Adaptive Human-Agent Dialogues for Reasoning about Health

by

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Abstract

The aim of this research is to develop new theories, methods and technology, which enables adaptive and personalised dialogues between a human and a software agent, to handle everyday queries about health that are perceived as meaningful and useful to the human. Some of the challenges to build such human-agent dialogue system are the following. The agent needs to have knowledge about the human, the topic of the dialogue, the knowledge domain of the topic, and also about the physical and social environment. Moreover, the agent must know about itself, its role, purpose and limitations. It must know how to be cooperative and be able to behave and express with empathy while conducting a dialogue activity. In some situations, it needs to reason and make decisions about a topic together with the human and about its own behavior. To be able to do this, it needs the capability to evaluate its behavior in the context in which the dialogue takes place. These challenges are addressed by developing formal semantic models to provide the agent with tools to build their knowledge and to be able to reason and make decisions. These models were developed based on literature studies, theories of human activity, argumentation theory, personas and scenarios.

The models were formalised and implemented using Semantic Web technology, and integrated into a human-agent dialogue system. The system was evaluated with a group of therapists and a group of elderly people, who showed curiosity and interest in having dialogues with a software agent on various topics.

The formal models that the agent constructs are adapted to the specific situation and to the human actor participating in a dialogue. They are based on four models: a model with knowledge about the human actor, a model of itself, a domain model, and a dialogue activity model. The dialogue activity is based on argumentation schemes, which function as patterns of reasoning and for the dialogue execution. These models allow the agent and the human actor to conduct flexible and nested sub-dialogues with different purposes within a main dialogue about a topic. The agent can adapt its moves to the human actor's trail of reasoning, to the human's priorities and goals, and to some extent behave in an empathic way during the dialogue, and in this way adapt to the human's emotional state. A method for the agent to be able to evaluate its behavior was also developed and evaluated. The proportion of appropriate moves in relation to the local context of earlier moves in the dialogue was 90% in the pilot study, which indicates that the agent's strategies for selecting moves can be improved.

Future research will focus on further development of reasoning methods, learning and assessment methods, and interface design. The results will be applied to additional knowledge domains to test its domain independence and will be evaluated with different groups of potential users.

Sammanfattning

Syftet med forskningen som presenteras i denna avhandling är att utveckla nya metoder, teorier och tekniker som möjliggör dialoger mellan människan och en mjukvaruagent, där dialogerna uppfattas av människan som meningsfulla och till hjälp i vardagsfrågor kring hälsa.

För att agenten ska uppfattas intelligent, social och empatisk, och kunna ha något att bidra med, behöver agenten formaliserad och exekverbar kunskap om människan och hennes omgivning, ämnesområdet för dialogen, om sig själv, sin roll och begränsningar. Dessutom behöver agenten ha kunskap om hur en dialog ska föras, hur resonera tillsammans med människan för att komma fram till beslut, lösningar, ny kunskap och möjliga nya aktiviteter för att människan ska nå sina mål. Agenten behöver också kunskaper om hur bete sig och kunna utvärdera sitt eget beteende.

Formella semantiska modeller utvecklades för att ge agenten verktyg för att bygga sin kunskap och för att kunna resonera och fatta beslut. Dessa modeller baserades på teoretiska modeller för mänsklig aktivitet, personas, scenarios och formell argumentationsteori. Modellerna implementerades i en semantisk webbstruktur baserad på RDF/OWL, som i sin tur integrerades i ett människa-dialog system. Systemet utvärderades i en pilotstudie med en grupp av terapeuter och en grupp äldre personer. Resultatet visade på ett intresse och nöje med att använda systemet, och det föreslogs kunna vara till nytta även i andra områden.

De formella modellerna som agenten konstruerar är anpassade till den specifika situationen och till människan som agenten har en dialog med. Den inkluderar en modell för människan, en modell för sig själv, en modell för ämnets kunskapsdomän, och en modell för dialogaktiviteten. Dialogaktiviteten med ingående resonemang och beslutsfattande är baserade på argumentationsscheman, som fungerar som mönster för resonerande och för dialogen. Dessa modeller tillåter agenten och människan att hålla flexibla dialoger med olika syften om ett ämne, med nästade dialoger om ämnen som relaterar till huvudämnet. Agenten kan anpassa dialogen till människans spår av resonemang, till människans prioriteringar och mål och i viss mån bete sig empatiskt i dialogen. En utvärderingsmetod baserad på människans värdering är integrerad som utvärderades i användarstudien. Andelen passande repliker i förhållande till kontexten var i pilotstudien 90%, vilket indikerar att agentens metoder för val av repliker kan förbättras.

Framtida forskning kommer att fokuseras på vidareutveckling av resonemangsmetoder, lärande- och utvärderingsmetoder, samt gränssnittsdesign. Resultaten kommer att appliceras på ytterligare kunskapsdomäner och utvärderas med olika grupper av potentiella användare.

Preface

This thesis is based upon the following three papers, which will be referred to in the text by their Roman numerals (Paper I, II & III). The order of the papers reflects the academic progress.

Paper I **Jayalakshmi Baskar**, Helena Lindgren. Towards personalised support for monitoring and improving health in risky environments. *In VIII Workshop on Agents Applied in Health Care (A2HC), Murcia, Spain*, pp. 93-104, 2013.

Paper II **Jayalakshmi Baskar**, Helena Lindgren. Cognitive Architecture of an Agent for Human-Agent Dialogues. *In Highlights in Practical Applications of Heterogeneous Multi-Agent Systems (PAAMS, A-Health), Salamanca, Spain* , Springer International Publishing, pp. 89-100, 2014.

Paper III **Jayalakshmi Baskar**, Helena Lindgren. Semantic Model for Adaptive Human -Agent Dialogues. *Submitted to Journal of Autonomous Agents and Multi-Agent Systems (JAAMAS)*, Sep 2014.

Other publications

- Helena Lindgren, **Jayalakshmi Baskar**, Esteban Guerrero, Juan Carlos Nieves, Dipak Surie, and Chunli Yan. Holistic Ubiquitous User Modeling - The case of the As-A-Pal Project. *Submitted to User Modeling and User-Adapted Interaction (UMUAI) journal*, 2014.
- **Jayalakshmi Baskar**, Helena Lindgren, Chunli Yan. User's control of personalised intelligent environments supporting health. *In Proceedings of the 9th International Conference on Intelligent Environments, Athens, Greece*, IEEE Computer Society Press, pp. 270-273, 2013.
- Helena Lindgren, Farahnaz Yekeh, **Jayalakshmi Baskar** and Chunli Yan. Agent-Supported Assessment for Personalized Ambient Assisted Living. *In proc. Workshop on Agents Applied in Health Care(A2HC), Valencia, Spain*, pp. 141-150, 2012.
- **Jayalakshmi Baskar**, Helena Lindgren, Dipak Surie, Chunli Yan, and Farahnaz Yekeh. Personalisation and User Models for Support in Daily Living. *In The 27th annual workshop of the Swedish Artificial Intelligence Society (SAIS), Örebro, Sweden*, pp. 7-15, 2012.

Acknowledgements

Known is a drop, unknown is an ocean. To begin with, I would like to give my deep regards and deliver my thanks to the divine power called God for giving me an opportunity to do research in Sweden. Let me discuss with my pal Coach Agent.

CA: Hi! I am Coach and here you can have a dialogue with me!

Jaya: Hi Coach! I wonder if not my ”Acknowledgment is complete”.

CA: Hi Jaya! Okay then I would like to ask about who you are *thankful* to?

Jaya: First of all I would like to thank my main advisor Helena Lindgren who has been very motivating. I enjoy hours and hours of inspiring discussions with her. Helena has not only helped me to grow up professionally but also as an independent woman. I am deeply grateful to my co-supervisor Lars-Erik Janlert for his insightful recommendations of literature to read and feedback on my presentations to help me become a better presenter. I am very thankful to Dipak Surie and Juan Carlos Nieves for constructive discussions and many comments on different drafts. Many thanks to Thomas Hellström and Suna Bensch, who in the ”Student conference course in Computing Science”, molded my writing skills. I am also thankful to all the staff at the Department of Computing Science, UMIT Research Lab, HPC2N, and particularly to the members of our UIKM research group for the friendly working environment.

CA: What makes you believe you might want to thank?

Jaya: I would not have done it without them.

CA: Tell me something about your family.

Jaya: I would like to extend my deep acknowledgment for the emotional and moral support provided by my parents and relatives as always.

CA: I see that now you are married to Subhash.

Jaya: Yes, I owe my deepest gratitude to Subhash and my parent-in-laws for their tremendous support and love.

Thank you all!

Jayalakshmi Baskar
Umeå, 2014

Contents

Chapter 1

Introduction

A software agent is defined as a computer system that is situated in some environment and that is capable of autonomous action in this environment to meet its design objectives [1]. Software agents have a wide range of applications such as supporting an expert's decision making, accessing and making use of distributed data sources or the coordination of the execution of assistive technology for healthcare activities [2].

Assistive technology is any product or service designed to enable independence for people. Assistive technology can be supportive, preventive or responsive [3]. Kennedy and co-workers define two types of assistive technology [4]: 1) *active* assistive technology which continues to process the health-related information during interactive use and may adapt its responses; 2) *passive* assistive technology which do not process information related to health or behavior change. For example, an interactive system can process user choices or preferences regarding presentation format (eg., video or text) and adapt to these choices during a session. However, this is not active assistance because the responses are not related to the semantic content of the health messages, but only to their formatting. In this work the definition of *active* assistive technology is applied. The purposes of active assistive technology include the following, targeting the human's needs: to increase knowledge and ability to perform activities, assist in deciding about actions to make, and promote changes of unhealthy behavior (i.e., in the form of *behavior change systems* [5, 4]). This thesis focuses on dialogues between a human actor and an active assistive technology in the form of an intelligent software agent.

A dialogue means that two participants exchange verbal messages or so-called *speech acts*, that take the form of *moves* in a sequence of exchanges [6]. The goal of a human-agent dialogue system is to communicate with a human, with a coherent structure. To successfully achieve this, the agents need to adapt themselves to the humans interacting with them. However, a number of challenges need to be tackled to build a system that is flexible and adaptive to its environment.

1.1 Research Challenges

Building a dialogue system, that is able to conduct and complete a dialogue with a human, is challenging. The system must be able to participate in a purposeful dialogue that includes ability to reference to items mentioned earlier in that dialogue and also to keep track of different sub-dialogues. It must also know the topic and the main goal of a dialogue to be able to make appropriate *moves*. The major challenge is to endow these capabilities that allow them to take a role of a pal (friend) that is usually only taken by a human, thus, making an agent less as a tool that people use and more as a peer or pal that people can relate to. As a consequence, hereafter, the concept of *human actor* is used instead of user. Thus, the whole interaction process is a dynamic one that relies on the capabilities of the agent to learn and adapt to the human actor. We identified the following capabilities as needed for an agent to be able to conduct meaningful dialogues with a human:

1. Knowledge about the human actor,
2. Knowledge about the topic of a dialogue and its domain,
3. Knowledge about the physical and social environment,
4. Knowledge about self, its role, purpose, limitations etc.,
5. Knowing how to conduct the dialogue activity,
6. Knowing how to reason and make decisions about its own behavior and about a topic together with human actor,
7. Knowing how to be social and empathic, i.e., behave,
8. Knowing how to evaluate its own behavior in the context in which it is performed.

To different extent, these challenges have also been described in literature (e.g., [7, 8, 2, 5, 9]). A key asset to address these challenges is *knowledge*, in a broad sense, which needs to be formalised and executable for an agent to have a dialogue with a human actor. However, some tacit knowledge will always remain in the human actor, which requires that the agent and the human actor *cooperate* in reasoning and decision-making as well as in improving the agent's behavior (Figure 1).

1.2 Objectives

This research aims at developing formal models for building the agent's dialogue and reasoning capabilities, which are based on an activity-centered and holistic view on human-agent interaction. The developed models are aimed to be integrated into a suitable cognitive architecture and implemented in a prototype dialogue system. The objective of the research is to achieve dialogues about health-related topics, which are perceived as meaningful to the human agent.

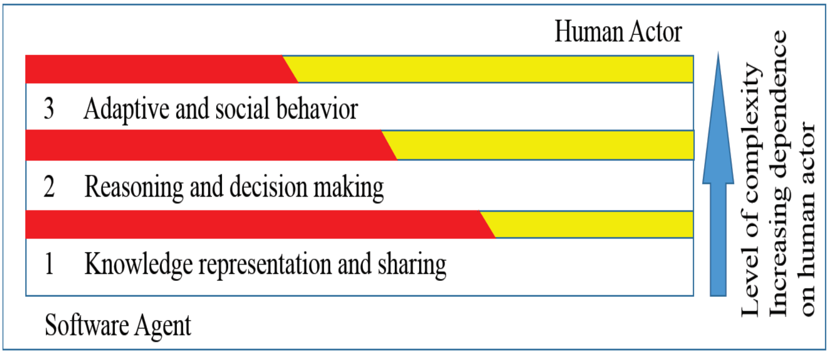

Figure 1: Level of complexity increases with increasing dependency on the human actor.

1.3 Thesis Outline

The remaining chapters of this thesis are organized as follows. Chapter 2 describes the methodology used. Chapter 3 focuses on representing and sharing knowledge, addressing challenges relating to an agent's knowledge about self, the human actor, the knowledge domain of the topic of a dialogue, and about the environment (Challenges 1-4). Chapter 4 focuses on the knowledge relating to how to conduct the dialogue activity, to reason, make decisions, how to behave and evaluate its behavior (Challenges 5-8). The contributions of this research are presented in Chapter 5. Finally, some directions of future work are discussed in Chapter 6.

Chapter 2

Methodology

A range of different research methods and theories have been applied in the process of developing theories, models, methods and technology for enabling adaptive human-agent dialogues. These methods are briefly described and motivated in the following sections.

2.1 Literature Review

A literature study was conducted to investigate how earlier research work presents the agent's role, the purpose of dialogue systems, the knowledge model of the agent, the user, the domain and the dialogue activity, who develops the knowledge model, sources for the knowledge, representation formats and how generic the representation is, and issues regarding the dialogue execution. The literature review provides a base for building the generic conceptual models as a part of this research.

2.2 Persona and Scenario

The semantic models for adaptive human-agent dialogues are designed partly based on personas and scenarios to meet our objectives [10, 11]. A persona functions as a knowledge artefact. In other words, the persona represents a group of users who share common goals, attitudes and behaviors when interacting with a particular product or service [12]. The scenario is a detailed description of how the persona will interact with the intelligent software agent to have a dialogue about a topic [13]. Personas help us remember the target audience by creating a vivid picture of the requirements and help as a guide in the design phase.

2.3 Theories of Human Activity

For understanding and modeling the human actor's aims, resources and behavior, Activity Theory [14] was used. Activity Theory originated in the work of the Russian psychologist Lev Vygotsky [15] in the early 20th century and has been developed by Kaptelinin among others [16]. Activity Theory is a theoretical framework developed to analyse human's activity and development of skills within the environment where the activity takes place. Every activity is directed towards a person's motive which corresponds to a need. The motive is crystallized in an objective, which defines the activity and is the focus of an activity. Activity is always mediated through the use of instruments, or tools, which are not in focus when conducting the activity. In this research the software agent is treated as an actor rather than a tool, since the purpose is to keep the focus on the topic of a dialogue. The instruments for conducting a dialogue are different sources of knowledge and mediating devices. Activity Theory provides a systemic framework of human activity and has been integrated in the resulting formal models of human-agent dialogues.

2.4 Argumentation Theory

As the Activity Theory emphasizes, over a period of time, both the human's and agent's knowledge changes as they develop. This changing knowledge results in a conflict with existing information/ beliefs and a need to handle the conflicts and potential *breakdown* situations, in terms of Activity Theory. Argumentation theory was used for handling new information and justification of beliefs [17, 18]. The main idea of argumentation is to structure the reasoning in the way that rules, which support a conclusion, can be defeated when new information arises. This is called non-monotonic reasoning, and reflects how people reason in everyday life. Consequently, the Argumentation Theory was a natural choice for enabling reasoning as a part of dialogues, that may be perceived as "natural" to the human actor.

2.5 Prototyping and Observations in User Studies

A pilot evaluation study was conducted involving a group of five female professionals in occupational therapy and physiotherapy, specialized in the needs of older adults, and a group of eleven older adults, six women and five men. The study was formative, with the results aimed to inform further development. The participants were observed using the prototype system and interviewed. A likert scale was integrated for measuring appropriateness of the agent's behavior, and evaluated as a potentially useful method for evaluating the agent's behavior.

2.6 Summary

The described methods and theories enable us to know the state of the art, specify the requirements from the human actor's perspective, relate a dialogue to the human's activity, enable reasoning when the dialogue participant's have conflicting beliefs and to evaluate our results. These methods and theories have been used to build the formal models, partly in collaboration with domain experts such as physicians and therapists, implement the results and evaluate the results with human actors.

Chapter 3

Representing and Sharing Knowledge

Knowledge representation is concerned with designing and implementing ways of representing information so that agents can use it for the purpose of communicating among systems and people with a common representation format, the agents can generate decisions and new knowledge, and bridging distributed and scattered knowledge sources. The types of knowledge we are interested in is typically incomplete, uncertain and ambiguous - thus requires representation formats, that can treat the knowledge in a sound and complete way. Knowledge is typically divided into *factual* and *procedural* knowledge [19]. Factual knowledge refers to representations of objects. The procedural knowledge is knowing how to do things to reach a particular objective or goal. An intelligent agent needs reasoning strategies, as well as representations of human activities, to put the human's actions into a meaningful context, predict and plan activity.

In an intelligent environment which aims at providing adaptive support tailored to the human actor, there are multiple sources of information to consider for an agent to have a dialogue with that human actor [20]. Some of the sources can be information about the human actor's daily activities observed by an activity recognition system at home, the information about the human actor's medical health condition obtained from domain professionals and relatives, and the human's preferences etc. An intelligent interactive behavior also requires social and emotional intelligence, which builds social interoperability.

In the following sections, the representation formats applied in this research for representing and sharing knowledge are introduced. Also approaches for representing the knowledge about the human actor, the agent and the dialogue context are briefly described.

