one's ability to live safely, independently, and comfortably in one's own home and community regardless of age and ability [17]. The concept of AIP has risen up as the world demographics are changing. One approach as a response to the demand is to support one's daily activities at home or local community using ICT, which is the one discussed in this paper. There are silver challenges that one must face in the context of AIP as the consequences of independent living and the lesser involvement of human caretakers:

- *Physical*. Declining physical health and stamina affecting one's capability to conduct daily tasks with some risks of disabilities.
- *Cognitive*. Declining mental health and memory capabilities for managing and organizing daily tasks.
- *Emotion*. Possible loss of motivation and risks of depression.
- *Social*. The need of being actively, safely, and comfortably engaged and connected with others.
- *Sustainability*. Continual responsibility to oneself, society, and surroundings.

To deal with the intertwining factors of the challenges, distributed networked computers and pervasive sensory devices can be used to make a smart-home environment. However, beyond unobtrusive monitoring through sensing devices that builds a comprehensive model of the situation, the system should promote better lifestyles. In that case, the system should also be persuasive by non-coercively trying to change the occupant's behavior, attitudes, or habits in order to address some of the silver challenges above. The effectiveness of persuasion depends on whether the target person is well motivated and having the ability to change towards the target behavior [18]. It is clear that persuasion needs thoughtful strategy and planning in order to be succesful [19].

An AIP system with persuasive capabilities has been developed to deal with the silver challenges above [20]. It consists of an assembly of virtual assistant agents each is designed to serve the user for particular aspects in the silver challenges. Different agents may take particular roles ranging from updating perceptual information to persuading the user. At this stage of the writing, two different persuasive agents have been implemented:

- *Smart butler* is a virtual assistant resided in a mobile device (smartphone or tablet) that focuses on daily activities, social connections, and sustainable living. It mostly take the role as a reminder and recommender in relation to daily living and social events.
- *Virtual nurse* is a virtual assistant running in dedicated computing device or personal computer displayed with human-like appearance. It can communicate naturally with the user using voice-based interaction. The main role of the nurse is a healthcare advisor that giving advice and persuading the user regarding healthier condition and lifestyle.

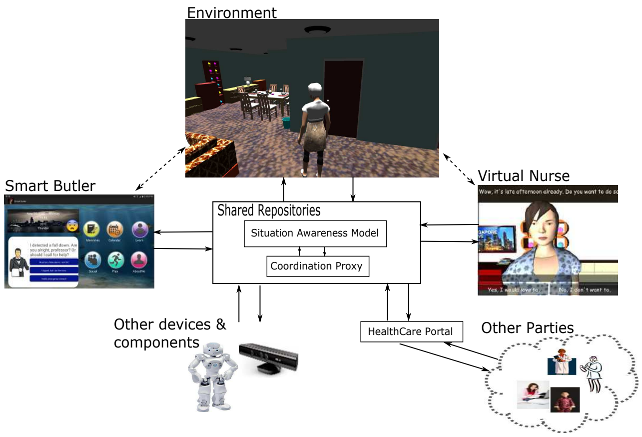

Fig. 1. Multi-agent Smarthome system for Ageing-in-Place

An agent by itself is fully functional as an application which can be deployed independently. However, it is required to operate together with others if they are deployed in the same domain environment. All agents share information through shared repositories consisting some parts as follows

- *Situation Awareness Model* is for maintaining and storing information about the context and actual situation happening in the environment including the condition of the occupant.
- *Coordination Proxy* is for maintaining information about the interaction and activity of the agents and the occupant. It is used to detect interdependency among the agents during their operations.

Figure 1 shows the multi-agent system for AIP wherein heterogeneous smart applications interact with each other as assistant agents through the shared repositories. It is shown in the figure that other devices or components can be easily integrated by letting them connected with the repositories. It also allows other parties (e.g relatives, doctors, health consultant, caregiver) to participate in the caring via a connected healthcare portal. This allows someone related to the occupant or with granted access to monitor and take necessary actions by controlling, to some extent, the agents' operations.

