Agent-Supported Assessment for Personalized Ambient Assisted Living

Helena Lindgren
Department of Computing Science
SE-901 87 Umeå
Sweden
helena@cs.umu.se

Farahnaz Yekeh
Department of Computing Science
SE-901 87 Umeå
Sweden
yekeh@cs.umu.se

Jayalakshmi Baskar
Department of Computing Science
SE-901 87 Umeå
Sweden
jaya@cs.umu.se

Chunli Yan
Department of Computing Science
SE-901 87 Umeå
Sweden
chunli@cs.umu.se

ABSTRACT

Existing approaches to ambient assisted living (AAL) often fail to consider a human agent's needs from a holistic perspective. In particular the regular assessment of their changing abilities, skills and limitations are often treated as a separate matter in healthcare, thereby affecting the possibilities to provide support tailored to their current condition. Therefore, the objective of this work is to integrate assessment done by the healthcare professional into the framework of AAL. We use a case scenario in the collaborative development with domain experts to demonstrate and develop the interaction between software agents and with the older adult in assessment and adaptation for supporting him/her in a home environment. The scenario also serves as an outline for a requirements analysis of the formal agent-based dialogues to be implemented. The results include a partial implementation of the scenario done by domain experts in their use of a semantic web-based knowledge and interaction modelling environment for domain professionals (ACKTUS). The resulting prototype applications are exemplified in a description of the scenario and an initial prototype implementation of selected agent-based diagnostic dialogues is presented.

Keywords

personalization; knowledge-based systems; agents; assessment; argumentation-based dialogues; ambient intelligence; smart environments; ubiquitous computing; pervasive healthcare

1. INTRODUCTION

In order to equip an individual with computer-based support in daily living for increasing autonomy, security, health, social inclusion and quality of life, a holistic view on the individual's situation needs to be adopted. The wishes, needs and abilities of the individual need to be assessed in order to optimize the design of the tailored support. Furthermore, the assessments need to be done continuously, in order to adjust the tailored support to changing needs, abilities, wishes and contextual factors. Therefore, we integrate assessment into a framework for developing and maintaining ambient assisted living, with a combination of methods where the professional assessment done by health care professionals, partly accomplished by agent-based dialogues, plays a key role [1]. The results of these assessments determine wether a person would benefit from using, or continuing using the system, and how it should be tailored to changing needs, e.g., in what way the individual best interacts with the system and what kind of support should be provided.

The framework proposed in [1] synthesized, and was built upon results from 1) a case study where eight older adults were using tailored web interfaces for activity support during two months, where the content and interaction design were based on occupational therapists assessments [2], 2) the work on developing a semantic web-based knowledge and interaction modelling environment for domain professionals (ACKTUS) [3, 4], and 3) the work on developing an adopting an ego-centric interaction model for assessing the interaction environment [5, 6, 7]. These prototype systems aim to collaborate by means of a service-oriented architecture through the proposed multi-agent system and constitute an ambient assisted living (AAL) home environment that serves the purpose to support and maintain a holistic user-centred view of an individual's life situation. The tailoring of the AAL environment to an individual is ideally based on a combination of automated methods for skills and ability detection, activity recognition and evaluation with the professional's regular assessment of the individual's ability, needs and wishes to perform different activities (e.g., ADL and leisure activities [8, 9]). The professional's assessment provides information about how interactive systems should be adapted to the individual, e.g., based on physical, cognitive, social and/or psychological limitations and abilities.

The purpose of the work presented in this paper is to

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develop a multi-agent system that takes knowledge repositories developed using ACKTUS into use in dialogues between agents and with human users. The contributions of this paper are the following: an architecture of the multi-agent system basing the functional requirements on a case scenario and a persona; an extension of an inquiry dialogue system for improving human agents' interaction with software agents; and a prototype implementation of selected agent-based diagnostic dialogues. For the purpose of this paper, we assume that the activity recognition system feeds information into the knowledge bases about the individual, to be used in assessments.

The paper is organized as follows. After our case scenario is described, we focus on the dialogues between human and software agents that utilize ACKTUS knowledge repositories. ACKTUS is described in subsequent section, followed by a section where ACKTUS is extended with agent-based argumentation dialogues. An initial prototype implementation of selected diagnostic dialogues is presented. A section reviewing related work is presented and the results are discussed.

2. THE RUT PERSONA AND SCENARIO

We focus our requirements analysis on a *persona*, an archetype of a potential user and a case scenario [10, 11]. The main obvious benefit of applying this approach is that it allows for sharing a common goal scenario among all professionals participating in the development and across professional domains. The persona functions as a knowledge artefact together with the knowledge artefacts in the form of support applications mediating the different professional domain's knowledge in the development process. Our scenario is a description of how the anticipated use situations may proceed when technology is developed to support the situations [12]. The main scenario is designed to capture a holistic perspective on assessment in a use situation (i.e. from a health care professional's perspective), which makes our scenario different from e.g., [13]. However, the intervention part gives also detailed descriptions of the desired activities to be performed from the perspective of the older adult. Moreover, we use the persona and scenario for specifying the functional requirements of the multi-agent system, which will be the focus in this paper, and for evaluating the developed support applications (a pilot study of the development driven by domain professionals and evaluation is presented in [14]).