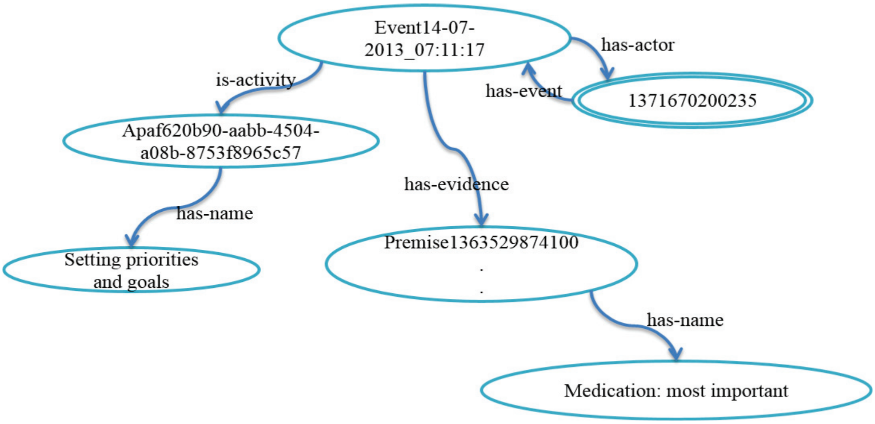

Figure 2: RDF example extracted from the Actor repository showing the information of an event in which a human actor's goals and motives are captured.

3.1 Representation Formats

A range of knowledge representation formats have evolved for different purposes, e.g., for reasoning over the World Wide Web (WWW). The Semantic Web was initially introduced by Tim Berners-Lee [21] and has evolved over the past 15 years with a growing research community, which explores how knowledge can be embedded, re-used and developed on the WWW in a more intelligent way. The Semantic Web can be viewed as "clouds" of interlinked pieces of information, where sometimes there are links between clouds, but most often they have content that is difficult to process and extract meaning by other systems [22]. The Semantic Web is built using primarily two representation formats: the Resource Description Format (RDF)[1] and the Web Ontology Language (OWL)[2].

RDF is a W3C (World Wide Web Consortium) standard for describing *web resources*. A web resource is any identifiable information on the web. It helps to ensure that the meaning of a web resource is interpreted as the author/publisher intended. RDF is a graph-based data model with labeled nodes and directed, labeled edges, which makes it a flexible model for representing data. The nodes and edges can be augmented with additional information, and the edges represent the relationship between two resources. Consequently, the structures can be used for reasoning. An example is provided in Figure 2, which shows an instance of an *event* in the Actor repository developed as a part of this research (Paper I [23]).

The Web Ontology Language (OWL) extends the RDF. OWL is an international standard for encoding and exchanging *ontologies* (i.e., terminology models) and is designed to support the Semantic Web. OWL is based on Description Logics [24]. Description Logic is a family of logics that are decidable fragments

[1] http://www.w3.org/RDF/
[2] http://www.w3.org/OWL/

of first-order predicate logic. These logics focus on describing classes and roles, and have a set-theoretic semantics. RDF and OWL are the underlying representation formats for the models developed as a part of this thesis.

FIPA (Foundation for Intelligent Physical Agents)[3] protocol is the most common format for agent's communication and knowledge sharing. It facilitates rapid development of multiagent systems. Several platforms have been developed that support FIPA messaging but these platforms are restricted to multi-agent systems without a human actor's involvement. In FIPA-ACL (Asynchronous Communication Language), the agent moves are called *communication acts*. The FIPA's communication acts have corresponding moves in our approach, for example, ($query\_if \equiv ask$), ($inform \equiv tell$). However, for enabling human-agent interaction using FIPA-ACL, a translation service is required to present the messages through a user-friendly interface, and it does not support argument-based interaction.

Argument Interchange Format (AIF) was developed for visualizing and sharing different arguments and argumentation schemes [25]. The purpose of AIF is to function as a common format for exchanging arguments on the WWW. The AIF model has been modelled as a Semantic Web ontology by Rahwan and colleagues [26]. With this AIF model, arguments may be posted/ shared by individuals on the WWW, in a structured format. The ambition with the AIF initiative and the research presented in this thesis is to provide instruments for querying the web and conduct argumentative reasoning with resources, i.e., knowledge, collected from different sources. Therefore, an extended AIF ontology, which is integrated in the ACKTUS[4] platform is used in this work for providing the agent tools for reasoning [27].

3.2 Representing the Actor

An actor needs a perception of "self" to be able to relate to other agents. Consequently, a software agent needs explicit models of self and of the human actor to reason about health issues with the human. The agent also needs behavioral knowledge which is generic regardless of the dialogue topic at focus [7].

3.2.1 The Human Actor

Human actors have different knowledge, learning styles, interests, background and preferences regarding information presentation over the Internet. This has paved way to research on *intelligent user interfaces* that can be designed to recognize the goals and characteristics of the human actor and adapt accordingly. To achieve adaptability, it is important to observe the human actor's behavior, and make predictions based on those observations. The method of obtaining *information* pertaining to an individual human from such observations is known

[3]http://www.fipa.org/

[4]ACKTUS- Activity Centered modelling of Knowledge and interaction Tailored to USers, http://acktus.cs.umu.se/

as *user modeling* (e.g., [28]). A user model, or a simple user profile, may consist of information collected by filling questionnaires, by observing user-actions, or by making inferences. *Personalisation* aims at providing human actors a system with the content and behavior that they need and desire without necessarily requiring the human actors to specify it explicitly [29].

User models have been used in the healthcare domain for instance, to provide management and retrieval of a person's or patient's data [30]. Two techniques available to model an adaptive web system are *feature-based modelling* and *stereotype-based modelling.* An example of the stereotype-based model is the *User Modelling and Profiling Service* (UMPS), which provides the methodology for context dependent personalisation and adaptivity of applications and services in the Amigo environment [31]. Normally, a stereotype model ignores the features and uses the stereotype as a whole. In UPMS the user profiles are built first based on stereotypes and explicit human input, and in the second step these profiles are refined using the interaction/context history.

In this thesis, the feature-based modelling is used to create user models (i.e., *human actor model*). Feature-based modelling attempts to model specific features such as the individual human actor's knowledge, interests, goals etc. The majority of modern web systems use the feature-based approach to represent and model information about the human actors. As a part of this thesis, the ACKTUS core ontology was further extended to incorporate information about a user's environment as presented in Paper I [23], for the purpose of forming a user model, which an agent can use for adapting a dialogue to the human actor. In this model, we extract information related to the chosen topic of a dialogue, combine this with information about the human actor's motives and preferences as they have assessed this in dialogues about goals and priorities. Based on the local context of a dialogue, a user model is created by the agent, which contains a priority of goals and which gives the agent an instrument for deciding about adaptation. The extended model contains concepts such as *space*, properties such as *action-is-situated-in*, to connect the situatedness of human activity with higher level reasoning about purpose and what to do next.

3.2.2 The Software Agent

The characteristics of an intelligent software agent are borrowed from both the domain of cognitive psychology and the domain of distributed intelligent systems [19]. In general, an agent for human-agent dialogues is represented by a cognitive architecture with components for *perception*, *planning*, *desire*, *intention*, *execution* and *communication* [32, 7]. A perception module analyses the data obtained from the environment and available information. It aggregates this information into beliefs. A planning module constructs and outputs abstract plans according to a situation and a desire generator uses these as input. The desire generator interprets an abstract plan as desires; it embodies a representation of current plans. An intention generator refines a desire into intentions. An execution module performs the necessary actions of an intention. A communication module allows the agent to interact; it is used by other modules such as the perception module to interpret received messages and by the execution module to send messages.

The most widely used cognitive architecture is the BDI architecture [19]. In this architecture, the state of the agent is represented by three structures: its *Beliefs*, its *Desires* and its *Intentions*. The agent's set of *beliefs* corresponds to its *knowledge* and represents its model of the world. Its *desires* correspond to its *goals* and provide some sort of ordering between states. The *intentions* correspond to the concept of *plans*, and are the things it has decided to do. The intentions of a BDI agent may be defined at various levels of abstraction; for example, an agent may intend to buy a book but may not have decided which shop to buy it from. A BDI agent gradually refines its intentions to elementary actions that can be executed. Several cognitive agent architectures have extended this BDI model to integrate features like planning, learning, interaction and reasoning.

The *canonical model of an agent* described by Fox and coworkers [8] is an extension of the BDI model (e.g., [7]) and provides formal semantics for the concepts argumentation, decision-making, action, belief, goal (desire) planning (intention) and learning for agents. Literature describes implementation in systems, however, mainly for multi-agent reasoning and decision making without active participation of a human agent in the process [8].

A cognitive architecture of an intelligent agent that can have a dialogue with a human on health-related topics is presented in [20] (Paper II). The Agent model represents the behavioral knowledge of an agent. Coach Agent was modeled as a separate project using the ACKTUS platform [33], which builds the Agent Knowledge repository in Figure 3. As a consequence, the Coach Agent shares the ACKTUS core ontology with the human actor and the domain models. The core ontology functions as the common vocabulary in the dialogues. Moreover, several agents with different characteristics, with some shared models of behavior, can be created. Each instantiated agent stores its specific learnt knowledge in a repository, (structured the same way as the Human Actor repository, the repository for human actor's information), based on events, e.g., a dialogue occasion with the human actor.

3.3 Representing Contextual Knowledge

In addition to the human actor's changing needs, abilities and wishes, the agent needs to adapt to contextual factors such as the knowledge related to the dialogue topic, which typically concerns a particular knowledge domain (e.g., pain, worries, etc), and the social and physical context, in which the dialogue takes place.

3.3.1 Epistemic Context

The epistemic contextual knowledge of human-agent dialogues applied in this thesis work is related to health, e.g., pain, worries, wellbeing, gait, cognition

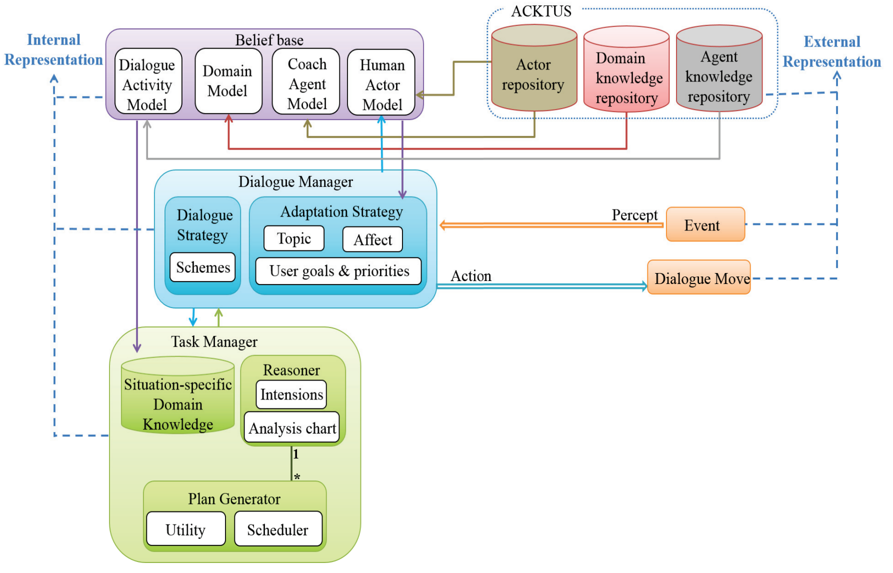

Figure 3: Cognitive agent architecture based on Paper II and Paper III.

etc. A dialogue topic is framed by a representation of the knowledge domain, which defines the reasoning context and associated questions, rules, knowledge sources etc. The knowledge is modeled by professionals who are experts in relevant domains, by using the ACKTUS platform [27]. The factual knowledge is modeled using an extended ICF(International Classification of Functioning, Disability and Health)[5] concept model and procedural knowledge is represented using the extended AIF model.

3.3.2 Physical and Social Context

The knowledge about the human actor's activities deals with what is being done, its purpose and how a particular activity is performed. The user may describe explicitly what activity is being performed and their environment, while the latter involves observation of both environment and activity, e.g., by the use of sensors as a part of a ubiquitous computing environment.

In dialogues between a software agent and a human actor about health-related topics, it is essential to reason about daily activities to situate a health-related topic in a context. The identification of activity needs to be related to level of importance to the user, user's preferences and goals, to reason about how the system should act upon the new knowledge, e.g., guidance in activity execution etc. Activity theory is useful for categorizing and interpreting observations to represent knowledge about purposeful activities [16]. The *egocentric*

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

conceptual model covers primarily concepts related to sensors, effectuators, interaction devices and their properties and their relation to the situative spaces [34]. As a part of our work, the ACKTUS core ontology was extended with models of activities of daily living, situated in a physical or virtual environment for the purpose to build more holistic models of the human actor and her activities. This was done by fusing the activity-theoretical model, the conceptual model of egocentric interaction and the results of hierarchical task analyses of selected human activities (presented in Paper I [23]).

Chapter 4

Conducting the Dialogue Activity

The purpose of a dialogue can be to allow the human actor to propose a claim about a topic and to participate in an elaborated discussion about the topic, with well-founded arguments in favor and against the claim. However, this is not always the case, since the coherence of a dialogue depends on its goal it is important to identify the various types of dialogues. Walton and Krabbe [6] have proposed six main categories of human dialogue that are based on the overall goal of the respective dialogue. The categories integrated in the *dialogue activity model* developed as a part of this work are the following:

- *Information-seeking dialogues,* where one participant seeks the answer to some question from another participant. The participant's aim is to gain knowledge or pass on knowledge to the other participant without having to reason to come to a conclusion about the topic of the question. The clinical interview as conducted in the healthcare domain is an example, where information is collected, however, the reasoning about e.g., diagnosis, or interventions may be done by other persons.

- *Inquiry dialogues* occur when the participants collaborate to search for an answer to some question and to validate a claim about a topic [35, 36]. Reasoning takes place, where the agents utilize their respective knowledge, which can be different and incomplete, and new knowledge is derived in cooperation.

- In *Deliberation dialogues* agents collaborate to decide what course of action should be adopted in some situation [37, 38]. In the healthcare domain, the decisions about interventions aimed at improving a person's daily life and medical condition are typical examples.

- *Persuasion dialogues* involve one agent seeking to persuade another to endorse a statement that this agent currently do not [39, 40]. Initially,

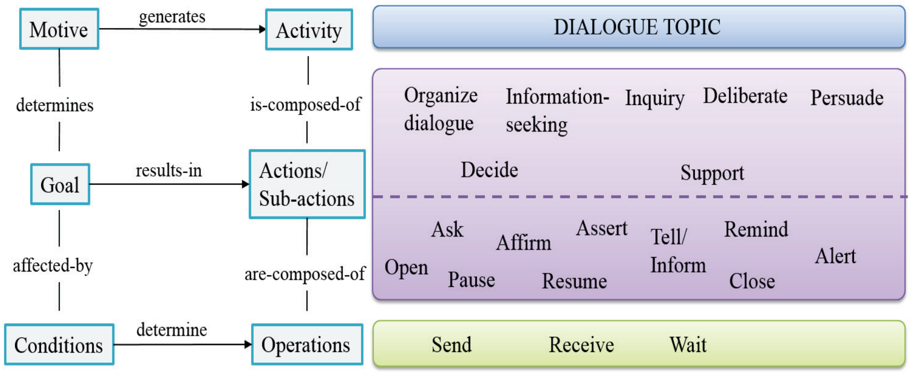

Figure 4: A model of the dialogue activity, which both a human and a software agent are expected to comply with (Paper III [41]).

agents involved in persuasion dialogues will have conflicting opinions about e.g., the importance of consulting the nurse about a pain condition, or when a changed behavior is judged to be beneficial for a person's health, eg., stop smoking, eat healthier, etc. [27]

This thesis will primarily focus on exploring the application of the three categories suitable for cooperative behavior: information-seeking, inquiry and deliberation dialogues. In addition, persuasive dialogues are included since one of the main obstacles to improving health is changing behavior.

We interpret and formalize the dialogue activity into a hierarchy of tasks with different goals and semantics, which builds up a model of the dialogue activity (Figure 4). In the dialogue activity model presented in Paper III [41], we identified the following generic set of actions to serve the overall motive of a dialogue, which is addressing the topic of the dialogue: *information-seeking, inquiry, deliberative, and persuade*, related to the common goals of different types of dialogues as described previously: seek information, construct/build new knowledge, decide upon actions to be made and lead the other agent to change opinion. To these actions, we added the actions *organize dialogue, decide* and *support dialogues*. Using this dialogue activity model, the nested dialogues about topics related to the main topic can be accomplished in our framework.

Some human-agent dialogues involve reasoning and decision-making aimed at reaching conclusions about new knowledge or action to take. Some other dialogues aim to collect information or pass the information, or provide emotional support to the human actor without reasoning. In the following sections, the two purposes are further described.

4.1 Reasoning, Generating New Information and Making Decisions

The software agents use their formal representations, or models of the world (i.e., knowledge) for reasoning, decision making and action selection. Rule-based approaches are the most commonly used approaches for reasoning about health-related conditions [42]. Typically, rules are built using classical monotonic logics, where premises and conclusions cannot be changed and adding new information is not allowed. However, humans possess the ability to identify the information that is appropriate to the context of the situation and change reasoning as new information appears. The classical logics require a fixed set of facts that are either true or false (called closed-world assumption). These fixed set of facts are used to make sound inferences to come to valid conclusions. Consequently, classical rule-based systems are not well suited for cooperative (plausible) reasoning with humans.

Given a situation with conflicting information, an agent is faced with the problem of deciding what it could reasonably believe. As advocated in various non-monotonic inference formalisms such as default logic [43], it is often possible to identify multiple reasonable positions. This idea has been adopted in *abstract argumentation theory* [44], which provides a formal framework for handling conflicting positions, potentially due to uncertain or inconsistent knowledge. This theory views logical derivations as abstract arguments (nodes in a graph), and conflicts as defeat relations (directed arcs) over these arguments without considering the content of a node or an argument.

