# Ontological Modeling of Motivational Messages for Physical Activity Coaching

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## ABSTRACT

Smart coaching systems are named to play a central role in both prevention and intervention strategies for behavioral change. While relevant progresses have been made in terms of automatic and continuous monitoring of behavioral aspects, e.g. amount and variety of physical activity, coaching and feedback techniques are still in an infancy stage. Current smart coaching strategies are mostly based on handcrafted messages which hardly personalize to the needs, context and preferences of each user. In order to make these recommendations more realistic, engaging and effective more flexible and sophisticated strategies are needed. This paper presents an ontology-based approach to model personalizable motivational messages for promoting healthy physical activity. The proposed ontology not only models the message intention and its components, e.g. argument, feedback or followup, but also its content, i.e. action, place, time or object required to perform the recommended activity. Through this ontology the messages can also be categorized into multiple classes, e.g. sedentary, mild or vigorous activities, and retrieved based on the preferences, needs and context of the user. Additional information not explicitly present on the messages can be inferred from the ontology by applying reasoning techniques and used to enhance the message retrieval process.


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## CCS CONCEPTS

**•Theory of computation →Description logics; Automated reasoning; •Applied computing →Health care information systems; Health informatics;**

## KEYWORDS

Ontology, Motivational Messages, Smart Coaching

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## 1 BACKGROUND

Lifestyle risk factors are nowadays recognized as leading contributors to morbidity and mortality in most developed countries. As a matter of fact, the majority of prevalent chronic health conditions, including cancer, cardiovascular diseases, obstructive lung illnesses and diabetes, are strongly connected to lifestyle [19]. Unhealthy behaviors not only raise the probability of developing chronic conditions at earlier ages but also exacerbate other preexisting conditions, which can severely impact people's wellbeing, productivity and, more in general, the healthcare system and social cost. Thus, avoiding unwholesome habits and promoting healthy behaviors turns to be a current key priority for governments, organizations and societies.

Changing people's behavior towards healthier habits has been shown to be quite a challenging task [6]. Adopting a healthy lifestyle means changing engrained patterns of behavior, something notoriously difficult to achieve without the proper and continuous support [2]. Smart technologies can help enabling personalized, ubiquitous, seamless and more effective strategies to coach people on healthier and more responsible behaviors. Tools to provide smart coaching are rapidly emerging, and in some domains, e.g. physical activity, have fairly penetrated the market. However, it is fair to say that most of these coaching solutions mainly focus on quantifying and reporting some numbers, such as sleep hours or calorie counts, with arguable utility for promoting effective behavioral change the way they are normally communicated to people. There is then a clear need for more human-like mechanisms capable of reaching not only experts but also average users.

Motivational messages represent the principal, and perhaps more natural, means for translating behavioral findings into easy-to-follow and realizable actions. One important challenge lies on the generation of relevant messages tailored to the performance, needs and characteristics of each specific user [12]. Moreover, not only is personalizing important but also fostering the diversity of these messages to increase adherence and make the coaching system more realistic and trustworthy [13].

There are numerous examples of smart coaching systems using textual mechanisms for channeling recommendations to end users [4, 5]. Some recent works have even tried to exploit the crowd to source the most widely accepted motivational messages [8]. In all these cases, the textual messages have a somewhat static and predefined structure, thus becoming difficult to personalize. This work rather considers the use of advanced semantic models, namely ontologies, for coping with these limitations. Ontologies have been used in various works for the generation of personalized advisory messages. For example, in [9] the authors present an ontology-based method for the production of customized recommendations part of an eHealth service. The proposed ontology models the main components of the message and its structure, as well as the user including their general information, abilities, interests and preferences. Ontologies have been used in the physical activity domain to model multimodal contexts [17] but also used for the generation of dynamic feedback. In [20], the ontology is used to find the appropriate feedback using context information to prune irrelevant branches of the ontology. The ontology models the predefined feedback messages which are candidates to be presented to the user. The system adapts the message selection process using derived probabilities about user preferences for certain message types. A practical framework for automatic generation of real-time tailored messages in behavior change applications is proposed in [13]. The framework builds on an ontology of messages modeling mainly their intention and an ontology of representation modalities.

Despite there exist some solutions modeling motivational messages in an ontological way, most of these models only include information about the structure of the message or its intention. These ontologies do not model to any extent the actual content of the messages, which proves quite important for the automatic selection of the most suitable messages to be delivered by the smart coach. This paper presents an ontological approach to comprehensively model motivational messages used by smart coaches in the domain of physical activity. The messages are modeled in an ontology which describes the main characteristics of motivational messages including the message metadata such as its length, type or composition but also information about the message content, e.g. place or object required to perform the recommended action. Ontological querying is used to retrieve from the database the most adequate message depending on the user's status, preferences and context.

The use of ontologies to model motivational messages presents different benefits. Ontologies [16] are semantic models which enable the automatic interpretation of the information about the motivational messages. This is a key characteristic to procure interoperability among different virtual coaches which may access a database of motivational messages and need to interpret them. Furthermore, the semantics encoded into the ontology enable the inference of new knowledge. Thus, reasoning on the ontological messages allows the inference of new knowledge about the messages which was not explicitly referred into the message. The new inferred knowledge can be used to enhance the retrieval of the most adequate message during the ontological querying process. Moreover, the ontological representation of the motivational messages supports the automatic categorization of these messages using ontological reasoning. Motivational messages with similar characteristics will belong to the same class, which will support the selection of messages with similar characteristics in case there is no perfect matching solution. The hierarchical structure of ontologies, with subclasses inheriting the properties from their ascendant classes, enables the possibility to retrieve a more generic class of messages if no matching result. Last but not least, ontologies have many other benefits which make them a suitable solution to model the motivational messages used by the smart coaches. For example, they surpass non-semantic models in terms of flexibility, extensibility, generality, expressiveness and decoupling of the knowledge from the code.

Summarizing, the two main contributions presented in this paper are an ontology of motivational messages for coaching in physical activity, and a method to automatically categorize the motivational messages according to the defined ontology and to retrieve the most adequate message. The rest of the paper is organized as follows. Section 2 presents the ontology of motivational messages. Section 3 presents the query method used by the virtual coaches to retrieve motivational messages. Finally, Section 4 presents the main conclusions and future steps.