Our scenario is based on an authentic case of an older woman who suffered from a few falls before a hip fracture became the result with a long hospitalization with severe anxiety, delirium and fatal complications as a consequence. We envision a different scenario and outcome by introducing the AAL environment as a supplementary intervention to better meet her changing needs. This case shares needs and wishes also with some of the participants in an earlier case study and is therefore considered representative [2]. The time period in focus spans over 8 months, initiated by a visit by the occupational therapist (OT) for the initial assessment. The reason for initiating the contact with the OT was not cognitive impairment, but the question was risen by the son. Interventions were decided upon and realized. Support applications are envisioned to be instrumental in the interventions, partly by enabling a continuous follow-up. We explore and describe the case study as five distinct but related activities: 1) initial assessment, 2) referral to physician for assessing a potential dementia, 3) determine interventions, 4) apply interventions in the daily life of the individual including a continuing assessment (and follow-up), and 5) a renewed assessment (Figure 1). In this paper we set focus on the dialogues envisioned between human and software agents. In the following subsections the different phases of the scenario is described, in addition to the different actors and how the knowledge-based support applications created by the domain experts are integrated in the scenario (*I-rehab* for OTs, *I-dementia* for physicians, *I-care* for nurses and *I-Help* designed for the older adult and relatives, see Figure 1). The user interface implemented for evaluating the dialogues to be conducted with the older adult is text-based with structured answer alternatives. However, in the future the content of dialogues can be medicated by other modality than text, tailored to the individual. The primary software agents identified are the *Domain Agents* (DA) representing different knowledge domains and the *Coach Agent* (CA). They are further described in Section 4.1.

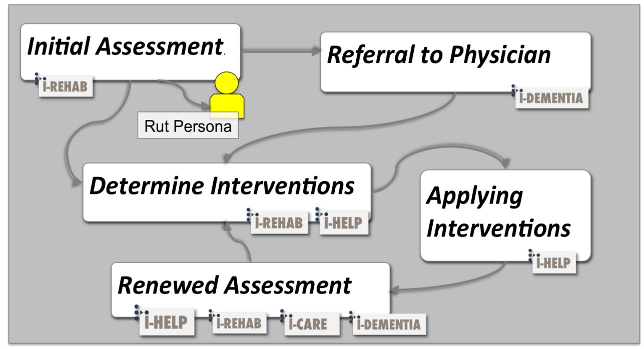

Figure 1: The Rut scenario and its prototype support applications.

2.1 Initial Assessment

The first dialogue is essentially an *information seeking* dialogue and involves OT, Rut and her son in their first encounter. The roles of the actors are basically that the OT asks and the others assert information, typically by selecting among a set of alternatives. Two supplementary instruments for assessing instrumental activities of daily living (iADL) and a simplified version of an interest checklist were used. All were accessible through the I-Rehab application, which is designed as a knowledge-based support system for the OTs. During the interview with Rut the OT used the web-versions of the instruments to note what Rut and her son were describing. This usage resulted in the knowledge repository about Rut that is later used in followup dialogues. This dialogue was also performed mediated by I-help, with the intention that Rut and her son could interact with the support system.

2.2 Determine Interventions

The part of the assessment where goals for intervention are identified is a critical part. This part can be seen as a dialogue with the goal to decide upon which actions to be performed. The following two types of questions form the base for defining goals: 1) How important is it for you to do activity A?, and 2) How satisfied are you with how you are able to do activity A? When an activity is identified as very

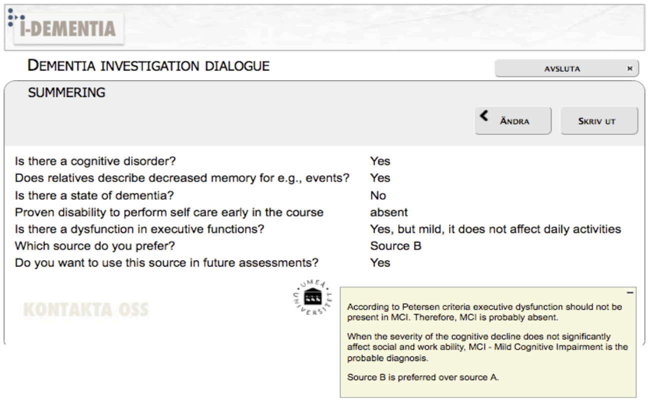

Figure 2: Summary of diagnostic dialogue as modelled by domain experts.

important and troublesome to perform, the reasons for the difficulties are identified in an information seeking dialogue. When an activity is judged being suitable to support by computerized means, I-Help comes into play as an intervention proposed by the OT. The tailoring of her I-Help application is based on a particular ACKTUS assessment protocol defined for the purpose, which underlies the dialogue that the system/OT has with Rut about the intervention.

2.3 Referral to Physician

Since Rut's son described difficulties with cognitively demanding tasks an assessment was done of whether Rut had an emerging dementia disease. In this assessment the physician used the application I-Dementia as a guide for the assessment. The diagnostic dialogue that takes place is of the type *inquiry* dialogue, the goal is to create new knowledge. Medical domain experts modeled the content and interactivity of this dialogue and part of the result is shown in Figure 2 [14]. In this work we use it as an example of the implementation of our agent system in Section 4.3 and details can be found in Table 1.

The data about Rut was analysed and a disagreement arose about which knowledge source to apply. The Physician suggested that Rut has mild cognitive impairment (MCI) (too mild to fulfill the criteria for dementia) based on a different source than the one the Domain Agent (DA) uses to exclude also the presence of MCI. Therefore, the Coach Agent (CA) explicitly asks for the physician's preference in the matter to be applied in future cases.

2.4 Applying Interventions

In the intervention part of the scenario typical and targeted activities performed by Rut in her daily life with the support from tailored applications are described. For space reasons we omit this, and focus on the evaluation of the activities done by the CA through the I-Help application. For some of the questions defined by the OT there are follow-up questions to assess degrees and some types of answers generate advice. The questions concern the activities identified as troublesome in the initial assessment and the key follow-up questions are the same: 1) How important is it for you to do activity A?, and 2) How satisfied are you with how you are able to do activity A?. Since Rut also was worried about different things, questions about worries were also included and a question about her current view on her health.

