Ontologies for social, cognitive and affective agent-based support of child's diabetes self-management

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Abstract. The PAL project is developing: (1) an embodied conversational agent (robot and its avatar); (2) applications for child-agent activities that help children from 8 to 14 years old to acquire the required knowledge, skills and attitude for adequate diabetes self-management; and (3) dashboards for caregivers to enhance their supportive role for this self-management learning process. A common ontology is constructed to support normative behavior in a flexible way, to establish mutual understanding in the human-agent system, to integrate and utilize knowledge from the application and scientific domains, and to produce sensible human-agent dialogues. This paper presents the general vision, approach, and state of the art.

1 Ontologies in Cognitive Engineering

In Europe, an increasing number of about 140,000 children (<14 year old) have Type 1 Diabetes Mellitus (T1DM) [1]. The PAL project develops an Embodied Conversational Agent (ECA: robot and its avatar) and several applications for child-agent activities (e.g., playing a quiz and maintaining a timeline with the agent) that help these children to enhance their self-management (PAL, Personal Assistant for healthy Lifestyle, is an European Horizon-2020 project; www.pal4u.eu). In addition, it develops dashboards for caregivers (like diabetes nurses and parents) to enhance their supportive role. The general objective is to establish a smooth transition of the diabetes care responsibility from caregiver to the developing child, so that the child will have the required knowledge, skills, and attitude for adequate self-management at adolescence.

PAL is part of a joint, cognitive system, in which humans and agents share information and learn to improve self-management. The required sharing of (evolving) knowledge in the envisioned "blended care" setting has four important challenges:

1. To address the values & norms of both the caregivers in their different hospitals (e.g., diabetes regimes), and the caretakers in their different contexts (e.g., privacy, literacy).
2. To establish mutual understanding (a) within and between the different stakeholders of the PAL system (e.g., the end-users like children and caregivers and research & developers like academics and engineers), and (b) between the humans and PAL-agents.
3. To continually acquire, utilize and deploy knowledge about child's self-management support.
4. To produce natural, flexible, personalized human-agent interactions that are sustainable in the long term as well as allow to extract data about the user from these interactions.

To meet these four challenges, we are developing an ontology as an integrated part of system development, i.e., in a systematic, iterative, and incremental cognitive engineering process. First, available ontologies and approaches are assessed and, possibly, improved and integrated for our purposes (section 2). Second, relevant theories and models of the concerning scientific research fields are identified and formalized for adoption in the ontology (section 3). Third, the ontology is implemented in an artefact or prototype (i.e., the PAL system) and, subsequently, tested and refined (section 4).

2 Models for Diabetes Self-Management

Because PAL covers a large domain of interest, we have developed ontology models as high-level building blocks for smaller, separate areas of interest (frames). First, appropriate frames were selected from existing (global) libraries and, if needed, tailored to the PAL purposes. Second, for the missing elements, frames were modeled by constructing a new ontology. Subsequently, the individual frame models were related (interlinked) in an integrated PAL model. Because most existing ontologies provide "only" a partial fit to the intended scope of PAL, we needed to adapt these models by extending them (e.g., when concepts were lacking), or by selectively downsizing them (e.g., when there were too many details or concepts in the model). The frames we have identified and modeled so far are among others: (1) human and machine roles involved in self-management; (2) emotions and sentiments that cover the emotional responses of both robot and child to interaction as well as the general state of mind of the child; (3) tasks that include among other things: learning and self-management tasks, associated goals, and objects; (4) issues related to medical examinations (e.g., lab values); and (5) dialogue management through a combination of dialogue acts and shallow semantics. A more elaborate PAL ontology will also include interaction and behavior models of robot and avatar, a model for privacy of information of self-management activities and a model to cover the agreements and social contracts between child and ECA.