With *coordination proxy*, the shared repositories allow the agents not just to infer or predict the intention of the user, but also be aware of the intentions of other agents especially in the context of persuasion. Figure 2(ii) shows a shared information structure that enables coordination among the agents. Agents may share what an agent (or the user) believes (Belief B) about what, when, who, and how things are happening or performing. They also exchange information about what they want and do (Intention I) so that they can coordinate their persuasion strategies to make them more effective 2(i).

Some challenges and issues in relation to the development of the AIP system can be identified as follows:

- **Coordinating persuasions**. Different persuasions or advices from different agents may interfere or support each other. In [21], different types of interdependency between persuasions in multiagent settings have been identified with some possible mechanisms of resolution [22].

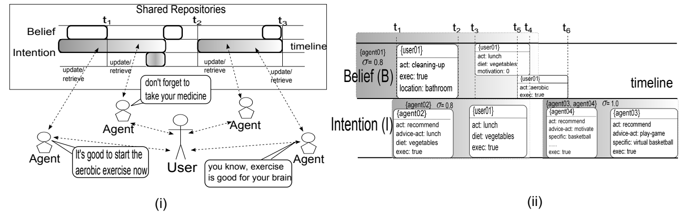

Fig. 2. Shared repositories: (i) Coordinating multiple persuasions by multiple agents; (ii) Information structure for coordination consisting of beliefs and intentions of all parties

- **User (elderly) and context (caregiving) modeling for persuasion**. Currently, no much data about the characteristics of elder user in the context of persuasive technology are available. One way to tackle this is by acquiring the model directly from the recorded user activity and interaction with the system. An adaptive model of persuasion strategy in this context is suggested in [23].
- **Social intelligence and open-ended adaptation**. A persuasive agent like the above must be able to distinguish one user or participant from another and adapt its persuasion strategy accordingly. As new agents or participants may join or leave anytime, the agent must be able to distinguish the one already known from a newcomer. In other words, the agent must be designed to be socially intelligent and can learn without limit.

IV. Teachable Cognitive Components

The challenges and issues described in the previous section mostly deal with the lack of information and knowledge in the corresponding field. On the one hand, the issues are social-ethical that the advices or persuasion must be appropriately delivered according to the particular characteristics and conditions of the user. On the other hand, there are technical issues in which the system must be flexible, adaptive, and autonomous enough to deal with ever-changing circumstances. In this section, the teachable framework is described from both perspectives: social-ethical consideration and technical constraints.

A. Instructional Framework

It is always risky and perhaps unethical (see [24]) to let the technology, no matter how sophisticated, take care someone fully automatically without human intervention. However, the question remains that how much autonomy the machine can be given to the task if human caretaker may still be involved at least partially. In this paper, the proposal is to let the agent be partially controlled by a skilled or more competent person but over time improves itself and adapt its level of autonomy accordingly.

Figure 3(i) illustrates the relationship between a person instructor, the agents, and the user. The human instructor may fully take the control of the tasks in the beginning while teaching or demonstrating the agents in carrying them out. Over time, as the agents have learnt much about the tasks, the role of the instructor is reduced and may be taken over by the agent at a certain level.

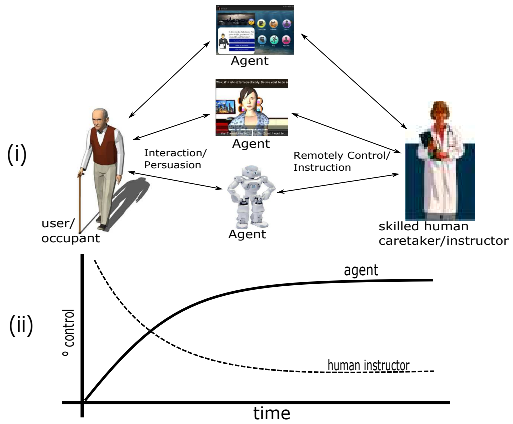

Fig. 3. (i) A skilled human caretaker or instructor remotely controls the agents to interact with the user; (ii) The change of the level of control between human instructor and the agent. The instructor should be less and less in control, and over time an agent may settle its autonomy to a certain degree.

