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An Ontology-based Framework Aiming to Support Personalized Exercise Prescription: Application in Cardiac Rehabilitation

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***Abstract*—Exercise constitutes an important intervention aiming to improve health and quality of life for several categories of patients. Personalized exercise prescription is a rather complicated issue, requiring several aspects to be taken into account, e.g. patient's medical history and response to exercise, medication treatment, personal preferences, etc. The present work proposes an ontology-based framework designed to facilitate healthcare professionals in personalized exercise prescription. The framework encapsulates the necessary domain knowledge and the appropriate inference logic, so as to generate exercise plan suggestions based on patient's profile. It also supports readjustments of a prescribed plan according to the patient's response with respect to goal achievement and changes in physical-medical status. An instantiation of the proposed framework for cardiac rehabilitation illustrates the virtue and the applicability of this work.**

I. INTRODUCTION

EXERCISE has been shown to have multiple benefits for the general population, e.g., improving quality of life for all, while supporting independent living of elderly persons. Exercise-related improvement has been reported in specific diseases [1], i.e. obesity, type 2 diabetes mellitus, colon cancer, stroke, with the most clear and quantitatively measurable benefits in cardiovascular and coronary artery disease, as well as all-cause mortality [2], [3]. Therefore, exercise training is part of many rehabilitation programs for patients, aiming towards enhancing their medical status and overall physical health, or setting more specific goals.

Exercise is beneficial for many patient groups, concerning a variety of diagnosis and age populations; however, an optimal effect requires a structured program, tailored to the individual patient following an initial assessment. Therefore, professionals setting up an exercise program should be familiar with or have support regarding the relevant guidelines and other medical knowledge related to exercise and physical activity. In this context, computer support systems have been shown to be useful in assisting the decision-making process for rehabilitation programs [4].

An additional aspect to be considered in exercise prescription is patient's attitude towards the exercise plan, as it is proposed by the medical professionals. Patient's positive attitude and acceptance of a prescribed plan is related to improved adherence, the latter being crucial for the achievement of the treatment's goals. In this regard, exercise prescription should take into account patient's preferences e.g. cycling, jogging, preferred time of day to exercise, and lifestyle aspects, e.g. previously sedentary lifestyle.

Aiming to support personalized exercise prescription, this paper presents an ontology-based framework considering the above aspects. In particular, the framework encapsulates the medical knowledge and inference logic to propose exercise plans for each patient case to healthcare professionals. It also supports the option to adjust a prescribed plan according to the patient's response with respect to goal achievement and changes in his/her physical-medical status.

The adoption of ontologies to model domain or application specific knowledge with ultimate goal the provision of decision support services in healthcare has been followed lately in several research efforts. For example, in the HEARTFAID project [5], an ontology has been developed incorporating medical knowledge and procedures for the treatment of heart failure patients, in accordance with the guidelines of the European Society of Cardiology. The Nuadu project dedicated to wellness has devised an ontology-based description for different aspects of daily life, such as activity, sleep, nutrition, and lifestyle [6]. A nutrition (food) ontology was developed in the PIPS project [7], in order to represent an abstract model of the different types of foods available for diabetic patients, together with their nutritional information, including the type and amount of nutrients, and the recommended daily intake.

In the following, the proposed framework is described. Section II highlights the overall methodology, while section III presents an instantiation of the proposed framework for cardiac rehabilitation, illustrating the virtue and the applicability of this work. Conclusions and future work directions are summarized in section IV.

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II. METHODOLOGY

A. Conceptual Framework

The purpose of the presented framework is supporting personalized exercise plan prescription. Since exercise treatment refers to a long-term procedure, in the scope of this work, an exercise plan may refer to one of the following three phases. The first phase is the initial phase and aims in assisting the patient to achieve a physical and medical status allowing him/her to follow the next stage. The latter is the improvement phase which is more intense and aims in achieving the desired goal e.g. HR regulation, VO_2max improvement, etc. Finally, after reaching the goal via the improvement phase, it is important to maintain this medical status, which is the aim of the maintenance phase.

Each of the above phases consists of several sessions, while each session is comprised of three parts. At the beginning, the patient warms up usually following an activity such as walking or cycling. Afterwards, the main activity takes place that is in general more intense. Finally, an activity such as stretching or walking is taking place in order to assist the patient to cool down.