## 2 ONTOLOGY OF MOTIVATIONAL MESSAGES

The ontology of motivational messages is an OWL 2 ontology [18] defining the messages used by smart coaches for translating behavioral findings into easy-to-follow and realizable actions. This ontology models the message intention and the message components (Section 2.1), the message content (Section 2.2) and several classes to categorize the motivational messages (Section 2.3). Figure 1 shows the graphical representation of the ontology.

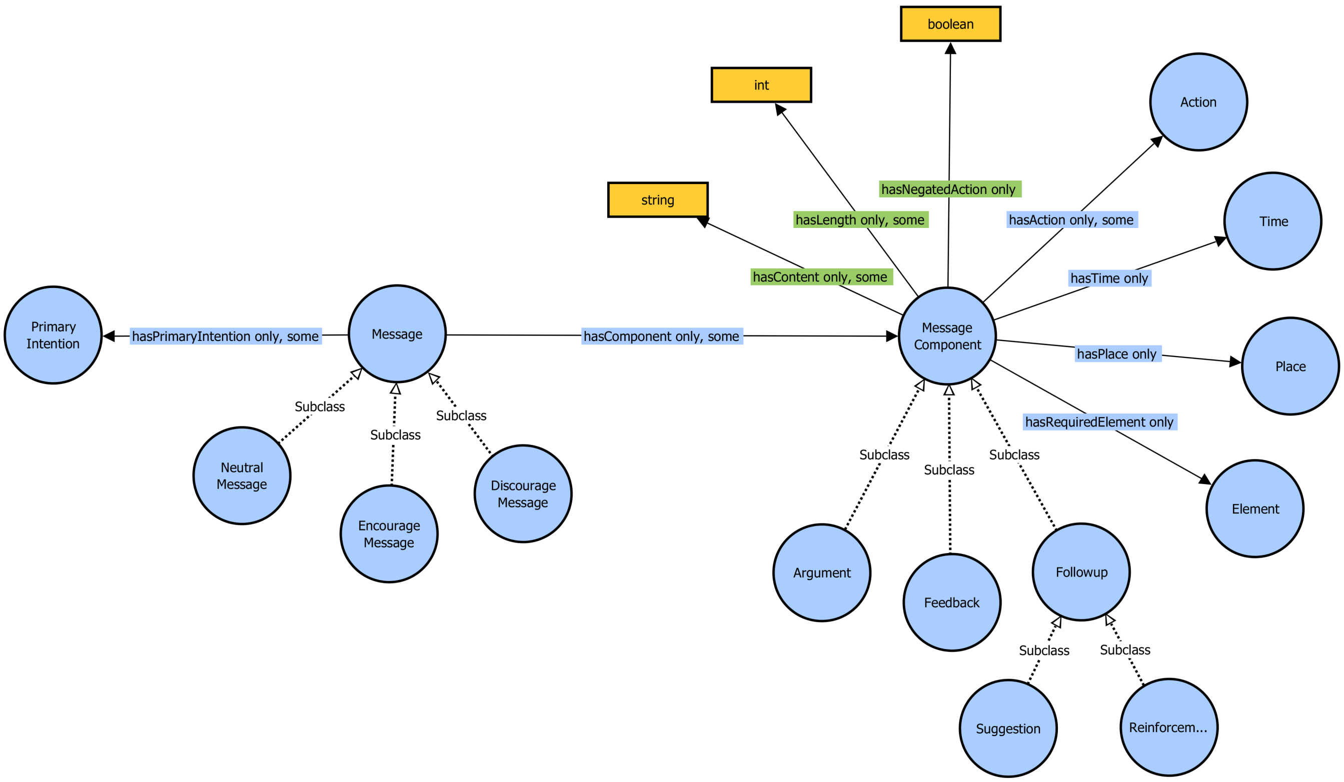



**Figure 1: Graphical representation of the main classes of the ontology and their relations. The keyword "some" is used to denote the existential restrictions (∃) and the keyword "only" the universal restrictions (∀).**

## 2.1 Modeling the Types and Components of Motivational Messages

The main class of the ontology of motivational messages is the class *Message*. The message has a primary intention modeled via the class *PrimaryIntention* and some components modeled via the class *MessageComponent*. Thus, the message can be described in the ontology as shown in (1).

$$\begin{aligned} Message \subseteq\ & \exists hasPrimaryIntention.PrimaryIntention \\ & \cap \forall hasPrimaryIntention.PrimaryIntention \\ & \cap \exists hasComponent.MessageComponent \\ & \cap \forall hasComponent.MessageComponent \end{aligned} \tag{1}$$

Depending on their primary intentions, the messages can be classified on three different classes of messages: *DiscourageMessage*, *EncourageMessage* and *NeutralMessage*. A message can have different components which are modeled via the subclasses of the class *MessageComponent*. Specifically, the different message components are *Argument*, *Feedback*, and *Followup*, and the subclasses of the latest: *Reinforcement* and *Suggestion*. Furthermore, for each type of messages, i.e., the subclasses of the class *Message*, it is stated the relation to possible components, i.e., to the subclasses the class *MessageComponent* which compose it. For example, both an encourage message and a discourage message must has a component of type suggestion, as presented in (2) and (3).

$$EncourageMessage \subseteq Message \cap \exists hasComponent.Suggestion \tag{2}$$

$$DiscourageMessage \subseteq Message \cap \exists hasComponent.Suggestion \tag{3}$$

## 2.2 Modeling the Content of Motivational Messages

The class *MessageComponent* is described as (4), where $xsd : string$ and $xsd : int$ are datatypes of the W3C XML Schema Definition Language (XSD) [14] which respectively represent the content of the message in plain text and its length.

$$\begin{aligned} MessageComponent \subseteq\ & \forall hasContent.xsd : string \\ & \cap \exists hasContent.xsd : string \\ & \cap \forall hasLength.xsd : int \\ & \cap \exists hasLength.xsd : int \end{aligned} \tag{4}$$