This model of interaction can be generalized as a component-based framework in which a number of components that make up the whole system are smart teachable agents. Figure 4(i) shows the diagram of a multi-agent system for caregiving in which several agents can be taught by the developer or a domain expert at runtime. However, it is also possible that other participants may be involved in the teaching-learning process like providing more information or instruct some of the agents in the system to perform particular tasks.

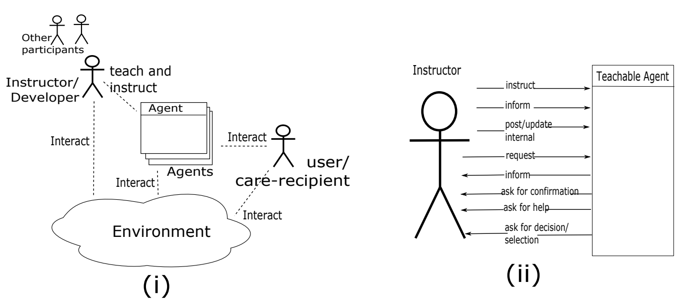

Fig. 4. Framework for teachable multi-agent systems in caregiving: (i) developer/instructor (and other participants) can teach the the agents to interact with the care-recipient; (ii) Teaching-learning protocol between the instructor and the agent.

Even though the agent can be fully autonomous to control its actions and make its own decision, some ethical issues may be addressed by keeping some important decisions to be made by human. Figure 4(ii) shows that an agent is not just performing what is instructed or asked by the user but may also question the instructor, at certain points, about important information or to let the instructor select the choice.

B. Cognitive Architectures

The framework requires domain specific operations and functionalities to be transparent or controllable by the agents (components). In that case, a teachable component can be considered as a wrapper object that encloses a domain-specific object or service that may interact directly with the domain environment as shown in Figure 5(a). *Agent façade* is the wrapper to control the domain object makes it teachable by providing the interface to interact with the user (developer) and other agents.

The *façade* maintains some data structures of mental notions following BDI agent architecture [25] as follows:

- *Belief, Desire, Intention,* and *Schema* specify respectively facts or actual situation in the world, what the agent wants at the moment, the decision made about them (the goal to achieve and the selected plan to realize it and execute), and the collection of recipe that the agent can follow (including rules or internal procedure for execution).
- *Episodic buffer* is a finite trace of events and actions to keep the teaching and learning dialog in context.

The BDI mental representation can also be nested and attributed to another agent (e.g user, instructor, or other agents) so that the agent may believe that the instructor intend to teach the agent to do a or the agent may intend that the user eventually wants to do b and so on. Figure 5(ii) shows the internal structure of the agent façade.

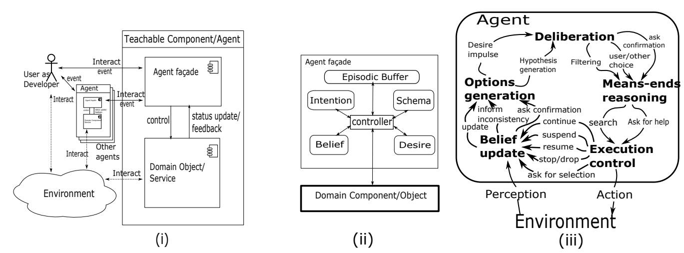

Fig. 5. (i) Framework for teachable multi-agent systems in caregiving; (ii) the internal structure of façade; deliberation cycle of a teachable agent.

As a BDI agent, each data structure is continually interpreted and updated by a controller in deliberation cycles [25] consisting of basic operations such as *belief updating* or updating, *generate options* to achieve, *deliberation* by weighing the options, *means-end reasoning* and *execution control*. However, it is also adapted to cater the agent with teachable features. As shown in Figure 5(iii), each basic step of the cycle have more branches or options including the ones incorporating others (e.g instructor, other agents). For example, in belief update process, some inconsistent beliefs may be posted or instructed by the user. As a part of the process the agent may ask the user for confirmation that the inconsistency is an error or on purpose. Similarly, when the agent has failed to find a way to achieve its desire, the agent may ask the instructor or others for help.

