# HeLiS: An Ontology for Supporting Healthy Lifestyles

Mauro Dragoni(✉), Tania Bailoni, Rosa Maimone, and Claudio Eccher

FBK-IRST, Trento, Italy
{dragoni,tbailoni,rmaimone,cleccher}@fbk.eu

**Abstract.** The use of knowledge resources in the digital health domain is a trending activity significantly grown in the last decade. In this paper, we present HeLiS: an ontology aiming to provide in tandem a representation of both the food and physical activity domains and the definition of concepts enabling the monitoring of users' actions and of their unhealthy behaviors. We describe the construction process, the plan for its maintenance, and how this ontology has been used into a real-world system with a focus on "Key to Health": a project for promoting healthy lifestyles on workplaces.

## 1 Introduction

Chronic diseases, such as heart disease, cancer, and diabetes, are responsible for approximately 70% of deaths among Europe and U.S. each year and they account for about 75% of the health spending[1,2]. Such chronic diseases can be largely preventable by eating healthy, exercising regularly, avoiding (tobacco) smoking, and receiving preventive services. Prevention at every stage of life would help people stay healthy, avoid or delay the onset of diseases, keep diseases they already have from becoming worse or debilitating; it would also help people lead productive lives and, at the end, reduce the costs of public health.

People can start their own prevention process by simply monitoring their lifestyles, in terms of dietary habits and physical activities they do. In order to support this, structured resources able to combine all information and to support the integration of monitoring facilities have to be developed.

In this paper, we address this challenge from the knowledge perspective by presenting HeLiS[3], an ontology aiming to provide an integrated representation of foods, physical activities, good practices, user preferences and habits in order to support the promotion of healthy lifestyles. The relevance of the HeLiS ontology with respect to the state of the art pivots around the integrated model representing (i) a fine-grained description of foods at a level that is not present in the state of the art; (ii) physical activities at the metabolic level enabling the definition of relationships with food entities; and, (iii) user profiles described through

1 http://www.who.int/nmh/publications/ncd_report_full_en.pdf.
2 https://www.cdc.gov/media/releases/2014/p0501-preventable-deaths.html.
3 http://w3id.org/helis.


D. Vrandečić et al. (Eds.): ISWC 2018, LNCS 11137, pp. 53–69, 2018.
https://doi.org/10.1007/978-3-030-00668-6_4

their physical status and possible allergies or pathologies. Moreover, the HeLiS ontology provides a flexible support to rules modeling that can be used for the reasoning on data provided by users. Besides the conceptual model per se, the HeLiS ontology represents a valuable resource for the healthcare domain thanks to the knowledge included into the provided resource.

Section 2 provides a brief overview of the main ontologies concerning the domains of food and physical activities. Then, in Sect. 3 we describe the HeLiS ontology by illustrating the methodology we followed and the main entities of the conceptual model. In Sect. 4, we show how to get and reuse the ontology together with examples of future projects that will integrate the ontology, while Sect. 5 presents an instantiation example of the HeLiS ontology into a real-world application. Section 6 discusses the sustainability and maintenance aspects, and, finally, Sect. 7 concludes the paper.

## 2 Related Work

We provide in this Section a brief summary of the most relevant work on ontologies describing both the food and the physical activity domains.

In [1] the authors describe food intake patterns identified by applying new food categories, in particular: (i) nutrient composition and energy density, (ii) current scientific evidence of health benefits, and (iii) culinary use of each food. In [2], a process is presented for a rapid prototyping of a food ontology oriented to the nutritional and health care domain that is used for sharing existing knowledge. However, unfortunately, this resource is no longer available.

The contribution presented in [3] discusses the design and development of a food-oriented ontology-driven system (FOODS), used for food or menu planning in a restaurant, clinic/hospital, or at home. FOODS comprises (i) a food ontology, (ii) an expert system using such an ontology and some knowledge about cooking methods and prices, and (iii) a user interface suitable for users with different levels of expertise. Its aim is to support the management of treatment plans for patients affected by type 1 or type 2 diabetes. Instead, the work presented in [4] focuses on the integration of different domain ontologies, like food, health, and nutrition, in order to help personalized information systems to retrieve food and health recommendations based on the user's health conditions and food preferences. Recently, the work presented in [5] describes an ontology modeling the protected names of brands, from the raw materials to the production process.

A set of ontologies have been proposed that collect information about packaged food. Examples are Open Food Facts[4] and Food Product Ontology [6]. However, their focus on categorizing and describing packaged food led to low coverage of concepts describing food compositions.

Recently, the FoodOn ontology[5] has been released. This ontology represents foods from a different perspective with respect to the HeLiS ontology. Instead of

[4] Open Food Facts. Available online: http://world.openfoodfacts.org/who-we-are.
[5] http://foodontology.github.io/foodon/.

focusing on food composition, they aim to realize a food description system that registers food manufacturers. Indeed, the FoodOn ontology includes, for each product, its origin, the physical attributes, processing, packaging, dietary uses and geographical origin.

Finally, in [7] the design steps are described, the working mechanism, and the case of use of the Ontology-Driven Mobile Safe Food Consumption System (FoodWiki) using semantic matching. This resource aims to address problems similar to the HeLiS ontology. However, no information about physical activities and their correlation with food categories are included in the ontology nor the possibility of modeling in a flexible way rules users should follow and the possible associated violations.

Concerning physical activity, we report two ontologies, both available through the BioPortal[6] website.

The first one is the SMASH (Semantic Mining of Activity, Social, and Health data)[7] ontology. The goal of the SMASH ontology is to describe concepts correlating physical activities and social networks. The system developed upon this ontology aims to sustain weight loss with continued intervention with frequent social contacts. The coverage of the SMASH ontology is very limited. Indeed, only 18 activities are defined.

