A Semantic Web Framework for Behavioral User Modeling and Action Planning for Personalized Behavior Modification

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Abstract. Behavior plays an important role in managing chronic illnesses, with e.g., smoking, unhealthy diet, and physical inactivity often causing or worsening chronic illnesses. To attain long-term healthy behaviors, personalized behavior modification programs are known to be effective. The design of such programs requires (a) developing a patient model that represents the patient's health needs, behavior challenges and preferences, as well as their perceived abilities; and (b) personalization of standard behaviour modification programs towards the patient model. We present a knowledge-driven, Semantic Web-based behavior modification framework, guided by Social Cognitive Theory, which computerizes core behavioral constructs into an OWL ontology. Based on this ontology, concrete patient models and behavior modification programs are instantiated. A preliminary scenario-based evaluation demonstrates the system's ability to personalize action plans towards unique patient models and behavioral challenges.

Keywords: personalized health; user modeling; behavioral modification; user personalization.

1 Introduction

The prevalence of chronic diseases is on the rise, which is placing a significant burden on the healthcare system and reducing people's quality of life [1]. Behavior plays an important role in the prevention and management of chronic diseases, with e.g., smoking, unhealthy diet, physical inactivity and alcohol abuse often leading to, or exacerbating, chronic illnesses [2]. Personalized behavior modification programs have been shown to be effective in motivating an individual to adopt healthy behaviors [3, 4]. However, these programs are also quite complex, as they require alignment with the individual's health needs, behavior challenges and preferences, as well as culture, perceived abilities (i.e., self-efficacy) and socio-economic factors [5, 6]. As such, designing effective, personalized behavior modification programs is challenging, and involves a holistic process of personalizing standard behavior modification programs based on a patient model, delivering timely behavior modification interventions (e.g., motivational messages), and adjusting the program based on compliance [7]. Existing computerized, person-specific behavior modification programs focus mostly on educational aspects, and, while often mentioning a behavioral-theoretic foundation, they do not elaborate on a computerized, knowledge-driven behavior modification approach.

In this paper, we present a knowledge-driven behavior modification framework based on Semantic Web technology, which performs patient modeling and personalization of standard behavior modification programs. The theoretical foundation for our framework is grounded in Social Cognitive Theory (SCT) [8]. We present a novel approach of computerizing SCT constructs, by (a) modeling the behavioral-theoretic knowledge in terms of an OWL ontology, (b) instantiating patient models and standard behavior modification programs using this ontology, and (c) performing personalization by identifying and ranking suitable programs. In this work, we focus on the long-term goal of improving physical activity but our approach can be readily extended towards other behaviors. Our system is implemented in Java and uses Apache Jena to work with semantic data. Previously, we introduced an SCT-based system [7] to deliver personalized educational and motivational messages, and later extended this work with mobile messaging [9] and applied it for behavior modification in diabetes patients [10].

Section 2 details our behavior modification approach, and Section 3 provides a scenario-based evaluation of the system. Section 4 states conclusions and future work.

2 Behavior Modeling and Personalization Approach

Our approach is grounded in the Social Cognitive Theory (SCT), which states that, unless there is sufficient motivation, a patient will not perform a particular behavior. With regards to motivation to attain healthy behaviors, Bandura [11] presented Self-Efficacy, i.e., one's perceived ability to perform a behavior, as a central factor. They further identified modes that inform one's self-efficacy: the most important mode, Mastery Experience, states that, when overcoming a non-trivial barrier, experiencing success enhances one's self-efficacy and failure reduces that sense.

To support Mastery Experience, our approach involves setting a series of achievable, short-term goals in the form of *action plans*. Each action plan assists the patient in overcoming a personal *barrier*, which is inhibiting their ability to achieve a *long-term goal* (e.g., regular physical activity). Progressively achieving action plans, each overcoming a non-trivial barrier, increases a patient's self-efficacy in long-term behavior change. To minimize the likelihood of failure, we target short-term (limited to a week) and achievable action plans, which are pre-selected and ranked based on suitability.

Our overall behavior modification process, which was adapted from the Chronic Disease Self-Management Program (CDSMP [12]), consists of the following steps:

(a) **Identification of the Problem**: the patient fills out a Self-Regulatory Efficacy Questionnaire (SREQ), resulting in a ranked list of self-perceived barriers.
(b) **Goal Selection**: the patient is prompted to select a self-perceived barrier.
(c) **Listing of Action Plan Suggestions**: based on the *Knowledge Model*, the *Action Planning* step computes a ranked list of suitable action plans.

(d) **Messaging**: the system sends educational and motivational messages to the patient.
(e) **Monitoring**: at the end of the week, the patient reports on the degree of success (1-10). In case success < 5, they are advised to try out a different plan for the barrier.

Below, we discuss the Knowledge Model and Action Planning components, which are the focus of this paper.

2.1 Knowledge Model

The Knowledge Model, implemented as an OWL ontology, allows effecting personalized behavior modification based on SCT. By encapsulating relevant knowledge in an ontology, we decouple action plan processes (see Section 2.2) from knowledge representation, thus allowing any kind of behavioral analysis to be performed.