Argumentation-based dialogues have been widely studied as a framework to support agreement among agent dialogues (e.g., [45, 35, 39, 46]). The arguments can be instances of argumentation schemes. The argumentation schemes are patterns of reasoning and regulate how a particular type of dialogue can be conducted. The argumentation schemes are also useful in finding missing premises, analysing arguments and evaluating them. These schemes represent defeasible inferences that are useful in reasoning about a plausible hypothesis under conditions of uncertainty and lack of knowledge. Several argumentation schemes have been defined and applied in various research studies [47, 48, 49]. As a part of this work existing schemes have been adapted and integrated, as well as new developed schemes in a dialogue activity model (Paper III [41], Figure 3).

McBurney and Parsons give an overview of dialogue games for argumentation in [45]. A dialogue between two participants is seen as a game in which each individual has objectives and a set of legal moves which can be used to obtain those objectives. In this game-theoretic approach to dialogues the speech acts are viewed as moves in a game and semantics indicating whether moves are appropriate at a specified time and are formulated as rules of the game [35]. An inquiry dialogue system has been presented by Black and Hunter [35]. Their system uses the game-theoretic approach and restricts each dialogue to one single topic, and a small set of moves (open, assert and close).

Since we need a more complex adoption of dialogues with different topics for accomplishing a dialogue that is perceived as natural by the human, we extended the set of *moves* to include the following moves as valid actions for the agent to take: *open, close, pause, resume, ask, assert, affirm, inform, remind* and *alert* (Figure 4).

The content of the dialogue type *support dialogue* introduced in Paper III [41], is typically the outcome of an earlier conducted deliberation dialogue, where the human agent and the Coach Agent have agreed upon a plan of actions to be conducted. The actions performed as support dialogues are one of the following: *inform*, i.e., provide the human agent with information or advice, *remind* the person of actions to make, and *alert* the person when important things need to be done. A remind and alert move are formal *arguments*, which contain the information about what is to be done (a *claim*), together with the motivations (the *grounds*), which support the claim (Paper III [41]).

4.2 Adaptive and Social Behavior

In a human-agent dialogue, an agent must adapt to the human actor. We identified three types of adaptation needed for an agent to exhibit adaptive and social behavior. Firstly, an agent needs to adapt to the *human actor's line of thinking*. This is accomplished through the *dialogue activity model* in combination with a *domain model*, which allows flexibility in conducting a dialogue (Figure 3). Secondly, the agent needs to adapt to the *human actor's needs, preferences and ability*. This accomplished through building a model of the human actor (*actor model*), which is used in the selection of topics and contents of dialogues e.g., tailored advices. Finally, the agent must also adapt to the *human actor's emotional states and norms*, which puts additional demand on situatedness and evaluation of the agent behavior.

Norms are an important part of human social systems, governing many aspects of cooperative decision-making [50]. The study of norm emergence, compliance, and adoption has resulted in new architectures and standards for social agents. Norms play an important role in determining the behavior of people in society. The norms have been used as a computational mechanism for creating coordinated action within multi-agent systems [51, 52]. Previous work on modeling norm life-cycles can be organized into two categories: *internal* and *external*. In the first category, norms are characterized as arising from internal mental processes that can be specified using cognitive modeling techniques, and social behavior is viewed as the outcome of internalizing external preferences. The agents are able to acquire new norms, rather than relying on preexisting constructs, and can reason and value about norm compliance. In the second category, the focus is on social interactions, and game-theoretic models are used to quantify the bottom-up process of recognizing and complying with norms in the external social system. Convergence occurs when agents arrive at a mutually agreed upon utility maximization strategy. A limitation of this type of system is that the agents lack a sense of normative expectation and do not distinguish between a strategy and a social norm [53].

Bickmore and co-workers [54] state that the establishment of norms is crucial in domains in which a human actor is attempting to undergo a change in behavior. They designed relational agents that build and maintain long-term, social-emotional relationships with their human actors [5].

In this thesis, for the Coach Agent to be able to conduct dialogues similar to natural dialogues, it was necessary to include generic behavioral knowledge. The behavioral knowledge needs to be generic regardless of which type of dialogue or topic is at focus. The initial version of the *agent model* developed as a part of this thesis work has been enriched with structures, which function as tools for the Coach Agent to use in the adaptation of its behavior. The Coach Agent associates each action with a concept that is common for both the human and the agents such as *starting, sustaining* and *ending* a conversation. These concepts were used to define certain behaviors that are typically appropriate in a phase of a dialogue, for example, *"hi"* is associated to concept *"starting a conversation"*. Similarly, for the dialogue moves, such as *affirm*, the agent emphasizes and affirms the emotional state, which the human actor expresses, by using empathic statements such as *"does not sound good"* and *"I see"*. This enables the Coach Agent to simulate the behavior of a participant who listens with empathy.

Chapter 5

Contributions

Paper I

The contributions of Paper I [23] include the extension of the ACKTUS core ontology with the user and domain models for incorporating situated models for environments and activities. This was done based on theoretical analysis, and comparisons with existing formal and informal models of human activity. As a consequence, the *event ontology* building the Actor repository was created as a supplement to the actor and activity models. Based on these models, the agent constructs its knowledge about the human actor, the topic of a dialogue and the environment, which corresponds to the Challenges 1-3 described in Section 1.1. These ontologies formed the basis of an initial implementation of a human-agent dialogue system, with a focus on the information-seeking type of dialogues using the JADE[1] platform. The agent architecture enforced by JADE was found to be a limitation for more flexible human-agent interaction, which is required for other types of dialogues.

Paper II

The contribution of Paper II is the design and partial implementation of the architecture of a cognitive agent potentially able to engage in a dialogue with a human actor. The architecture consists of different components including the dialogue adaptation strategies and reasoning strategies, in addition to the models presented in Paper I. This paper focuses in particular on the dialogue manager, building on the idea of schemes. A basic strategy for adaptation to the human actor's line of thinking, goals and priorities was formed.

[1] Java Agent Development Environment, http://jade.tilab.com/

Paper III

Paper III supplements Paper I and Paper II, addressing the agent's knowledge about self, its role, purposes and limitations, by taking a holistic and activity-centered perspective on the human-agent dialogue activity. The contributions of this paper include an *agent model*, a *dialogue activity model* and the integration of the *human actor model*, the agent model, the dialogue activity model and the *domain model* for building the belief base of the agent (see challenges 4,5,7 and 8, described in Section 1.1). The human-agent dialogue system introduced in Paper II was further developed based on these semantic models, and integrated in the web-based support application Vardagsvis (I-Help), designed for older adults. A pilot evaluation study of the prototype system was done with five therapists and eleven older adults to investigate the overall idea of a dialogue system for supporting everyday issues, how a sense-making dialogue would unfold and what topics would be interesting to elaborate upon.

In general, the available dialogue topics were considered interesting and relevant. The participants suggested additional health-related topics for human-agent dialogues relating to eating habits and eating disorders. Enthusiasm and curiosity was expressed about the idea and the wish to use the dialogue system merely for the fun of it: "...this is fun, let me try another one!"

A purpose was also to evaluate the appropriateness of each dialogue move made by the agent. A method for the agent to be able to evaluate its behavior was developed and evaluated. Two types of appropriateness were identified and evaluated: *context-related* appropriateness and *topic-related* appropriateness. The context-related appropriateness relates the agent's move to the context in the dialogue line in which it occurs (i.e., measures the agent's adaptivity). The proportion of appropriate moves in relation to the local context of earlier moves in the dialogue line was 90% in the pilot study, which indicates that the agent's strategies for selecting moves can be improved. The topic-related appropriateness relates the agent's move to the knowledge domain (i.e., evaluates the knowledge domain). The approach was found to add significant value to the evaluation study, without disturbing the participant from participating in the dialogue.

Chapter 6

Future Work

Several directions of research are considered as a part of future work. The main topics relate to continued development of the modules in the cognitive agent architecture. One obvious line of future work is to develop reasoning and adaptation strategies for the agent to improve its ability to adapt, to the individual and to the situatedness of context during a dialogue. Another interesting line of future work is to build a learning algorithm for the agent to plan next dialogue move based on the human actor's feedback data collected by the evaluation method developed in Paper III.

The additional topics for future work relate to how the dialogue can be mediated to the human actor through purposefully designed user interfaces, and user environments. The potential mediation of dialogues with human actors using avatars and humanoid service robots will be investigated, as well as using modalities for communication other than the text-based prototypes. A full-scale prototype will be built and embedded with other applications to test its domain independence. The adaptivity, agent behaviors and knowledge context will be evaluated with different user groups of the human-agent dialogue system.

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Towards Personalised Support for Monitoring and Improving Health in Risky Environments

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Abstract. The research presented in this paper aims at supporting an individual in their daily living in a home environment. Our objective is to fulfill the scenario of an individual older adult having breakfast and who would like to have social interaction and be aware of happenings outside of her home. This is accomplished by extending the existing ACKTUS ontology with an ubiquitous perspective for activity recognition and secondly, to tailor support and provide personalised services to an older adult in home environment based on activity recognition. This is done by means of an agent system, enabling dialogues between agents and between the human and a software agent.

1 Introduction

There is a need for methods for software agents to reason about risks and risky situations, based on synthesised information obtained from different sources of information in a ubiquitous environment [1, 2]. This is for the purpose to make decisions about what advices to provide the user, or in which way to adapt the environment to the user's needs. These decisions should be founded in the obtained information specific to the user combined with generic knowledge about hazardous factors in an environment. Moreover, in order to use the intelligent environment for empowering the user, there is also a need for methods to allow the user to maintain the power over the intelligent environment [3].

The presented research addresses adaptive computer-based personalised support for monitoring and improving health of older adults for the purpose to lead an independent life. In order to achieve adaptability of personalised information, it is important to observe the user's behaviour, and make predictions based on those observations. The information pertaining to individual user obtained from such observations is known as an *user model* (e.g., [4]). Personalisation aims at providing users with the content that they need without necessarily requiring the users to specify it explicitly [5]. Thus categories of knowledge needed to provide personalised support for activities are knowledge about *the user*, *the user's activities and environment*, and *generic domain knowledge*. The knowledge about the user consists of the individual's preferences [6], ability, interests, habits, needs, wishes and social network, etc. The knowledge about the user's activities deals with what is being done, its purpose and how a particular activity is performed. The third category is environmental knowledge that concerns physical, social and virtual components. To a certain extent these types of knowledge can be obtained by a system through *information-seeking dialogues* between the user and the system agent [7]. This method can be supplemented with observations of the user in activity. The user may describe explicitly what activity is being performed and their environment, while the latter involves observation of both environment and activity, e.g., by the use of sensors as part of a ubiquitous computing environment [8, 10, 11]. The user, activity and environment knowledge is specific to an individual whereas the last category, the domain knowledge is generic and created by domain experts such as a health care professional based on reliable knowledge-sources [12].

The main contribution of this work is a developed terminology model used for agents' reasoning about activities performed in an ambient assisted living (AAL) home environment. Moreover, an initial implementation of an activity recognition system and a multi-agent dialogue system reasoning about activities are presented. A pilot study with the purpose to investigate needs and motives of older adults related to accomplishing activities they wanted to perform, generated a generic model of purposeful activity [13]. The following activities were identified: 1) feeling safe and secure, 2) having knowledge and control (e.g., keeping up with news), and 3) feeling good, engaged, active, having fun. The second result i.e., keeping up with news and third to be socially active have been a motivation for this research work.

The results consist of the following: 1) an extension of the ACKTUS core ontology for the purpose to capture activities in a physical and virtual environment, 2) initial design and implementation of the MUDRA system for activity recognition and evaluation, and 3) an initial design and implementation of an agent dialogue system where agents communicate with the end user in a home environment.

The paper is organized as follows. In Section 2 the ACKTUS tool is introduced and an architecture of the system for personalised support in home environment with a case scenario is described. In Section 3 the extension of ACKTUS ontology from ubiquitous computing perspective is presented. In Section 4, activity recognition has been discussed with a brief explanation about MUDRA system for activity recognition, followed by multi-agent dialogues and some conclusions and directions for future work.

2 System architecture

The ACKTUS (Activity Centered Knowledge and interaction modeling Tailored to Users) platform is used by domain professionals for modeling the domain knowledge, user models and personalised behavior of a knowledge-based support system [14]. Such system may utilize sensor information from an ambient assisted living (AAL) environment for the categorisation and interpretation of observations in order to represent knowledge about recognisable purposeful activities, useful for support provision. The system architecture is shown in Figure 1. ACKTUS-care and a part of the functionality of I-Help are developed using the ACKTUS platform, which domain expert physicians can use for modifying the knowledge content and interaction design [14, 15].

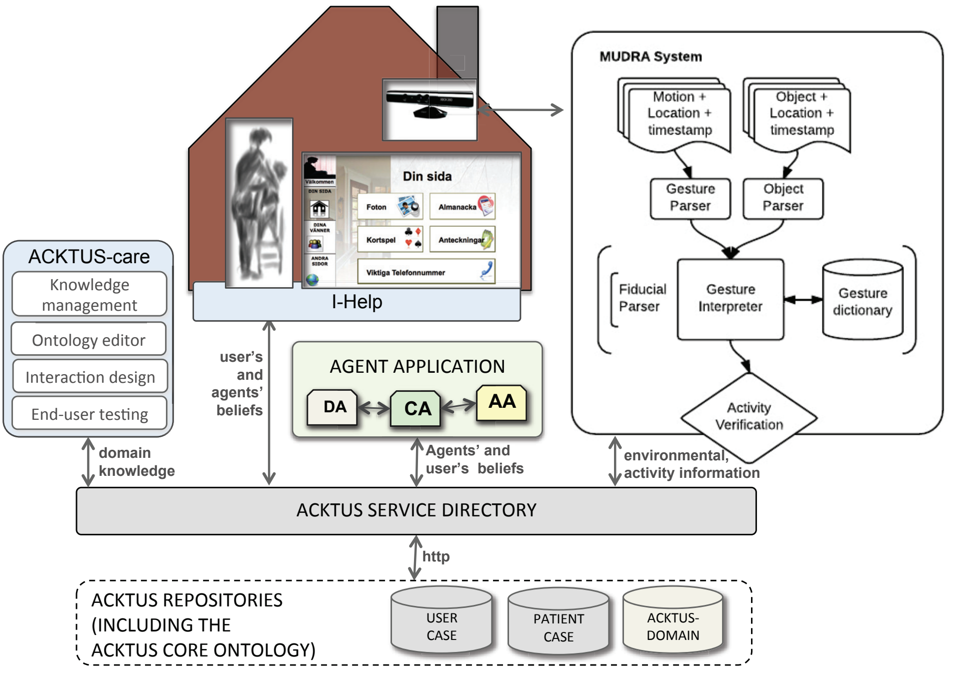

Fig. 1. Architecture.

2.1 Rut Scenario

Our scenario is based on an older woman who suffered from a few falls before a hip fracture [12]. Part from having pain when walking around, she is also very worried that she might fall again. She has mild cognitive dysfunction, showing that she sometimes forgets to take medication and eat properly. She likes to lead an independent life without a caretaker and thus she needs a solution to monitor and improve her health along with fulfillment of her wishes and needs of daily living.

3 Ontology

For representing the necessary knowledge to be used in reasoning about tailored support in an intelligent environment, we extend the ACKTUS ontology, which contains a basic model of the user and activity [15]. ACKTUS is based on models of human occupation [16], the International Classification of Disability, Functioning and Health (ICF) provided by the World Health Organization [17], and other medical terminologies. We take a persona and a case scenario as starting point for the development of an individual's supportive knowledge-based environment [12]. It is then used to extend the *ACKTUS user model*, to create an *environment ontology* and *activity ontology*. Activity theory has been used to categorize and interpret activities in order to represent knowledge about recognizable activities [16].

In order to create a holistic understanding of Rut's environment as an adaptable and adaptive AAL environment, we evaluated the conceptual models underlying the two frameworks ACKTUS and egocentric interaction [8]. The selected part is the breakfast moment, specified by Rut's physical presence during a time frame from when she enters the dining area to when she leaves the area. Based on this the ACKTUS ontology was extended to include the class *space*, which can be both physical and virtual. Spaces are locations where objects and actors are situated during activities. Features that relate to the physical home environment (located in spaces) are captured by the ACKTUS ontology at a generic level using the *building* class (Figure 2). In our example we identify the particular sub-space in the kitchen as dining area.

Activities fall under the *Activities and Participation* class, following the ICF categorisation as basic structure (Figure 2). The activities that are performed in the space in focus during Rut's breakfast moment are done partly in parallel and are the following: having breakfast (includes actions such as eating, drinking, pouring water into the coffee cup, and milk into the porridge plate and a glass); keeping up with society by reading news, keeping up with her social network by having a dialogue with her friend Greta; caring for her health by taking her medication; train and get some entertainment by playing with cognitive training tool; plan the day by checking her agenda/schedule; and finally, in order to reflect upon daily life she has a weekly dialogue with the *Coach Agent* (CA) (refer Section 4.2) of the AAL environment. In the initial assessment phase of our scenario, the motives behind these activities were identified by the occupational therapist, Rut and her son, and the activities were selected as being important activities that Rut wanted to have support with. The dialogue with the CA serves as a followup of how Rut thinks that her daily life works, and of her emotional state (e.g., Figure 4). This subjective view is to become supplemented in this project with an activity recognition functionality.