Figure 1 provides a simple example of the task frame (cf. [2]). An Agent, such as a child or avatar, is an entity that performs a certain task, like an educative quiz game. An associated goal

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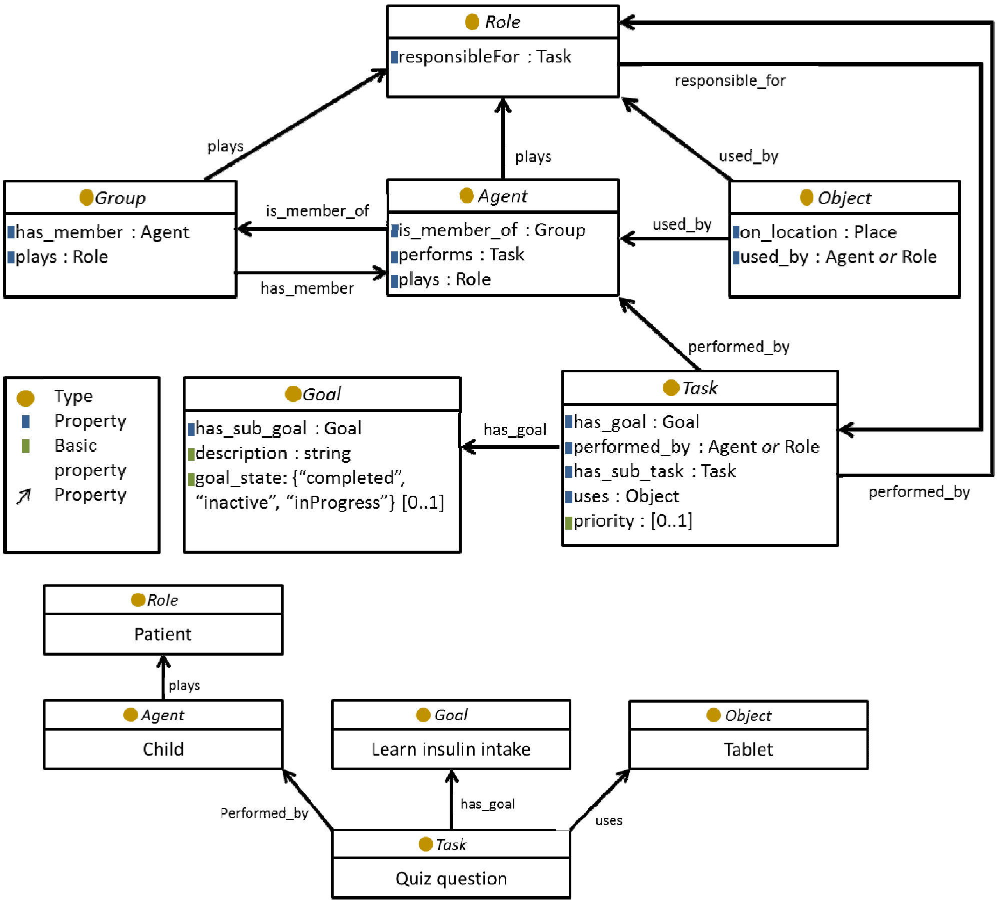

Figure 1: Simple example of the general task frame at the top and an instantiation at the bottom.

(e.g., learning about Insulin taking) can be attained by performing the related task (e.g., answering related questions correctly while playing the quiz). Objects such as a tablet device, are typically used when performing the task. The agent has a role while performing the task (e.g., patient) and can be part of a group of agents (e.g., parents).

Important objectives of the PAL ontology are norm-compliancy, shared understanding, interpretation, reasoning, and generation of verbal utterances. The ontology is based on a uniform representation of an application semantics that uses dialogue acts and frames that are defined in an extended RDF and OWL ontology [3]. In addition, all data that influence multimodal utterance generation are specified in the ontology (e.g., user data), which facilitates access and combination of the different bits of information. We heavily extended existing processing components, e.g., the reasoning engine HFC from DFKI and its database layer [4], which make information available to the interaction management and analysis. We defined a new formalism for the specification of dialogue policies that combines dialogue rules, transaction time-based knowledge representation [5], and dialogue history in a unique way. One important part of the PAL ontology combines dialogue acts using the DIT++ standard [6] and semantic frames, loosely based on thematic relations [7], used in today's frameworks VerbNet, VerbOcean, or FrameNet. Below, we show a simplified version of the combined representation, built for the sentence: "I could show you a picture of the last football game".

Offer(Showing, theme=Picture, sender=I MYSELF, addressee=NAO ROBOT, topic=Football).