This relationship with others including the instructor is also reflected in Figure 4(ii) in which the component may not just be following what has been instructed but may also be questioning it like asking for confirmation (to update belief or to keep the hypothesis to process) if some interfering conditions are detected. This bi-directional communication between the developer and the component being used is reasonable since instructions provided by a human instructor can be incomplete, erroneous, or missing significant parts that can be very helpful to retrieve the appropriate choice. In that case the component must employ a kind of similarity matching between what is presented by the instructor and what have been stored in the *schema* repertoire.

To learn a new schema with sequential and hierarchical structure, it should be considered that the component may also need to distinguish a new specific situation from the one that is just a generalization of existing class and make some exceptional condition if necessary. For example, a component must be able to learn that in general the occupant like do to any kind of activity related to working out in spare time, but not in a particular time and day since the one prefer to watch a favorite TV program. In this case the component must learn to make exceptions.

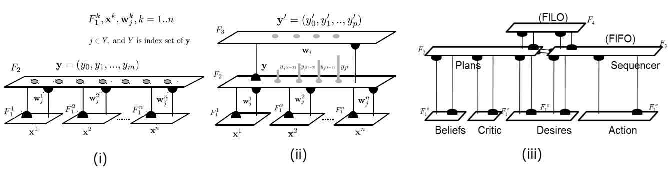

Fig. 6. Fusion-ART-based architecture: (i) Fusion-ART; (ii) fusion-ART based Episodic Memory [26]; (iii) iFALCON for hierarchical planning [27]

Learning the activities and schemas like above is non-trivial for most existing machine learning techniques. A potential approach is to use Fusion-ART (Adaptive Resonance Theory) based neural network architecture which is relatively light-weight in computation (suitable for components) and robust to noises. A fusion-ART network [28] has particular features that are unique compared to the others neural networks: incrementally growing (adding) categorical neurons; can detect mismatch and decide whether to generalize or store patterns as a new class; no separation between categorization and learning phases; and support multi-paradigms of learning (supervised, unsupervised, and reinforcement learning). By treating a single fusion-ART as the building block of multi-layered networks, it is also possible to make it robustly learn and matching sequential and hierarchical patterns. Different configurations of the network can be seen in Figure 6. The promising results of each configuration can be depicted in Figure 7.

V. Implemented Examples

In a preliminary study about the teachable framework. The component model has been applied to a custom built simulation framework for the ageing-in-place. In the simulation, an artificial occupant is made as an avatar residing in a virtual house environment. The occupant resided in a virtual house in which its movement inside it can be controlled externally by the user (developer) or it can be based on a programmed script. Figure 8 shows the screenshot of the simulation GUI with 3D virtual environment display in a web browser (implemented with Unity 3D and HTML5). The teachable model can be employed to the virtual occupant to ease the development of its behavior. Figure 8 shows that the instructor can observe the options and hypothesis that the agent (occupant) generated based on the activity timeline display. Whenever the controlled movement is detected to potentially obstruct an existing intention, the occupant agent asks the user for choices like suspending the current activity, or continue the actions while and ignore the last control instruction (treated as an error). Similarly, when it identifies the intention of the instruction, the new recorded actions may be learnt as a new schema.