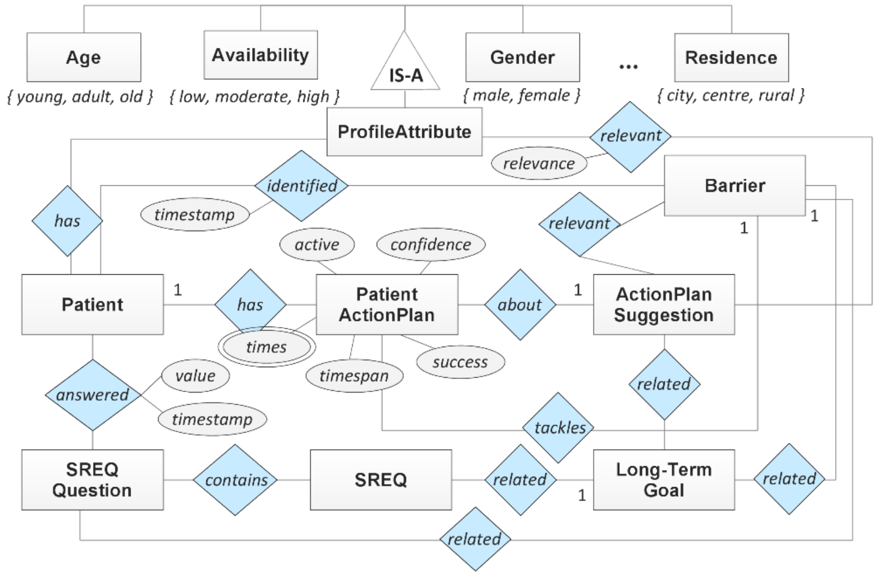

Fig. 1. EER diagram of the Knowledge Model ontology.

Fig. 1 shows a high-level EER diagram of the Knowledge Model OWL ontology. The Patient subclass represents the *Patient Model*. It keeps a set of profile attribute values (*ProfileAttribute*) describing the patient's current situation, physiological properties and relevant medical issues. It also keeps the patient's perceived barriers, which are obtained by filling out a Self-Regulatory Efficacy Questionnaire (*SREQ*) comprising a set of *SREQ Questions*, each of which pertain to a *Barrier*. Answering these questions enables the patient to self-identify personal barriers to be overcome (*identified* property). An *ActionPlanSuggestion* (ActiPS) is a standard behavior modification program and is related to the barriers it can help to overcome, as well as profile attributes to which it is relevant, with related relevance scores (0 < score < 1). For our work, we re-used the physical activity SREQ from Bandura et al. [13] and included its barriers in our Knowledge Model. Furthermore, for each barrier, a health expert extracted a set of ActiPS from well-known health sources, including WebMD, MayoClinic, CDC and the American Heart Association, which were integrated into the Knowledge Model.

2.2 Action Planning

Action planning involves finding and ranking suitable ActiPS based on the knowledge model. To calculate the suitability of an action plan, we consider (a) whether the action plan tackles the patient's chosen barrier, and (b) relevance towards patient profile attributes. In case an attribute has 0 relevance (e.g., plans unsuitable for the disabled will have a 0 relevance for the *disabled* attribute), or the action plan does not target the patient's barrier, the suitability score will be 0. Else, the score will equal the sum of relevance scores, normalized by the total number of profile attributes. The process also collects whether and how often the patient already followed the plan. Based on this data, it ranks the found ActiPS, using as first criterium (ascending) the number of completions by the patient, and as second criterium (descending) its suitability score.

3 Scenario-based Evaluation

This section illustrates the usage of our behaviour modification system by Jane, a homemaker living in the suburbs with plenty of free time, who has a musculo-skeletal condition. She currently does not participate in sports but has training equipment at home.

By filling in the SREQ questionnaire (a), Jane self-identifies the following barriers: she often feels too tired for physical activities due to her musculo-skeletal condition, and cannot go outside due to bad weather. The patient chooses to overcome her weather-related barrier (b). Based on her selection and profile, the system selects a top-5 ActiPS list (c): (1) *Exercise while watching TV*; (2) *Do mall walking when dropping family off at shopping mall*; (3) *Get up and move around for a few minutes / hour*; (4) *Visit local shopping mall and walk*; (5) *Move around while making phone call*.

In the Knowledge Model, all these action plans are related to Jane's chosen barrier (i.e., can be performed indoors). Further, no typical homemaker activities (e.g., cleaning the house) were suggested, since Jane is a homemaker and thus likely performs them already. In the Knowledge Model, such activities are indicated with a 0 relevance to the *homeMakerOccupation* attribute. Since Jane has plenty of time, some of the activities are time-consuming as well, including visiting the local mall (4); and since Jane has equipment at home, the system suggests exercising while watching TV (1). To that end, the Knowledge Model relates e.g., *mallWalking* to *highTimeAvailability*, and *tvExercising* to *homeEquipmentAvailability*, with non-zero relevance. The activity already tried by Jane, namely moving around while calling (5), is ranked lowest.

4 Conclusion

We presented a novel behavior modification framework based on validated behavioral theory (i.e., SCT) that is driven by a Knowledge Model. In our action-planning approach, the patient completes a sequence of personalized short-term action plans, targeted to overcome non-trivial barriers. Our initial, scenario-based evaluation shows that our approach is able to cope with patients' unique barriers and restrictions.

Future work involves utilizing the *Social Modeling* mode, stating that *Self-Efficacy* is influenced by the achievements of similar people. E.g., by keeping collective patient achievements, suggestions may be ranked on the success rates of similar patients.

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