The description of the message component shown in (4) only models the message content as a sentence in the plain text; however, the semantic representation needs to model the content in a more meaningful way. This means including information about the action described in the motivational message, and the time and location in which such an action takes place. Thus, the class *MessageComponent* is further described as (5), where *Action* is the class modeling the action stated in the motivational message, *Time* is the class modeling the time of the day in which the action takes place, *Place* is the class modeling the location where the action takes place, *Element* is the class modeling the elements, such as objects, required to perform the action, and the data property *hasNegatedAction* is used to state whether the action is negated in the message. One should notice that only the relationship to the class *Action* is mandatory, since there is a universal and an existential restriction on the property *hasAction*. However, the rest of the relationships might exist or not, but if they exist they need to be to members of the respective classes.

$$\begin{aligned} MessageComponent \subseteq\ & \forall hasAction.Action \\ & \cap \exists hasAction.Action \\ & \cap \forall hasNegatedAction.xsd : boolean \\ & \cap \forall hasTime.Time \\ & \cap \forall hasPlace.Place \\ & \cap \forall hasRequiredElement.Element \end{aligned} \tag{5}$$

The class *Action* models the actions stated in the motivational messages. Commonplace physical activities, happening during the daily living, related to unhealthy behaviors or to fitness and sport practices, are modeled in this work. Specifically, the ontology models the physical activities described in the 2011 Compendium of Physical Activities [3]. This compendium, designed to enable the comparison of self-report physical activities across studies, contains activities such as home activities, inactivity, self care, sports, and walking among others. In order to model the different categories of physical activities in the compendium, different subclasses of the class *Action* are asserted (see (6)).

$$\begin{aligned} & Bicycling \subseteq Action \\ & ConditioningExercise \subseteq Action \\ & Dancing \subseteq Action \\ & FishingAndHunting \subseteq Action \\ & HomeActivities \subseteq Action \\ & HomeRepair \subseteq Action \\ & Inactivity \subseteq Action \\ & LawnAndGarden \subseteq Action \\ & MusicPlaying \subseteq Action \\ & Occupation \subseteq Action \\ & Running \subseteq Action \\ & SelfCare \subseteq Action \\ & SexualActivity \subseteq Action \\ & Sports \subseteq Action \\ & Transportation \subseteq Action \\ & Walking \subseteq Action \\ & WaterActivities \subseteq Action \\ & WinterActivities \subseteq Action \\ & ReligiousActivities \subseteq Action \\ & VolunteerActivities \subseteq Action \end{aligned} \tag{6}$$

The subclasses of *Action* are further subclassed to model concepts such as *ClimbingHill*, *DescendingStair* or *Hiking* which are subclasses of *Walking*, or *Eating* which is a subclass of *SelfCare* (see (7)).

$$\begin{aligned} & ClimbingHill \subseteq Walking \\ & DescendingStair \subseteq Walking \\ & Hiking \subseteq Walking \\ & Eating \subseteq SelfCare \end{aligned} \tag{7}$$

Finally, individuals of the subclasses of *Action* are created in order to represent the actual physical activities. For example, *bicycling* is an individual of the class *Bicycling*, *walking* and *strolling* are individuals of the class *Walking*, *climbing_hill* is an individual of the class *ClimbingHill*, *dusting* and *washing_dishes* are individuals of the class *HomeActivities*, and *eating*, *having_breakfast*, *having_lunch* and *having_dinner* are individuals of the class *Eating* (see (8)).

$$\begin{aligned} & Bicycling(bicycling) \\ & Walking(walking) \\ & Walking(strolling) \\ & ClimbingHill(climbing\_hill) \\ & Eating(eating) \\ & Eating(having\_breakfast) \\ & Eating(having\_lunch) \\ & Eating(having\_dinner) \\ & HomeActivities(dusting) \\ & HomeActivities(washing\_dishes) \end{aligned} \tag{8}$$

The 2011 Compendium of Physical Activities provides a value for the intensity of each activity. In the ontology of motivational messages, the intensity of an action is modeled through the existential restriction and the universal restriction on the data property *hasIntensity* which define the class *Action* (see (9)). The value of the intensity is asserted for each member of the class *Action*; for example, the individual *walking* has an intensity of 3.5 and the individual *eating* an intensity of 1.5 (see (10)).

$$Action \subseteq \forall hasIntensity.xsd : double \cap \exists hasIntensity.xsd : double \tag{9}$$

$$\begin{aligned} & hasIntensity(walking, \text{“3.5”}double) \\ & hasIntensity(eating, \text{“1.5”}double) \\ & hasIntensity(washing\_dishes, \text{“2.5”}double) \end{aligned} \tag{10}$$

The class *Time* models the discrete parts of the day: morning, afternoon, evening and night. Thus, its definition is shown in (11) where the individuals *morning*, *afternoon*, *evening* and *night* are members of the class *Time* (see (12)).

$$Time \equiv \{morning, afternoon, evening, night\} \tag{11}$$

$$\begin{aligned} & Time(morning) \\ & Time(afternoon) \\ & Time(evening) \\ & Time(night) \end{aligned} \tag{12}$$

The members of the class $Time$ can be linked to individuals of the class *Action* in order to model the time in which an action takes place. For example, the action having breakfast will always take place in the morning and therefore the individual $having\_breakfast$ is related via the object property $hasTime$ to the individual *morning*. Similarly, other definitions including time could be asserted in the ontology (see (13)).

$$\begin{aligned} &hasTime(having\_breakfast, morning)\\ &hasTime(having\_lunch, afternoon)\\ &hasTime(having\_dinner, evening) \end{aligned} \tag{13}$$

The class *Place* models the places where people spend their daily life and where their actions take place. The places are organized hierarchically according to different categories, following a structure similar to the one provided by the DBpedia ontology [11]. The subclasses of the class *Place*, which describe the main locations modeling where the previously presented physical activities occur, are presented in (14).