2.5 Renewed Assessment

The CA detects a change in activity pattern based on information from the activity recognition system after a period, Rut starts to walk around nighttime. The information is contradicting earlier information, leading to further dialogues to resolve the conflict. This leads to an initiation of dialogues with other system agents (DAs for the different domains) to find reasons for conflicting information. In our scenario, after the dialogues between the software agents there is still insufficient information for resolving the reasons for Rut to be wandering about nighttime. This leads the CA to initiate a dialogue with Rut the next morning with the same topic (Disturbed sleep patterns), leading to questions about sleeping pills, worries, pain, stomach issues and incontinence, and nested dialogues with the purpose to ask Rut if she wants to have contact with a professional to discuss the potential reasons for disturbed sleep that come up during the dialogue. At the end of the dialogue, the CA also shows Rut a summary of the dialogue, and asks for Rut's permission to send the summary to the nurse as a preparation of a visit. The nurse who evaluated the dialogues pointed out that an essential part of the knowledge is common between the nursing and the rehabilitation domains, and they typically cooperate. Therefore, she would make use of parts of the rehab content of the prototype in addition to the care content if she would have met the client in her home for a followup [14].

3. ACKTUS

The knowledge-based prototype applications are developed using ACKTUS (activity-centred knowledge and interaction modelling tailored to users) (Figure 3) [4]. ACKTUS is an evolving semantic web application that is designed to allow domain experts who are typically not familiar with knowledge engineering to author and model the knowledge content of, and design the interaction with, knowledge-based applications. The purpose is to bridge the knowledge gap between medical experts and knowledge engineers, so that the domain experts can use ACKTUS for adjusting the tailoring of applications as part of the development of their daily practice. ACKTUS has emerged as a result from experiences in developing socio-technical systems for the medical and health domains [2, 15, 16, 17].

ACKTUS consists of a service-oriented architecture, which includes an RDF/OWL ontology, Sesame repositories and dedicated user interfaces (Figure 3). The different services to be provided by the system are currently being developed, among which the reasoning services can be accessed and utilized by the agent system outlined in this paper.

3.1 ACKTUS Ontology

The core ontology implements a generic model of activity [18, 3] and captures 1) components of reasoning in the form of an argumentation framework, 2) components used for tailoring interaction with the resulting knowledge applications and 3) components for modelling the user agents as actors in a situation where the application is used, e.g., for reasoning, performing daily activities, for entertainment or social interaction. The ACKTUS applications share this common core ontology, which is extended with specifics for each knowledge domain. Thus, for each knowledge domain

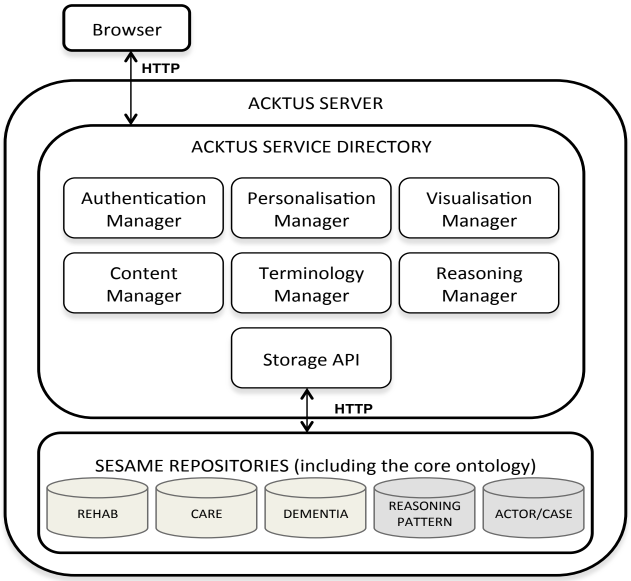

Figure 3: ACKTUS architecture

(care, rehabilitation, etc.) a domain knowledge repository is created in the modelling of knowledge, containing validated assessment instruments (e.g., [8, 9]), clinical practice guidelines (e.g., [19]), etc. Preference orders among knowledge sources, level of expertise in knowledge domains and other personal and contextual factors may be taken into account in adjustments made in a person's home environment for increasing ability in activity performance.

A key feature of the ontology is the concept system, to which each object that carries knowledge is associated. In the domain experts' modelling they also model the concept structure and identify key concepts for their domains. The basic structure of the concept system is common between the domain applications and is based on ICF (International classification of ability, functioning and health)[1] extended with diseases and syndromes. However, the representatives from the different knowledge domains refine branches of the concept tree differently, mirroring their different specialties. As in clinical practice where the different types of professionals supplement each other in daily knowledge work, these domain ontologies are supplementary. Moreover, the concept-system-node class serves as the data structure for the information about the user and/or patient/client. The concept system provides the terminology and semantics of expressions, allowing for an agent to specify a topic of a dialogue comprehensible to other agents.

Data to be fed into rules is collected by templates for the purpose, designed by the domain experts. These frame and define the content of the locutions in dialogues with the user. The templates are ordered by the user into possibly nested *assessment protocols*, used for representing structured data capture activity. While the reasoning contexts are suitable for supporting reasoning at a higher level of cognitive complexity, the assessment protocols are suitable for supporting lower level reasoning (e.g., data capture), typically as part of applying reasoning contexts.

The rules that are defined by the domain experts are simple structures with a set of claims as body and as head of the rule one conclusion (also a claim about a topic), an advice or an action (assessment protocol) to be activated. The underlying structure for rules, schemes and critical questions is based on the Argument Interchange Format (AIF) developed for facilitating sharing and visualization of arguments using the WWW [20].