The second one is the Ontology of Physical Exercises (OPE)[8]. Here, physical activities are modeled from the functional perspective. Thus, exercises are described in terms of movements, how the different musculoskeletal parts of the human body are engaged, and which are the expected health outcomes. Also in this case, the coverage of the physical activity domain is limited because only general categories of activities, like *AerobicExercise* or *IsotonicExercise*, are defined.

With respect to the state of the art, the main contribution of the HeLiS ontology is twofold. First, the coverage is definitely wider in both the food and the physical activity domains. Second, the HeLiS ontology defines concepts enabling the monitoring of users' actions and the representation of their unhealthy behaviors.

## 3 The HeLiS Ontology

The development of the HeLiS ontology followed the need of providing a knowledge artifact able not only to provide a representation of domains concerning healthier lifestyles, but, also, to support further activities like, for example, remote medical monitoring. The proposed ontology has been modeled with a focus on the connection between diet and physical behaviors with people health.

The process for building the HeLiS ontology followed the METHONTOLOGY [8] methodology. This approach is composed by seven stages: Specification,

[6] http://bioportal.bioontology.org/.
[7] http://bioportal.bioontology.org/ontologies/SMASHPHYSICAL.
[8] https://bioportal.bioontology.org/ontologies/OPE.

Knowledge Acquisition, Conceptualization, Integration, Implementation, Evaluation, and Documentation. The overall process involved three knowledge engineers and six domain experts from the Trentino Healthcare Department. More precisely, two knowledge engineers and four domain experts participated to the ontology modeling stages (hereafter, the modeling team). While, the remaining knowledge engineer and two domain experts were in charge of evaluating the ontology (hereafter, the evaluators).

The choice of METHONTOLOGY was driven by the necessity of adopting a lifecycle split in well-defined steps. The development of the HeLiS ontology requires the involvement of the experts in-situ. Thus, the adoption of a methodology having a clear definition of the tasks to perform was preferred. Other methodologies, like DILIGENT [9] and NeOn [10], were considered before starting the construction of the HeLiS ontology. However, the characteristics of such methodologies, like the emphasis on the decentralized engineering, did not fit our scenario well.

***Specification.*** The purpose of the HeLiS ontology is two-fold. On the one hand, we want to provide a detailed and integrated model of the food and physical activity domain. On the other hand, we want to support a synergistic analysis of user data leading to different exploitation possibilities. Examples range from a simple report concerning dietary information to a complex analysis of users' behaviors according to a set of rules provided by domain experts.

The HeLiS ontology is modeled with a *high* granularity level. Concerning food representation, we modeled food composition till micro-nutrients level. While concerning physical activities, we classify them by their categories or by their effort levels. The latter allows to report precise information about the calories spent in one minute for each kilogram of body weight. Thanks to this granularity level, we favor the integration of the HeLiS ontology into several solutions going from simple mobile applications to expert systems.

***Knowledge Acquisition.*** The acquisition of the knowledge necessary for building the HeLiS ontology has been done in two steps: (i) the analysis of unstructured resources containing information of interest about the food and physical activity domains; and, (ii) discussions with domain experts for deciding how to model classes, individuals and properties exploited to support the monitoring activity.

Information concerning both the food and physical activity domains has been modeled by starting from the following unstructured resources: (i) the archives of the Italian Minister of Agriculture[9] and of the Italian Epidemiological department[10] to collect information about the composition of basic foods and nutrients; (ii) the Turconi's atlas [11] to acquire information about recipes and to map recipe's ingredients with basic food's instances; and, (iii) the Compendium of Physical Activities[11] to create the taxonomy of physical activities and model all

[9] http://nut.entecra.it/.
[10] http://www.bda-ieo.it/.
[11] https://sites.google.com/site/compendiumofphysicalactivities/home.

information concerning the associated effort. In this step, we drafted, with the support of the domain experts, the main properties that have to be associated with entities.

The second step consisted in defining the proper entities enabling the reasoning on the data provided by users. Here, we defined two main entities (the *MonitoringRule* and the *Violation* concepts, described in Sect. 3.1), that (i) support the definition of rules used for monitoring users' behavior, and, (ii) allow the representation of violations associated with these rules. Violations instances can then be used as input for other services or applications. Properties associated with these concepts and their possible values have been designed according with the guidelines provided by the experts.

***Conceptualization.*** The conceptualization of the HeLiS ontology was split into two steps. The first one was covered by the knowledge acquisition stage, where most of the terminology is collected and directly modeled into the ontology. Examples are the food and physical activity categories and the name of nutrients. While the second step consisted in deciding how to represent, as classes or as individuals, the information we collected from unstructured resources. Then, we modeled the properties used for supporting all the requirements.

During this stage we relied on several ontology design patterns (ODP) [12]. However, in some cases we renamed some properties upon the request of domain experts. In particular, we exploit the logical patterns *Tree* and *N-Ary Relation*, the alignment pattern *Class Equivalence*, and the content patterns *Parameter*, *Time Interval*, *Action*, *Classification*.

***Integration.*** The integration of the HeLiS ontology has two objectives: (i) to align it with a foundational ontology, and (ii) to link it with the Linked Open Data (LOD) cloud. The first objective was satisfied by aligning the main concepts of the HeLiS ontology with ones defined within the DOLCE [13] top-level ontology. While, the second objective was satisfied by aligning our ontology with AGROVOC[12]. Recently AGROVOC has been included within the LOD cloud. This way, it may work as a bridge between the latter and the HeLiS ontology.

***Implementation.*** The HeLiS ontology is represented by using the RDF/XML language in order to provide a formal representation enabling the check of inconsistencies, the visualization of ontology structure, and the ease of maintenance. The editing of the ontology is demanded to the MoKi tool [14], while the exposure of the ontology is granted by the services available from the HeLiS ontology website.