Some of these activities are taking place in both a physical space (dining area) and in virtual spaces (a news forum on the web, a social media application that gives access to her friend and her home, a web-based cognitive training tool, etc) making these activities taking place in a *mixed-reality space*. This characteristic feature is also captured by the egocentric conceptual model. A significant difference between the models is that while the ACKTUS ontology covers purposeful activities, their tools, motives, actors and locations, as how Rut and health professionals perceive activity, the egocentric conceptual model covers primarily concepts related to sensors, effectuators, interaction devices and

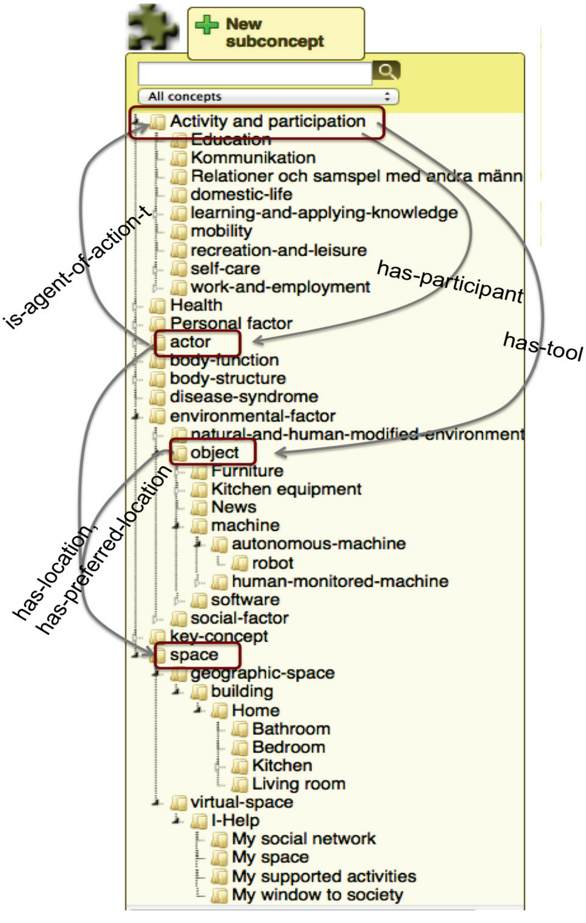

Fig. 2. An overview of the nodes in the extended core ontology that builds the user, activity and tool models. Some of the added classes and their properties are shown, e.g., space and its subclasses, and additional objects relevant in a home environment.

their properties and their relation to the situative spaces [8]. This means that focus lies on the operational level of activity, e.g., how accessible objects are to the actor and through which modalities information is communicated. In this way the two conceptual models are supplementary. e.g., Rut's preferences regarding how to interact with the systems captured at the purposeful level of activity and by the ACKTUS model can be effectuated by the egocentric interaction framework.

4 Activity recognition

A pilot study was conducted to investigate in which way gesture based interaction could be a means for performing activities. Another purpose was to develop a system, which can form the base for activity recognition and evaluation both in home and work environments. A hierarchical task analysis was done for the purpose to identify suitable tasks to be identified using 3D sensors (refer Figure 3). Hierarchical task analysis (HTA) is a method that was developed to understand how a specific process is performed [9], in a step by step manner. The task analysis was based on the use case scenario and the persona's needs and wishes. The tasks, which were assumed suitable to be identified through sensors, were studied in an empirical study involving a convenient sample of 20 individuals (10 male and 10 female) with the purpose to explore which gestures are most natural for each task. The results of this pilot study form the basis for the development of a prototype system MUDRA (Machine Understandable Decision about Recognisable Activity) for activity recognition based on gesture and object identification.

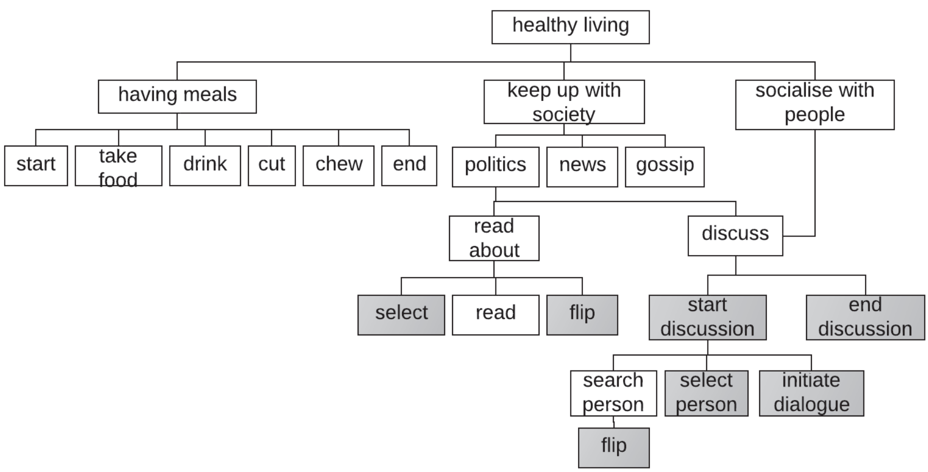

Fig. 3. Part of the task analysis is shown with the selected tasks to be identified by a gesture recognition system highlighted in darker color.

4.1 The MUDRA system for activity recognition

We take as starting point the selected activities, which the user prioritizes as important and which the user wants to have support with. Consequently, we also need to identify activities. For this purpose, an activity recognition system is being developed, based on 3D sensors. Since the core task is to detect movement of limbs, we start by performing a pilot study to find out what types of gesture based interaction could be used for performing activities. By developing gesture recognition and evaluation, a base for detecting also other movement characteristic for activities is formed.

The prioritized activities in focus for activity recognition as part of this work, are keeping up with what is happening in society by reading the news, and at the same time, having a conversation with a friend about the news through a social network application. The targeted actions to be detected in the initial phase of our work, were *select* person to communicate with, *start* and *end* a dialogue. Moreover, the task to *flip* (e.g., for changing page of a news paper, or scroll between pages in an application) was included.

In the breakfast scenario, there are two types of interaction identified 1) interaction with a digital portrait, which mediates a social network functionality integrated in I-Help (Figure 1), and 2) interaction with kitchen objects such as a cup for accomplishing the task of having breakfast. Focus has been on development of algorithms to *detect and identify gestures and objects* and their manipulations. Moreover, *activity verification and evaluation* involves distinguishing between similar gestures used for different purposes, e.g., social activity conducted in parallel to having breakfast and reading news. MUDRA allows an older adult to interact with a digital portrait on the wall, with natural hand gestures. The purpose is to select a person in her social network and initiate a conversation with this person. When MUDRA has recognized the gesture as a dialogue control maneuver, the corresponding command is sent to the social network application. In other cases, the interpretation of activity is negotiated as part of an agent dialogue procedure involving the Activity Agent (AA) and the Coach Agent (CA).

4.2 Agent-based dialogues about activities in a home environment

For accomplishing reasoning and dialogue-based support we develop a multi-agent dialogue system, which enables dialogues between a human and software agents. It essentially follows the outline in [12] including the following software agents: a Domain Agent (DA), which uses a domain knowledge repository as belief base, and a Coach Agent (CA), which manages the user model by reasoning with other agents about conflicting interpretations of the human activities, and preferences obtained from different sources [18]. It is also the CA's task to protect the user's interests in dialogues with other agents. For the purpose of this work, human-agent dialogues are viewed as a means to providing the user control over the AAL environment, which is a goal for the work. Therefore, we design and implement the human-agent dialogue system partly for this purpose.

The goal of the multi-agent system is to provide analyses at two levels. Firstly, to detect and identify activity based on sensor data about objects and body movements, and on a user profile containing activity patterns and habits. Second, the identification of activity needs to be related to level of importance to the user, user's preferences and goals, in order to reason about how the system should act upon the new knowledge, e.g., providing advice, support in the form of new tasks to be performed, etc. In this section we provide initial results feeding into a system which can accomplish tailoring of the support provided an individual.

An *Activity Agent* (AA) is introduced, which collaborates with the CA and DA agents (Figure 1). The purpose of the AA is to collect information about observed activities obtained from different sources. In our system it is the MUDRA system which provides the environmental information and information about performed activities.

5 Agent dialogues for reasoning about purposeful activities

The user may control the AAL environment by explicitly expressing e.g., preferences, priorities, interests, and adjust these over time. The base for interaction is implemented as information-seeking dialogues as defined in [7], through which the user can inform the system about preferences, priorities, interests, etc. Based on the information the system provides feedback to the user in the form of: 1) suggestions of decisions, 2) advices, and 3) suggestions of actions to make for obtaining more knowledge about a situation. Currently, the actions are formally defined as ACKTUS assessment protocols. The information capture, inferences and responses are built upon knowledge and interaction flows modeled by the domain professionals.

Domain experts modeled the domain knowledge, user models and content of the dialogues required to realize our use case scenario (e.g., Figure 4). The domain experts could also model the flow of dialogues. For illustrating the dialogues in the development sessions with domain experts, we used an algorithm for executing, or simulating, the different types of dialogues. The algorithm makes use of ACKTUS assessment protocols, their content, their associated rules and their consequents as dialogue flows the way they were structured by the domain experts in the modeling 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 were, at the point of modeling the dialogues, in control of the agent's behavior. The same building blocks created using ACKTUS are used in the agent-based dialogues implemented as part of this work.

Important activities that the older adult wants to be able to perform in a satisfactory way can be identified and selected in the initial assessment and added into their user profiles. This is accomplished through the information-seeking dialogue systems described earlier. This selection will be used in a training phase of the activity recognition system. The information-seeking dialogue system implementing ACKTUS dialogues is being extended with a dialogue system where the user can interact with the system agents, proposing supportive and contradictory arguments. The initial design of this extension has been created, and the implementation is ongoing. The dialogues between human and software agents aim at providing a natural dialogue with the system. Therefore, the interaction design of the dialogues will be an important issue to explore in future work.

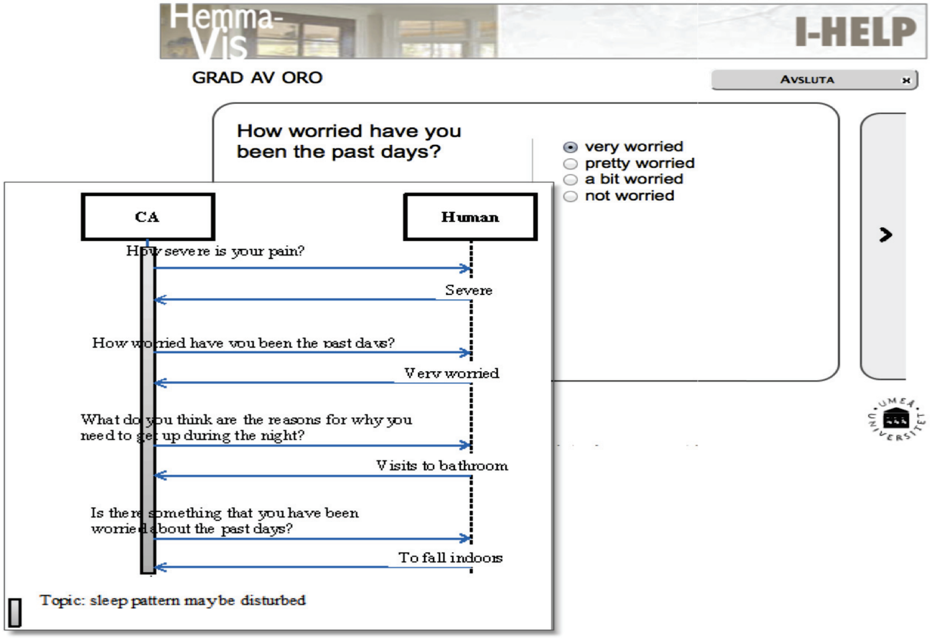

Fig. 4. Dialogue example of a weekly follow-up dialogue between CA and Rut.

5.1 Dialogue examples

Consider the case when Rut has had her breakfast one morning, and AA detects the following:

- Breakfast is completed
- Rut has moved away from her kitchen table without her walking aid
- Rut has not interacted with the pill dispenser
- Rut has had a conversation with her friend
- Rut has read the news

AA concludes the following:

- Rut has not taken her medication
- Rut is walking around in an unstable manner

The information is entered into Rut's profile, which causes a conflict with other information, which CA detects. CA initiates a dialogue with AA with the topic *"Rut has taken her pills"*, since this is the information CA has as default assumption based on Rut's testimony. AA attacks this with the argument: *"Rut has not taken her medication, based on the observation that she has not interacted with the pill dispenser"*.

This causes CA to initiate a dialogue with Rut with the same topic. CA poses the question about whether Rut has remembered to take her pills today? Rut responds that she thinks so, but checks the pill dispenser, and discovers that the pills for this morning is still there. Then she confirms that she had not, but that she will take them at that point instead.

Another topic, this time initiated by AA, is concerning the risk for falling. Since Rut is worried about falling, this is a prioritized topic in her case. Therefore, AA initiates a dialogue with CA and claims that Rut is walking around in an unstable manner. Since CA has the belief that Rut is sufficiently stable only with her walking aid, and that Rut has testified that she always uses the walking aid, CA argues against AA's claim. However, since AA builds its claim on the observation that Rut and the walking aid is not at the same place, CA again turns to Rut to resolve the conflicting views. The reasons for why Rut is not using the walking aid can be that she forgets to use it, or that there is something wrong with it. Another reason may be that she feels better, and more stable than before. To determine whether her experience matches her actual state a renewed assessment by a therapist is required, who considers a potential decrease in judgment ability, possible due to medication or an evolving dementia disease.

6 Conclusion and future work

The knowledge needed for the provision of personalised support for activities in an AAL environment consists of the individuals preferences, ability, interests, habits, needs, wishes, activities and social network. The goal of this work was to develop a model used for agents' reasoning about activities performed in an ambient assisted living (AAL) home environment.The results include an ACKTUS ontology extended with environmental and activity information, an initial design of a multi-agent dialogue system and of the activity recognition system - MUDRA, based on 3D sensors. Future work involves an extension of MUDRA from home environment to work environment where a support application for risk assessment of hazardous work environments will be integrated with sensor data in the mining work environment. By feeding more person-specific information into the algorithms we expect that the accuracy of the activity recognitions and risk assessments will increase. As an integral part of the development, end users will be involved in the design process and in evaluation studies.

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II

Cognitive Architecture of an Agent for Human-Agent Dialogues

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Abstract. This paper proposes a cognitive architecture of an intelligent agent that can have a dialogue with a human agent on health-related topics. This architecture consists of four main components, namely, the *Belief Base*, the *Dialogue Manager*, the *Task Manager* and the *Plan Generator*. Each component has sub-components that perform a set of tasks for the purpose to enable the agent to be enrolled in a dialogue. In this paper the particular sub-component of the Dialogue Manager, the *Dialogue Strategy* has been discussed in detail. A notion of *scheme* is introduced, which functions as a template with variables that are instantiated each time a state is entered. The agent's dialogue strategy is implemented as a combination of the schemes and the state transitions that the agent makes in response to the human's request. We used a combination of finite-state and agent-based dialogue strategies for dialogue management. This combined dialogue strategy enables a multi-topic dialogue between a human and an agent.

Keywords. Human-computer interaction, dialogue, agent architecture

1 Introduction

This paper proposes a cognitive architecture of an intelligent software agent that can have a dialogue with a human agent on health-related topics. The main challenge for the agents having a dialogue with a human is deciding *what* information to communicate to the human and *how* and *when* to communicate it. This highly contextual and situated perspective on human-agent dialogues was exemplified in [1], where dialogues were aimed at taking place in an ambient assisted living environment. A persona of an older adult and a case scenario was introduced, as illustration of the different building blocks of an architecture for an ambient assisted living environment, integrating support by a multi-agent system. The cognitive architecture of the agents presented in this work extends the architecture in [1] by concentrating on the components for constructing an intelligent agent that interacts with a human in a more autonomous, and purposeful way.

The architecture presented in [1] integrates knowledge repositories, developed using ACKTUS (Activity Centered modelling of Knowledge and interaction Tailored to USers). ACKTUS is a platform for engineering knowledge-based systems in the medical and health domain. These repositories are built on semantic models, which were in [2] extended to integrate components vital for enabling agent dialogues, based on the canonical model for agent architectures presented by Fox and coworkers [3].

An initial design and implementation of an agent-based dialogue system where agents communicate with the end user in a home environment for establishing a baseline user model was presented in [4]. The base for interaction was implemented as information-seeking dialogues through which the user can inform the system about preferences, priorities and interests. Based on this information, the system provides feedback to the user in the form of: 1) suggestions of decisions, 2) advices and 3) suggestions of actions to make for obtaining more knowledge about a situation.

The agent's knowledge was obtained from the ACKTUS repository, which had been created by domain experts in the rehabilitation domain [5]. The knowledge consisted of both factual and procedural knowledge, as well as interactive templates, or protocols for assessment of different aspects. The knowledge had been structured and implemented by the domain experts to be used as assessment protocols by therapists in clinical interviews, or in human-agent dialogues. However, in order to accomplish other types of dialogues, which are less structured than the *information-seeking* dialogues, an agent architecture is needed, which allows the agent to plan the moves based on e.g., the purpose of the dialogue, the situation, the knowledge available, etc.

Therefore, this paper extends earlier work, by concentrating on the components for constructing an intelligent agent that interacts with a human in a more autonomous, and purposeful way.

We deal with a complex environment where there are multiple sources of information to consider for an agent: 1) the information about the human agent's daily activities observed by an activity recognition system at home, 2) the information about the human agent's medical health condition obtained from domain professionals and relatives, and 3) the human's preferences, obtained initially as a part of the baseline assessment, which, however may change.

Our aim is to enable dialogues between a human agent and an intelligent agent. For this purpose, the agent needs the following capabilities, which has to different extent also been described in literature (e.g., [6, 7, 8, 9]):

- Autonomous (e.g., decides upon actions to make, takes initiatives in order to reach a goal),
- Handle knowledge obtained from different heterogenous sources, e.g., in a home environment,
- Reason and make decisions in the presence of uncertain and incomplete information,
- Generate new knowledge (e.g., by learning methods such as machine learning, case-based reasoning, etc.),
- Utilize a shared semantic model between human and agent for communication and knowledge exchange purposes,
- Being cooperative,

– Being able to deal with affective components and topics in a dialogue.

In our proposed cognitive architecture, we aim to combine the above mentioned capabilities to build an intelligent agent that interacts with the human as their personalised assistant, i.e., as a *Coach Agent* as described in [1].

The contribution of this paper is the cognitive agent architecture, that directs and organizes the agent's own internal behavior and the behavior performed by the agent in the interaction with the human agent.