$$\begin{aligned} &ArchitecturalStructure \subseteq Place\\ &Building \subseteq ArchitecturalStructure\\ &Dwelling \subseteq Building\\ &Factory \subseteq Building\\ &Hospital \subseteq Building\\ &Hotel \subseteq Building\\ &Restaurant \subseteq Building\\ &ShoppingMall \subseteq Building\\ &SportFacility \subseteq ArchitecturalStructure\\ &Stadium \subseteq SportFacility\\ &SkiArea \subseteq SportFacility\\ &NaturalPlace \subseteq Place\\ &Beach \subseteq NaturalPlace\\ &Cave \subseteq NaturalPlace\\ &Mountain \subseteq NaturalPlace\\ &Park \subseteq Place\\ &Garden \subseteq Place \end{aligned} \tag{14}$$

The actual places are members of the subclasses of $Place$. For example, the individual *house* is a member of the class $Dwelling$, and the individuals *hill* and $mountain$ are members of the class $Mountain$ (see (15)).

$$\begin{aligned} &Dwelling(house)\\ &Mountain(hill)\\ &Mountain(mountain) \end{aligned} \tag{15}$$

The concepts modeled via the class *Place* can be linked to the class *Action* in order to establish the relationship between the two domains. This means that some physical activities will always take place on a given location and this link should be modeled in the ontology. For example, the action climbing a hill will always take place on a hill and therefore the individual *climbing_hill* is related via the object property *hasPlace* to the individual *hill*. Similarly, all the household activities modeled as individuals of the class *HomeActivities* will take place in a house. Thus, the individuals *dusting* and *washing_dishes* are linked via the object property *hasPlace* to the individual *house* (see (16)).

$$\begin{aligned} &hasPlace(climbing\_hill, hill)\\ &hasPlace(dusting, house)\\ &hasPlace(washing\_dishes, house) \end{aligned} \tag{16}$$

Furthermore, the members of the class *Place* can represent either indoor and outdoor locations. Thus, two subclasses of the class *Location* are defined (see (17)) and all the subclasses of the class *Place* presented in (14) are either asserted to be a subclass of the class *IndoorLocation* or the class *OutdoorLocation* (see (18)).

$$\begin{aligned} &IndoorLocation \subseteq Location\\ &OutdoorLocation \subseteq Location \end{aligned} \tag{17}$$

$$\begin{aligned} &Building \subseteq IndoorLocation\\ &Stadium \subseteq OutdoorLocation\\ &SkiArea \subseteq OutdoorLocation\\ &Beach \subseteq OutdoorLocation\\ &Cave \subseteq IndoorLocation\\ &Mountain \subseteq OutdoorLocation\\ &Park \subseteq OutdoorLocation\\ &Garden \subseteq OutdoorLocation \end{aligned} \tag{18}$$

Finally, the class *Element* models the elements which might be required to perform an action. The class *Element* is subclassed into *Animal*, *Device* and $Transport$ (see (19)).

$$\begin{aligned} &Animal \subseteq Element\\ &Device \subseteq Element\\ &Transport \subseteq Element \end{aligned} \tag{19}$$

The actual elements involved in the actions are members of the subclasses of $Element$. For example, the individual *dog* is a member of the class *Animal*, and the individuals *bike* and *car* are members of the class $Transport$ (see (20)).

$$\begin{aligned} &Animal(dog)\\ &Transport(bike)\\ &Transport(car) \end{aligned} \tag{20}$$

Some of the concepts modeled in the class *Element* can have a direct relationship to the concepts represented by the subclasses of *Action* since the action requires from a certain element to be realized. For example, the action of bicycling always requires the use of a bike. In order to model this fact, the link between the individuals *bicycling* and *bike* is established via the property *hasRequiredElement* (see (21)).

$$hasRequiredElement(bicycling, bike) \tag{21}$$

### 2.3 Categorization of the Motivational Messages

Motivational messages can be categorized according to several definitions. Categorizing the messages is useful to identify similar messages, i.e., messages which have some shared characteristics and thus they belong to the same class. In order to support the automatic categorization of motivational messages, several classes have been defined in the ontology. The specification for each of these classes, which are direct subclasses of *MessageComponent*, is described in the following.

The first option would by categorizing the messages depending on the type of action, for example, if the physical activity is sedentary, it is a mild activity or a vigorous one. This categorization is done according to the values of the intensities of the physical activities defined in the 2011 Compendium of Physical Activities and modeled in the class *Action*. Therefore, the class *MildActivityRelatedMessageComponent* is defined as (22), where the data property *hasIntensity* of all the individuals belonging to this class takes a value among 2 and 5. The classes *SedentaryActivityRelatedMessageComponent* and *VigorousActivityRelatedMessageComponent* are defined similarly but just adjusting the thresholds in which the intensity of the activity lies.

$$\begin{aligned} &MildActivityRelatedMessageComponent \\ &\quad \equiv MessageComponent \\ &\quad\quad \sqcap \exists hasAction.(Action \sqcap \\ &\quad\quad (\exists hasIntensity.double[>= \text{“2”}double) \sqcap \\ &\quad\quad (\exists hasIntensity.double[< \text{“5”}double])) \end{aligned} \tag{22}$$

The categorization according to the intensity of the actions is done depending on the values of the property *hasIntensity* of the class *Action* and only the information provided in the definition of this class is taken into consideration. Thus, it is not needed that information of the intensity of the activity is present in the text message itself, since this information will be obtained from the ontology. For example, the message component "You have not walked enough today", which would be modeled in the ontology as (23), does not contain information about the intensity of the action walking. However, the knowledge modeled in the ontology for the definition of the individual *walking* (shown in (10)) allows the categorization of the message component as belonging to the class *MildActivityRelatedMessageComponent*.

$$\begin{aligned} &MessageComponent(mc\_01) \\ &hasAction(mc\_01, walking) \\ &hasNegatedAction(mc\_01, true) \end{aligned} \tag{23}$$