3 Integrating Relevant Theories

In the PAL project, dedicated studies of models in the concerning scientific research areas are being conducted. For supporting the *social processes* that are involved in self-management learning, PAL models relationships in terms of familiarity or intimacy, liking, attitude and benevolence [8]. Particularly, the child-ECA bonding process is being supported by the Dyadic Disclosure Dialog Module (3DM) that supports the mutual child-agent self-disclosures. The PAL ontology distinguishes three main classes for these dialogues: disclosure, prompt and closer. In addition to valence and topic, each disclosure has an intimacy level according to the 4-level Disclosure Intimacy Rating Scale (DIRS). Burger et al. (2016) provide more detailed information on the 3DM of PAL and its theoretical foundations [9].

For supporting the *cognitive processes*, the diabetes knowledge and corresponding learning goals have been modeled to monitor and reason about progress (e.g., on diabetes regimes, self-control, food, physical exercises, and stress coping). Goal attainment is an important indicator of the changes in behavior of children [10], and can be supported by personalized feedback of the ECA. Figure 2 provides a simplified sketch of a dialogue instantiation in the PAL system. Answering a quiz question is an example of a task (Fig 1). Answering correctly (partly) fulfills one or more (learning) goals. Note that the same goal can be satisfied by another task too, such as a sorting game. The different goals have specific difficulty levels (0-3). The caregivers decide what goals are currently relevant and achievable for a child. Together with caregivers, a child selects the specific goals to attain: <child:URI> <hasGoal> <goal:URI>. Since the system will only suggest tasks that can achieve the child's current goals, these tasks are implicitly following these same difficulty levels. For example, a quiz question that satisfies a level 3 goal will be more difficult than a question satisfying a level 0 goal. Goal attainment is an important aspect of self-management. PAL will monitor the goal attainment progress: <Goal:URI> <hasProgress> float. For every goal, the ontology defines what tasks, and (sub-)goals should be achieved to achieve the goal itself. GoalProgress is function of goal:neededForAsClass and goal:requiresAsClass. By computing the percentage of tasks, subtasks, and sub-goals currently achieved, the system computes a current progress on this goal. This is recorded with a time stamp, so that progress over time can be calculated.

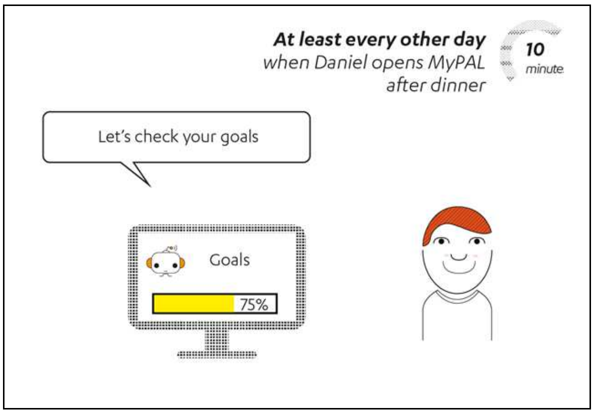

Figure 2: Simplified situated speech act of the avatar.

For supporting the *affective processes*, the PAL system introduces several methods to model the affective state of a child. First, sentiment mining technology is applied to estimate child's mood in the child-PAL textual dialogues [11]. Second, in the tablet application, the child can further self-report on the experienced emotions and moods for activities the child performed during the day. Third, the child model will estimate emotions experienced by the child resulting from activities proposed by the ECA. For example, the ECA can propose to play a quiz with the child, and predict joy when the child did well during the quiz. This child model is based on the belief desire theory of emotions [12, 13], in which emotions are a direct consequence of beliefs and desires of an individual. For example, if one beliefs X and desires X, then one is happy about X. This way, the child model can reason about the child's beliefs and desires. The model improves over time. If the child self-reports positive emotions during an activity while the child model estimates negative ones, then the child model updates the beliefs-desire assumptions concerning the child. The PAL ontology will represent complex affective states. Emotions are directed at objects, or events, and are short intense episodes. Moods are undirected and less intense, but linger for a prolonged period of time. Emotions are stored with the activity that had this emotion as a consequence. Moods contain a timestamp, indicating when it was measured. This representation makes it possible to find correlations between activities and affect over a prolonged period of time.

4 Implementation and Evaluation

The PAL system consists of several modules with dedicated support objectives. For example, the dialogue manager aims at engaging conversations between child and the ECA, the action-selection module HAMMER [14] learns over time what the best actions are (e.g., proposing to play a quiz, or starting a new dialogue) to improve the child's knowledge of diabetes while maintaining a positive emotional state for the child, and the child model aims at estimating the emotional states.