***Evaluation.*** The evaluation procedure was conducted by one knowledge engineer and two domain experts that did not participate to the modeling process. To evaluate our ontology we adopted the metrics described in [15–19]: *Accuracy*, *Adaptability*, *Clarity*, *Completeness*, *Computational Efficiency*, *Conciseness*, *Consistency/Coherence*, and *Organizational fitness*.

[12] http://aims.fao.org/vest-registry/vocabularies/agrovoc.

The overall *Accuracy* of the ontology has been judged as good. The knowledge of the domain experts was in-line with the complexity of the use axioms. Indeed, within the HeLiS ontology there are not very complex axioms. Then, by considering the representation of the real world, the evaluators agreed on the correctness of the ontology in describing the domain.

Concerning the *Adaptability* of the ontology, the evaluators focused on the possible extension aspects. They verified that the ontology can be extended and specialized monotonically. Here, the question has to be addressed from two perspectives. Firstly, concerning the extension of the ontology from the content perspectives (i.e., adding new foods, recipes, activities, dietary profiles, etc.), the result was positive because any extension of the ontology did not require to remove any axiom. Secondly, concerning the representation of users' profiles, the update of the ontology was not monotonic because if a user is associated to a new profile the old association is removed. Anyway, the ontology does not react negatively to these changes because its consistency is preserved.

About the *Clarity* of the ontology, the evaluators agreed with the strategy decided by the modeling team about using concept labels communicating the intended meaning of each concept and the use of definitions and descriptions of the main concepts of the ontology, especially for the root concepts of each branch. Moreover, each definition has been well documented within the ontology in order to make the meaning of each concept understandable by who uses the ontology.

The experts agreed about the *Completeness* of the HeLiS ontology. However, they distinguished among the TBox and the ABox. Indeed, concerning the TBox, the evaluators agreed about the completeness of the ontology and the lexical representations of the concepts. In particular, they verified that all the represented nutrients appropriately cover the health domain and that all the information needed for the realization of tools supporting a healthy lifestyle were modeled within the ontology. While, regarding the ABox, the evaluators highlighted the necessity of including individuals concerning commercial products. This observation is interesting, especially, if we consider the possibility of developing end-users applications. Indeed, the presence of commercial products will improve the overall user engagement.

In order to verify the *Computational efficiency* of HeLiS, we observed how the ontology behaved within the scenario described in Sect. 5. Indeed, the HeLiS ontology itself does not contain axioms representing a criticism for reasoners. On the contrary, the final aim of the ontology is to be used for analyzing data provided by users. In Sect. 5 we show an example about how the ontology is used and we provide statistics regarding the amount of time needed for completing the reasoning activity with respect to the dimension of elaborated data.

The evaluators judged the HeLiS ontology *Concise* because all the axioms included are relevant with regards to the healthy lifestyle domain and there are no redundancies.

The HeLiS ontology has been judged, also, *Consistent* and *Coherent*. Consistent because no contradictions were found by the evaluators. Coherent because the evaluators observed little bias between the documentation containing the informal description of the concepts and their formalization.

Finally, concerning the *Organizational fitness*, the HeLiS ontology has been deployed within the organization as a web service in order to make it easily accessible by the community and potential stakeholders. Moreover, as described in Sect. 6, the ontology has been deployed also, within external architectures. A focus group has been organized with both the modeling team and the evaluators for discussing about the adopted methodology, that was judged appropriate by considering the necessity of working in-situ all together and of synchronizing the commitments of all the people involved.

***Documentation.*** The documentation of the HeLiS ontology has been done from two perspectives. First, during the whole modeling process, a document has been prepared by the people involved in the construction process. This activity was necessary because, as we will mention in Sect. 6, the development of the HeLiS ontology and its sustainability are granted by a public funding program. Thus, all performed steps were documented and archived within the funding dossier. Second, in order to ease the readiness of the ontology for users, we provided a different documentation file generated by using the LODE[13] system and available on the ontology website.

### 3.1 Inside the HeLiS Ontology

The ontology contains six root concepts: *Activity*, *Food*, *MonitoringEntity*, *Nutrient*, *TemporalEvent*, and *UserEvent*. Beside these, we also defined the *User* concept that does not play the role of superclass of any concept but that is fundamental for associating specific events with the people did them.

Figure 1 shows a general overview of the ontology with the main concepts.

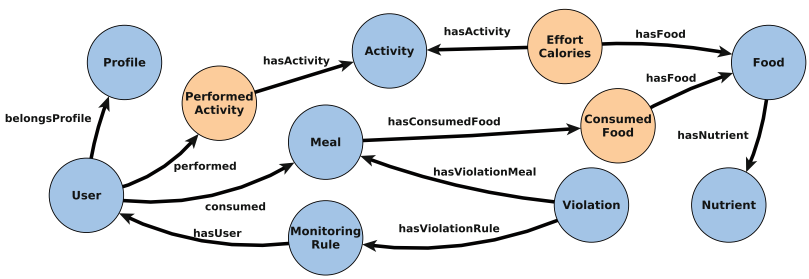


**Fig. 1.** Overview of the HeLiS ontology.

Below, we detail the entities associated with each root concept by providing the semantic meaning of the most important entities.

**Food and Nutrient.** The *Food* root concept subsumes two macro-groups of entities descending from *BasicFood* and *Recipe* concepts. Instances of the

[13] http://www.essepuntato.it/lode.

*BasicFood* concept describe foods for which micro-information concerning nutrients (carbohydrates, lipids, proteins, minerals, and vitamins) is available, while instances of the *Recipe* concept describe the composition of complex dishes (such as *Lasagna*) by expressing them as a list of instances of the *RecipeFood* concepts. This concept reifies the relationships between each *Recipe* individual, the list of *BasicFood* it contains and the amount of each *BasicFood*. Besides this dual classification, instances of both *BasicFood* and *Recipe* concepts are more fine-grained categorized. While, concerning the number of individuals, currently, the HeLiS ontology contains 986 individuals of type *BasicFood* and 4408 individuals of type *Recipe*.