[1]http://www.who.int/classifications/icf/en/

4. EXTENDING ACKTUS WITH TAILORED AGENT-BASED DIALOGUES

A major purpose of the domain-specific support applications developed using ACKTUS is to educate the user and provide new evidence-based knowledge at the point where it is useful. The goal is to improve the daily care of individuals (e.g., early detecting an emerging dementia disease). In this work we take the mediation of this formalized knowledge a step further, by developing a multi-agent system where the purpose is to challenge and support the professional. Moreover, in the same way as the professional is supported in their daily work, the older adult in their home can be supported in their daily activities. The motivation for using a multi-agent dialogue perspective in our work is that this approach allows for modeling the conditions for knowledge development in individuals as well as the system, in spite of ambiguous and incomplete domain knowledge. In addition, we anticipate that agent-based dialogues will facilitate more intuitive and natural dialogues between the user and the system.

The purpose of the agents' dialogues is to share (defeasible) knowledge to construct arguments supporting beliefs, and in this way increase each agent's knowledge repository (belief base). We adopt the BDI framework for agents, meaning that each agent has beliefs, desires and intentions. We assume that the participants are cooperative and reliable, aiming at disseminating and increasing knowledge and finding optimal decisions and actions in client cases. We assume also that one single medical actor does not possess all knowledge required for providing a client optimal care, but that the knowledge is distributed over a team of professionals with different viewpoints of a clinical situation. Indirectly, the implemented knowledge in the clinical decision-support system (CDS) represents the knowledge of an expert in the domain, without assuring that this expert possesses all knowledge relevant for a clinical situation (which is also the case in real clinical situations).

The dialogues can be activated by any of the agents, and the content of messages is selected from their belief bases, based on the topic for the dialogue [21]. The topic is framed by the underlying ontology, which defines the reasoning context and associated critical questions, rules, knowledge sources, etc. [3]. Critical questions function as locutions in dialogues. A dialogue can also involve the human agent, then visible through the I-help application and possibly through audio modality. A topic needs to be selected, possibly among predefined topics visible through a graphical user interface, or by vocal interaction. In this paper we assume that information about the activity patterns is collected by the egocentric interaction model for assessing the interaction environment [5, 6] and that this information is interpreted and fed into the client repository and belief base of a Coach Agent through a service directory.

In the following subsections types of dialogues, their formal properties and functional requirements will be described (e.g., agent roles, rules for speaker order, termination rules, commitment stores and belief bases). Furthermore, an initial prototype implementation of the diagnostic dialogues involving a physician, the Domain Agent and the Coach Agent is described and evaluated.

4.1 Agent Roles

In our framework a Mediator Agent (MA) organizes the dialogues between different application agents, where knowledge can be used between knowledge repositories, depending on the topic to investigate and on users' authorization. Apart from a Mediator Agent, which functions as a service provider and does not contribute to nor affect the content of dialogues, a Coach Agent and a Domain Agent are activated in the interaction with an ACKTUS application (Figure 4).

The Coach Agent (CA) acts on behalf of the user, represents the user and guards the user's interests. It detects what the human user agent does in interaction with the application, organizes and updates the user's belief base, and acts when the user does not follow previously stated preference orders or pattern of interaction (partly represented in the user's belief base). The CA also organizes the user model, which collects the information about the user's limitations and resources (e.g., physical, cognitive, social) and preferences about e.g., who has access to the information. In our scenario the CA detects pattern of activity as well as deviations from pattern of activity in an individual user partly based on information from the personal activity-centric middleware [7].

The Domain Agent (DA) acts as a domain professional, making use of the domain knowledge repository. In the interaction with the CA and the therapist user in the assessment application, the DA provides the expert perspective to reasoning, when possible based on evidence-based guidelines and validated assessment instruments for the purpose to educate the therapist and support daily work with e.g., older persons who need adjustments in their home environment. DA represents a domain professional in the dialogues with CA, and CA represents the individual. DA may also act as the domain professional in interaction with the individual through the I-Help application.

4.2 Dialogue Types, their Formal Properties and Design

Dialogue games are commonly used to describe and characterize argument-based dialogues involving one or more agents (e.g., [22]). Dialogue games are typically organized by a limited set of allowed acts, or moves, with rules (representing a protocol) directing how the moves can be done at each point in the dialogue, the outcome of a move, and when a game is terminated. The purpose of a dialogue game can be different, corresponding to the motives the agent or agents have with their participation.

We analysed the different dialogues exemplified in our scenario, interpreted them as dialogue games, and categorised them into three of the types of dialogues described by Walton and Krabbe [23]: *information seeking, inquiry* and *deliberation dialogue*. They differ by their purpose where an *information seeking* dialogue aims at collecting information, *inquiry dialogues* aim at collaboratively create new knowledge and a *deliberation dialogue* aims at collaboratively decide upon a plan of action to be performed.

For each of the dialogues we also identified the different purposes of moves (locutions) that the agents make.

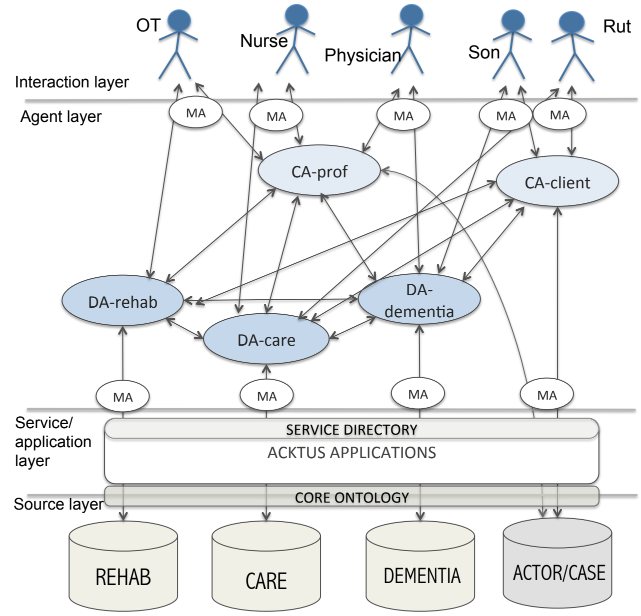

Figure 4: Extension of the ACKTUS architecture with an agent layer based on the case scenario.