2 Related Work

Research literature shows an increasing number of applications of software agents that interact with human actors for health-related purposes (e.g., [10, 11, 9, 12, 13, 14]). One example is the automated system, which has been developed for older adults with cognitive impairment described in [10]. However, it focuses mainly on generating reminders about the activities of their daily living and takes no part in a complex dialogue with the user. Agent-based systems which interact with human actors through dialogues are less common. They are most commonly developed for a specific task or for a limited domain, and the dialogues are tested in specialized environments [14, 12]. In the healthcare domain, the agents have the potential to support the medical professionals in better diagnosis of their patients (e.g., [15]). An agent provides an effective interface modality especially for the applications that require repeated interactions over longer period of time, such as applications developed for supporting behavior change [16, 17].

Bickmore et. al [14] developed an animated conversational agent that provides information about a patient's hospital discharge plan in an empathic fashion. The patients rated the agent very high on measures of satisfaction and ease of use, and also as being the most preferred over their doctors or nurses in the hospital when receiving their discharge information. This was related to the agent capability to adapt to the user's pace of learning and giving information in a nonjudgmental manner. Another reason for the positive results was the amount of time that the agent spent with users helped them to establish a stronger emotional bond.

An automated counseling dialogue system is discussed in [17], which uses an ontology to represent the knowledge and the user model. In their approach, the agent performs motivational interviewing with its knowledge about behavioral medicine and uses empathy in dialogues. It provides the human agent with some advice about exercise and healthy actions and follows up by asking the human followup questions. However it limits its services to counseling only and does not reason with evidence about the human's change of behavior based on information about their activities.

The canonical model of an agent described by Fox and coworkers [7] is an extension of the Belief-Desire-Intention (BDI) model of an autonomous agent (e.g., [6]) and provides formal semantics for the concepts argumentation, decision-making, action, belief, goal (desire) planning (intention) and learning for agents. Literature describes implementation in systems, however, mainly for multi-agent reasoning and decision making without active participation of a human agent in the process [7]. To our knowledge, this model has not served as a base for dialogues between software agents and human agents beyond simple alerts or providing decisions. These generic concepts are incorporated in our proposed architecture, and the implementation and execution of these are organized by the modules in the architecture.

For an agent to be able to reason about what actions to make in the process of a dialogue, it needs to follow a dialogue strategy. Dialogue systems presented in research literature typically use one of the three following existing dialogue strategies [18]. In *finite-state* strategies, the dialogue path is represented as a finite state machine, in which transitions to new dialogue states are determined by the user's selections from fixed sets of responses to system questions. In *frame-based* strategies, the system constructs the dialogue in order to fill in the slots of a predetermined frame. Finally, in an *agent-based* dialogue path, the system constructs the dialogue as it recognizes and attempts to satisfy the user's objectives.

Recent extensions are concerned with multi-strategy dialogue management, where two or more strategies are combined for question answering applications [19, 20]. However, these approaches mainly focus on combining finite-state and frame-based dialogue strategies. In this work, we developed a strategy similar to a human agent's strategy that has more than one information elicitation strategy and is able to change strategy according to circumstances. This was done by combining finite-state and agent-based dialogue strategies.

3 Human-Agent Dialogue Scenario and Design

The system developed in this paper is designed based on the persona and scenario of a female older adult, and the dialogues aimed for self-care assistance described in [1, 5]. Our persona called Rut [1] shares similarity with some of the participants in a study conducted by Lindgren and Nilsson [21], and is therefore considered representative. Rut is 84 years old, who suffers from pain in her back and legs and suffered from few falls before a hip fracture.

We envision that Rut begins to walk around nighttime, and that she may discuss the situation and her sleep with a nurse. The nurse asks a few specific questions about Rut's activities and health, and the dialogue will wander from one aspect to another, sometimes coming back to a topic already mentioned.

This example of a natural dialogue is rather different from dialogues described in literature, which aims at reaching one particular goal of a dialogue (e.g., [22]. Following the categorization of dialogue types, described by Walton and Krabbe [23], the dialogue with the nurse is a simplified example of a combination of different goals: finding information (*information-seeking* type), generate new knowledge, i.e., conclusions (*inquiry dialogue* type) and deciding upon actions to make (*deliberation* type). In case one of the agents has reasons for arguing for one particular action to be made with the purpose to convince the other, e.g. for safety reasons, the dialogue may include a *persuasive* part, e.g., to convince

Rut that she needs to go to the hospital for investigation. Based on this, we can define a set of *generic goals* for the agent to use in its organization of dialogues. More concretely, the generic outcome of each type of dialogue is the following: *information*, *new derived knowledge*, *plan of actions* and a *change of priority*. It may be that all of these types of dialogues need to be conducted in order to fully explore a particular *topic*. These generic goals will correspond to *schemes* described in Section 5.

Consequently, the agent needs to be able to handle nested multi-purposed dialogues with different topics. In order to accomplish this, the agent needs to be able to distinguish between *topic*, *generic goal* and have a semantic model of how these inter-relate in a particular situation. For instance, if the agent would have the dialogue with Rut instead of the nurse, the agent needs a semantic model for how walking around nighttime relates to sleep patterns, pain, cognitive ability, medication, worries, etc. Moreover, it needs strategies to plan next moves, based on a knowledge model, which may not provide with a pre-defined hierarchically organized plan of actions based on goals and sub-goals to be followed, but rather a collection of prioritized actions, among which the order may become determined and changed by the dialogue evolvement and Rut's line of thinking.

The *topics* relate to the human agent's goals and priorities. Consequently, from the human agent's perspective, goals relate to finding answers to questions, finding and deciding about actions to make in order to increase levels of satisfaction, evaluate actions made, etc. Consequently, for the human agent, goals are purposeful, topic-driven and context dependent.

Therefore, the agent in our approach combines a generic goal with a specific topic, in order to identify the *specific goal* with an action. In the following we give the example of a dialogue, where the topic selected by the human agent is the following: "Sleep pattern may be disturbed", which is a claim representing a belief, which has not been verified. The agent can chose to conduct a dialogue with the purpose to find information about sleep (specific goal) and initiates an information-seeking dialogue. Topics related to sleep are e.g., pain and medication, and consequently, in this situation, the sub-goals are to *find information about pain* and *medication*, respectively.

The following is an example of a part of a dialogue, generated by the system in collaboration with Rut, where CA represents the Coach Agent:

- Rut: Hi Coach, I wonder if not my "Sleep pattern may be disturbed".
- CA: Hi, Rut. Okay, then I would like to ask about *sleep*. Did the sleeping pills work for you tonight?
- Rut: No.
- CA: Why did you not sleep well last night?
- Rut: Needed to pee and pain.
- CA: Now I would like to ask about *pain*. Where do you have pain?
- Rut: In my back.
- CA: How severe is your pain?
- Rut: Severe.
- CA: Let us go back to *sleep*. How often do you need to get up each night?

4 Cognitive Architecture for the Agent

This section introduces the cognitive agent architecture based on the scenario and requirements introduced in the introduction of this paper. It consists of the following four main components (Figure 1); 1) the *Belief Base*, 2) the *Dialogue Manager*, 3) the *Task Manager*, and 4) the *Plan Generator*. Each component is assigned a set of responsibilities that enable the agent to act purposefully. The components are explained in detail in the following sections.

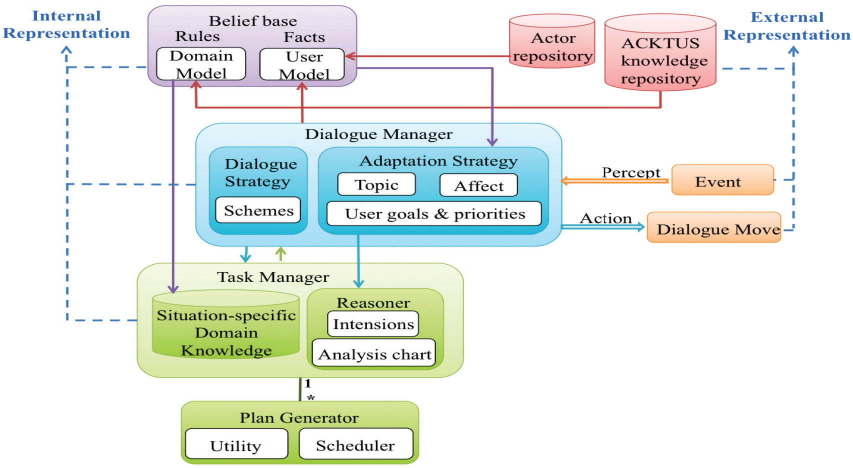

Fig. 1. Cognitive agent architecture

4.1 Belief Base

A belief base consists of a set of beliefs, which can be both facts and rules. The beliefs are extracted from the common semantic model used in ACKTUS for sharing arguments and information. Each agent participating in a dialogue has its own belief base. When a dialogue is initiated, and a topic is selected by human, a *user model* and a *domain model* are created from information relevant to the topic. The domain model may reveal missing information in the user model, and the agent can identify a set of questions, which can constitute templates for the agent to use for the purpose to obtain new facts in dialogues with the human agent or other software agents. When the Coach Agent has answers to these questions, they come in the form of information nodes, which can be interpreted using the semantic model and knowledge context provided by ACKTUS in dialogues and be reasoned about, e.g., a health condition.

Each belief is given a priority value. This value is assigned based on the following: (1) preferences given by the domain experts such as the doctors or the occupational therapist (2) priorities and goals set by the human and (3) follow up by the agent itself in a case where a rule remains to be used from previous dialogue. For example, if the human selects the same topic for a dialogue after a few days, then the agent retrieves any unanswered question from that dialogue and then the agent prioritises that rule in its belief base.

The Coach Agent performs two types of reasoning. Firstly it uses its belief base to reason about the message content of each of its moves during the dialogue. Secondly it uses a component of the task manager to reason about intension behind each move discussed in Section 4.3. The Coach Agent uses its knowledge from its belief base to find opportunities for contributing with help, advices and suggestions of actions to take.

4.2 Dialogue Manager

The agent uses a dialogue manager to decide which of the potential moves will be optimal in each state, to meet the goals of the user. The dialogue manager consists of two sub-components: the *dialogue strategy* and the *adaptation strategy*. The dialogue manager is based on a state machine. Each state specifies a transition state from the current state and the condition to validate that transition, as well as a syntax for what the human can use as response in that state (for example, single-choice option or multi-choice option in the case when a question is posed to the user). State definitions also include the specification of agent *schemes* as templates with variables that are instantiated each time the state is entered. Schemes are a type of protocols, which directs a specific type of dialogue and its completion. The dialogue manager is further described in section 5.

4.3 Task Manager

The task manager contains the situation-specific domain knowledge and the reasoner. The situation-specific knowledge is about the possibilities that exist to make next move in the dialogue. For an information-seeking dialogue for example, the task manager organizes the various questions related to the topic that need to be asked the human if the information is missing. The reasoner is the agent's deliberation module and therefore it organizes the intensions and consists of an analysis chart based on the previous dialogues. The agent uses the reasoner to reason about its intension behind making each move.

4.4 Plan Generator

The plan generator is the final component of the architecture. After making a list of tasks to be performed for a particular dialogue, the plan generator is responsible for deciding about the execution of tasks. In the information-seeking dialogue example, after generating a list of questions to be asked from the human, the plan generator determines the order in which questions need to be asked. It measures the utility of the outcome of each task and prioritizes them. As a result, this module generates a plan for the agent to act upon, which typically needs revision, depending on the human's actions. The agent uses the scheduler to regulate the conditions for when and how the agent will initiate a dialogue with the human.

5 Implementation of the Dialogue Manager

A prototype system for human-agent dialogues has been developed in Java and the Java Agent DEvelopment Framework (JADE) has been used to build the Coach Agent. The knowledge repository used in this system is developed using ACKTUS, and designed for rehabilitation purposes by domain experts [5]. This knowledge is modeled as an ontology, represented in RDF/OWL, and stored in a RDF (Resource Description Framework) repository (Figure 1).

The Dialogue manager utilizes two components in the creation of a dialogue: a *dialogue strategy* and an *adaptation strategy*. The base for adaptation is the priorities and goals defined by the human actor, which the agent obtains from the *Actor repository*, the *topic* for the dialogue, and potential *affective* information.

As previously described, the therapist conducts an interview with the older adult. This baseline assessment results in information about the user regarding their health conditions, medications, preferences, goals and priorities, which is stored in the Actor repository, also based on a semantic model containing assessment events (Figure 1). The information can be interpreted using the ACKTUS semantic model, e.g., when the Coach Agent needs to build a *user model* for a situation. The information about the user, represented as information nodes in the Coach Agent's belief base, is supplemented with a *domain model* relevant to the selected dialogue *topic*.

The dialogue moves are currently visualized to the user as texts, and the user contributes to the dialogue by selecting among a limited set of answer alternatives determined by the domain experts' implementation in the case of a question, and among a list of topics obtained from the repository in case the user is initiating the dialogue. In the following section the dialogue strategy will be further described.

5.1 Dialogue Strategy

Apart from the understanding of human's message and having reliable reasoning techniques, there is a challenge for the agent to know *what it should send as next move* in response to the human's previous move. A message is the request or response that is selected and sent by the human to the agent. Dialogue management is a challenge, as described in [13]. In our case, it is important to prioritize the order in which, e.g., the questions need to be addressed the user by the agent in the case of an information-seeking dialogue, or when an advice should be given. Therefore, an agent in a healthcare system, having a dialogue with human, needs to follow a strategy to decide which of the potential moves will be optimal in each state.

Our method for dialogue strategy selection combines the application of multi-strategy dialogue management [19] with adaptation strategies, and a method for calculating agent's performance based on a utility function. Since the dialogue manager is based on a state machine, each state specifies a transition state from the current state and the condition to validate that transition, as well as a syntax for what the human can use as response in that state State definitions also include the specification of agent *schemes* as templates (e.g., Figure 2), with variables that are instantiated each time the state is entered.

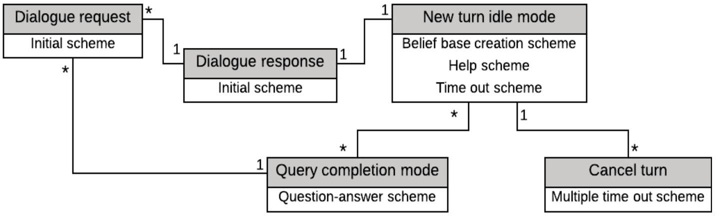

Fig. 2. Entity relationship diagram of a dialogue. Each entity represents a state and its scheme.

An agent's dialogue strategy is implemented as a combination of the schemes and the state transitions that the agent makes in response to the human's request. The schemes are protocols for regulating some generic goal-oriented tasks to be conducted by the agent as sub-tasks to the dialogue, and as such they are different from the *argumentation schemes* defined in [24]. The following schemes are defined:

1. An *initiation scheme*, which regulates how the agent behaves in the initiation of a dialogue.
2. A *belief-base creation scheme*, which regulates how the agent populates its belief base containing relevant information for the current situation and dialogue, based on the knowledge and Actor repository, and previous states.
3. A *dialogue body execution scheme*, which directs how both participants send and receive requests and responses on time. In our example of an information-seeking dialogue we utilize a *question-answer scheme*
4. A *help scheme*, which regulates how the agent may take action for referring responsibility to an external actor such as a nurse or therapist.
5. *Multiple time-out schemes*, which regulate the handling of interruptions, pauses or cancellation of dialogues, e.g., in the case when the human agent does not respond.

The transitions between states are driven by the user's conversational behavior, such as whether he/she makes a move, the content of a move, or the interpretation of the human's request. We introduce the following states and corresponding behaviors for an agent participating in a human-agent dialogue:

1. The *dialogue request state*, in which the request from human to have a dialogue is received.
2. In *dialogue response state*, the agent follows an initial scheme to acknowledge the human agent regarding its availability to have a dialogue.
3. On successful initiation of dialogue, the agent enters the *new turn idle mode* where it creates a belief base.
4. In the *query completion mode*, after the creation of the belief base and within the question-answer scheme, the agent asks questions to the human agent.
5. The *cancel turn state* is entered in the case when no response is received at some point of the dialogue.

6 Discussion

The proposed architecture has the following advantages. Firstly, it is based on a semantic model, which is common for different applications in the smart environment in which the agents act. The agent utilizes a format for reasoning, which is generic, and can be shared among agents. The architecture modules add cognitive models for the agent's internal behavior, which corresponds to goal-directed behavior, with the possibility to adapt its behavior depending on a situation. These characteristics make it reusable, scalable and applicable to any health-related domain, which shares the common semantic model.

The schemes can be used regardless if the other agent is a human or another software agent. In order to meet the agent's goal to conduct the dialogue body, a number of different schemes need to be defined, partly corresponding to the different types of dialogues, which the agent should be able to participate in. Apart from the question-answer scheme, which meets the goal to find new information (i.e., conduct an information-seeking dialogue), we envision schemes for the purpose to conduct deliberation (reason about actions, what to do) or persuasive (reason about why conduct an activity) dialogues. If the question-answer scheme is extended with some possibilities to also create new knowledge (for instance, assert conclusions based on argumentation), then the scheme may regulate inquiry dialogues. Moreover, a particular scheme can be designed for conducting dialogues with affective topics or content.

While argumentation schemes represent patterns of reasoning in argumentative dialogues [24] the dialogue strategy schemes can be seen as templates for dialogues at a higher level, where argumentation schemes can be utilized in the execution of a particular part of a dialogue body.

The current implementation partly implements the cognitive architecture and dialogues, and ongoing work includes the implementation of the dialogue manager's protocols for the dialogue initiation and termination that regulate the conditions for when and how the agent will initiate and terminate a particular type of dialogue with the human. We are exploring this issue in ongoing work, as well as extending the dialogues with additional schemes, for the agent to be more flexible in how the agent approaches the generic purposes of a dialogue (e.g., create new knowledge, learn, make decisions, seek information, deliberation, persuasion, etc.).

7 Conclusions and future work

The capabilities required for an intelligent software agent to be interacting with a human agent in dialogues about health-related topics has been outlined and discussed. A cognitive architecture was proposed for an agent consisting of the four main components belief base, dialogue manager, task manager and plan generator.

