Assessment of Agent Architectures for Telehealth

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Abstract. On government level, Denmark has published both strategies and technical guidelines to strengthen implementation and use of telehealth in the Danish healthcare sector in the future. Consequently telehealth solutions will become an integrated part of the daily life of the patients equipped with these solutions. This paper proposes an architecture for a multi-agent system to be implemented together with the telehealth solution in a patient's home. The purpose of the multi-agent system is to incorporate more intelligence into the gathering of healthcare related data and thereby learn about the behavior and level of physical activity of the patient, and other interesting context information.

Keywords: BDI, infrastructure, healthcare, telehealth, user modeling.

1 Introduction

The societal challenges dictated by the aging population over the next decades needs no further introduction. The general awareness of the consequences has increased over the last years, and politicians have highlighted it in the context of the financial crises.

Healthcare expenses will increase dramatically over the coming years unless solutions are found that empower users to be more self-maintained and take more responsibility for their care and rehabilitation. Chronic disease management is a serious burden to all healthcare systems – 70-80% of healthcare budgets in European countries are spend on chronic patients.

Telehealth is envisioned to be one of the primary cost-savers, and medical devices to monitor vital parameters in the home of the patients are both available and reliable. However, the infrastructure to bridge communication both ways between the home and healthcare professionals (primarily hospitals and practitioners), and within the home setting is not yet mature. Standards are too complex for most developers and with telehealth being part of the daily life activities of the patients, more focus on user preferences and individualization will make the solutions much more flexible, and thereby more focused on the individual user and quality of life.

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A multi-agent based architecture provides some of the characteristics requested for systems in this domain; adaptability, customization, and the ability to handle dynamics and complexity. Thus, in this paper we will evaluate different general architectures for multi-agent systems in the perspective of telehealth, and we will introduce our proposal for an agent based architecture for telehealth solutions in the context of the Danish healthcare sector and the standards used within.

2 Architectures for Multi-agent Systems

2.1 BDI

BDI [1], an abbreviation for Belief-Desire-Intention, is an architecture for designing intelligent agents, the main software components of multi-agent systems, henceforth MAS. The BDI theory is based on the three concepts of beliefs, desires, and intentions [1]. By combining and implementing those three concepts into a software agent, it becomes an intelligent agent capable of practical reasoning like the process humans go through multiple times daily in their everyday life [2].

The ‘belief’ component represents the knowledge base of the agent [3]. The term belief is preferred to that of knowledge because the information may be imperfect, and not true outside the scope of a certain agent. An agent must store information about its beliefs, possibly about both the surroundings and itself, for it to be able to make decisions on an updated foundation.

The second component ‘desire’ describes the motivational state of an agent, i.e. descriptions of the objectives the agent wishes to accomplish [1]. An agent may have multiple desires. With multiple desires it is the internal reasoning of the agent that has the task of deciding which objective to achieve at a certain point. Information such as payoffs and priorities, associated with the objectives, can be used in the reasoning process.

The third and final component of the BDI architecture is ‘intention’. The intention states which desires the agent has committed to achieve [2]. When an agent have decided upon an intention, it will try to achieve the desire through execution of plans containing a set of actions the agent can perform [1, 3]. Agents operate in dynamic environments, where the surroundings can change, hence the belief component. Based on the information about the environment and the desires of the agent, the intention component has the purpose of deciding if and when the agent should commit to achieving another desire, and leave the previous one unachieved.

2.2 ACT-R

ACT-R [4] is an abbreviation for Adaptive Control of Thought-Rational. ACT-R is an architecture that enables modeling of cognitive tasks, such as learning, decision making, and working memory [4, 5]. According to [5] ACT-R can be used in the MAS to play the role of a human because ACT-R is capable of predicting and explaining human behavior. The architecture of ACT-R is found in Fig. 1.