Another option would be the categorization of the messages depending on the time. Some messages might contain in the plain text some information about the time in which the action should take place. This information would be directly mapped to the corresponding member of the class *Time* and could be used to categorize the message depending on the value this class takes. For example, in the message "Why don't you go for a walk early in the morning?", the word morning in the text of the message is mapped in the ontology to the individual *morning* which is the object of the property *hasTime* for the individual *mc_02*. Thus, the message component representing this sentence looks like (24). In some other cases the time is not explicitly stated in the message but it can be derived from the content of the message itself, for example if the action described in the message usually takes place at a given time. Let us consider the message "It is important that you have breakfast to replenish your supply of glucose". In this message the word morning does not appear explicitly; however, it could be derived from the fact that having breakfast is an action that normally takes place in the morning. In the ontology this message would be modeled as (25), i.e, only asserting the value for the property *hasAction* but not the value of the property *hasTime*. However, one would expect that the value of the property *hasTime* would be automatically inferred thanks to the ontological statement which links the individuals *having_breakfast* and *morning* as defined in (13); thus, generating the knowledge shown in (26).

$$\begin{aligned} &MessageComponent(mc\_02) \\ &hasAction(mc\_02, walking) \\ &hasTime(mc\_02, morning) \end{aligned} \tag{24}$$

$$\begin{aligned} &MessageComponent(mc\_03) \\ &hasAction(mc\_03, having\_breakfast) \end{aligned} \tag{25}$$

$$hasTime(mc\_03, morning) \tag{26}$$

According to this discussion, it can be stated that a message component referring to the concept morning is defined as a message component which has the word morning in the text of the message or as a message component referring to an action that normally takes place in the morning. Therefore, the class *MorningRelatedMessageComponent* is defined as (27) for the case in which there is an explicit reference to morning, and as (28) for the case in which the activity usually takes place in the morning but there is no explicit reference to it in the message. Similarly, the classes *AfternoonRelatedMessageComponent*, *EveningRelatedMessageComponent* and *NightRelatedMessageComponent* are defined to categorize the messages describing activities taking place in the different parts of the day. Both message components presented in (24) and (25) would be categorized as belonging to the class *MorningRelatedMessageComponent* since they respectively comply with the definitions (27) and (28).

$$\begin{aligned} &MorningRelatedMessageComponent \\ &\quad \equiv MessageComponent \sqcap \exists hasTime.morning \end{aligned} \tag{27}$$

$$\begin{aligned} &MorningRelatedMessageComponent \\ &\quad \equiv MessageComponent \\ &\quad\quad \sqcap \exists hasAction.(Action \sqcap \exists hasTime.morning) \end{aligned} \tag{28}$$

A third option for the categorization of the messages would be taking into consideration the location where the action takes place, for example, if the action takes place outdoors or indoors. The explicit information whether the location is outdoor or indoor does not need to appear in the message itself and can be derived from the place where the action is performed thanks to the modeling of the classes *IndoorLocation* and *OutdoorLocation* in the ontology. Therefore, if the message contains information about a place, this will be directly mapped to the corresponding member of the class *Place*, which will be automatically classified as belonging to one of the subclasses of *Location*. For example, in the message "What about going for a walk in the park?", the word park is mapped into the individual *park* of the ontology and asserted to be the object of the property *hasLocation* for the individual *mc*_04. Thus, this sentence is represented by the message component shown in (29), where *park* would be inferred to belong to the class *OutdoorLocation*. In some other cases, not even the place is explicitly stated in the message, for example if the action described in the message usually takes place in a given location. Let us consider the message "You have been too inactive, why don't you wash the dishes?". In this message there is no mention at all to a location; however, it could be derived from the fact that washing the dishes is a home activity, that it will takes place in the house. In the ontology this message would be modeled as (30), i.e, only asserting the value for the property *hasAction* but not the value of the property *hasPlace*. However, thanks to the ontological statement linking the individuals *washing_dishes* and *house* via the property *hasPlace* as defined in (16), it could be derived that the action will take place in a house, and thus in an indoor location.

$$\begin{aligned} &MessageComponent(mc\_04)\\ &hasAction(mc\_04, walking)\\ &hasPlace(mc\_04, park) \end{aligned} \tag{29}$$

$$\begin{aligned} &MessageComponent(mc\_05)\\ &hasAction(mc\_05, washing\_dishes) \end{aligned} \tag{30}$$

As a conclusion of this discussion, a message component referring to an outdoor location is defined as a message component which has in the text information about a place belonging to an outdoor location or as a message component which referring to an action that normally takes place in an outdoor location. Therefore, the class *OutdoorLocationRelatedMessageComponent* is defined as (31) for the case in which there is an explicit reference to a place which is an outdoor location and as (32) for the case in which the activity usually takes place in an outdoor location but there is no explicit reference to it in the message. Similarly, the class *IndoorLocationRelatedMessageComponent* is defined to categorize the messages describing activities taking place on an indoor location. The message component presented in (29) would be categorized as belonging to the class *OutdoorLocationRelatedMessageComponent*, whereas the message components presented in (29) as the class *IndoorLocationRelatedMessageComponent*.

$$\begin{aligned} &OutdoorLocationRelatedMessageComponent\\ &\quad \equiv MessageComponent \sqcap \exists hasPlace.OutdoorLocation \end{aligned} \tag{31}$$

$$\begin{aligned} &OutdoorLocationRelatedMessageComponent\\ &\quad \equiv MessageComponent\\ &\qquad \sqcap \exists hasAction.(Action \sqcap \exists hasPlace.OutdoorLocation) \end{aligned} \tag{32}$$

The ontology has been created using Protégé [1], an open-source ontology editor, and reasoning on the available knowledge has been performed using Pellet [15], an open source OWL 2 DL reasoner. The ontology has been modeled in a way that all the knowledge is directly inferred from the description logic without the need of adding extra rules. Figure 2 shows the ontological modeling in Protégé of the previously presented messages, including the asserted axioms and the ones inferred using reasoning, e.g., the inferred types representing the classes into which the message component has been categorized.