An initial prototype of the dialogue manager with a set of schemes added to an agent's dialogue strategy was presented and discussed. During the conduction of a human-agent dialogue, an agent transits from one state to another and the scheme of dialogue strategy also changes. The advantage of this approach is that the agent can decide which state to navigate to from the current state, based on the scheme. This is different compared to the multi-agent dialogues in which an agent follows linearly ordered dialogue protocols. Consequently, the schemes enable an agent to be more flexible in making a decision about its next dialogue move based on the human agent's response. The task manager and the plan generator will be implemented in future work.

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Semantic Model for Adaptive Human-Agent Dialogues

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Abstract —— A common conversation between an older adult and a nurse about health-related issues includes topics such as troubles with sleep, reasons for walking around nighttime, pain conditions, etc. Such a dialogue can be regarded as a "natural" dialogue emerging from the participating agents' lines of thinking, their roles, needs and motives, while switching between topics as the dialogue unfolds. The purpose of this work is to define a generic model of purposeful human-agent dialogues suitable for health-related topics. This is done based on analyses of scenarios, personas and models of human behavior. The results include four models, which need to be included in a software agent's belief base; i) a user model, ii) a model of the domain knowledge related to the topic of the dialogue, iii) an agent model, and iv) a dialogue activity model. The models were implemented into a prototype system for human-agent dialogues, which was evaluated by therapists and a group of older adults.

Keywords Personalization · Dialogue systems · Health promotion · Argumentation · Intelligent agent · User model

1 Introduction

Assistive technology aims to support an individual in accomplishing activities, which they need to be able to do in the presence of decreased functionality or ability. In this work the definition of *active* assistive technology used by Kennedy and co-workers [1] is applied to distinguish systems, which includes automated processing of health information during a human agent's interaction with the system and which may output tailored responses to the human

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agent in the process. The purposes of active assistive technology include the following: to increase knowledge, assist in deciding about actions to make, and promote changes of unhealthy behavior (i.e., in the form of *behavior change systems*).

Our work focuses on dialogues between a human actor and an active assistive technology in the form of an intelligent software agent. The concept of Embodied Cognitive Agents (ECA) is generally used for such systems. The ECA uses a virtual representation of a human with the ability to send information through body language in addition to linguistic messages. However, we restrict the focus in this work to structured linguistic dialogues based on semantic models of relevant knowledge.

In this article, a dialogue system is presented, which enables a human actor to conduct a dialogue with a software agent for the purpose of handling health-related issues in a home environment. The aim is to enable the dialogues between a human agent and a software agent, which are tailored to the human's needs, preferences and goals. For this purpose, the software agent needs the following capabilities, which has to different extent also been described in literature (e.g., [2–6]):

1. Being autonomous (e.g., decides upon actions to make, takes initiatives in order to reach a goal),
2. Utilize a *semantic model* shared between the human and the agent for communication and knowledge exchange purposes,
3. Handle knowledge obtained from different heterogeneous sources, e.g., in a home environment,
4. Reason and make decisions in the presence of uncertain and incomplete information,
5. Generate new knowledge and learn,
6. Being cooperative,
7. Being able to deal with affective components and topics in a dialogue,
8. Being adaptive to the human's needs, preferences and the situation.

The goal is to develop and combine the above-mentioned capabilities to build a software agent that interacts with the human as their personal coach, friend or a discussion partner, i.e., as a *Coach Agent* as described in [7].

Typically, a team of healthcare professionals can be involved in an elderly person's care, such as doctors, nurses and occupational therapists. These together with the human cooperate to gain optimal understanding of the human's health condition. The support provided to the human is aimed to be person-centered. Consequently, there is a need for combining information from different sources to understand the external factors affecting the human. We deal with a complex environment where there are multiple sources of information to consider for an agent: 1) the information about the human agent's daily activities observed by an activity recognition system at home, 2) the information about the human agent's medical health condition obtained from the human agent, domain professionals and relatives, and 3) the human's preferences, obtained initially as a part of the baseline assessment, which, however may change later.

In this paper, we focus on the knowledge, which the software agent needs to have and obtain for contributing to the dialogue, and for behaving in a purposeful way. The main contribution of this paper is a conceptual and formal model of the Coach Agent's knowledge including a model of the dialogue activity, which enables a purposeful interaction between the human agent and the Coach Agent in the pursue of understanding and improving the human's health condition.

An initial prototype dialogue tool was implemented and integrated in a support application, which enables the human actor to conduct a dialogue with the Coach Agent in their home environment. The prototype was evaluated in a pilot study involving a group of older adults and a group of therapists.

This paper is organized as follows. In the following section the methods are described and in Section 3 an analysis of related work is provided. Section 4 introduces the use case scenario of an older woman and the results of the analysis of the scenario, which provided requirements and motivations for our design. In Section 5 a model of the dialogue activity is provided and in Section 6 a model of the Coach Agent is provided. Section 7 describes the pilot evaluation study. The results are discussed and the article ends with conclusions and comments on future work.

2 Methods

A literature study was conducted where the following topics were studied: i) the agent's role, ii) the purpose of dialogue systems, iii) the knowledge model of the agent, the user, the domain and the dialogue activity, iv) who develops the knowledge model, v) sources for the knowledge, vi) representation format and how generic the representation is, and vii) issues regarding the dialogue execution.

The semantic model for adaptive human-agent dialogues is designed based on the persona and scenario of a female older adult named Rut, and the dialogues aimed for supporting a human actor described in [7,8]. The scenario was analyzed, providing baseline requirements and a conceptual model of goal-directied activity.

The theoretical base for analysis is Activity Theory [9], which also informed the models generated as results of our work.

A pilot evaluation study was conducted involving a group of five female professionals in occupational therapy and physiotherapy, specialized in the needs of older adults, and a group of eleven older adults, six women and five men. The study was formative, with the results aimed to inform further development.

The main research questions, which were targeted by the evaluation study related to the overall idea of a dialogue system for supporting everyday issues, how a sense-making dialogue would unfold and what topics would be interesting to elaborate upon. Other research questions relate to interaction design of the dialogue system.

The evaluation study was limited to the initiation of inquiry dialogues and the conduction of nested information-seeking dialogues, in the context of the use case scenario of an older adult named Rut. The information about Rut was forming the base for the Coach Agent's user model and the priorities of goals and tasks. This information and consequently, the user model changed during the testing, depending on how the participants interacted with the system.

Observation of use and interviews were the methods used for collecting data. The older adults and two of the therapists were individually given the task to play the role of the persona in our scenario, other person or themselves, select topics of interest to initiate a dialogue and responding the way they wished to.

The user was also asked to evaluate the appropriateness of each statement of the Coach Agent within its context where it was stated by marking one of four alternatives on a Likert scale, presented in connection to each of the Coach Agent's statements. A purpose of the pilot study was also to evaluate this method.

The system and the scenario was demonstrated to the remaining three therapists in a focus group session and discussed.

The data was analyzed qualitatively using content analysis.

3 Related Work

Research literature shows an increasing number of applications of software agents that interact with the human actors for health-related purposes (e.g., [10, 11, 5, 12–14]). A review of behavior change systems utilizing personalization technologies for accomplishing active assistance is provided in [1]. It was concluded that an agent provides an effective interface modality especially for the applications that require repeated interactions over longer period of time, which is crucial for applications supporting behavior change [1, 15].

One example is the system, which has been developed for older adults with cognitive impairment described in [10]. However, it focuses mainly on generating reminders about the activities of their daily living and takes no part in a complex dialogue with the user. Agent-based systems which interact with human actors through dialogues are less common. They are typically developed for a specific task or for a limited domain, and the dialogues are tested in specialized environments [14, 12].

Bickmore et. al [14] developed an animated conversational agent that provides information about a patient's hospital discharge plan in an empathic fashion. The patients rated the agent very high on measures of satisfaction and ease of use, and also as being the most preferred over their doctors or nurses in the hospital when receiving their discharge information. This was related to the agent's capability to adapt to the user's pace of learning and giving information in a nonjudgmental manner. Another reason for the positive results was the amount of time that the agent spent with users helped them to establish a stronger emotional bond.

In the counseling dialogue system discussed in [15], the agent performs motivational interviewing with its knowledge about behavioral medicine and expresses empathy in dialogues. It provides the human agent with advice about exercise and healthy actions and follows up by asking the human followup questions. However it limits its services to counseling only and does not reason with evidence about the human's change of behavior based on information about their activities.

The agent-based approach to diagnostic decision-making presented in [16] has the potential to support the medical professionals in improving their diagnostic assessments of patients. The purpose is to guide the user in the diagnostic reasoning and support learning and a change of behavior. However, the user's active participation in the dialogue is limited.

To summarize, the most common Agent roles, and consequently, the purposes of the exemplified dialogue systems are the following: i) promoting the human actor to maintain control, learn and change behavior, ii) to guide in reasoning, decision-making and other activities, and iii) to inform in an emphatic and patient way, and behave in a way tailored to the human agent's pace, needs and preferences.

The canonical model of an agent described by Fox and coworkers [3] is an extension of the Belief-Desire-Intention (BDI) model of an autonomous agent (e.g., [2]) and provides formal semantics for the concepts argumentation, decision-making, action, belief, goal (desire) planning (intention) and learning for agents. Literature describes implementation in systems, however, mainly for multi-agent reasoning and decision making without active participation of a human agent in the process [3]. To our knowledge, this model has not served as a base for dialogues between software agents and human agents beyond simple alerts or providing decisions.

The architecture of the agent-based ambient assistive living system presented in [7] integrates knowledge repositories, developed using ACKTUS (Activity-Centered modeling of Knowledge and interaction Tailored to USers), which is a platform for end-user development of knowledge-based systems in the medical and health domain. These repositories are built on semantic models represented using RDF/OWL, which were in [17] extended to integrate components vital for enabling the agent dialogues, based on the canonical model for agent architectures presented by Fox and coworkers [18]. This work led to a multi-agent system, which simulates a dialogue between an agent representing a physician who is the user of the system and who selects a diagnostic hypothesis in a patient case, and an agent representing a domain expert [16]. The domain knowledge and patient knowledge was used for creating arguments, based on sources with different strengths, which the agent-system evaluated for providing the user support in diagnostic decision-making. The domain knowledge was in this case retrieved from clinical practice guidelines, consensus guidelines, and other medical sources.

The ACKTUS core ontology was further extended to incorporate information about a user's environment, for the purpose of forming a user model, which an agent can use for adaptation of support in daily activities [19].

An initial design and implementation of an agent-based dialogue system where an agent communicates with the end user in a home environment on health-related topics is presented in [20]. The agent's belief base was created by obtaining information from the ACKTUS knowledge repositories, which had been created by domain experts in the rehabilitation domain [8]. The knowledge consisted of both factual knowledge related to a user, which was used for creating a baseline user model, and procedural knowledge, in the form of rules obtained from domain knowledge repositories. Moreover, interactive templates, or protocols for assessment of different aspects were retrieved from the domain knowledge repositories. The knowledge had been structured and implemented by the domain experts, to be used as assessment protocols by therapists in clinical interviews, or in human-agent dialogues.

The counseling dialogue system discussed in [15] also uses an ontology to represent the user model and the domain knowledge. The domain knowledge is based on behavioral medicine. Their approach consists of six models: theory model, behavior model, protocol model, user model, external data model and a task model. The authors have themselves developed the ontology based on a review of concepts in behavioral medicine, prior work, and discussions with experts in behavioral medicine, and computerized interventions. Their task model consists of the dialogue activity information with dialogue actions. However, the domain experts are not directly involved in the modeling of the agent's knowledge in this system therefore it lacks features for modifications such as future changes in domain knowledge and also it lacks the representation of goals which drives the behavior of the dialogue system.

Only a few applications developed for behavior change integrated into the system with semantic models grounded in theories relevant for behavior change [1].

In argumentation literature there are several theoretical frameworks, which aim to formalize dialogues of different types for multi-agent systems. Typically, these adopt the approach of *dialogue games*, since they aim at selecting a "winner" of a dialogue, and then the game rules aims to create the dialogue game a fair competition (e.g., [21]). Based on argumentation schemes, dialogues can be built, e.g., for reasoning about actions to make related to the value of conducting a particular action [22]. Theoretical frameworks have been formalized also for handling nested dialogues of different types (e.g., [21]). However, these are typically not tested with dialogue information from real situations, and consequently, their applicability in situations such as our use case remains to be evaluated.

The base for interaction in [20] was implemented as information-seeking dialogues through which the user can inform the system about preferences, priorities and interests. Based on this information, the system provides feedback to the user in the form of: 1) suggestions of decisions, 2) advices and 3) suggestions of actions to make for obtaining more knowledge about a situation.

However, to accomplish other types of dialogues, which are less structured than the *information-seeking* dialogues, an agent architecture is needed, which allows the agent to plan the moves based on e.g., the purpose of the dialogue, the situation, the knowledge available, etc. Therefore, this paper extends earlier work, by developing the components for constructing an intelligent software agent that interacts with a human in a more autonomous, adaptive and purposeful way.

4 Model Based on a Scenario

Our persona called Rut [7] shares similarity with some of the participants in a study conducted by Lindgren and Nilsson [23], and is therefore considered representative. Rut is 84 years old, suffers from pain in her back and legs and had suffered from few falls before a hip fracture. We envision that Rut begins to walk around nighttime, and that she may discuss the situation and her sleep with a nurse. The nurse asks a few specific questions about Rut's activities and health, and this dialogue will wander from one aspect to another, sometimes coming back to a topic already mentioned.

This example of a natural dialogue is rather different from dialogues described in literature, which aims at reaching one particular goal of a dialogue, e.g., [24]. Following the categorization of dialogue types, described by Walton and Krabbe [25], the dialogue with the nurse is a simplified example of a combination of different goals: finding information (*information-seeking* type), generating new knowledge, i.e., conclusions (*inquiry dialogue* type) and deciding upon actions to make (*deliberation* type). In case one of the agents has reasons for arguing for one particular action to be made with the purpose to convince the other, e.g. for safety reasons, the dialogue may include a *persuasive* part, e.g., to convince Rut that she needs to go to the hospital for investigation. Based on this, we can define a set of *generic goals* for the agent to use in its organization of dialogues. More concretely, the generic outcome of each type of dialogue is the following: *information*, *new derived knowledge*, *plan of actions* and a *change of priority*. It may be that all of these types of dialogues need to be conducted to fully explore a particular *topic*. These generic goals will correspond to actions defined in Section 5 and *schemes* described in Section 5.2.

Consequently, the agent needs to be able to handle nested multi-purposed dialogues with different topics. To accomplish this, the agent needs to be able to distinguish between *topic*, *generic goal* and have a semantic model of how these inter-relate in a particular situation. For instance, if the agent would have the dialogue with Rut instead of the nurse, the agent needs a semantic model for how walking around nighttime relates to sleep patterns, pain, cognitive ability, medication, worries, etc. (i.e., a *domain model*). Moreover, it needs strategies to plan next moves, based on a knowledge model, which may not provide a pre-defined hierarchically organized plan of actions based on goals and sub-goals to be followed, but rather a collection of prioritized actions, among which the order may become determined and changed by the dialogue evolvement and Rut's line of thinking (enabling *situatedness* of dialogues and the agent to adapt).

The *topics* relate to the human agent's goals and priorities. From the software agent's perspective, goals relate to finding answers to questions, finding and deciding about actions to make to increase levels of satisfaction, evaluate actions made, etc. Consequently, for the human agent, goals are purposeful, topic-driven and context dependent.

Therefore, the agent in our approach combines a generic goal with a specific topic, to identify the *specific goal* with an action. In the following we give an example of a dialogue, where the topic selected by the human agent is "Sleep pattern may be disturbed", which is a claim representing a belief, which has not been verified. This is an example of the initiation of an *inquiry* dialogue, aimed at finding and verifying new knowledge. The agent can choose to conduct a dialogue with the purpose to find information about sleep (specific goal) and initiate an information-seeking dialogue. Topics related to sleep are e.g., pain and medication, and consequently, in this situation, the sub-goals are to *find information about pain* and *medication*, respectively. This is an example of how different types of dialogues can be nested, for the purpose to feed information and knowledge into the cooperative reasoning process of solving the overall topic, here chosen by the human actor.

The following is an example of a part of a dialogue, generated by the prototype system in collaboration with Rut, where CA represents the Coach Agent:

1. Rut: Hi Coach, I wonder if not my "Sleep pattern may be disturbed".
2. CA: Hi, Rut. Okay, then I would like to ask about *sleep*. Did the sleeping pills work for you tonight?
3. Rut: No.
4. CA: Why did you not sleep well last night?
5. Rut: Needed to pee and pain.
6. CA: Now I would like to ask about *pain*. Where do you have pain?
7. Rut: In my back.
8. CA: How severe is your pain?
9. Rut: Severe.
10. CA: Let us go back to *sleep*. How often do you need to get up each night?

To summarize, the scenario emphasizes the need for the following three semantic models for enabling human-agent dialogues: 1) a *domain model*, which contains generic knowledge about a particular domain, 2) a *user model*, which contains the collected knowledge about the human agent, and 3) a *dialogue activity model*, which provides the relations between topics, generic and specific goals and actions to be made by the participating agents in a dialogue. Moreover, the third model can be seen as the generic behavior knowledge model of the Coach Agent, however, enriched with specific knowledge, which relates only to the Coach Agent, forming the fourth model: 4) an *agent model* (Figure 1).

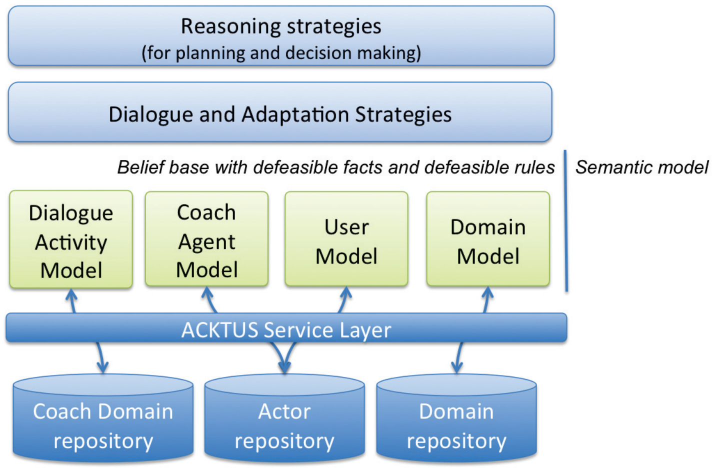

Fig. 1 The agent architecture, containing the Coach Agent's belief base consisting of four models, and its different sources of knowledge.