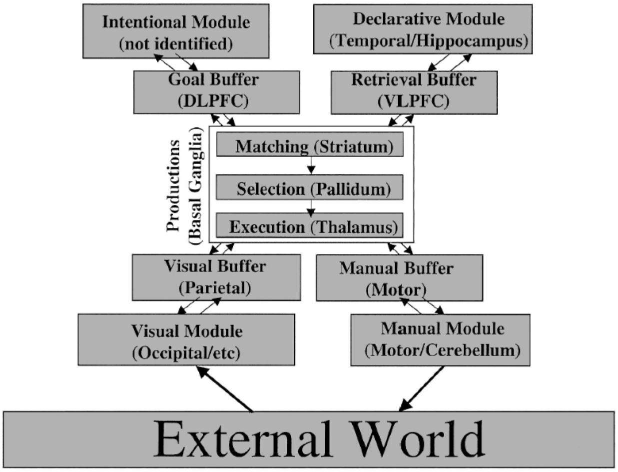

Fig. 1. The ACT-R architecture [4]

As can be seen from Fig. 1 the ACT-R architecture consists of five different components. Based on [4, 5], each of the components are described shortly.

- The Intentional module keeps track of the intentions of the human/agent being modeled, as well as the behavior and sub goals that is expected to lead to the intentions. The intention modules in ACT-R and BDI are alike in that both contain plans/behavior/sub goals leading towards a certain target. However, the purposes of the two modules are quite different. In BDI, when an agent decides upon a certain intention to pursue, it will execute the actions in the plan expected to lead toward the fulfillment of that intention. In ACT-R, on the other hand, the behavior of the intention will not be executed until the Production module has retrieved the intention through the goal buffer.
- The Declarative module is the memory of the architecture. The information found in this module is the facts and experiences of the agent. The declarative information can be retrieved by the Productions module based on the activation level of the information.
- The Productions module is the central component of the architecture. It communicates with the other four components through buffers, each with a capacity of one piece of information at a time. Through production rules, and the information in the buffers, the production system decides upon the operations to be performed by the agent.
- The Visual module is one of two components that communicate with the external world. The purpose of this module is to identify objects in the external world
- The Motor module is the component that is capable of changing the external world.

2.3 AT

AT, an abbreviation for Activity Theory, is a psychological theory, that defines a framework for studying how an activity leads to an outcome [6, 7].

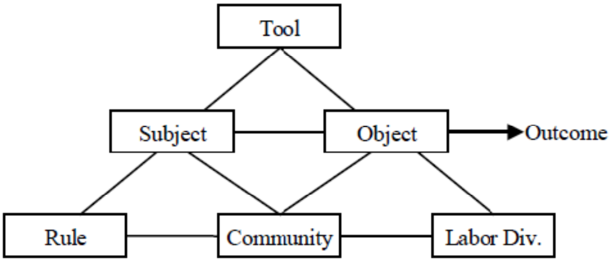

Fig. 2. Components in an Activity Theory system [7]

From Fig. 2 it can be seen that AT defines six different components. Within these components it is possible to describe the elements pertaining to an activity, which lead to an outcome/goal [7-9]. The six components are [7-9]:

- Tool refers to instruments that the subject can utilize to achieve an objective. Tools can be both psychological and physical. In the agent paradigm the tools can be the actions an agent can execute.
- Subject is the individual that works towards achieving the objective. In the agent paradigm the subject is an agent.
- Object is the purpose of the activity.
- Rule mediates between the subject and a community. This mediation includes social relations and norms.
- Community contains all the subjects in the environment, in which the activity happens. According to [9] AT "*rejects the isolated human being as an adequate unit of analysis*". That means for an agent to be able to achieve an object it has to part of a MAS.
- Division of labor mediates between the community and the object. This component describes how the subjects in the environment are related to object, i.e. who does what in terms of achieving the outcome.

Though AT is a psychological theory it is relevant in the context of this paper, because there are examples of scientific work, where AT is used within the multi-agent paradigm or discussed in relation to it [6-8].

Unlike the BDI and ACT-R; AT has a more holistic view on the whole system, i.e. the elements in the surroundings of the subject (the specific agent), than the subject' cognitive capabilities, to be used to achieve its objects/goals/intentions. An example of this is [7], where AT is used in the context of healthcare, to understand and simplify the complex activities in the domain. Ricci et al. [6] do present some interesting thoughts on the coordination of MAS. At a later point these thoughts may be considered in relation to the MAS that will be implemented in the Patient@Home project (http://www.patientathome.dk/).