Entities subsumed by the *BasicFood* concepts are the range of the *hasMonitoredEntityType* object property linking each individual of the *MonitoringRule* concept (described below) with a specific category of food. We can also notice that all instances of *BasicFood* and *Recipe* concepts are within the domain of the *hasPositiveProperty* and *hasNegativeProperty* data properties having as range a string value.

Beside the food-related concepts, the classification of nutrients is also defined. The *Nutrient* concept subsumes 81 different type of nutrients properly categorized. Nutrients are instantiated with through individuals describing a specific amount of a nutrient. Then each *BasicFood* is linked to all the necessary nutrients' individuals through the *hasNutrient* object property.

**Activity.** The second groups of entities relates to physical activities. The *PhysicalActivity* concepts subsumes 21 subclasses representing likewise physical activity categories and a total of 856 individuals each one referring to a different kind of activity. For each activity, we defined datatype properties providing the amount of calories consumed in one minute for each kilogram of weight and the MET (Metabolic Equivalent of Task) value expressing the energy cost of the activity. MET values allow to split activities in *LightActivity* (MET $< 3$), *ModerateActivity* (MET $[3, 6]$), and *VigorousActivity* (MET $> 6$).

**TemporalEvent.** The *TemporalEvent* concept defines entities used for representing specific moments or delimited timespan which the data to analyze refers to. These concepts are used in two ways. First, when users provide data concerning the food consumption, these data have to be associated with a specific temporal event that, in the case of food consumption, is the *Meal* concept. In turn, the *Meal* concept subsumes other concepts defining specific kind of meals (i.e. *Breakfast*, *Snack*, *Lunch*, and *Dinner*). Second, the other descendant of the *TemporalEvent* concept is the *Timespan* one. Instances of the children of *Timespan* are used for driving the data selection and reasoning operations to a specific portion of data. Indeed, as shown later in this Section and also in Sect. 5, the definition of a rule must contain the link a *TemporalEvent* instance.

**UserEvent.** This concept subsumes the conceptualization of information that a user can provide, i.e. food consumption and performed activities, and also links them with the possible violation that can be generated after their analysis. Concerning the representation of users' activities and personalized information, we modeled the *ConsumedFood* and the *PerformedActivity* concepts. Both concepts are used as reification of the fact that a user consumed a specific quantity of a food or performed an activity for a specific amount of time. In the first case, every *Meal* is associated with a list of *ConsumedFood* through the *hasConsumedFood* object property. While, in the second case, instances of the *PerformedActivity* concept associate a user with the amount of time he/she spent in performing a specific activity. Here, we did not use a concept for grouping a list of activities a user is routinely doing (including sleeping), thus a further concept for grouping activities is useless. Then, we included also the possibility of providing user-specific information representing the energy consumption equivalence, e.g. how much a specific user has to run for burning 100 grams of pasta. This information is represented by instantiating the *EffortCaloriesEquivalent* concept (EffortCalories in Fig. 1). Then, instances of the *User* concept are used as object for the *hasViolationUser* object property defined on the *Violation* concept (described below).

For the sake of clarity, we provide below two examples presenting how these concepts are used. Figure 2 shows are the *User* and the *ConsumedFood* concepts are linked. While Fig. 3 shows this link exists between the *User* and the *PerformedActivity* concepts.

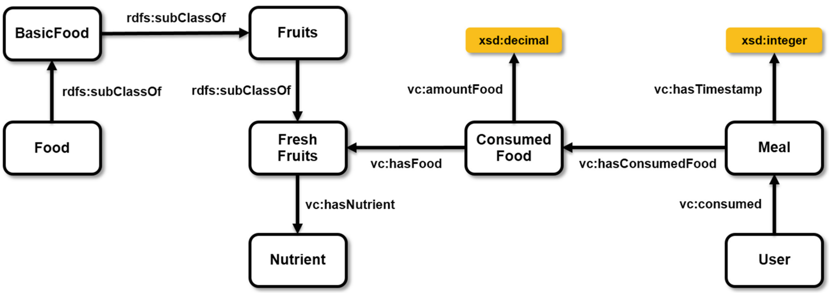


**Fig. 2.** Example describing the representation of a user eating some fresh fruits.

**MonitoringEntity.** Concepts subsumed by the *MonitoringEntity* one are responsible for modeling the knowledge enabling the monitoring of users' behaviors. Here, we can appreciate five concepts: *MonitoringRule*, *Violation*, *Profile*, *Goal*, and *Interval*. The *MonitoringRule* concept provides a structured representation of the parameters inserted by the domain experts for defining how users should behave. First of all, it is necessary to determine the entities affected by the monitoring rule, and the time period to be considered during the rule evaluation process. This information is provided through two object properties and one annotation property: *monitoredEntity* (e.g. *Corn* or *Walk*) and *monitoredEntityType* (e.g. *Food* or *Activity*) object properties; while the time period is provided

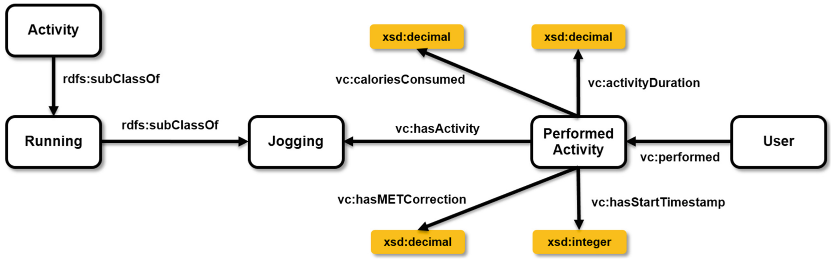


**Fig. 3.** Example describing the representation of a user performing a running session.

through the *timing* annotation property that may contain the URI of the *Timespan* concept. *MonitoringRule* instances are the directives that can be exploited by a reasoner for analyzing user data. The content of the *command* datatype property specifies how the reasoner has to behave when it analyzes data of type *monitoredEntity*. The *command* is accompanied by the *hasOperator* datatype property that specifies the kind of comparison that the reasoner has to make with respect to the value/s specified through the *hasMonitoredValue* datatype property or the *hasMonitoredInterval* object property. In the first case, a classic comparison is performed between provided data and the values contained in the monitoring rule, while, the second case indicates to the reasoner that the value specified into the rule is not a fixed value, but an interval. If the second case occurs, the reasoner will get the *ValueInterval* object linked through the *hasMonitoredInterval* object property and will check the value of the provided data with the interval specified by the *lowerBound* and *upperBound* datatype properties associated with the *ValueInterval* object.