Finally, the need for *strategies*, which enable dynamic dialogues following the human agent's line of thinking is illuminated by the scenario.

The user and domain models are extracted from the ACKTUS ontologies [26] in the dialogues between human and software agents. The dialogue activity model and a model of the Coach Agent have been developed as a part of this work, and presented in the following sections.

5 A Model of the Dialogue Activity

As described in Section 4, and following the second requirement listed in the Introduction, the software agent needs to share a common semantic model with the human agent, to be able to reason and decide upon which actions are valuable to the human agent. In this section the dialogue activity model will be defined.

The activity theoretical model of human activity was used for organizing actions and their goals at different levels [9]. The Activity Theory captures the complexity in human activity, including human *needs and motives* as driving force, *goal-directed actions*, and *operations*, which constitute basic actions conditioned by the agents and the environment.

Figure 2 provides an overview of the shared model of a dialogue activity in which both a human and software agent participate. As can be seen, in the dialogues a common *topic* is the representation of the overall *motive for an activity*. Each dialogue is initiated by one of the agents, by posing a selected topic to the other agent.

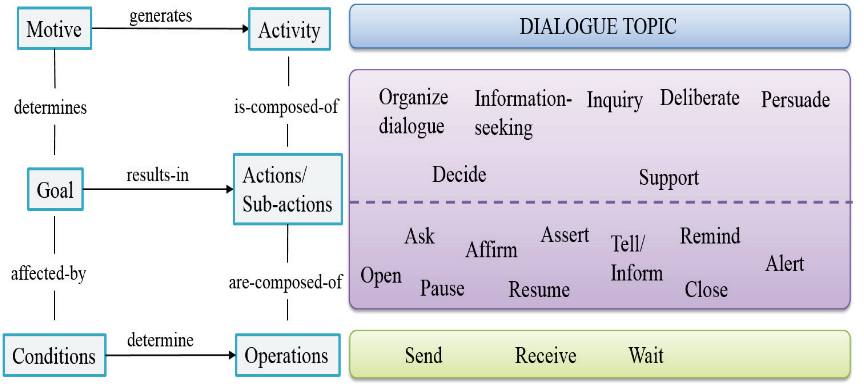

Fig. 2 A model of the dialogue activity, which both a human and a software agent are expected to comply with.

The identified operations relate to passing information to and receive information from the other agent(s) (*send* and *receive* in Figure 2), and wait for responses.

In addition to these basic and top levels of activity, a set of potential generic sub-actions have been defined, which may take place in the conduction of a dialogue. These are also organized in a hierarchical representation, since an action may serve as a sub-action to more than one action at different levels. However, we identify the following generic set of actions at the highest level: *information-seeking, inquiry, deliberative,* and *persuasive*, related to the common goals of different types of dialogues described in Section 4: seek information, find new knowledge, decide upon actions to be made and lead the other agent to change opinion. To these actions, we add the action *organize dialogue*, which contains the sub-actions typical for multi agent dialogues, e.g., *open* and *close*. These sub-actions are called *moves* in multiagent literature [24]. We extend the set of moves (i.e., sub-actions) and include the following moves as valid actions for the agent to take as part of the different actions: *open, close, pause, resume, ask, assert, affirm, inform, remind* and *alert*.

The model of dialogue activity presented in this section defines the actions, which need to be common between the participating agents as a part of a common semantic model. In addition to these, there are tasks, which are conducted by the agent "internally" during a dialogue, which also relates to the execution of a dialogue. These tasks are aimed to handle interruptions in a dialogue, cases when the human agent does not respond, etc. Other tasks are creating and updating the agent's own belief base, decide about what move to make next, which dialogue to initiate, etc. A description of these tasks included in the generic organization of a dialogue mentioned in Figure 2 is provided in [27], while the tasks included in the collaborative decision-making conducted as a part of human-agent dialogues are described in the following sections (Figure 1). To distinguish the lower level actions, which represent different types of moves in a dialogue, we hereafter call these *moves*, and denote the different dialogue types at a higher level as *actions*.

5.1 Dialogue Moves

Formally, a dialogue move for the agent in this work, is a tuple (t, a, m) where t is timepoint of the dailogue move, a is the agent and m is the dialogue move. The set of dialogue types (d) includes the following: information-seeking (is), inquiry $(wi$ or $ai)$, deliberate (dd), persuasive (pd) and support dialogue (sd). Based on this (t, a, m) tuple, we define the actions as follows (Table 1).

Table 1 Valid actions, i.e., moves and their formats. All moves contain the time identifier t_n and a_i, the identification of the agent, which performs the move.

Move	Form	Comment
Open	$(t_n, a_i, open(d_o, \alpha_m))$	α_m is the topic of a dialogue
Close	$(t_n, a_i, close(d_o, \alpha_m))$	α_m is the topic of a dialogue
Ask	$(t_n, a_i, ask(CQ))$	CQ is a structured question
Affirm	$(t_n, a_i, affirm(\alpha_m))$	α_m is a confirmative expression
Tell	$(t_n, a_i, tell(\alpha_m))$	α_m is the message, typically an advice or information
Remind	$(t_n, a_i, remind((\alpha_m, G), a_j))$	α_m is the reminder, G is the set of reasons for the reminder, and a_j is the agent targeted for the reminder
Alert	$(t_n, a_i, alert((\alpha_m, G), a_j, t_l))$	t_l is the timeout for the action
Assert	$(t_n, a_i, assert(\alpha_m, G))$	α_m is the claim and G is the set of grounds for the claim

The *Open* move is the first action carried out to initiate a dialogue, and the *Close* move is used for closing, or stating the end of a dialogue. *Tell* is the simplest form of action that an agent makes. The *Remind* action is used by the agent to remind the human to do an action. The *Alert* move is also similar to the remind action but with a timeout. It recommends the human to take an immediate or urgent action for a critical situation, for example, if Rut had forgotten to take medication after breakfast then send alert to take medicine. When an activity needs to be urgently completed, then a timeout is attached with that activity so that the reminder can be repeated in different ways. In this work, when the agent needs to obtain information from the human actor, it uses the *Ask* move. It fetches the relevant questions to be asked from the ACKTUS knowledge repository and stores them in its knowledge base. The *Assert* move is used for making a claim about some topic, and it is supported by the set of grounds G on which the claim is being based. The claim is a defeasible fact.

The *Affirm* move is used to acknowledge the other agent and its expressions in a more generic way. The typical purpose is to make the other agent comfortable, providing a "fill" in the dialogue.

5.1.1 Rules for Dialogue Moves

There are rules related to how the moves can be applied. In dialogue games, the restriction that agents take turn in the dialogues, and are allowed to perform only one move at the time does not apply in our dialogues. The reason is that the agents are not competing for ”winning” the dialogue, and natural dialogues do not follow this restriction.

Other restrictions apply, such as the open move for a particular dialogue needs to take place before a close move. Similarly, in case a pause move is done, then no move can be done within this dialogue until the dialogue is resumed by a resume move.

Only one dialogue can be active at a particular time point. This means that when a new dialogue is opened by an open move, and if there is an ongoing dialogue, then this ongoing dialogue is paused.

To close a dialogue, both agents need to agree to close, which is done by a close move by each agent.

Some moves have the purpose to defer the responsibility for acting to the other agent. Such moves are *ask*, where the asking agent expects a response, and *alert*, when the alerting agent expects the other agent to take action since the situation requires action. Consequently, the agent needs strategies to handle the situation when the other agent does not respond as expected.

5.2 Dialogue Actions

The higher-level actions in Figure 2, which relate to different types of dialogues, can be nested to meet sub-goals in the process of achieving the overall motive for the dialogue activity defined by the topic. In addition, each nested dialogue is initiated by posing a topic, in the same way as the main dialogue is initiated. As a consequence, the execution of the dialogue body needs to handle the different types of dialogues, motives, their outcomes, the organization of these in the dynamic way, which is needed for the agent to be adaptive and flexible. In this process, some constructs are useful for formalizing the dialogues and their outcomes, and for organizing the process of reaching decisions about e.g, actions to make, and their reasons (arguments). The different types of dialogues, their goals, topics and allowed moves are summarized in Table 2.

The purpose of *argumentation dialogues* is to collaboratively compare different views and generate conclusions about which one is best in a situation. This can be what conclusion to draw, what new knowledge do derive, what action to make, and what changes of priority can be achieved. This is a decision-making approach, which provides strategies for handling conflicting information and views. Information, inference rules and conclusions are typically considered *defeasible*, which means that they can be challenged (*attacked*) and defeated. In our work, we assume that all information is defeasible, and no rules are strict rules, valid in all circumstances. Arguments can be attacked in three ways: on their *premises*, on their *inference* (example in Table

Table 2 Dialogue types and their characteristics. The topic is drawn from the ACKTUS repositories, using the semantic characteristics of the knowledge nodes.

Type	Goal	Topic	Valid moves
information-seeking	collect information	*concept*	open, ask, tell, affirm, close
inquiry	create new knowledge in the form of defeasible facts or defeasible rules	*i-node* (defeasible fact) or *s-node* (defeasible rule)	open, assert, affirm, close
deliberation	decide about actions to be taken	*i-node* (defeasible fact) or *s-node* (defeasible rule)	open, assert, affirm, close
persuasion	change a priority	*i-node* (defeasible fact) or *s-node* (defeasible rule), in particular their *value* as a part of a *scale*	open, assert, affirm, remind, close
support	enhance human agent's ability	*information-node* or *conclusion*	open, affirm, tell, alert, remind, close

4, row 23) and on their *conclusion* (example in Table 4, row 19). In argumentation literature the notion of *argument scheme* is applied for providing semi-formal or formal templates and defeasible inference rules for different kinds of dialogues [28]. A common example is the scheme "Argument from expert opinion". Sometimes *critical questions* are defined and associated to a particular scheme, which typically are pointers to counterarguments following Prakken's definition [29]. For the purpose of formalizing the different types of dialogues, the concepts *scheme* and *critical question* are applied and modified. It should be noted, that the evaluation of arguments or the application of schemes alone is not sufficient for evaluating a dialogue. The whole process needs to be completed [29]. In the following, the common features of argumentation are described, which will be followed by a number of subsections in which each type of dialogue is defined.

Typically, a formal argumentation framework provides the semantics for solving conflicting arguments for or against a particular topic, regardless what the topic is. The effort to establish an *Argument Interchange Format* (AIF) for exchanging arguments on the World Wide Web is such example [30]. AIF is presented as an ontology, which takes different types of argumentation schemes, scheme-implementation nodes and their relations into consideration, without relating these to a concept-node system for topics. Most frameworks also do not consider vagueness, or uncertainty, or how these factors may change depending on the context of reasoning. Some theoretical work on argumentation frameworks consider *preferences* and *audiences* (e.g., [31–34]), which relate to the context of reasoning. In the presentation of AIF it is mentioned that the nodes may incorporate values, e.g., representing uncertainty, and domain knowledge, but not how such information is included in a formal way. In this work, there is a need to take such factors into consideration in dialogues. Therefore, AIF is applied, and extended with domain knowledge in the form of a concept-node system and templates for assessments of features with associated sets of allowed values. The approach to argumentation dialogues is still generic, since the knowledge domain can be replaced, depending on the topic of interest.

The topic of dialogues is retrieved from the ontology incorporating both AIF and the domain knowledge. The domain ontology contains a concept-node system with concepts and their relations. The information-seeking dialogues have a concept as topic, which makes this type of dialogue very generic. Moreover, the domain ontology contains a kind of information node, which has a concept but no values, and functions as the topic for the supportive dialogues (Table 2).

The AIF concepts *i-node* (a different kind of information node, which in this approach is associated to both a concept and a value), and *s-node* (scheme-node, from which rules are generated) are used as topic in inquiry, deliberation and persuasion dialogues, with some differences. The formal distinction made in this approach between the inquiry and deliberation dialogues is that the *claim*, i.e., i-node, is in deliberation dialogues associated to a concept related to the node *activity and participation* in the domain ontology, while in the inquiry dialogues the concept is a *thing*. Persuasive dialogues can have both kinds, since the focus is the *evaluation of* the phenomenon represented by the concept. This evaluation is represented by its *value*, which is targeted to be changed.

A *dialogue line* is the sequence of moves conducted by the agents and their time points (e.g., [24]). Such sequence is visible in the example of a dialogue, presented in Table 3 and Table 4. In the following sections each type of dialogue is further described, and exemplified.

5.2.1 Inquiry Dialogues (wi and ai)

The inquiry dialogue is distinguished from other dialogues in that it is divided into two types following the approach in [24]: *warrant inquiry* (wi) dialogue and *argument inquiry* (ai) dialogue. The topic of a warrant inquiry dialogue is a defeasible fact, while the topic of an argument inquiry dialogue is a defeasible rule. The purpose of the first kind is to create new knowledge, and for the second kind is to create arguments.

The example dialogue shown in Table 3, starts out as a warrant inquiry (wi) dialogue, since the main purpose is to find out whether there is a sleep disorder. The inquiry dialogue evolves when different hypotheses are evaluated and can be assumed to take place after Row 15 in Table 3.

There is a large number of argumentation schemes defined for reaching new knowledge, representing different reasoning strategies and the confidence in the actor, e.g., argument from expert opinion, argument from a position to know, etc [28]. Some reasoning strategy definitions mirror the range of logical inference strategies, e.g., deductive and inductive reasoning, causal reasoning etc. Consequently, the agents can apply different strategies, depending on the purpose and quality of the available information. For our purposes, we assume

Table 3 Example of different types of dialogues unfolding in a dialogue line.

t_i	Agent	Statement	Formal representation of a move
1	Rut	Hi Coach, I wonder if not my *Sleep pattern may be disturbed.*	$(t_1, a_1, open(wi_1, i\text{-}node_1))$
2	CA	Hi, Rut. Okay,	$(t_2, a_2, affirm(info\text{-}node_1))$
3	CA	Then I would like to talk about *sleep.*	$(t_3, a_2, open(is_1, concept_1))$ $(t_3, a_2, pause(wi_1, i\text{-}node_1))$
3	CA	Did the sleeping pills work for you tonight?	$(t_3, a_2, ask(CQ_1))$
4	Rut	No.	$(t_4, a_1, tell(i\text{-}node_2))$
5	CA	Why did you not sleep well last night?	$(t_5, a_2, ask(CQ_2))$
6	Rut	Needed to pee and pain.	$(t_6, a_1, tell(i\text{-}node_3))$, $(t_6, a_1, tell(i\text{-}node_4))$
7	CA	Okay, I see.	$(t_7, a_2, affirm(info\text{-}node_2))$
8	CA	Now I would like to ask about *pain.*	$(t_8, a_2, open(is_2, concept_2))$ $(t_8, a_2, pause(is_1, concept_1))$
9	CA	Where do you have pain?	$(t_9, a_2, ask(CQ_3))$
10	Rut	In my back.	$(t_{10}, a_1, tell(i\text{-}node_5))$
11	CA	How severe is your pain?	$(t_{11}, a_2, ask(CQ_4))$
12	Rut	Severe.	$(t_{12}, a_1, tell(i\text{-}node_6))$
13	CA	Okay, does not sound good.	$(t_{13}, a_2, affirm(info\text{-}node_3))$
14	CA	Let us go back to the topic *sleep.*	$(t_{14}, a_2, close(is_2, concept_2))$ $(t_{14}, a_2, resume(is_1, concept_1))$
15	CA	How often do you need to get up each night?	$(t_{15}, a_2, ask(CQ_5))$

at this point that the agents apply an abductive reasoning method, which includes possibilistic values. The following is the scheme defined for abductive argumentation:

Example 1 Abductive argumentation scheme: F is a finding or given set of facts, E is a satisfactory explanation of F, and no alternative explanation E2 given so far is as satisfactory as E. Then E is plausible, as a hypothesis.

This Abductive argumentation scheme example can be applied to our human agent example as follows:

Example 2 The human agent is walking around nighttime (F), the human agent's severe pain (E) is a satisfactory explanation of F, and no alternative explanation given so far is as satisfactory as E, therefore, E is plausible as a hypothesis.

To execute this type of dialogue, the agent first creates a domain model of how different conditions such as pain or incontinence affect the quality of sleep in general. The following is an example, where $\rightarrow$ is used for representing a defeasible causal relationship: ((pain, severe) $\rightarrow$ (disturbed sleep, probable)). The agent combines this knowledge with the knowledge about the human agent represented in the user model, which relates to manifested conditions or observations and the user's priorities: (pain, severe), (walking nighttime), (maintaining pain at endurable levels, highest priority), (maintaining good sleep, highest priority).

However, since there are other potential hypotheses, which may be generated, the Coach Agent needs to continue the reasoning and dialogue to reach a satisfactory complete view of the human agent's situation, following an *exhaustive* method for investigation. The situation is common when there may be more than one hypothesis with same level of satisfaction as the explanation of a finding. Consequently, we will adapt the scheme for allowing the agent work with more than one hypothesis in parallel, and generate an outcome of the inquiry dialogue, which can be utilized as base for further actions. For instance, in the situation when two or more explanatory hypotheses are present with same level of satisfaction, this may lead to the initiation of an information-seeking dialogue, or a deliberation dialogue about what actions to take to resolve the situation with conflicting hypotheses, e.g., involving a healthcare professional (e.g., Table 4).

5.2.2 Deliberation Dialogues (dd)

Argumentative reasoning with the goal to decide about what actions to make is often denoted *practical reasoning* in literature (e.g., [22]). The following scheme for practical reasoning is defined by Walton [35]:

Example 3 In the current circumstances R, we should perform action A, which will result in new circumstances S, which will achieve goal G, which will promote value V.

In our scenario, this may correspond to the following:

Example 4 We know that the pain is severe (R), and if the pain is reduced (A), this will result in the new circumstance where the pain is mild (S), which will achieve the goal to keep the level of pain at a manageable level (G), which promotes good sleep (V).