2.4 Comparison of BDI and ACT-R

Table 1 shows a concise comparison of BDI and ACT-R in relation to the architecture described in section 3.

Table 1. Comparison of BDI, ACT-R, and AT

	Advantages	Disadvantages
BDI	- Is situated, goal directed, reactive, and social [10]. - Ability to handle and work in a dynamic environment.	- In the original BDI were there no mechanisms of learning from experiences [10].
ACT-R	- Based on cognitive psychology and brain imaging and thereby able to simulate human cognition and behavior.	- Each of the buffers only has a capacity of one element. - Developed to simulate the human brain and behavior [10], however the architecture includes other components that need to be modeled and developed as well.

3 System Architecture

Fig. 3 is a high-level illustration of our thoughts for a system architecture in a Danish telehealth context.

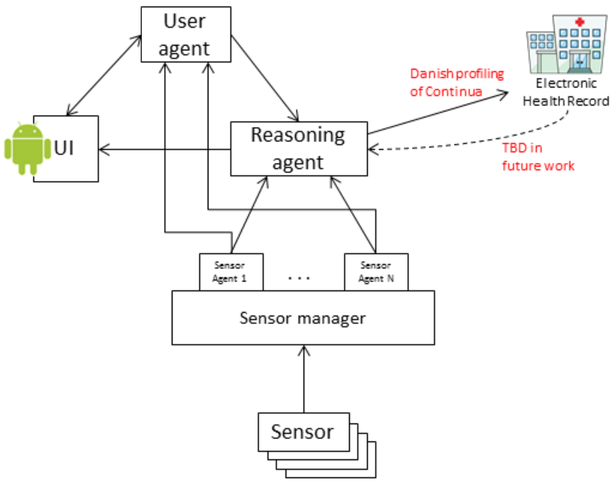

Fig. 3. Expected system architecture of agent system

The data collected and used within the system will come from state-of-the-art healthcare device/sensors for the personal use in the context of telehealth. The devices can, for instance, be wearable, connected to training equipment, and/or location constrained (e.g. home setting). In the future another source of data can be the EHR systems in Denmark. However, at this point, no standard has yet been agreed upon of how to implement bidirectional exchange of healthcare data with the Danish EHR systems. This is a challenge, which is expected to be focused on at a later stage in the Patient@Home project. Therefore at the moment the agent architecture in Fig. 3 will be focused on data collected from the devices for personal use.

The MAS proposed in this paper consists of three types of agents: sensor, reasoning, and user. The remainder of this section is dedicated to describing the purposes and capabilities of each of these agents.

3.1 Sensor Agents

The purpose of the sensor agents will be to handle data concerning new readings from state-of-the-art telehealth devices. A later study will identify the exact devices and standards to build the architecture upon. Stated briefly, obvious candidates are devices based on the ISO/IEEE 11073 standard and/or ANT+ [11]. The ISO/IEEE 11073 is the standard chosen by the Continua Health Alliance [12] for their certified devices. Denmark, as the first country worldwide, has decided that the future national infrastructure for telehealth should be based on the initiatives of CHA [13-15]. The strength of ANT+ is that the number of devices and possible managers implementing the ANT+-stack increases rapidly.

Compared to the other types of agents in the MAS, the sensor agents will have a limited scope. The sensor agent must be able to:

- Observe new readings from its environment.
- Parse a new reading into the language used within the MAS for agent communication.
- Communicate to the rest of the MAS, that a new reading has been observed.

As mentioned above the sensors providing the data for system can be used in many different locations, and depending on the situation a non-fixed-subset of the sensors may be in close proximity with the manager/hosting device collecting the data. Despite the changing environment the system must be able to continue its execution without failure in data collection and unnecessary disturbance for the user.

3.2 User Agent

The focus of this research is to make the future telehealth systems in Denmark even more centered on the individuals, using them as an integrated part of their everyday life. The user agent of the MAS will be an essential component to achieve this. The user agent must be able to:

- Receive new readings data from the sensor agents.
- Store user preferences. The preferences must be changeable through the UI.

- Respond to various requests by the reasoning agent about preferences and Activities of Daily Living (ADL) [16].