*Violation* instances describe the results of the reasoning activities and they can be used by third party applications. The content of each *Violation* instance is computed according to the user data that triggered the violation. Information materialized at runtime is contained in the *hasViolationHistory* and *hasViolationLevel* datatype properties. The former contains the number of times the *MonitoringRule* associated with the generated violation has been already triggered by the user. The latter represents the severity of the violation. Indeed, the knowledge base contains a set of pre-modeled intervals representing different levels of violations, expressed in terms of percentage with respect to the monitored value defined within the rule. When a rule is violated, the reasoner queries the violation intervals for knowing the level of the generated violation. Finally, the *hasTimestamp* datatype property contains the timestamp in which the violation instance is generated.

Each *MonitoringRule* is linked to at least one *Profile* concept. A *Profile* represents a set of rules which a *User* should follow for being compliant with an alimentary guideline. An example of *Profile* is the Mediterranean Diet that contains around 220 dietary rules. While, in case of diseases, a *Profile* may contain a set of rules specifically thought for managing that disease.

The *Goal* concepts represents a specific objective, in the context of a *Profile*, that a user is expected to achieve within a given timestamp. In practice, a *Goal* is composed by a subset of the *MonitoringRule* instances linked to a *Profile*. However, with respect to a *Profile*, that is only linked to a *User* through the *belongsProfile* object property, the definition of a *Goal* includes more information. First of all, a *Goal* is associated with a *Profile* through the *appliesTo* object property. Then, a *Goal* is associated with one or more *MonitoringRule* through the *hasMonitoringRule* object property. The temporal validity of a *Goal* is expressed by the *timing* object property that specifies for how much time a *User* has to respect the violations' limits associated with the *Goal*. The range of this object property is the *TemporalEvent* concept. Finally, we mentioned above that each *Goal* specifies a limit of violations that a *User* must not reach. Thus, a *Goal* is associated with comparison operator (*hasOperator* datatype property) and with a value to monitor (*hasMonitoredValue*). As example, by assuming to have the rule "MR1", the timing of "28 days", the comparison operator "less" and the monitored value 2, it means that a *User* associated with this goal does not have to violate the rule "MR1" more than two times within a period of 28 days.

Finally, the *Interval* concepts subsumes concepts used for describing interval of values. Beside the *ValueInterval* concept introduced above, the current version of HeLiS defines the *ViolationInterval* one. Instances of this concept allows to transform the percentage representing the difference between expected and observed values into discrete levels representing how much a *MonitoringRule* has been violated.

## 4 Availability and Reusability

The HeLiS ontology is licensed under the Creative Commons Attribution-NonCommercial-ShareAlike 4.0[14] and it can be downloaded from the PerKApp project website at the link reported at the beginning of the paper. The rational behind the CC BY-NC-SA 4.0 is that the Trentino Healthcare Department, that funds the project in which the HeLiS ontology has been developed, was not in favor of releasing this ontology for business purposes. Hence, they force the adoption of this type of license for releasing the ontology. The HeLiS ontology can be downloaded in two different modalities: (i) the conceptual model only, where the user can download a light version of the ontology that does not contain any individual, or (ii) the full package, where the ontology is populated with all the individuals we have already modeled. The HeLiS ontology is constantly updated due to the project activities using the ontology as core component.

The ontology is available also as web service. Detailed instructions are provided on the ontology website. Briefly, the service exposes a set of *informative* methods enabling the access to a JSON representation of the individuals included into the ontology.

[14] https://creativecommons.org/licenses/by-nc-sa/4.0/.

The reusability aspect of the HeLiS ontology can be seen from three perspectives. First, the HeLiS ontology contains structured supervised knowledge about the food and physical activity domains. Provided information has a high granularity and the consistency of the modeled data have been validated by domain experts. Hence, the ontology represents a valuable artifact for the digital health domain. Second, the ontology model represents a relevant resource of medical knowledge. In particular, the ontology contains a set of rules, modeling good practices, related to what a person should eat and which physical activities a person should do for maintaining a good health, and the relationships between food's allergies or intolerances and specific food categories. This kind of knowledge is presented, for the first time, in a structured way and it can be reused in several third-party applications for different purposes. Third, the HeLiS ontology enables the construction of health-based (but not limited to this domain) applications exploiting the whole content of the ontology as well as the sole conceptual model.

## 5 HeLiS Ontology in Action

The topic area of the HeLiS ontology is timely for researchers and developers working on digital health applications (including mobile) who are now exploring the use of Semantic Web technology in the form of knowledge graphs and rules to analyze the nutrition intake over time, activities, and their association with health risks and symptoms related to chronic diseases.

The HeLiS ontology can be integrated within applications going beyond the mere access to the resource for informative purposes. Indeed, the *Monitoring* branch of the ontology can be populated to properly respond to the needs of the solutions integrating the HeLiS ontology. An instantiation example is the PerKApp platform.