The execution of this type of dialogue follows the same procedure as in previous example. The topic of the dialogue is *reduce pain*, which is an action (Table 1). The agent creates a domain model of how pain and other conditions and medication may affect the quality of sleep in general: ((pain, severe) $\rightarrow$ (disturbed sleep, probable)), (painkiller $\rightarrow$ reduced pain). The agent combines this knowledge with the knowledge about the human agent represented in the user model: (pain, severe), (walking nighttime), (maintaining pain at endurable levels, highest priority), (maintaining good sleep, highest priority).

The dialogue in this situation will deal with what to do to reduce the pain level, to affect the sleep disturbance in a positive way. In our example, using painkiller to reduce pain would be the suggestion (rows 21-25 in Table 4).

5.2.3 Persuasive Dialogues (pd)

Persuasive dialogues aims at resolving a conflict of opinion [29].

To formalize this type of dialogue, the agent creates a user model of the human's prioritized activities, for example: (taking medication, important), (wellbeing, very important) and (maintaining good sleep, highest priority).

Table 4 Brief example of persuasive and deliberation dialogues.

14	CA	Let us go back to the topic *sleep* and *priority*.	$(t_{14}, a_2, close(is_2, concept_1))$ $(t_{14}, a_2, open(pd_1, i\text{-}node_7))$
15	CA	You said that maintaining good sleep is of highest priority.	$(t_{15}, a_2, remind(i\text{-}node_8, \{\}), a_1)$
16	Rut	Yes.	$(t_{16}, a_1, affirm(info\text{-}node_4))$
17	CA	You also told earlier that maintaining pain at endurable levels is not important.	$(t_{17}, a_2, remind(i\text{-}node_7, \{\}), a_1)$
18	Rut	Yes.	$(t_{18}, a_1, affirm(info\text{-}node_4))$
19	CA	Since it is likely that severe pain causes disturbed sleep, and you have severe pain, and you think maintaining good sleep is of highest priority, then it should be important to maintain pain condition at an acceptable level. What do you think?	$(t_{19}, a_2, assert(i\text{-}node_9, \{s\text{-}node_1, i\text{-}node_6, i\text{-}node_8\}))$ $(t_{19}, a_2, ask(CQ_6))$
20	Rut	Okay, important I guess.	$(t_{20}, a_1, affirm(info\text{-}node_1))$ $(t_{20}, a_1, assert(i\text{-}node_9, \{s\text{-}node_1, i\text{-}node_6, i\text{-}node_8\}))$
21	CA	Okay, let us talk about what to do about the *pain*.	$(t_{21}, a_2, affirm(info\text{-}node_1))$ $(t_{21}, a_2, close(pd_1, i\text{-}node_7))$ $(t_{21}, a_2, open(dd_1, i\text{-}node_{10}))$
22	CA	Since taking painkiller typically reduces pain, then you can take painkiller. What do you think?	$(t_{22}, a_2, assert(i\text{-}node_{10}, \{s\text{-}node_2\}))$ $(t_{22}, a_2, ask(CQ_6))$
23	Rut	No, painkiller does not work.	$(t_{23}, a_1, tell(i\text{-}node_5))$ $(t_{23}, a_1, assert(i\text{-}node_{11}, \{s\text{-}node_3\}))$
24	CA	Okay, I see. Do you want to talk to your nurse about medication?	$(t_{24}, a_2, affirm(info\text{-}node_2))$ $(t_{24}, a_2, ask(CQ_7))$
25	Rut	Yes.	$(t_{25}, a_1, tell(i\text{-}node_{11}))$
26	CA	Okay then I wonder if I could *inform nurse about summary* for you.	$(t_{26}, a_2, affirm(info\text{-}node_1))$ $(t_{26}, a_2, close(dd_1, i\text{-}node_{10}))$ $(t_{26}, a_2, open(sd_1, concl_1))$ $(t_{26}, a_2, tell(info\text{-}node_5))$
27	Rut	Yes.	$(t_{27}, a_1, tell(i\text{-}node_{11}))$
28	CA	Okay, don't forget to talk to the nurse about your medication!	$(t_{28}, a_2, affirm(info\text{-}node_1))$ $(t_{28}, a_2, remind(i\text{-}node_{11}, \{s\text{-}node_3, s\text{-}node_1, i\text{-}node_6, i\text{-}node_8\}), a_1)$
29	Rut	Yes. Goodbye!	$(t_{29}, a_1, tell(i\text{-}node_{11}))$ $(t_{29}, a_1, close(sd_1, concl_1))$

For illustrating a persuasive dialogue, the user's preference regarding managing pain is set to the the following: (maintaining pain at endurable levels, not important). Then the agent combines this knowledge with the knowledge obtained from the human actor during the dialogue. Suppose the human has disturbed sleep and initiates a dialogue with the Coach Agent about the topic "sleep patterns may be disturbed". During the information seeking dialogue, the agent asks the human about pain and if the human responds that a pain condition is present, and the pain is ”severe”, then the agent updates its user model with (pain condition, yes) and (pain, severe), and initiates a persuasive dialogue (rows 14-20 in Table 4) based on its knowledge about the relationship between sleep and pain condition.

The agent makes new statements, reminds the human about the relationship between pain and sleep, and the human changes the evaluation of the importance of managing the pain condition (the value *important* is stronger than the value *not important*). Next step for the agent is to propose actions to do something about the situation.

5.2.4 Information-Seeking Dialogues (is)

The topic of an information-seeking dialogue is a *concept*, which is a broader topic than the defeasible facts or rules, used as topics for an inquiry, deliberation or persuasion dialogue. An information-seeking dialogue typically unfolds as an interview, where the Coach Agent in our examples asks relevant questions to the human agent, and receives answers. To some extent the agent evaluates the new information, however, primarily for deciding upon next step, typically what question to ask next. Therefore, we use the move *tell* in the information seeking dialogues instead of *assert*, to distinguish between answering questions for reasoning purposes such as in inquiry dialogues, and answering primarily for collecting information.

5.2.5 Support Dialogues (sd)

The topic of a supportive dialogue is an *information-node*, which is not associated to a value. The content of a support dialogue is typically the outcome of an earlier conducted deliberation dialogue, where the human agent and the Coach Agent have agreed upon a plan of actions to be conducted. The actions performed as support dialogues are one of the following: provide the human agent with information or advice, remind the person of actions to make, and alert the person when important things need to be done. A remind and alert move are arguments, which contain the information about what is to be done, i.e., a claim, together with the motivations, i.e., the grounds, which support the claim.

6 A Model of the Coach Agent

For the Coach Agent to be able to conduct dialogues similar to natural dialogues, it was necessary to design the agent as an autonomous actor, with its own knowledge base, goals and priorities. There is for instance, behavioral knowledge, which is generic regardless which type of dialogue or topic is at focus. Since this knowledge needs its own semantic model, yet related to the human actor's, the Coach Agent was modeled as a separate project in ACKTUS (Figure 1). As a consequence, the Coach Agent shares the core ontology with the human agent and the domain models. This function as the common vocabulary in dialogues.

The Agent model contains structures, which function as tools for the Coach Agent to use in the adaptation of its behavior. These tools aids the agent in the *conceptualization, knowledge acquisition and reasoning*, related to cooperative human-agent activities.

The Coach Agent associates each action with a concept that is common for both the human and the agents such as *starting, sustaining* and *ending a conversation*. These concepts are used to define certain behaviors that are typically appropriate in a phase of a dialogue, for example, *"Hi"* is associated to concept *"starting a conversation"*. The different types of dialogues and dialogue moves described in previous section are also integrated in the agent's model of dialogue activity, for instance, the move *affirm*, means that the agent emphasizes and affirms the emotional state, which the human agent expresses, by using different empathic statements such as *"does not sound good"* and *"I see"*. This enables the Coach Agent to simulate the behavior of a participant who listens with empathy. The agent shares also the same conceptual model of entities as the human actors, which are relevant to a human actor based on the International Classification of Functioning, Disability and Health (ICF)[1].

The Coach Agent acquires new knowledge partly by posing explicit questions. One example is in the situation when the Coach Agent presents a claim about a topic, followed by the question *"What do you think?"* (e.g., Line 19 and 22 in the dialogue example in Table 4). This is a generic question, which gives the agent some indication if the human agent agrees to the claim or if the agent needs to adjust its strategies for the next move in the dialogue. The question about perceived appropriateness of a question, which the agent asks, and which was used in the evaluation study is also retrieved from the agent model (Section 7).

The agent also retrieves formal models from the agent domain repository, which can be used for reasoning, in the same way the agent retrieves models from another domain repository in the dialogues about a topic.

7 Pilot Evaluation Study Results

The main research questions addressed in the evaluation study is related to the overall idea of a dialogue system for supporting everyday issues, how a sense-making dialogue would unfold and what topics would be interesting to elaborate upon. Other research questions are related to interaction design of the dialogue system. Since the evaluation study was limited to a subset of the models described in this article, and the study sample was small, the results are only indicative, aimed to inform further development.

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

A purpose was also to evaluate the method to allow the user to evaluate the appropriateness of each of the Coach Agent's statements within its context where it was stated. A question about the appropriateness of the agent's behavior was associated to a four-item Likert scale with the values *inappropriate (1), somewhat inappropriate (2), somewhat appropriate (3)* and *appropriate (4)*. The 13 participants' interaction with the dialogue application was logged, and resulted in a corpus with a total of 28 dialogues, 156 complete turns, and a total elapsed time of 2 hours (approximately 10 minutes per participant). The examples from the dialogues presented in this section have been translated from the participants' native language into English.

The results are divided into results related to the purposes of dialogues, the appropriateness of the agent's behavior and interaction design in the following sections.

7.1 Purposes of Dialogues

The dialogues were based on the fictive persona Rut's health and priorities. Most of the participants could personally relate to the dialogue topics, a few referred to a family member. In general, the available dialogue topics were considered interesting and relevant.

A generic attitude among the participants was that there is need for supportive dialogue systems, on various themes. Additional health-related topics, which were suggested were topics related to eating habits and eating disorders. Besides having healthcare issues to discuss, some pointed out the need in particular situations, when getting lost in the forest, or misplaced a car in the forest or bike in the city center. Others pointed out the potential benefits relating to getting access to social networks, having dialogues about societal issues such as politics, weather, golf and other sports.

A few expressed enthusiasm and curiosity about the idea and wanted to use the dialogue system merely for the fun of it: "...this is fun, let me try another one!"

Two of the older adults expressed skepticism, and did not see the point in using the dialogue system. One of these had also some difficulties using a smart phone, which may indicate a threshold for using new technology in general. By contrast, the other skeptical older adult was already using alternative ways to accomplish potential dialogue purposes, by using search engines for health issues, GPS for navigating, etc. Consequently, the group of participating older adults, including the two skeptical persons, illustrates the broad heterogeneity of the group of older adults.

The therapists highlighted the potential benefits of using a proactive human-agent dialogue system for providing active support for improving strength and balance, e.g., by supplementing the dialogues with sensor information from daily activities and physical exercises performed, analyzed over time.

7.2 Perceived Appropriateness of the Agent's Moves

One of the therapists who tested the system perceived the approach to evaluate the moves within the context it occurs, as highly beneficial. She compared it to structured clinical interviews, where it is typically not known how the patient perceives the appropriateness of the question asked.

The question, which was used for evaluating the appropriateness of the agent's moves, was found to be used in two different ways. Based on this observation, we distinguish between two types:

1. *Context-related appropriateness*: the appropriateness based on the immediate context of the agent's move, e.g., placement in the dialogue line, and
2. *Topic-related appropriateness*: appropriateness related to the topic of the dialogue.

The moves, which were categorized as the first kind and valued inappropriate to some level, were considered a failure of the agent, and are aimed to be minimized by improved strategies for the agent to use when choosing behavior. Consequently, these were removed, when analyzing the second kind, which was considered relating to the domain knowledge and not behavior issues.

7.2.1 Context-related appropriateness

Regarding the context-related appropriateness, some of the agent's moves were considered as inappropriate to some extent due to the agent's inadequate understanding of the human's responses. The agent needs to understand the context of human's response, update its belief base and act accordingly. Therefore the agent needs strategies for wisely selecting moves based on the human's response and the unfolding of the dialogue line. For evaluating the agent's improvement of behavior for future studies, a Contextual Appropriateness Value was defined and tested on this data sample. The total contextual appropriateness value for the complete corpus was 90.4%, and consequently, the error rate was 9.6% (16 of 167 moves) (Table 5).

7.2.2 Topic-related appropriateness

To what extent the agent's moves were perceived by the participants to be relevant to the overall dialogue topic was analyzed. The agent uses the domain knowledge, which it retrieves from a domain knowledge repository modeled by domain experts, to build a model of the knowledge domain, related to the selected topic of a dialogue. The domain experts have in their modeling created a knowledge model with interrelated topics following their view on to what extent different phenomenon are relevant to each other. However, human individuals who have a dialogue with the agent may perceive the level of appropriateness differently. We evaluated this topic-related appropriateness based on the participants' answers to the question about appropriateness, and mapped them to the concept associated to the content of the agent's move.

Table 5 Total number of dialogue turns (Turns), number of Contextual Appropriateness Errors (CAE: turns, which are to some extent inappropriate), and mean of errors

User	Turns	CAE
1	13	1
2	13	1
3	8	1
4	9	4
5	13	1
6	28	0
7	28	3
8	9	2
9	9	0
10	9	1
11	8	1
12	9	1
13	11	0
Total	167	16
Mean	12.8	1.2

The most common topic, which the participants selected was the topic *sleep patterns may be disturbed*. The corresponding concept is *sleep*. Table 6 provides a summary of the participants' responses about appropriateness of different moves in relation to sleep. After removing the contextual errors and missing information (marked as not available (n/a) in Table 6) , we can observe that most of the turns made by the agent were considered as appropriate to the topic sleep.

7.2.3 Discussion

To summarize, identifying the topic-related appropriateness of participant's moves is to a large extent dependent on the perspective of an individual. Some participants considered the questions related to pain and the presence of worries as appropriate while some others considered the same topics as inappropriate to different extent. Some comments by the participants indicated that they associated these questions to their own situation and health conditions, rather than the persona Rut's situation, which was the reason for why these moves were perceived as inadequate. Consequently, if the participants had been able to create their own profile in the system for the agent to build a user model from in the dialogues, then some of these less appropriateness evaluations had been different.

The question about reasons for why getting up at night had a broad range of answering alternatives, among which a few participants found less relevant alternatives.

The overall goal of our human-agent dialogue system is to minimize the contextual appropriateness errors and maximize the topic-related appropriateness. To attain this goal, future work includes developing strategies for the agent to wisely select moves based on changes in its belief base. Moreover, these improvements will be evaluated with a group of older adults who create their own profiles in the system, for evaluating to what extent the perceived inappropriateness is related to the domain knowledge, and the differences in the view on this. If the differences are significant, a machine learning method will be built for the agent to learn how an individual values the topic-related appropriateness and adapt its selection of moves to that individual.

Table 6 Perceived topic-related appropriateness: inappropriate (✘), somewhat inappropriate (✗), somewhat appropriate(✓) and appropriate(✔) . The abbreviation (n/a) (not available) represents missing information where a particular question was not asked to the user or the user chose not to give feedback.

Ques \ Users	1	2	3	4	5	6	7	8	9	10	11	12	13
Sleeping well all night	✔	✔	✓	n/a	✔	✓	✔	✓	✔	✘	✓	n/a	✔
Cause of getting up at night	✔	✔	✓	✔	✓	✓	✔	✔	✓	✔	n/a	✔	✔
Severity of pain	✔	✔	✓	n/a	✔	✔	✔	✔	✓	n/a	n/a	✔	✓
Having worries	✘	n/a	n/a	✔	n/a	✓	✓	✔	✓	n/a	n/a	✓	✓
Severity of worries	✓	✗	n/a	✔	✓	✓	✔	n/a	✓	✗	✘	n/a	✓
Taking some medication	✔	n/a	✔	n/a	✔	✓	n/a	n/a	✓	✔	n/a	n/a	✓
Handling medications	n/a	n/a	✘	✔	n/a	✓	✓	✓	✓	n/a	n/a	✓	✓

To summarize the evaluation of the described method of valuing the appropriateness of the agent's behavior within its context where it occurs, the approach was found to add significant value to the evaluation study, without disturbing the participant from participating in the dialogue. However, considering the limitations of the pilot study, and the two possible ways to interpret the question, the method will also be further evaluated in future studies.

7.3 Interaction Design

The older adults did not comment on the visualization of dialogues in the graphical interface. By contrast, the therapists put significantly more interest in how the dialogues would appear to the user. They commented on what parts of the dialogue line were visible at different phases in the dialogue, the unfolding of dialogues, on how the responses would be given by the user, etc. Their main concern was how reducing the amount of information presented to the user, while not losing the information about in which context the dialogue was situated. The interface design will be improved based on their comments and suggestions.

One therapist mentioned the concept of an "avatar", sometimes used for representing an Embodied Cognitive Agent (ECA). She viewed the Coach Agent as such, and discussed how body language could be added to the static figure used in the graphical user interface for representing the Coach Agent.

Other comments related to the benefits of, and how mediate, the dialogues through spoken language instead of text. Testing voice-based dialogues will be a natural step towards a more adaptive human-agent dialogue system, considering the large proportion of older adults who have sight impairments. One obvious benefit from using the ontology-based semantics of dialogues, was illustrated in the pilot evaluation study, since it allowed to apply the two languages needed by the participants. This will also facilitate the inclusion of additional modalities in the interaction design, which will be evaluated in future studies.

8 Conclusions

The purpose of this work was to define a generic model of purposeful human-agent dialogues about health-related topics. This was done based on analyses of scenarios, personas and models of human behavior. The resulting conceptual model includes four models to be included in a software agent's belief base; i) a user model, ii) a model of the domain knowledge related to the topic of the dialogue, iii) an agent model, and iv) a dialogue activity model. The major contributions of this work are the agent model and the dialogue activity model, the latter to be shared between the human and software agents. The models were implemented into a prototype system for human-agent dialogues, which was evaluated by therapists and a group of older adults.

Future work includes the development of the dialogue and reasoning strategies for the agent to improve its ability to adapt to the individual and the situatedness of contextual and natural dialogues.

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