The following purposes were considered a minimal set necessary to execute the dialogues in our scenario: *open/initiate, close/terminate, ask* and *assert*. For illustrating the dialogues in our use scenario in the development sessions with domain experts, we use an algorithm for executing the information seeking dialogues and for simulating the inquiry and deliberation dialogues. The algorithm only makes use of ACKTUS assessment protocols, their content, their associated rules and their consequents as dialogue flows structured by the domain experts in the modelling sessions. In this highly structured form, the autonomy of agents is limited to a minimum. However, it serves as a starting point for our user-driven approach to development of agent-based dialogues. The domain professionals are in control of the agent's behavior. The algorithm is as follows:

1. Identify the assessment protocol and add its ordered contents to the list of items that need to be executed

2. For each item in the list:

   (a) Deliver the message and add the user's response as a new belief to the belief base

   (b) Match the new belief with the ACKTUS rules and ACKTUS information, then compare the result of matching to:

      i. If the result is a new assessment protocol, start the execution of this assessment protocol (activity)

      ii. If the result is a new advice, show the advice immediately and/or save it for showing in summary page

      iii. If the result is a conclusion, add the conclusion (the new knowledge) to the belief base and to the case repository

3. Show the summary page including conclusions, advices, asked questions and the user's responses (see example in Figure 2)

The same building blocks created using ACKTUS and executed in the simulated agent-dialogues, are used in the agent-based dialogues. Consequently, we can accomplish information-seeking dialogues by using the ACKTUS assessment protocols, since they are designed for the purpose. We can also reuse the protocols for reasoning about which actions to make, when the aim is to investigate and collect more information to be used in reasoning about topics. The topics are identified using the ACKTUS concept system or by critical questions, which define reasoning contexts. For the implementation of the agent-based dialogues of the inquiry type, we adapt the approach developed by Black and Hunter [22], further described in the following subsection.

4.2.1 Inquiry Dialogues

In [21] an inquiry dialogue system developed by Black and Hunter [22] was applied for capturing diagnostic dialogues concerning dementia. The formal protocols for dialogues are adopted from [22] and are extended with values and preferences drawn from the ACKTUS argumentation framework and knowledge repositories. The work presented in [22] is adapted to ACKTUS mainly in that we consider individuals' preferences as central for personalization and tailored feed-back in a learning process. We also make use of the ACKTUS *reasoning contexts* to identify the topic of a dialogue (a concept identifiable in the ACKTUS ontology) and to activate a corresponding subset of the knowledge base to form the belief base of the CDS agent. This way the dialogues can follow the user's trail of thinking in that the user choses topics, e.g., in a differential diagnostic reasoning process. Our adaptation will be described from the perspective of a practical diagnostic example, and the interested reader finds the formal definitions in [22].

In the following summative description of inquiry dialogues, we apply Black and Hunter's distinction between two sub-types of warrant dialogues; *warrant inquiry dialogue* and *argument inquiry dialogue*. The difference is that the outcome of a warrant inquiry dialogue is a dialectical tree with argument nodes marked as defeated or undefeated, while the argument inquiry dialogue builds the argument to be fed into the warrant inquiry dialogue. Their approach limits the set of possible moves to *open, close* and *assert*. Therefore, for our purposes we add the move *ask* whenever there is a reason for an agent to ask instead of making a close move. We also apply the rules for dialogue execution specified in [22]. To terminate a dialogue, all agents should make a close move. It is allowed to have argument inquiry dialogue nested within warrant inquiry dialogues, but not vice versa. Argument inquiry dialogues can be performed within other argument inquiry dialogues. In none of the cases an agent is able on its own to construct the argument or the dialectical tree, based on its limited set of beliefs. All agents take turn in making moves in the dialogue.

A major difference between the two types of inquiry dialogues is that in an argument inquiry dialogue the agents are not allowed to determine the acceptability of the arguments constructed, while in the warrant inquiry dialogue determining acceptability is the purpose. Therefore, argument inquiry dialogues are often embedded within warrant inquiry dialogues. Another difference is that the topic of an argument inquiry dialogue is a defeasible rule, while the topic of a warrant inquiry dialogue is a defeasible fact. There are three legal moves defined in [22] for the two types of dialogue: *open* ($\langle x$, *open*, *dialogue*$(\theta, \gamma)\rangle$), *assert* ($\langle x$, *assert*, $\langle \Phi, \phi\rangle\rangle$) and *close* ($\langle x$, *close*, *dialogue*$(\theta, \gamma)\rangle$). The format used for moves in the example dialogue in Table 1 follows the format described in [22], where x represents the agent, $\langle \Phi, \phi\rangle$ is an argument, $\theta = wi$ and γ represents a defeasible fact for a warrant inquiry, and in the case of an argument inquiry $\theta = ai$ and γ represents a defeasible rule. In our example we add the move *ask* in the following format: *ask* ($\langle x$, *ask*, $\langle \gamma, cq_y\rangle\rangle$), where γ represents an unknown defeasible fact. Each agent has a possibly inconsistent belief base and it is assumed that all agents have the same role [22]. By making a query store (which is loaded with for the topic relevant sub-topics) and each agent's commitment store (loaded with asserted knowledge during the dialogue) public, the agents can make use of common knowledge in the dialogue. A dialogue is terminated when all participants have made a close move, which guarantees that all relevant information has been taken into consideration.