Figure 3 shows the data flows of the PAL system with an extendable set of modules that communicate through a common Nexus. When a module has new information to share with other modules (e.g., action selection proposes to play a quiz) then this information is posted on the Nexus. Any module can read and use this new information. The application can then read this proposal and start a quiz on the tablet, and/or the dialogue manager can start a small dialogue by asking the child whether he/she wants to play a quiz. The PAL ontology provides the shared knowledge representations, defined in the extended HFC reasoner and allowing for testing and refining.

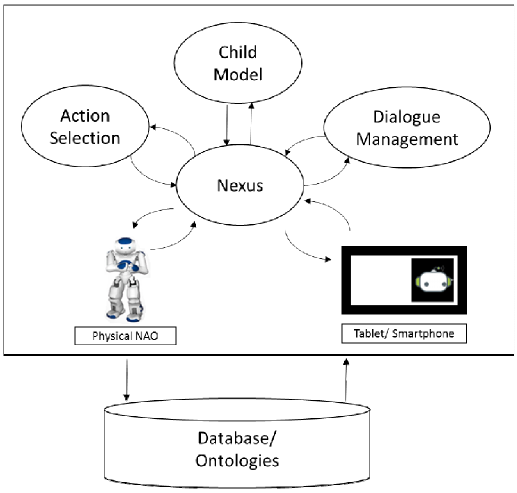

Figure 3: The PAL system.

Currently, we are analyzing the first data sets of children and caregivers that used the PAL system in diabetes camps, hospitals and at home (in Italy and in the Netherlands) from a few days to 4 weeks. Based on the ontological concepts, we can identify meaningful patterns in the data that will be used to improve the intelligence of PAL, e.g. concerning the goal attainment progress (i.e., enhance the knowledge base with refined ontology and reasoning mechanisms). Furthermore, the data analysis will help to refine the ontology substantially. For example, parents' relationship (cohabit or divorce) seems to affect child's PAL usage (quantity and regularity) substantially. These concepts with their mutual relations are being added to the ontology to "feed" mitigating support functions. A second example concerns the identified cultural differences in Italian and Dutch children for the wealth and directness of their multimodal interactions with the robot [11]. Among other things based on these results, the child and robot models will be enriched to establish adaptive — personalized and culture-harmonized— child-robot interactions.

5 Discussion

The PAL project develops personalized support for children, helping them to acquire the required attitude, knowledge and skills for adequate diabetes self-management. It applies a situated Cognitive Engineering (sCE) methodology to design and test: (1) an ECA for children, (2) several (educative) child-ECA activities, and (3) dashboards for caregivers. This methodology includes an ontology engineering component to establish a system's knowledge base that is univocal, theoretically sound, coherent, consistent and transparent [15]. The resulting common ontology is used to establish mutual understanding in the human-agent system, to integrate and utilize knowledge from the application and scientific domains, and to produce sensible human-agent dialogues. For the first version of the PAL ontology, a network of connected ontologies ("frames") have been constructed, each consisting of general concepts and their relations. The "dialogue management frame" was worked out in more detail, i.e., the specification of the data structures to be used by the dialogue specifications, dialogue history, and information state. Furthermore, the reasoning components were adapted, so that this knowledge source can be used efficiently once the formalism specification is fully implemented.

The PAL project entails multi-disciplinary research and design of a "blended care" system with the involvement of a large diversity of stakeholders. In general, the ontology construction helped to identify (interrelated) key concepts that should be univocally addressed in the design (e.g., requirements), implementation (e.g., dialogues) and evaluations (e.g., goal attainment). Furthermore, it enforces the systematic integration of relevant theories on social, cognitive and affective processes into the support system (e.g., on bonding, goal-driven learning and emotion). In line with the general iterative development process, the ontology will be refined for enhanced self-management support in the next versions of the PAL system.

It is interesting to note that the PAL ontology can be viewed as a frame-based ontology in terms of Minsky [16] and Hoekstra [17]: An explicit, structured, and semantically rich representation of declarative knowledge like psychological theories of human cognition use, distinguishing "frames" or "classes" (upper level) from "instantiations" (lower level). This approach seems therefore particularly appropriate for representing knowledge involved in learning [15], e.g., learning to cope with a chronic disease.

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