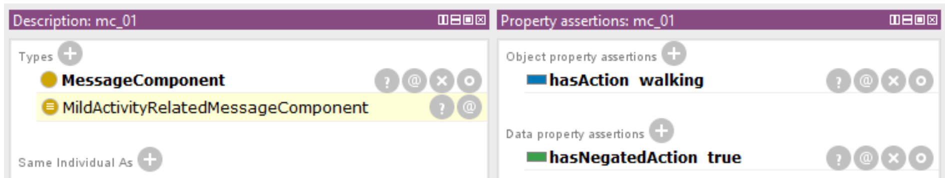
## 3 RETRIEVAL OF PERSONALIZED MOTIVATIONAL MESSAGES

The messages represented in the ontology will be used by the virtual coaches for physical activity in order to transmit to the users the recommendations and findings about the human behavior analysis. Thus, virtual coaches will need to access the ontological motivational messages stored in the knowledge base. Not only the asserted knowledge will be available to the physical activity coaches but also the inferred knowledge obtained through reasoning will be used to determine the most suitable message.

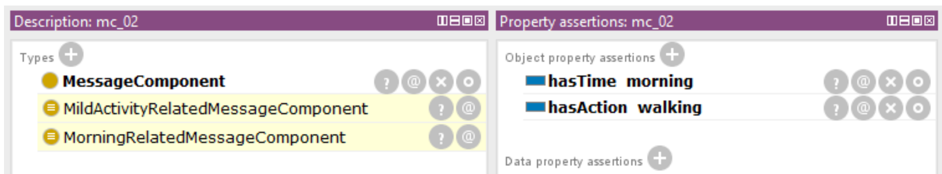
In order to facilitate the development of virtual coaches, an easy method to retrieve motivational messages from the knowledge base is here provided. This method is based on ontological querying, specifically SPARQL [10], a query language for RDF[7], is utilized in the retrieval method because of its fully potential to query OWL 2 data. Several SPARQL queries are provided as an example and they need to be combined and particularized in order to adapt to the specific coach necessities. This means that virtual coaches will use one or another SPARQL depending on their necessities. However, the templates are already available making their task quite simple.

Let us consider that in the most simple case the coach would like to retrieve all the motivational messages making reference to a given action, e.g., walking. The coach has detected that the person has had a sedentary behavior and wants to recommend that the user goes for a walk. In this case the coach would pose the SPARQL presented in Listing 1 and would obtain as result the message components *mc*_01, *mc*_02 and *mc*_04 (shown in Figure 2). In case the coach requires the retrieval of other actions, the coach will use a SPARQL query following the same structure but substituting the string "walking" by the name of the specific instance of the class *Action* representing the desired action.

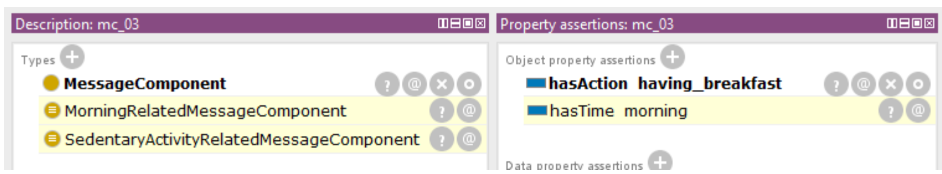
In some cases the virtual coach would like to obtain a broader scope of results. For example, if the coach is aware that the user likes the activity walking because it is stated in the user profile or user preferences, the coach might consider that other actions belonging to the same type of action, such as strolling, would be also a good recommendation. Therefore, the coach has the possibility to retrieve all the messages making reference to a specific type of action, e.g., all the actions modeled via the class *Walking*. This more generic SPARQL query is presented in Listing 2 and would produce



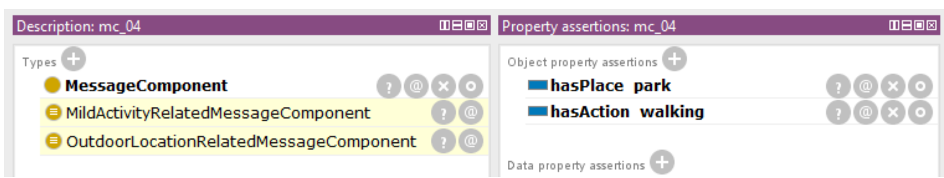

(a)



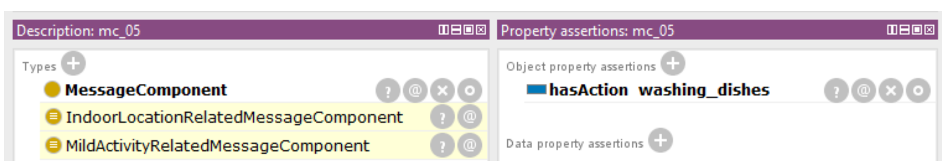

(b)




(c)




(d)




(e)

**Figure 2: Ontological modeling of the presented messages in Protégé, including the asserted axioms (in bold) and the inferred ones (highlighted in orange). The inferred types represent the classes into which the message component has been categorized.**

```
SELECT ?m ?mc
WHERE {
 ?m hasComponent ?mc .
 ?mc rdf:type MessageComponent ;
     hasAction walking }
```

**Listing 1: SPARQL query to retrieve the message components making reference to the action walking.**

as result all the messages related to walking but also the ones involving strolling or climbing a hill. For the messages described in Figure 2 and stored in the knowledge base, this SPARQL query will return the same results than the SPARQL shown in Listing 1, i.e., *mc*_01, *mc*_02 and *mc*_04.

Another option for a coach would be retrieving all the motivational messages for which the action belongs to a given category according to its intensity. This is useful for example, if the message has to be delivered to an elder, and the virtual coach would like to adjust the recommended actions to only mild activities. Thus, Listing 3 presents the SPARQL query to retrieve all the message components referring to an action categorized into the class *MildActivityRelatedMessageComponent*. This query will produce as result the message components *mc*_01, *mc*_02, *mc*_04 and *mc*_05 (shown in Figure 2).