Black and Hunter provide a protocol for modeling inquiry dialogues and a strategy for generating dialogues (choosing among candidate moves in a dialogue), which uses an adapted version of Garcia and Simari's Defeasible Logic Programming (DeLP) for representing agents' beliefs [24]. DeLP is adapted by making the sets of strict rules and facts empty and define a defeasible fact. This way all knowledge becomes defeasible, which is suitable for their as well as our purposes. A defeasible rule is denoted $\alpha_1 \wedge ... \wedge \alpha_n \rightarrow \alpha_0$ where α_i is a literal for $0 \leq$ i $\leq$ n. A defeasible fact is denoted α where α is a literal.

Black and Hunter also associate a preference level with a defeasible rule or fact in the formation of a belief, although they do not account for the source of this preference level. The preference ordering is used in the comparison of two arguments. We replace the numbers used in [22] with an explicit ranking among knowledge sources to make the comparison in our example transparent and associate this ranking to defeasible rules. Furthermore, we use an ordered set of values to associate strength to defeasible facts. A belief is a pair (ϕ, S) where ϕ is either a defeasible rule or a defeasible fact. If ϕ is a defeasible rule then S $\in S_0 = \{$*cpg*, *cons*, *rot*$\}$ and if ϕ is a defeasible fact then in our example S $\in S_1 = \{$*present*, *unknown*, *absent*$\}$. Clinical practice guidelines (*cpg*) are considered more reliable than consensus guidelines (*cons*), while both are considered more reliable than a 'rule-of-thumb' (*rot*), which is often based on fragmented experiences of an individual professional [21]. Therefore, the following additional beliefs about the strength of knowledge sources are integrated in the CDS agent's belief base: (*cpg* > *cons*, *cpg* > *rot*, *cons* > *rot*), where > is a binary relation meaning 'strictly preferred to'. In our example given in Table 1 two comparable sources of the same type is used (Sources A and B), and the physician's preference directs the final outcome. Moreover, in our example dialogue the Physician (A_1) and the DA (A_2) reuse the following beliefs stored after earlier dialogues about Rut: {(Dementia, *absent*), (CogDis, *present*)}. When the dialogue has ended, a dialectical tree can be formed, where arguments can be evaluated as being *Defeated* or *Undefeated*. In our example two contradicting outcomes can be found, using rules based on two different sources. Since the sources are equally

Table 1: Example of a warrant inquiry dialogue with nested argument inquiry dialogues, where t represents timepoints, CS is commitment store and m_t is a move at timepoint t.

t	A_1 CS	m_t	A_2 CS
1		$\langle$1, *open*, wi_1 (MCI, *present*)$\rangle$	
2		$\langle$2, *open*, ai_1 ((CogDis, *present*) $\wedge$ (Dementia, *absent*) $\wedge$ (ADL, *absent*) $\wedge$ (Exec, *absent*) $\rightarrow$ $\langle$MCI, *present*$\rangle$), Source C$\rangle$	
3	(CogDis, *present*)	$\langle$1, *assert* $\langle\{$(CogDis, *present*)$\}$, (CogDis, *present*)$\rangle\rangle$	
4		$\langle$2, *ask* $\langle\{$(ADL, *unknown*)$\}$, Trouble with self care?$\rangle\rangle$	(CogDis, *present*)
5	(ADL, *absent*)	$\langle$1, *assert* $\langle\{$(ADL, *absent*)$\}$, (ADL, *absent*)$\rangle\rangle$	
6		$\langle$2, *ask* $\langle\{$(Exec, *unknown*)$\}$, Executive dysfunctions?$\rangle\rangle$	(ADL, *absent*)
7	(Exec, *mild*)	$\langle$1, *assert* $\langle\{$(Exec, *Mild*)$\}$, (Exec, *Mild*)$\rangle\rangle$	
8		$\langle$2, *close*, ai_1 ((CogDis, *present*) $\wedge$ (Dementia, *absent*) $\wedge$ (ADL, *absent*) $\wedge$ (Exec, *absent*) $\rightarrow$ $\langle$MCI, *present*$\rangle$)$\rangle$	(Exec, *mild*)
9		$\langle$1, *close*, ai_1 ((CogDis, *present*) $\wedge$ (Dementia, *absent*) $\wedge$ (ADL, *absent*) $\wedge$ (Exec, *absent*) $\rightarrow$ $\langle$MCI, *present*$\rangle$)$\rangle$	
10		$\langle$2, *open*, ai_2 ((Exec, *mild*) $\rightarrow$ $\langle$MCI, *absent*$\rangle$), Source C$\rangle$	
11	(MCI, *absent*)	$\langle$1, *assert Arg1* $\langle\{$(Exec, *mild*), ((Exec, *mild*) $\rightarrow$ $\langle$MCI, *absent*$\rangle$)$\}$, (MCI, *absent*), Source A$\rangle\rangle$	
12		$\langle$2, *close*, ai_2 ((Exec, *mild*) $\rightarrow$ $\langle$MCI, *absent*$\rangle$)$\rangle$	(MCI, *absent*)
13		$\langle$1, *close*, ai_2 ((Exec, *mild*) $\rightarrow$ $\langle$MCI, *absent*$\rangle$)$\rangle$	
14		$\langle$2, *close*, wi_1 (MCI, *present*)$\rangle$	
15		$\langle$1, *open*, ai_3 ((CogDis, *present*) $\wedge$ (Dementia, *absent*) $\wedge$ (ADL, *absent*) $\wedge$ (Exec, *mild*) $\rightarrow$ $\langle$MCI, *present*$\rangle$), Source D$\rangle$	
16		$\langle$2, *assert Arg2* $\langle\{$(CogDis, *present*), (Dementia, *absent*), (ADL, *absent*), (Exec, *mild*), (CogDis, *present*) $\wedge$ (Dementia, *absent*) $\wedge$ (ADL, *absent*) $\wedge$ (Exec, *mild*) $\rightarrow$ $\langle$MCI, *present*$\rangle$), Source B$\rangle\rangle$	(MCI, *present*)
17	(MCI, *present*)	$\langle$1, *close*, ai_3 ((CogDis, *present*) $\wedge$ (Dementia, *absent*) $\wedge$ (ADL, *absent*) $\wedge$ (Exec, *mild*) $\rightarrow$ $\langle$MCI, *present*$\rangle$)$\rangle$	
18		$\langle$2, *close*, ai_3 ((CogDis, *present*), (Dementia, *absent*), (ADL, *absent*), (Exec, *mild*) $\rightarrow$ $\langle$MCI, *present*$\rangle$)$\rangle$	
19		$\langle$1, *close*, wi_1 (MCI, *present*)$\rangle$	
20		$\langle$2, *assert Arg3* $\langle\{$(Source A > Source B), Arg1, Arg 2$\}$, (MCI, *absent*)$\rangle\rangle$	(A>B)
21	(A>B) (B>A)	$\langle$1, *assert Arg4* $\langle\{$(Source B > Source A), Arg1, Arg 2$\}$, (MCI, *present*)$\rangle\rangle$	
11		$\langle$2, *close*, wi_1 (MCI, *present*)$\rangle$	(B>A)
12		$\langle$1, *close* wi_1, (MCI, *present*)$\rangle$	
	conclusion:	Resulting dialectical tree: (Claim - Argument 0: MCI present): Undefeated -: (Argument 1: MCI absent): Defeated -: (Argument 2: MCI present): Undefeated -: (Argument 3: MCI absent): Defeated -: (Argument 4: MCI present): Undefeated.	