Through the data received from the sensor agents, the user agent will be a *Doppelgänger* [17] of the actual user. The user agent is expected to learn the behavior of the user (e.g. eating patterns, patterns in the intake of medication, when telehealth devices are preferably used), the user's level of physical activity, the "normal" level/threshold values of vital signs from medical devices. All this context information, contributes to an understanding of the patient's ADL.

3.3 Reasoning Agent

The reasoning agent is the most central component in the system architecture depicted on Fig. 3. The reasoning agent must be able to:

- Receive new readings data from the sensor agents.
- Receive data about the user. These data will affect the decision making within the reasoning agent.
- Send data to the UI component to be presented to the user.
- If integrated with the rest of the Danish healthcare sector; to send healthcare data based on the HL7 PHMR document format, and to receive relevant patient related data from the Danish healthcare sector to provide the patient with a full picture of his/her condition. The last element (shown on Fig. 3 with a dotted line) is a challenge that will be addressed at a later stage in the Patient@Home project.

In section 3.2 the concept of ADL was mentioned. According to [16] keeping track of the patient' ADL can help the identification of deterioration of well-being. This will be an important task of the reasoning agent. As stated above, the reasoning agent is supposed to send healthcare data to other systems in the Danish healthcare sector. Through the data about ADL and new readings, the reasoning agent can add appropriate context information to the healthcare data, and thereby give the healthcare professionals additional and possibly valuable data to evaluate.

4 Discussion

This section is dedicated to identifying the agent architectures (BDI or ACT-R), which fits the different intelligent agents (sensor, user, and reasoning) in the MAS best.

Considering the capabilities of sensor agents the obvious choice of design architecture is BDI: The belief of the agent will be a new reading; the desire of the agent is to inform the MAS about new readings; and the intention of the agent is to send information about the a new reading as soon as it is received and properly parsed.

The user agent in the MAS will be a doppelgänger for the actual patient through gathering of sensor data, but it will also contain preferences, that the user him/her-self can change. Being a cognitive architecture, ACT-R, was a consideration as agent architecture for modeling the user in this MAS. However, after reading existing literature by Nunes et al. [18, 19] on developing user models and personal preferences in MAS, BDI has been chosen as the architecture to build the user agent upon. In their work on user modeling Nunes et al. have contributed with a domain independent software framework to support the development of Personal Assistance Software (PAS). Telehealth solutions in home settings are PAS applications. The PAS software framework contains a user model, one of the most fundamental components, which is created and evolves upon the preferences of the user. In [18] the BDI architecture is recommended, in relation to user modeling, because it "*facilitates the implementation of user customizations in a modular fashion so that components can be added and removed as the user model changes*".

Both the sensor agents and user agents will be based on the BDI architecture, and so will the reasoning agent. Besides making sense in terms of the MAS simpler by using only one agent architecture, BDI is the most applied architecture for deliberative agents [20], which is the behavior the reasoning agent is expected to expose.

5 Conclusion and Future Work

This paper constitutes the foundation for the development of a software platform for the telehealth domain. The platform will be a multi-agent system based on the BDI architecture with three different types of agents: user, reasoning, and sensor. The purpose of the agent architecture is to incorporate more intelligence into the gathering and handling of patients' telehealth data through the ability to understand and use relevant context information.

The work described in this paper is one of the initial steps towards the development of the complete agent architecture. The next step in the development of the architecture is to design an ontology, which will define the concepts, properties, and interrelationships in the telehealth domain. The purpose of the ontology in the Patient@Home project is to make it easier to integrate new applications in the system described in section 3, through a shared vocabulary which is a foundation for securing semantic interoperability.

The ontology will be designed based on the state-of-the-art in terms of 1) devices and other data sources available for both monitoring and context information, and 2) existing ontologies for the healthcare domain, context aware systems, and user modeling. The identification of the state-of-the-art in these areas is currently ongoing through the review of relevant literature.

The implementation of this agent based architecture will begin when the ontology has been designed. The agent platform is expected to be implemented in the Java based framework BDI4JADE [21]. This decision is due to previous experiences with the JADE framework, and the identified need for the BDI architecture. The ontology is expected to be built in the Protégé ontology editor [22].

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