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Relational approach to knowledge engineering for POMDP-based assistance systems as a translation of a psychological model

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ABSTRACT

Assistive systems for persons with cognitive disabilities (e.g., dementia) are difficult to build due to the wide range of different approaches people can take to accomplishing the same task, and the significant uncertainties that arise from both the unpredictability of client's behaviours and from noise in sensor readings. Partially observable Markov decision process (POMDP) models have been used successfully as the reasoning engine behind such assistive systems for small multi-step tasks such as hand washing. POMDP models are a powerful, yet flexible framework for modelling assistance that can deal with uncertainty and utility. Unfortunately, POMDPs usually require a very labour intensive, manual procedure for their definition and construction. Our previous work has described a knowledge driven method for automatically generating POMDP activity recognition and context sensitive prompting systems for complex tasks. We call the resulting POMDP a SNAP (SyNdetic Assistance Process). The spreadsheet-like result of the analysis does not correspond to the POMDP model directly and the translation to a formal POMDP representation is required. To date, this translation had to be performed manually by a trained POMDP expert. In this paper, we formalise and automate this translation process using a probabilistic relational model (PRM) encoded in a relational database. The database encodes the relational skeleton of the PRM, and includes the goals, action preconditions, environment states, cognitive model, client and system actions (i.e., the outcome of the SNAP analysis), as well as relevant sensor models. The database is easy to approach for someone who is not an expert in POMDPs, allowing them to fill in the necessary details of a task using a simple and intuitive procedure. The database, when filled, implicitly defines a ground instance of the relational skeleton, which we extract using an automated procedure, thus generating a POMDP model of the assistance task. A strength of the database is that it allows constraints to be specified, such that we can verify the POMDP model is, indeed, valid for the task given the analysis. We demonstrate the method by eliciting three assistance tasks from non-experts: handwashing, and toothbrushing for elderly persons with dementia, and on a factory assembly task for persons with a cognitive disability. We validate the resulting POMDP models using case-based simulations to show that they are reasonable for the domains. We also show a complete case study of a designer specifying one database, including an evaluation in a real-life experiment with a human actor.

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1. Introduction

Quality of life (QOL) of persons with a cognitive disability (e.g., dementia, developmental disabilities) is increased significantly if they can engage in 'normal' routines in their own homes, workplaces, and communities. However, they generally require some assistance in order to do so. For example, difficulties performing common activities such as self-care or work-related tasks, may trigger the need for personal assistance or relocation to residential care settings [1]. Moreover, it is associated with diminished QOL, poor self-esteem, anxiety, and social isolation for the person and their caregiver [2].

Technology to support people in their need to live independently is currently available in the form of personal and social alarms and environmental adaptations and aids. Looking to the future, we can imagine intelligent, pervasive computing technologies using sensors and effectors that help with more difficult cognitive problems in planning, sequencing and attention. A key problem in the construction of such intelligent technologies is the automatic analysis of people's behaviours from sensory data. Activities need to be recognised and, by incorporating domain specific expert knowledge, reasonable conclusions have to be drawn which ultimately enables the environment to perform appropriate actions through a set of actuators. In the example of assisting people with dementia, the smart environment would prompt (i.e., issue a voice or video prompt) whenever the clients get stuck in their activities of daily living.

The technical challenges of developing useful prompts and a sensing and modelling system that allows them to be delivered only at the appropriate time have been tackled through the use of advanced planning and decision making approaches. One of the more sophisticated of these types of systems is the COACH [3]. COACH uses computer vision to monitor the progress of a person with dementia washing their hands and prompts only when necessary. COACH uses a partially observable Markov decision process (POMDP), a temporal probabilistic model that represents a decision making process based on environmental observations. The COACH model is flexible in that it can be applied to different tasks [4]. However, each new task requires substantial re-engineering and re-design to produce a working assistance system, which currently requires massive expert knowledge for generalisation and broader applicability to different tasks. An automatic generation of such prompting systems would substantially reduce the manual efforts necessary for creating assistance systems, which are tailored to specific situations and tasks, and environments. In general, the use of a priori knowledge in the design of assistance systems is a key unsolved research question. Researchers have looked at specifying and using ontologies [5], information from the Internet [6], logical knowledge bases [5,7], and programming interfaces for context aware human-computer interaction [8].

In our previous work, we have developed a knowledge driven method for automatically generating POMDP activity recognition and context sensitive prompting systems [9]. The approach starts with a description of a task and the environment in which it is to be carried out that is relatively easy to generate. Interaction unit (IU) analysis [10], a psychologically motivated method for transcoding interactions relevant for fulfilling a certain task, is used for obtaining a formalised, i.e., machine interpretable task description. We call the resulting model a SyNdetic Assistance Process (SNAP). However, the current system uses an ad hoc method for transcoding the IU analysis into the POMDP. While each of the factors are well defined, fairly detailed and manual specification is required to enable the translation.

The long-term goal of the approach presented in this paper is to allow end-users, such as health professionals, caregivers, and family members, to specify and develop their own context sensitive prompting systems for their needs as they arise. This paper describes a step in this direction by proposing a probabilistic relational model (PRM) [11] defined as a relational database that encodes a domain independent relational dynamic model and serves to mediate the translation between the IU analysis and the POMDP specification. The PRM encodes the constraints required by the POMDP in such a way that, once specified, the database can be used to generate a POMDP specification automatically that is guaranteed to be valid (according to the SNAP model). The PRM serves as a schema that can be instantiated for a particular task using a simple and intuitive specification method. The probabilistic dependencies in the PRM are boiled down to a small set of parameters that additionally need to be specified to produce a working POMDP-based assistance system. We show how the method requires little prior knowledge of POMDPs, and how it makes specification of relatively complex tasks a matter of a few hours of work for a single coder.

The remainder of this paper is structured as follows. First, we give an overview of the basic building blocks: POMDPs, the IU analysis, knowledge engineering, and probabilistic relational models (PRMs). Then, Section 3 describes the specific PRM and relational database that we use, and shows how the database can be leveraged in the translation of the IU analysis to a POMDP planning system. In Section 4, we show a case study that explains step-by-step the design process of an example prompting system. Section 5 shows how the method can be applied to three tasks, including the real-life simulation with a human actor, and then the paper concludes.

This paper is describing assistive systems to help persons with a cognitive disability. Throughout the paper, we will refer to the person requiring assistance as the *client*, and to any person providing this assistance as the *caregiver*. A third person involved is the *designer*, who will be the one using the system we describe in this paper to create the assistive technology. Thus, our primary target user in this paper is the *designer*.

2. Overview of core concepts

We start by introducing the concept of POMDPs (Section 2.1) which is the core mathematical model and represents the final outcome of our modelling task, i.e., the actual machine-readable specification of the prompting system. Next, we