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

J.M. Corchado et al. (Eds.): PAAMS 2014 Workshops, CCIS 430, pp. 89–100, 2014.

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.

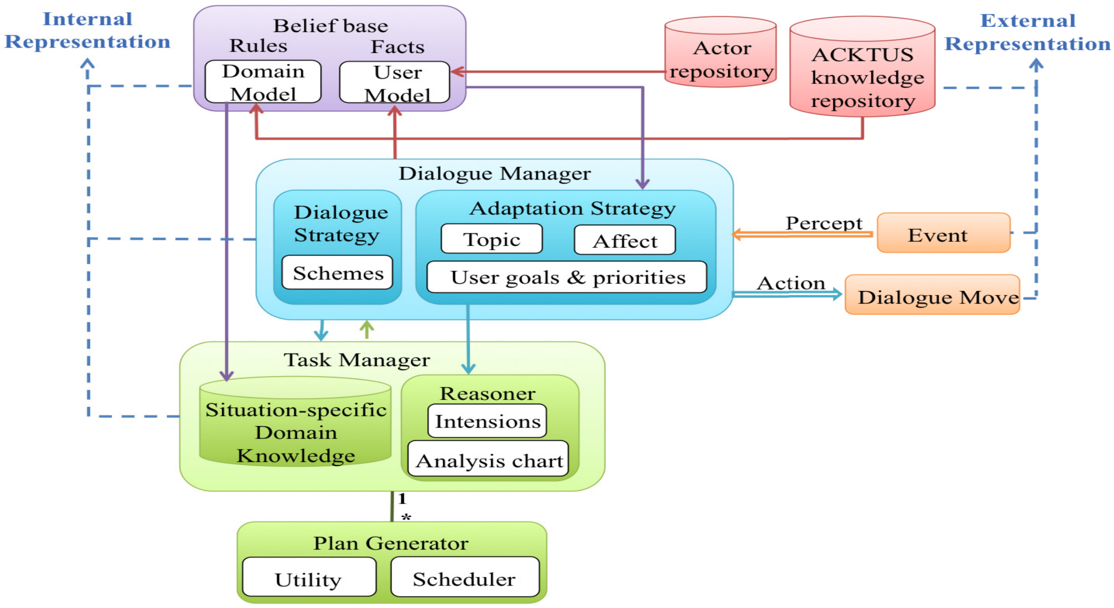

Fig. 1. Cognitive agent architecture

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.

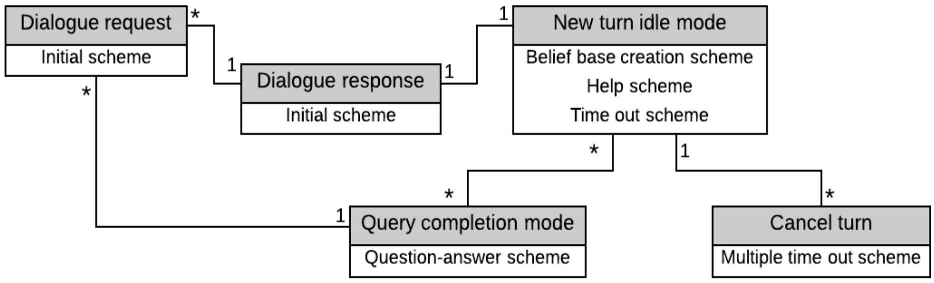

Fig. 2. Entity relationship diagram of a dialogue. Each entity represents a state and its scheme.

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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