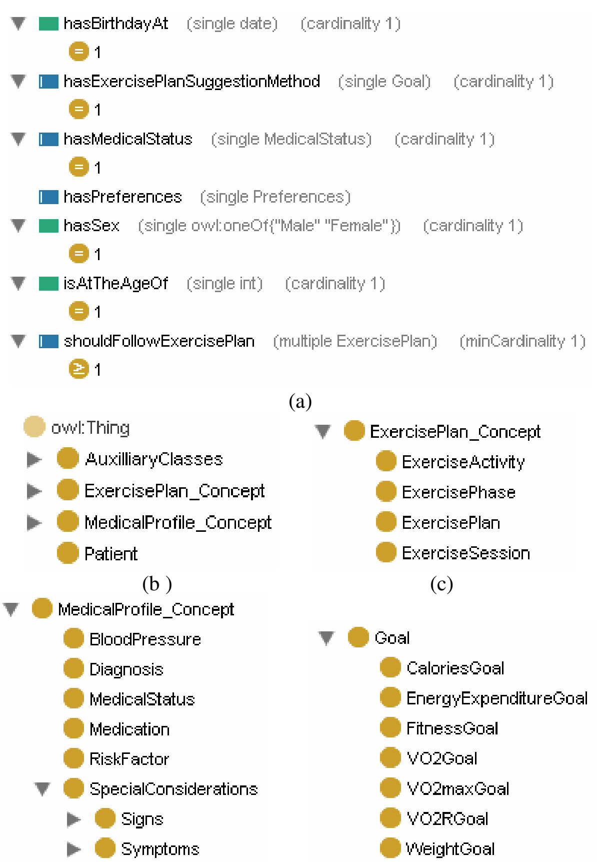

Fig. 1. (a) Main properties of the Patient class linked with the application discourse, i.e., exercise plan prescription. (b) Top-level hierarchy of the ontology and (c) major classes defining the Exercise Plan concept. (d) The MedicalProfile_Concept class encapsulating concepts that comprise the patient's medical profile related to personalized exercise prescription, and (e) the Goal class corresponding to the expected outcomes a patient shall have linked with the application of an exercise plan.

In order to suggest an exercise plan, each session has to be tailored according to the patient's profile. Patient's profile is comprised of the relevant medical status, for example possible diagnosis or medication treatment as also parameters such as age, gender, blood pressure, body mass index (BMI) and so on. Moreover, patient's profile includes personal preferences in terms of preferred activity and activity intensity.

In this regard, an ontology has been designed encapsulating the concepts related to exercise plan prescription based on the above features. The ontology encapsulates also semantic rules in order to associate the various concepts included in the domain knowledge, which in turn undertake the necessary logical process for suggesting personalized exercise plans given a patient instance. The exercise plan suggestion workflow is depicted in Fig. 2.

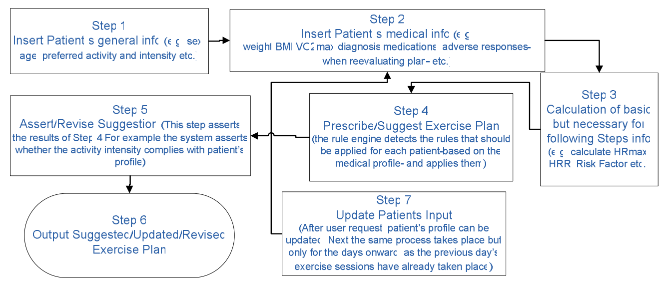

Fig. 2. Exercise Plan Suggestion Workflow.

B. Ontology Model

The proposed ontology is the core of the designed framework, encapsulating the medical knowledge as concerns the domain concepts related to exercise prescription and their relations. In the present section, the main classes of the ontology are illustrated. The ontology has been designed in Protégé (http://protege.stanford.edu/) and encoded in OWL (http://www.w3.org/TR/owl-ref/).

The major class defined is named *Patient*, which encloses all the necessary properties concerning a patient related to exercise plan prescription (Fig. 1(a)). Additionally, the ontology consists of three more major concepts as depicted in (Fig. 1(b)). In particular, the *Exercise Plan* concept describes the exercise plan structure (e.g. phases, sessions, activities) (Fig. 1(c)), and the *Medical Profile* concept contains all the necessary information for patient's medical status (Fig. 1(d)) and finally the *Auxiliary Classes* concept. The latter is comprised of classes that are not strictly a medical or exercise plan concept but are utilized in the plan suggestion process, e.g., the *TimeStamp* and *Today* classes are utilized as a calendar during calculations, while the class *Range* describes value ranges for different features like normal Blood Pressure and class *Goal* (Fig. 1(e)) describes the goal of the prescribed plan.