Abbreviations

CogDis: Cognitive disorder
Exec: Executive dysfunction
ADL: Activities of daily living
MCI: Mild Cognitive Impairment

reliable considering their types, we include the preference orders of both the DA and the Physician. Since the physician is responsible for the diagnostic decisions to be made, the Physician agent in our example overrules the DA's preferences (Table 1).

4.3 Implementation of Dialogues about Medical Diagnosis

An initial prototype implementation of the inquiry dialogues described in 2.3 was developed using the JADE (Java Agent Development Framework) platform [25].

Table 2: Algorithm for dialogue implementation

1	**Initiating Agent:**	
	Selects and sends the topic of dialogue	$\langle open \rangle$ *wi*
2	**Agent:**	
	Receive and Check MessageType	
	If RecMessageType==$\langle assert \rangle$	
	Update CS	
	If RecMessageType==$\langle ask \rangle$	
	SelectNextMove $\rightarrow$ *assert/close*	
	Else	
	SelectNextMove $\rightarrow$ *open/assert /ask/close*	
	If NextMove==$\langle open \rangle$	
	ai=SelectDefeasibleRule	
	Put the literals of the rule in	
	the QS and send the topic	$\langle open \rangle$ *ai*
	Wait to receive next message	
	If NextMove==$\langle assert \rangle$	
	Construct the argument: collect	
	the set of grounds that supports	
	the claim (beliefs)	
	arg = SelectArgument	
	Send the argument	$\langle assert \rangle$ *arg*
	Wait to receive next message	
	If NextMove==$\langle ask \rangle$	
	Based on unknown facts in QS	
	cq= SelectCriticalQuestion	
	Send the critical question	$\langle ask \rangle$ *cq*
	Wait to receive next message	
	If NextMove==$\langle close \rangle$	
	Send close request	$\langle close \rangle$ *ai/wi*
	If RecMessageType==$\langle close \rangle$	
	Go to Step 3	
	Else	
	Wait to receive next message	
3	**Conclude**	

The Physician and the DA have their own belief bases. The Physician's belief base consists of observations and other knowledge about Rut, and rules (possibly rules-of-thumb or clinical guideline-based), while the DA's belief base is obtained from ACKTUS. The belief base consists of defeasible rules associated to schemes and critical questions stored in ACKTUS repositories.

A dialogue may be initiated by the Physician or the DA and the topic is sent to the other one. Agents participating in the dialogue apply a priority order in the selection of moves, namely *open*, *assert*, *ask* and finally *close*. By prioritizing *open* and *assert*, new knowledge will be created, which serves the purpose of supporting learning in the end user. However, if the received message is of the type *ask*, the responding agent is required to select between the two moves *assert* and *close*. The purpose of the *ask* move is to switch the burden of proof to another agent. Each agent has a Commitment Store (CS), which is updated with new beliefs when any (including itself) agent asserts an argument. A dialogue might include a Query Store (QS) which stores the literals of the rule when an argument inquiry dialogue is opened.

The algorithm for conducting the argumentative dialogue between these agents is presented in Table 2. When the application has been started, the participant agents are instantiated. One of the agents (Physician or DA) starts the dialogue by sending the topic for conversation to the other one (Step 1). Then, the receiver agent selects and performs its move and sends it to the initiator. Similarly, it is the initiator's turn to perform the execution and specify its move. They continue until both of them send the *close* moves respectively. Finally, it is time to conclude the dialogue (Step 3). At this stage the dialectical tree is constructed by the DA, which serves as a conclusion to be presented to the Physician agent.

The selection process for each move in each agent is as follows. The agent checks its belief base and commitment store. Then, it replies with a move with the type and the content which are selected by its *SelectNextMove* and *SelectDefeasibleRule*, *SelectArgument* or *SelectCriticalQuestion* functions. After sending the message, the agent waits to receive a message from the other one. If each agent has no more rules for opening argument inquiry dialogues related to the topic, no new knowledge to assert and no more question to ask, it closes the dialogue.