The PerKApp platform[15] develops a personalized healthy lifestyle recommendation system addressing the challenge of monitoring people behaviors with the aim of promoting possible behavioral changes. Here, the HeLiS ontology is used to support the reasoning activities on the data provided by users. The collection and modeling of domain knowledge is performed integrating specific user facilities into the MoKi tool [14], this tool has been used to support the work of domain experts that are responsible for modeling the rules used to validate user data. The inference engine is powered by the RDFPro tool [20], a tool that allows us to consider the aforementioned aspects by supporting out-of-the-box OWL 2 RL and the fixed point evaluation of `INSERT... WHERE...` SPARQL-like entailment rules that leverage the full expressivity of SPARQL (e.g., `GROUP BY` aggregation, negation via `FILTER NOT EXISTS`, derivation of RDF nodes via `BIND`).

***Summing-Up Example.*** Let us consider the following scenario. After a colloquium with her physicians, Michelle has to follow these two rules: (i) the total

15 http://perkapp.fbk.eu/.

amount of calories for each meal has to be lower than 1000 and (ii) the number of portions of the *SweetBeveragesAndJuices* food category should be restricted to maximum one per day. At first, the doctor created a user associated to Michelle and inserted profile's details. Then, he defined the two rules that the PerKApp system has to validate every day.

```
:Hyperglycemia a :Profile.

:Michelle a :User; :hasUserId "493853"^^xsd:integer; :belongsProfile :Hyperglycemia.

:MR1 a :MonitoringRule;
    :appliesTo :Hyperglycemia; :timing :Meal; :monitoredEntity :Food;
    :command "hasCalories"; :hasOperator "lower"; :hasMonitoredValue "1000"^^xsd:integer;
    :hasRuleId "1"^^xsd:integer; :hasPriority "2"^^xsd:integer.

:MR2 a :MonitoringRule;
    :appliesTo :Hyperglycemia; :timing :Day; :monitoredEntity :SweetBeveragesAndJuices;
    :command "portion"; :hasOperator "greater"; :hasMonitoredValue "1"^^xsd:integer;
    :hasRuleId "2"^^xsd:integer; :hasPriority "1"^^xsd:integer.
```

For the first two days, Michelle inserted the data about her food intake correctly as shown below (for brevity, we reported only the meals, or snacks, that trigger persuasive actions):

```
:Michelle :consumed :Breakfast-493853-1, :Snack-493853-2, :Snack-493853-3, :Dinner-493853-4.
:Michelle :consumed :Breakfast-493853-5, :Meal-493853-6, :Snack-493853-7, :Dinner-493853-8.

:Breakfast-493853-1 a :Breakfast;
    :hasTimestamp "2016-12-14T07:19:00Z";
    :hasConsumedFood [ :hasFood :AlmondMilk; :amountFood "250"^^xsd:integer ],
                     [ :hasFood :RiceFlakes; :amountFood "100"^^xsd:integer ].

:Snack-493853-3 a :Snack;
    :hasTimestamp "2016-12-14T11:34:00Z";
    :hasConsumedFood [ :hasFood :CannedOrangeSoda; :amountFood "300"^^xsd:integer ],
                     [ :hasFood :Apple; :amountFood "150"^^xsd:integer ].

:Breakfast-493853-5 a :Breakfast;
    :hasTimestamp "2016-12-15T07:23:00Z";
    :hasConsumedFood [ :hasFood :FruitJuices; :amountFood "200"^^xsd:integer ],
                     [ :hasFood :RiceFlakes; :amountFood "100"^^xsd:integer ].

:Snack-493853-7 a :Snack;
    :hasTimestamp "2016-12-15T15:52:00Z";
    :hasConsumedFood [ :hasFood :FruitJuices; :amountFood "200"^^xsd:integer ],
                     [ :hasFood :Sandwich; :amountFood "150"^^xsd:integer ].

:Dinner-493853-8 a :Dinner;
    :hasTimestamp "2016-12-15T19:45:00Z";
    :hasConsumedFood [ :hasFood :CocaCola; :amountFood "330"^^xsd:integer ],
                     [ :hasFood :Pizza; :amountFood "450"^^xsd:integer ].
```

Based on the provided data, on the ontology currently available in the PerKApp platform, and on the RDF encoding of the monitoring rules, the PerKApp reasoner determines that the amount of kilo-calories consumed during each meal, except for *Dinner-493853-8*, satisfies the rule *MR1*. However, the reasoner determines that the rule *MR2* has been violated in both days. This event triggers into the knowledge base the assertion of the following *Violation* individuals:

```
:violation-493853-1-20161214 a :Violation;
    :hasViolationRule :MR2; :hasViolationUser :Michelle; :hasViolationMeal :Breakfast-493853-1;
    :hasViolationMeal :Snack-493853-3; :hasViolationQuantity 2;
    :hasViolationExpectedQuantity 1; :hasViolationLevel 1;
    :hasTimestamp "2016-12-14T22:30:00Z"; :hasPriority 1; ...

:violation-493853-1-20161214 a :Violation;
    :hasViolationRule :MR2; :hasViolationUser :Michelle; :hasViolationMeal :Breakfast-493853-5;
    :hasViolationMeal :Snack-493853-7; :hasViolationMeal :Dinner-493853-8;
    :hasViolationQuantity 3; :hasViolationExpectedQuantity 1;
    :hasViolationLevel 2; :hasTimestamp "2016-12-15T22:30:00Z"; :hasPriority 1; ...

:violation-493853-8-20161215 a :Violation;
    :hasViolationRule :MR1; :hasViolationUser :Michelle; :hasViolationMeal :Dinner-493853-8;
    :hasViolationQuantity 1356; :hasViolationExpectedQuantity 1000; :hasViolationLevel 2;
    :hasTimestamp "2016-12-15T19:45:00Z"; :hasPriority 2; ...
```

Among the violations shown above, one is selected by the PerKApp platform as the most appropriate one to generate the feedback, then sent to Michelle. In this particular case, Michelle is advised that she is consuming too much sweet beverages and juices. This kind of feedback aims at reminding Michelle that she has to follow the doctor's suggestions in order to avoid the possible insurgence of diabetes, due to the excessive consumption of sugar.