Not only the actions are relevant for the selection of motivational messages but the coach might require a message making reference to a specific time. The coach might have determined that the best

```
SELECT ?m ?mc
WHERE {
 ?m hasComponent ?mc .
 ?mc rdf:type MessageComponent ;
     hasAction ?act .
 ?act rdf:type Walking }
```

**Listing 2: SPARQL query to retrieve the message components making reference to an action of the type walking such as walking or strolling.**

```
SELECT ?m ?mc
WHERE {
 ?m hasComponent ?mc .
 ?mc rdf:type MildActivityRelatedMessageComponent }
```

**Listing 3: SPARQL query to retrieve the message components belonging to the category of mild physical activities.**

```
SELECT ?m ?mc
WHERE {
 ?m hasComponent ?mc .
 ?mc rdf:type MorningRelatedMessageComponent }
```

**Listing 4: SPARQL query to retrieve the message components in which the action takes place in the morning.**

```
SELECT ?m ?mc
WHERE {
 ?m hasComponent ?mc .
 ?mc rdf:type MildActivityRelatedMessageComponent ;
     rdf:type MorningRelatedMessageComponent }
```

**Listing 5: SPARQL query to retrieve the message components belonging to the category of mild activities and taking place in the morning.**

moment to perform the action is in the morning; thus, it would like to retrieve from the knowledge base all the motivational messages related to the morning. Therefore, the virtual coach will use the SPARQL query presented in Listing 4 and will obtain as results the message components *mc*_02 and *mc*_03 (see Figure 2).

In fact the previously presented SPARQL queries could be easily combined in order to obtain more precise results. For example, if the virtual coach would like to retrieve all the motivational messages belonging to the category of mild activities and which take place in the morning, it would use the query presented Listing 5, that combines the queries in Listing 3 and Listing 4. Similarly, the SPARQL presented in Listing 6 combines the queries in Listing 1 and Listing 4 and it is useful for the coach to retrieve the message components making reference to the specific action of walking in the morning. Both the queries presented in Listing 5 and in Listing 6 produce as result the message component *mc*_02 (shown in Figure 2).

The virtual coach could also determine that the physical activity to be performed should take place either in an outdoor location or in an indoor one. These could be due to the fact that the coach has detected that the user has spent too much time at home and it would like to recommend an outdoor activity. However, if the coach is aware that at the moment it is raining, it might want to recommend to the user an indoor activity. The SPARQL query to

```
SELECT ?m ?mc
WHERE {
 ?m hasComponent ?mc .
 ?mc rdf:type MessageComponent ;
     rdf:type MorningRelatedMessageComponent ;
     hasAction walking }
```

**Listing 6: SPARQL query to retrieve the message components making reference to the action walking in the morning.**

```
SELECT ?m ?mc
WHERE {
 ?m hasComponent ?mc .
 ?mc rdf:type OutdoorLocationRelatedMessageComponent }
```

**Listing 7: SPARQL query to retrieve the message components categorized as being related to an action taking place in an outdoor location.**

```
SELECT ?m ?mc
WHERE {
 ?m hasComponent ?mc .
 ?mc rdf:type MessageComponent .
 { ?mc hasPlace house }
 UNION
 { ?mc hasAction ?act .
   ?act hasPlace house }}
```

**Listing 8: SPARQL query to retrieve the message components for which the action takes place in the house.**

```
SELECT ?m ?mc
WHERE {
 ?m hasComponent ?mc .
 ?mc rdf:type MessageComponent .
 { ?mc hasPlace ?p .
   ?p rdf:type Dwelling }
 UNION
 { ?mc hasAction ?act .
   ?act hasPlace ?p .
   ?p rdf:type Dwelling }}
```

**Listing 9: SPARQL query to retrieve the message components referring to actions occurring in any place of type dwelling.**

be used in these situations and which retrieves the motivational messages categorized as being related to an action taking place in an outdoor location is shown in Listing 7 and produces as result the message component *mc*_04 (shown in Figure 2).

Another option for the coach is retrieving the messages referring to any action taking place in an specific location, e.g., at home. Thus, the SPARQL query presented in Listing 8 can be used by the coach to retrieve the motivational messages for which the action takes place in the house. Similarly, the virtual coach might require all the messages referring to actions taking place in an specific type of location, e.g., a dwelling. In this case, the coach would use the SPARQL query presented in Listing 9 to retrieve any action located in place modeled via the class *Dwelling* and not only the places modeled via the individual *house* like in Listing 8. In fact, for the knowledge base with the message presented in Figure 2, both the queries presented in Listing 8 and in Listing 9 produce as result the message component *mc*_05.

```
SELECT ?m ?mc
WHERE {
 ?m hasComponent ?mc .
 ?mc rdf:type MessageComponent .
 { ?mc hasElement dog }
 UNION
 { ?mc hasAction ?act .
   ?act hasElement dog }}
```

**Listing 10: SPARQL query to retrieve the message components in which the action requires a dog to be performed.**

Finally, the virtual coach could also search the knowledge base of motivational messages depending on the elements required to perform an action. For example, if the user does not have a bike, the coach should not recommend any activity requiring a bike to be performed. Similarly, if the user has a dog, the coach could recommend any message related to the concept of dog, such as the action "walking the dog". Therefore, the coach will use the SPARQL query presented in Listing 10 to retrieve any message component in which the action requires a dog to be performed.

## 4 CONCLUSIONS

This paper has presented a new ontology for modeling motivational messages for coaching in physical activity. The proposed ontology not only models the message intention and its components, e.g. argument, feedback or followup, but also its content, i.e. action, place, time or object required to perform the recommended activity. The paper has also contributed with an automatic categorization of the motivational messages according to the defined ontology. Through ontological reasoning, the messages can be categorized into multiple aspects, e.g. referring to sedentary, mild or vigorous activities; or to indoor or outdoor locations; or to actions taking place in the different parts of the day. Finally, a query method for the virtual coach to retrieve the most adequate messages has been presented in this paper. The categorization of the messages, their semantic modeling and the ontological queries enable the coach to retrieve them based on the preferences, needs and context of the user.

The proposed ontology as well as the categorization and retrieval methods have been designed for coaching in the domain of physical activity. However, they could be easily extended to be applied to any other domain such as cognitive functioning, mental health or social interaction. Thus, future work will include the extension of the ontology to cover many other concepts in the physical activity domain but also to expand to new domains. Another interesting future research area would be automatizing the knowledge acquisition phase, i.e., the population of the text messages into the knowledge base. This would imply investigating on the provision of some methods to automatically map plain text messages into their semantic ontological representation, e.g., using techniques of natural language processing.