C. Semantic Rules for Exercise Plan Suggestions

In order to utilize the domain knowledge and subsequently suggest an adequate exercise plan, several semantic rules have been defined expressed in SWRL (Semantic Web Rule Language) language. These rules undertake the inference logic of the framework aiming to generate exercise plan suggestions according to each patient's profile and needs.

The rules are of different types referring to:

1) Initiation of an exercise plan by picking its parts that are indicated or not-contraindicated depending on the patient's medical status, treatment, goals, etc. For example, a relevant ruleset that has been defined consists of: a) *Rule-SuggestPlanPhases* that defines the instances of the plan's phases; b) *Rule-SuggestPhaseWeeksDuration* which suggests the duration for each of the phases defined by the previous rule in weeks; c) *Rule-SuggestPhaseSessions* that defines the relative sessions for each phase; d) *Rule-SuggestActivity* which defines three activities for each session (warm up, main and cool down) for each phase, e) *Rule-SuggestIntensityLevel* that suggests an intensity level for each activity, and f) *Rule-PrescribeActivityFrequencyDurationRepeatTimes* which defines the frequency (per week and per day) and the repetitions for each activity per phase.

2) Adaptation of an existing exercise plan based on the progress and the needs of a patient. In practice, the ruleset for suggesting the plan is again applied for the current day and onward (rule *Rule-CalculateCurrentPlanWeek* is employed to perform day tracking of the executed plan), taking also into account both the activities that have been followed and the reason that lead to plan modification, i.e. an altered patient profile. When adjusting the plan, additional information may be available for use, such as **hasAdverseResponce,** which is usually unknown during the initial suggestion.

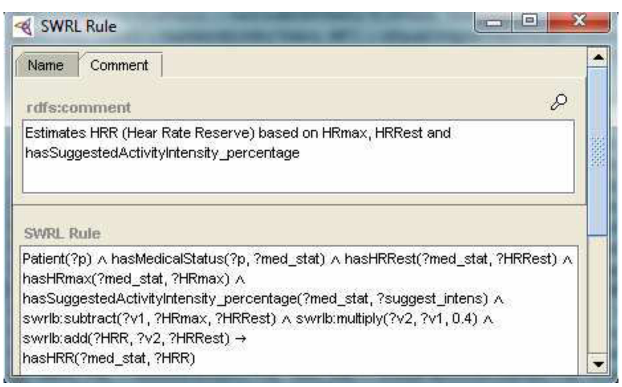

Fig. 3. Example rule in SWRL for the estimation of Heart Rate Reserve expressed.

3) Processing rules for the calculation of intermediate parameters such as BMI (body mass index) and heart rate at rest (HRR). Thus, example rules defined for applying intermediate calculations are: a) *Rule-CalculateBMI* that is used to calculate BMI based on patient's weight and height and b) *Rule-EstimateHRR* that is used to calculate Heart Rate Reserve (HRR) based on HRmax and HRRest. Figure 3 illustrates the latter expressed in SWRL.

TABLE I
PATIENT WITH CARDIAC TRANSPLANT (PROFILE & INFERRED DATA IN BOLD)

Property	Value
hasSex	male
isAtTheAgeOf	78
hasExercisePlanSuggestionMethod	
PrefersActivity	walking
PrefersIntensity	moderate
hasHRmax	142
hasHRRest	82
hasBMI	**24.2**
hasHRR	60
hasSuggestedActivityIntensity_percentage	**40%**
hasVO2max	
weights	70
hasHeight	170
hasDiastolicBP	90
hasSystolicBP	140
hasRiskFactor	**ModerateRiskFactor**
hasSuggestedActivityIntensityLevel	**Low**
followsMedicationTreatment	None
hasAdverseResponce	
hasDiagnosis	Cardiac Transplant
shouldFollowExercisePlan	**ExercisePlanCardiacTransplant**

The rules above are processed by Jess (http://www.jessrules.com/) using the Protégé SWRLTab plugin (http://protege.cim3.net/cgi-bin/wiki.pl?SWRLTab).

III. RESULTS

In this section, an example is illustrated concerning a 78 years old male with a cardiac transplant (profile presented in Table I), who is supposed to be prescribed a new exercise plan. After applying the ruleset, the patient's parameters are inferred as that is presented in Table I in bold. In particular, the *hasRiskFactor* property has been set from empty to **ModerateRiskFactor**, indicating that the patient has a severe problem and, consequently, different risk stratification should be followed, while the property *shouldFollowExercisePlan* has been also set with the instance of the suggested plan, i.e. **ExercisePlanCardiacTransplant**.