*Violation* individuals are generated through reasoner integrated into RDF-pro. Reasoning activities on the HeLiS ontology have the goal of verifying that a user's lifestyle is consistent with the monitoring rules defined by domain experts, detecting and possibly materializing violations in the knowledge base, upon which further actions may be taken. Reasoning can be implemented via the fixed point, forward chaining evaluation of IF-THEN *entailment rules* (cf. *monitoring rules*, which are RDF individuals in the PerKApp ontology) that implement the semantics of OWL 2 RL (to account for TBox declarations in the ontology) and of monitoring rules by matching non-conforming patterns in RDF data and asserting corresponding *Violation* individuals.

Below, we show one of the SPARQL queries we implemented for the PerKApp project. In particular, we report the query used to detect if the portions of a specific food category consumed by a user exceeded the daily quota or not.

```
:check_contains_food_portion_less_day a rr:Rule, rr:NonFixpointRule;
  rr:phase  10;
  rr:insert """ ?v :hasViolationRule ?rule; :hasViolationGoal ?goal; :hasViolationUser ?user;
                   :hasViolationQuantity ?quantity; :hasViolationConstraint ?operator;
                   :hasViolationEntityType ?et; :hasViolationLevel ?level;
                   :hasViolationStartTime ?minTimestamp; :hasViolationEndTime ?timestamp;
                   :hasTimestamp ?timestamp. """;
  rr:where  """ {
                  SELECT ?rule ?goal ?user ?et ?mv (MAX(?mealTs) AS ?timestamp)
                        (MIN(?mealTs) AS ?minTimestamp) (COUNT(DISTINCT ?cf) AS ?quantity)
                  WHERE {
                    ?rule a :MonitoringRule; :timing ?timing; :command "portion";
                            :monitoredEntityType :Food; :hasMonitoredValue ?mv;
                            :monitoredEntity ?class.
                    FILTER EXISTS {?rule :hasOperator "less"}
                    FILTER EXISTS {?rule :timing :Day}
                    {SELECT DISTINCT ?rule ?goal ?user WHERE {
                      {?rule :appliesTo ?user} UNION
                      {?rule :appliesTo ?goal. ?goal ^:belongsProfile ?user.}}}
                    ?meal :hasUser|^:consumed ?user; :hasTimestamp ?mealTs.
                    {?timing rdfs:subClassOf :Timespan} UNION {?meal a ?timing}
```

```
22.        BIND (:mintEntityType(?class) AS ?et)
23.                  ?cf   ^:hasConsumedFood ?meal; :hasFood ?food; :amountFood ?amount .
24.                  FILTER(?amount > 0.0)
25.                  ?food a ?class. }
26.               GROUP BY ?rule ?goal ?user ?et ?mv }
27.              ?user :hasUserId ?userId.
28.              ?rule :hasOperator ?operator; :hasMonitoredValue ?value; :hasRuleId ?ruleId.
29.              FILTER (?operator = "less" && ?quantity >= ?value)
30.              BIND (:computeViolationLevel(?mv, ?quantity) AS ?level)
31.              BIND (:mintViolation(?ruleId, ?userId, ?timestamp) AS ?v) """.
```

Rows from 3 to 7 contain the definition of the *Violation* individual. From row 12 to row 16 the reasoner selects which rules to validate, in this case the ones focusing on the consumption of the number of *portions* of foods (instead of quantities) that should not exceed (*less* operator) the daily (timing *:Day*) limit. Rows from 17 to 19 allows to verify if the current user is associated to a profile linked to the selected *MonitoringRule*. Rows from 23 to 25 check if the food consumed by the current user is of the same type of the food monitored by the rule. Rows 28 and 29 perform trivial checks about the coherence between the rule's operator and the computed quantity. Finally, at rows 30 and 31 we included two functions we implemented to compute the violation level based on the difference between the detected number of portions and the expected one, and for generating the *Violation* identifier.

## 6 Resource Sustainability and Maintenance

As mentioned in the previous section, the presented ontology is the result of a collaborative work between several experts. While, on the one hand this collaboration led to the development of an effective and useful ontology, on the other hand the sustainability and the maintenance of the produced artifact represent a criticality.

Concerning the sustainability, this ontology has been developed in the context of the *Key to Health* project[16]. The goal of this project is to "combine efforts of employers, employees, and society to improve the mental and physical health and well-being of people at work"[17] and it aims at preventing the onset of chronic diseases related to an incorrect lifestyle through organizational interventions directed to workers. Actions might concern the promotion of correct diet, physical activity, social and individual well-being, as well as the discouragement of bad habits, such as smoking and alcohol consumption. This project, recently started within FBK, aims to promote healthy behaviors on workplaces and it is part of the "Trentino Salute 4.0" framework promoted by the Trentino's local government. One of the goals of this framework is to promote the integration of artificial intelligence solutions into digital health platforms with the long term goal of improving the life quality of citizens. The presented ontology is part of the core technologies used in this framework. The overall sustainability plan for

[16] https://sites.google.com/fbk.eu/keytohealth.

[17] Luxembourg Declaration on Workplace health promotion in the European Union. 1997.

the continuous update and expansion of the HeLiS ontology is granted by this framework and by the projects mentioned in Sect. 4.

The maintenance aspect is managed by the infrastructure available within FBK from both the hardware and software perspectives. In particular, we enable the remote collaboration between experts thanks to the use of the MoKi [14] tool (details about the tool are out of the scope of this paper). Here, it is important only to remark that this tool implements the support for the collaborative editing of ontologies by providing different views based on the kind of experts (domain expert, language expert, ontology engineer, etc.) that has to carry out changes to the ontology.