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## REFERENCES


[1] 2016. Protégé. Available online: http://protege.stanford.edu/ (Accessed: 2017-03-17). (2016).

[2] Frances E Aboud and Daisy R Singla. 2012. Challenges to changing health behaviours in developing countries: a critical overview. *Social science & medicine* 75, 4 (2012), 589–594.

[3] Barbara E. Ainsworth, William L. Haskell, Stephen D. Herrmann, Nathanael Meckes, David R. Bassett, Catrine Tudor-Locke, Jennifer L. Greer, Jesse Vezina, Melicia C. Whitt-Glover, and Arthur S. Leon. 2011. 2011 compendium of physical activities: A second update of codes and MET values. *Medicine and Science in Sports and Exercise* 43, 8 (8 2011), 1575–1581. DOI: http://dx.doi.org/10.1249/MSS.0b013e31821ece12

[4] Oresti Banos, Muhammad Amin, Wahajat Khan, Taqdir Ali, Muhammad Afzal, Byeong Kang, and Sungyoung Lee. 2015. Mining Minds: an innovative framework for personalized health and wellness support. *EAI Endorsed Transactions on Pervasive Health and Technology* 15, 2 (8 2015). DOI: http://dx.doi.org/10.4108/icst.pervasivehealth.2015.259083

[5] Oresti Banos, Muhammad Bilal Amin, Wajahat Ali Khan, Muhammad Afzal, Maqbool Hussain, Byeong Ho Kang, and Sungyong Lee. 2016. The Mining Minds digital health and wellness framework. *BioMedical Engineering OnLine* 15, 1 (2016), 165–186. DOI: http://dx.doi.org/10.1186/s12938-016-0179-9

[6] Lawrence R Brawley, W Jack Rejeski, and Abby C King. 2003. Promoting physical activity for older adults: the challenges for changing behavior. *American journal of preventive medicine* 25, 3 (2003), 172–183.

[7] Richard Cyganiak, David Wood, and Markus Lanthaler. 25 February 2014. *RDF 1.1 Concepts and Abstract Syntax*. W3C Recommendation. Available at https://www.w3.org/TR/rdf11-concepts/.

[8] Roelof A.J. de Vries, Khiet P. Truong, Sigrid Kwint, Constance H.C. Drossaert, and Vanessa Evers. 2016. Crowd-Designed Motivation: Motivational Messages for Exercise Adherence Based on Behavior Change Theory. In *Conference on Human Factors in Computing Systems (CHI '16)*. ACM, New York, NY, USA, 297–308. DOI: http://dx.doi.org/10.1145/2858036.2858229

[9] Elisabetta Erriquez and Floriana Grasso. 2008. Generation of Personalised Advisory Messages: An Ontology Based Approach. In *2008 21st IEEE International Symposium on Computer-Based Medical Systems*. 437–442. DOI: http://dx.doi.org/10.1109/CBMS.2008.103

[10] Steve Harris and Andy Seaborne. 21 March 2013. *SPARQL 1.1 (SPARQL Query Language for RDF)*. W3C Recommendation. Available at http://www.w3.org/TR/sparql11-query/.

[11] Jens Lehmann, Robert Isele, Max Jakob, Anja Jentzsch, Dimitris Kontokostas, Pablo Mendes, Sebastian Hellmann, Mohamed Morsey, Patrick van Kleef, Sören Auer, and Chris Bizer. 2014. DBpedia - A Large-scale, Multilingual Knowledge Base Extracted from Wikipedia. *Semantic Web Journal* (2014).

[12] Seth M Noar, Christina N Benac, and Melissa S Harris. 2007. Does tailoring matter? Meta-analytic review of tailored print health behavior change interventions. *Psychological bulletin* 133, 4 (2007), 673.

[13] Harm op den Akker, Miriam Cabrita, Rieks op den Akker, Valerie M. Jones, and Hermie J. Hermens. 2015. Tailored motivational message generation: A model and practical framework for real-time physical activity coaching. *Journal of Biomedical Informatics* 55 (2015), 104 – 115. DOI: http://dx.doi.org/10.1016/j.jbi.2015.03.005

[14] David Peterson, Shudi Gao, Ashok Malhotra, C. M. Sperberg-McQueen, and Henry S. Thompson. 5 April 2012. *W3C XML Schema Definition Language (XSD) 1.1 Part 2: Datatypes*. W3C Recommendation. Available at http://www.w3.org/TR/xmlschema11-2/.

[15] Evren Sirin, Bijan Parsia, Bernardo Cuenca Grau, Aditya Kalyanpur, and Yarden Katz. 2007. Pellet: A practical OWL-DL reasoner. *Journal of Web Semantics* 5, 2 (2007).

[16] Steffen Staab and Rudi Studer. 2009. *Handbook on Ontologies* (2nd ed.). Springer Publishing Company Inc.

[17] Claudia Villalonga, Muhammad Asif Razzaq, Wajahat Ali Khan, Hector Pomares, Ignacio Rojas, Sungyoung Lee, and Oresti Banos. 2016. Ontology-Based High-Level Context Inference for Human Behavior Identification. *Sensors* 16, 10 (2016), 1617. DOI: http://dx.doi.org/10.3390/s16101617

[18] W3C OWL Working Group. 11 December 2012. *OWL 2 Web Ontology Language: Document Overview (Second Edition)*. W3C Recommendation. Available at http://www.w3.org/TR/owl2-overview/.

[19] WHO. 2014. *Global status report on noncommunicable diseases 2014*. Technical Report. World Health Organization.

[20] Wilko Wieringa, Harm op den Akker, Valerie M. Jones, Rieks op den Akker, and Hermie J. Hermens. 2011. Ontology-Based Generation of Dynamic Feedback on Physical Activity. In *Artificial Intelligence in Medicine: 13th Conference on Artificial Intelligence in Medicine, AIME 2011, Bled, Slovenia, July 2-6, 2011. Proceedings*, Mor Peleg, Nada Lavrač, and Carlo Combi (Eds.). Springer Berlin Heidelberg, Berlin, Heidelberg, 55–59. DOI: http://dx.doi.org/10.1007/978-3-642-22218-4_7