TABLE II
SUGGESTED EXERCISE PLAN (DETAILS SHOWN AT THE PHASES LEVEL)

Property	Value
startsAtDate	10 April 2011
isAtCurrentWeek	1
hasCurrentSession	ExerciseSession_Initial_Cardiac_Transplant
hasInitialExercisePhase	ExercisePhase_Initial_Cardiac_Transplant
hasImprovementExercisePhase	ExercisePhase_Improvement_Cardiac_Transplant
hasMaintenanceExercisePhase	ExercisePhase_Maintenance_Cardiac_Transplant

In more detail, the major parts of the proposed exercise plan are depicted in Tables II - III. In Table II, the suggested exercise plan, i.e. the instance retrieved from the ontology via the execution of rules described in subsection II.C, is illustrated in detail (as class properties and instance values), with the three major components corresponding to the three exercise phases. In this example, we focus on the initial phase. Table III presents details of the initial phase (value of property **hasInitialExercisePhase** in Table II), and specifically the properties and values of the instance “ExercisePhase_Initial_Cardiac_Transplant” of the class ExercisePhase. As it can be seen, its duration has been suggested to be 4 weeks. Cascading information concerning the sessions of this phase, and the relevant activities are also presented in Table III (MET: Metabolic Equivalent of Task).

TABLE III
INSTANCE OF THE INITIALLY PROPOSED EXERCISE PLAN FOR A CARDIAC TRANSPLANT PATIENT

ATTRIBUTES OF THE INITIAL PHASE OF THE PROPOSED EXERCISE PLAN

Property	Value
hasDurationInWeeks	4
hasExerciseSessions	Exercise_Initial_Cardiac_Transplant

SESSIONS OF THE PROPOSED EXERCISE PLAN

Property	Value
takesPlaceAtWeeks	1, 2, 3,4
hasWarmUpActivities	ExerciseActivity_WarmUp_Cardiac_Transplant
hasMainActivities	ExerciseActivity_Main_Cardiac_Transplant
hasCoolDownActivities	ExerciseActivity_CoolDown_Cardiac_Transplant

PROPOSED ACTIVITIES

Property	Warm Up Activity	Main Activity	Cool Down Activity
hasActivityDescription	Walking	Walking	Walking
repeatTimes	1	1	1
takesPlace	Indoor and Outdoor	Indoor and Outdoor	Indoor and Outdoor
demandsFunctionalCapacity	3 METs	3 METs	3 METs
hasDuration	15mins	15mins	10mins
hasFrequencyPerWeek	3	5	3
hasIntensityLevel	Low	Moderate	Low

IV. DISCUSSION

The present work constitutes an initial proposal for a semantically-enriched Knowledge Base concerning exercise plans for patients, aiming to formulate the basis for a framework that may support clinicians in exercise plan prescription via appropriate suggestions which are personalized to their patients. Under this perspective, population of the ontology is required with a larger number of exercise plans to explore the full virtue of the proposed approach. In addition, the embodied inference logic has to be validated in terms of medical relevance, while user acceptance of this framework has to be extensively evaluated by medical experts prior to its use in a real clinical setting.

While the proposed conceptual model, and respectively the ontology, constitutes an initial proposal that has been approved by medical experts in an early validation stage, a series of steps are foreseen for further enhancement. Although some relevant knowledge has been included, for example with respect to HRmax calculation, when Betablockers are taken, information concerning patient’s medication is a significant factor for exercise and could thus be more extensively elaborated. In addition, the disease model can be extended in order to include more detailed medical conditions that introduce constraints or lead to new options, e.g. exercise contraindications. In addition, field values which are now manually defined could be inferred by medical algorithms or more explicit parameters. For example, Duke Activity Status Index [8] can infer the functional capacity and therefore the patient’s physical status, while numerous algorithms exist for the calculation of cardiovascular risk based on clinical parameters. A challenge would be to model patient preferences in more detail.

Regarding the rules and the reasoning mechanism of the framework, an interesting future perspective would be to include a similarity measure among the exercise plans to further support optimal plan selection, especially in case of multiple plan suggestions. Finally, the temporal dimension of planning exercise programs in rehabilitation, a rather complex issue, has to be further elaborated.

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