The canonical citation for the HeLiS ontology is "Dragoni M., Bailoni T., Maimone R., and Eccher C. HeLiS: An Ontology For Supporting Healthy Lifestyles (2018) http://w3id.org/helis".[18]

## 7 Conclusions and Future Work

In this paper, we presented the HeLiS ontology: a knowledge artifact for the digital health domain specifically developed to support healthy lifestyles. The knowledge modeled within the HeLiS ontology combines information extracted from unstructured resources with the ones collected from domain experts coming from the medical domain. We described the process we followed to build the ontology and which information we included. Then, we presented how the ontology can be reused and we briefly introduced the projects and use cases that will adopt the HeLiS ontology.

Future work will focus on the integration of our model with classification schemata describing the food and physical activity domains from different perspectives, like LanguaL[19] and OPE (see Footnote 8). Moreover, our intent is to populate the HeLiS ontology with data describing the nutritional information of commercial products. Finally, we aim to integrate knowledge from the mindfulness domain in order to support the correlation between the mental and the physical health status of people.

## References

1. Grafenauer, S., Tapsell, L., Beck, E.: Beyond nutrients: classification of foods to identify dietary patterns for weight management. In: 16th International congress of Dietetics (2012)
2. Cantais, J., Dominguez, D., Gigante, V., Laera, L., Tamma, V.: An example of food ontology for diabetes control. In: Proceedings of the International Semantic Web Conference 2005 Workshop on Ontology Patterns for the Semantic Web (2005)
3. Snae, C., Bruckner, M.: Foods: a food-oriented ontology-driven system, pp. 168–176 (2008)

[18] DOI of the ontology file will be provided in case of acceptance in order to include possible refinements suggested by Reviewers.

[19] http://langual.org/.

4. Helmy, T., Al-Nazer, A., Al-Bukhitan, S., Iqbal, A.: Health, food and user's profile ontologies for personalized information retrieval. In: Shakshuki, E.M. (ed.) Proceedings of the ANT 2015, London, pp. 1071–1076, 2–5 June 2015
5. Peroni, S., Lodi, G., Asprino, L., Gangemi, A., Presutti, V.: FOOD: food in open data. In: Groth, P., et al. (eds.) ISWC 2016. LNCS, vol. 9982, pp. 168–176. Springer, Cham (2016). https://doi.org/10.1007/978-3-319-46547-0_18
6. Kolchin, M., Zamula, D.: Food product ontology: initial implementation of a vocabulary for describing food products. In: Proceedings of the 14th Conference of Open Innovations Association FRUCT. FRUCT 2014, Helsinki, FRUCT Oy, pp. 191–196 (2013)
7. Çelik Ertuğrul, D.: FoodWiki: a mobile app examines side effects of food additives via semantic web. J. Med. Syst. **40**(2), 1–15 (2016)
8. Fernández-López, M., Gómez-Pérez, A., Juristo, N.: Methontology: from ontological art towards ontological engineering. In: Proceedings of AAAI-Spring Symposium on Ontological Engineering of AAAI (1997)
9. Pinto, H.S., Staab, S., Tempich, C.: DILIGENT: towards a fine-grained methodology for distributed, loosely-controlled and evolving engineering of ontologies. In: de Mántaras, R.L., Saitta, L. (eds.) Proceedings of the 16th Eureopean Conference on Artificial Intelligence, ECAI 2004, Including Prestigious Applicants of Intelligent Systems, PAIS 2004, Valencia, 22–27 August 2004, pp. 393–397. IOS Press (2004)
10. Suárez-Figueroa, M.C.: NeOn methodology for building ontology networks: specification, scheduling and reuse. Ph.D. thesis, Technical University of Madrid (2012)
11. Turconi, G., Roggi, C.: Atlante fotografico alimentare. Uno strumento per le indagini nutrizionali
12. Hitzler, P., Gangemi, A., Janowicz, K., Krisnadhi, A., Presutti, V. (eds.): Ontology Engineering with Ontology Design Patterns - Foundations and Applications. Studies on the Semantic Web, vol. 25. IOS Press (2016)
13. Gangemi, A., Guarino, N., Masolo, C., Oltramari, A., Schneider, L.: Sweetening ontologies with DOLCE. In: Gómez-Pérez, A., Benjamins, V.R. (eds.) EKAW 2002. LNCS (LNAI), vol. 2473, pp. 166–181. Springer, Heidelberg (2002). https://doi.org/10.1007/3-540-45810-7_18
14. Dragoni, M., Bosca, A., Casu, M., Rexha, A.: Modeling, managing, exposing, and linking ontologies with a wiki-based tool. In: LREC, pp. 1668–1675 (2014)
15. Obrst, L., Ceusters, W., Mani, I., Ray, S., Smith, B.: The Evaluation of Ontologies, pp. 139–158. Springer, Boston (2007). https://doi.org/10.1007/978-0-387-48438-9_8
16. Gangemi, A., Catenacci, C., Ciaramita, M., Lehmann, J.: Modelling ontology evaluation and validation. In: Sure, Y., Domingue, J. (eds.) ESWC 2006. LNCS, vol. 4011, pp. 140–154. Springer, Heidelberg (2006). https://doi.org/10.1007/11762256_13
17. Gómez-Pérez, A.: Ontology evaluation. In: Staab, S., Studer, R. (eds.) Handbook on Ontologies. International Handbooks on Information Systems, pp. 251–274. Springer, Heidelberg (2004). https://doi.org/10.1007/978-3-540-24750-0_13
18. Gruber, T.R.: Toward principles for the design of ontologies used for knowledge sharing? Int. J. Hum. Comput. Stud. **43**(5–6), 907–928 (1995)
19. Grüninger, M., Fox, M.: Methodology for the design and evaluation of ontologies. In: Workshop on Basic Ontological Issues in Knowledge Sharing, IJCAI 1995, 13 April 1995
20. Corcoglioniti, F., Rospocher, M., Mostarda, M., Amadori, M.: Processing billions of RDF triples on a single machine using streaming and sorting. In: ACM SAC, pp. 368–375 (2015)