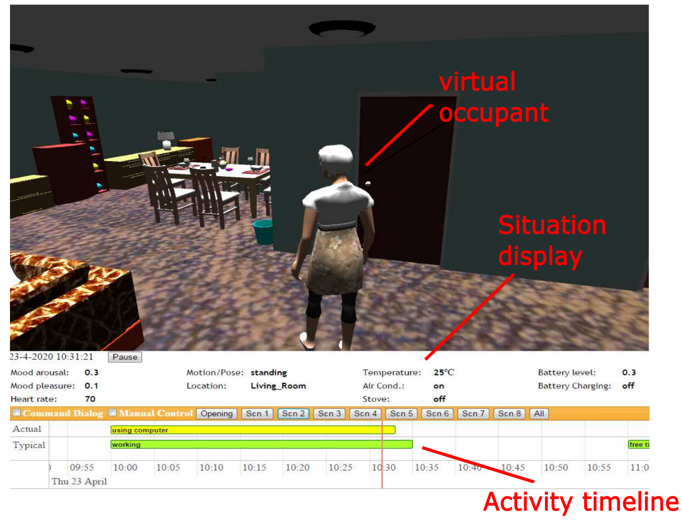

Fig. 8. Framework for teachable multi-agent systems in caregiving

The teachable framework can also be applied to persuasive agents. For example, when a conflict of persuasion occurs (e.g one agent advises the user to do exercise, while the other suggests taking a rest), the instructor may suspend the persuasive intention of one agent while passing the advice from another. In this case, more than one instructors can be involved and the agents should learn about conflict resolutions. Until this stage of writing, this simulation platform is still under development and not all features as discussed above are implemented or applied yet.

VI. Conclusion

A framework of teachable components for runtime development of caretaking system has been proposed. The proposed model allows the developer to instruct or teach every component in the system to learn new behavior or operations. The approach brings the method of agent-based modeling to system or software development beyond generative science in which variables and parameters in the system can be tweaked and explored at runtime. The desired configuration of the system can be captured as the agents learn to interpret the instruction and adopt the correct procedural knowledge from instructions and experiences. Consequently, the component must be able to generalize input streams while separate particular inputs as explicitly taught or are specific to the context. It must also be able to robustly handle sequential learning and hierarchical inferences. The features described in the framework have been partially implemented in a virtual ageing-in-place environment wherein a virtual occupant and some persuasive agents are teachable.

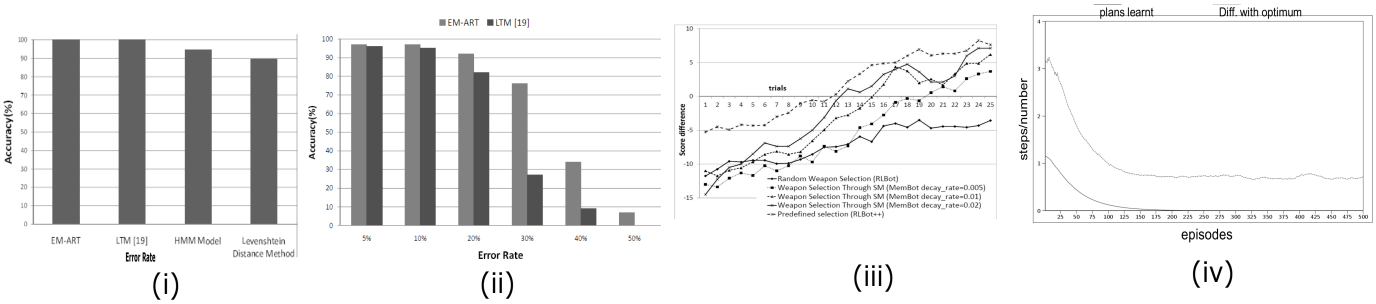

Fig. 7. (i)Episodic memory with the ART is robust compared with others like hidden markov and basic text matching [26]; (ii) ART-based episodic memory is robust compared to the other approach given the noisy input [26]; (iii) Reinforcement Learning can be applied side-by-side with memory consolidation system to improve performance [29]; (iv) iFALCON can learn and converge strategies in blocks-world planning domain [27].

This study in the teachable components framework is still preliminary and far from complete. Making most of the components and elements in the system to be teachable is the main target to complete. In this case, the teaching-learning protocol may also need to be updated according to the particular situation in domain environment. On the other hand, it is also worthwhile to apply the framework to another domain besides elderly care. Other fields like hospitality, military, or education may also be constrained with ethical issues that could be addressed in similar ways.

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