The algorithm is generic in order to be applicable in a situation when more than two agents participate in the dialogue. Participating agents must have a predefined order to send their messages, according to their turn and the dialogue is concluded and terminated after all of them have made a close move.

5. RELATED WORK

Formal argumentation frameworks and argumentation schemes have the potential to improve the reasoning and communication capabilities within and between software agents (e.g., [26]). In a system that contains different agents, each might have different knowledge. One agent can also have conflicting information contained in a belief base. These agents with their different expertise may collaborate and utilize their individual knowledge, participate in the reasoning process to make a decision or achieve a common goal. In some frameworks there are also mechanisms that allow an agent to learn from dialogues.

There are several proposals of formal frameworks for capturing the factors influencing an argumentation-based dialogue, and for resolving which arguments are valid and which are defeated. The most influential is the Dung semantics of argumentation frameworks, which have been extended and applied in many example cases, implementations of reasoners and argumentation software for different purposes (e.g., [24, 27]). Another example is the formal framework presented by Black and Atkinson [28] combining inquiry dialogue argumentation and practical reasoning (i.e., reasoning about actions). The combination of these approaches makes the reasoning easier among the agents with different perspectives on a subject. They have taken a formal specification of the two mentioned types of dialogues, extended it with additional critical questions, which make it possible to make more arguments while trying to find some consensus. The critical questions are generic, which is a difference from our work where the knowledge and associated questions are mainly domain-specific. However, it will be investigated in future work in what way our agent protocols conform to their generic framework. The implementation of their framework was also done using JADE (Java Agent Development Framework) [25].

Other approaches take a real world situation as starting point and frame the need for agent-based support. SHARE-IT [29] (Supported human autonomy for recovery and enhancement of cognitive and motor abilities using information technologies) implements a combination of multi-agent system and other techniques to aid the elders based on user scenarios [13]. The agents hold information about all physical devices that exist in the environment to control daily living activities and the conceptual world's information. The multi-agent system (MAS) includes a *patient agent, vehicle agent, caregiver agents, environment agent* and a *home agent* that monitor users and their activities, and manage their profiles. A difference in our work is that we integrate assessment into the context of use, and aim at using the professionals' instruments for continuing followup supported by agents.

Tolchinsky and coworkers presented an argumentation framework with heterogeneous agents to argue about the viability of transplantation of a human organ [30]. The purpose of their work is to improve the process of transplantation. The argumentation type supported in their work is a deliberation dialogue, since the participating agents collaboratively decide upon viability of human organs for transplantation. A mediator agent directs the deliberation and based on the arguments presents the final decision. The software agent uses argumentation schemes and critical questions submitted by doctors in order to direct exchange of argumentation among human and/or software agents [30]. The argumentation is done between a donor agent (an agent representing the hospital where the donor is located) and a potential recipient. In order to mediate the protocol based exchange of arguments between donor and recipient agents (that are assumed to be human doctors), a software agent named mediator agent is involved. As the arguments submitted by the agents and the dialogue ended, the mediator agent created the conversation graph and evaluates the argumentation. The mediator agent references the knowledge sources (a knowledge base of acceptability criteria, case base of earlier patient cases, and the reputation of the agent) to determine the validity of the submitted arguments and the strength of the argument. The approach by Tolchinsky et al. shares features with the work presented in this paper. They also used a dedicated web-based user interface for the domain experts to model the medical knowledge and they utilize agents with different roles to contribute to the decisions about actions. The main difference is that they focus on one particular decision problem where they utilize deliberation dialogues, while our scenario spans different decision situations that require different types of dialogues. The conversation-based protocol that mediator agent uses to direct submissions of arguments by donor and recipient agents, has been implemented using COGENT [31].

6. DISCUSSION

A persona and a case scenario have been used for outlining the requirements of a multi-agent system for argumentation-based dialogues. The main location for the activities in the scenario is the home of the older adult. The home environment integrates in our scenario ambient assisted living in the form of an activity recognition system that interacts with the agents of a knowledge-based system. Characteristics of the dialogues taking place at different points in the envisioned scenario were identified, such as types of dialogues, types of moves, which agent takes initiatives, content and structure of locutions.

In [21] an inquiry dialogue system developed by Black and Hunter was applied for capturing diagnostic dialogues concerning dementia. However, their approach limits the set of moves to open, close and assert. In interaction with human agents the possibility to pose questions is essential to achieve a dialogue that is perceived as natural by the human. Therefore, we add the move *ask* to our example scenario as the practical outcome when a knowledge-seeking (curious) agent does not know and can only make a close move otherwise. A dialogue about diagnosis defined in the scenario was implemented using JADE featuring the designed MAS utilizing ACKTUS knowledge repositories.

The development of the support application for the older adult targets other central issues, both with respect to ethical and privacy issues, but also the challenge to optimise personalisation and adaptability to changing abilities and needs in the individual. We have addressed these issues in our work, and outlined a possible scenario where the support applications may adapt to changes. Ongoing and future work includes finalizing the user-driven development of the knowledge-based support systems, the agent-based dialogue implementation, its formal framework and a suitable interaction design for the older adults as end users. Moreover, the activity recognition system will be integrated in a demonstrator environment so that the scenario can be evaluated in practice with older adults. Combining the activity recognition system with the knowledge-based support applications, the resulting support environment has the potential to support activity of importance to the individual, as compared to the majority of the existing approaches to AAL. Typically AAL environments are designed to control the physical surroundings and detect hazardous events such as falls, and activity at a basic operational level (types of movement, location, eating, sleep, etc). By adding meaning to activities at a higher level defined by the older adult, the older adult also becomes the designer and may get a sense of control over the AAL environment. This is an essential part of a system aiming at increasing an individual's autonomy and sense of coherence in daily life.

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