Modeling a Functional Status Knowledge Graph For Personal Health

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Abstract
Functional Status Information (FSI) describes physical and mental wellness at the whole-person level, and includes information on activity performance, social role participation, and environmental and personal factors that affect the well-being and quality of life. Collecting and analyzing this information is critical to address the needs for caring for an aging global population, and to provide effective care for individuals with chronic conditions, multi-morbidity, and disability. Personal knowledge graphs (PKGs) represent a suitable way for representing in a complete and structured way all information related to persons' FSI and for reasoning over them in order to build tailored coaching solutions supporting them in daily life for conducting a healthy living. In this paper, we present the development process related to the creation of a PKG by starting from the HeLiS ontology in order to enable the design of an AI-enabled system with the aim of increasing, within people, the self-awareness of their own functional status. In particular, we focus on the three modules extending the HeLiS ontology aiming to represent (i) enablers and (ii) barriers playing potential roles about improving (or deteriorating) own functional status and (iii) arguments driving the FSI collection process. Finally, we show how these modules have been instantiated into real-world scenarios.

Keywords
Knowledge Graph, Functional Status, Digital Health, Intelligent Agents Support

1. Introduction

There is a growing trend to develop virtual health and well-being assistants to support lifestyle and disease management, partly due to the growing societal needs for managing health and preventing illness. To improve an individual's situation, a change of behavior is typically necessary, which puts focus on how a digital coach can act in collaboration with the individual to support their ambition to improve their health through behavior change, e.g. by adhering to medical guidelines or treatment protocols, increasing physical activity, changing nutrition habits, reducing stress or intake of toxic substances. As a basis for deciding how to act, the digital coach may explore functional status information (FSI) of the monitored individual.

A necessary foundation for a medical and health-related system's reasoning, decision making and acting is (i) the medical knowledge that the digital coach utilizes, (ii) the theories and

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knowledge about how humans form motivation and change behavior as well as manage physical, social, and psychological barriers, and (iii) the FSI (data) about the individual as well as the individuals' narrative about their behavior change journey, that needs to be treated following ethical guidelines and regulations. Moreover, such systems rely on the integration of effective, efficient and ethical strategies for adapting their behavior according to the individual's context, personal preferences, and needs (e.g. display motivational messages that are tailored to each individual's resources and current situation). A proper representation of this information requires (i) a strategy able to mitigate the diversity of the information managed and (ii) a conceptual model enabling the exploitation of such information by preserving, at the same time, the privacy aspects. Personal knowledge graphs (PKGs) are a valid way for providing an effective representation of FSI and for connecting such information with users' personal records (e.g. electronic health record) to enable the design of AI-based systems implementing the coaching paradigm for avoiding FS deterioration in target users.

In this article, we present the design process adopted to extend the HeLiS ontology [1] with three new modules, namely *Enablers*, *Barriers*, and *Arguments*, enabling the definition and tracking of users' FSI [1]. Hereafter, we adopt the acronym FuS-KG as reference for the *Functional Status Knowledge Graph* containing the HeLiS ontology and the three developed extensions. This ontology, as a middle layer for the design of explainable behavior change systems, allows (i) to model conceptual information representing individuals' FSI and use the information to adapt the generation of explanatory and motivational messages; (ii) to support interoperability among different systems which could share for example, databases of motivational messages or explainability algorithms; and, (iii) to manage privacy and ethical issues relating to user data. Through the conceptualization of each enabler, barrier and argument, it is possible (i) to acquire personal FSI of users and to properly store them within the ontology and, (ii) to manage which information can be shared with respect to the target user and, at the same time, design systems that are *transparent by design*. Indeed, the use of the ontology enables the linking of information contained in black-box systems with conceptual information for exposing them.

2. Related Work

Understanding the functional status of a person is important for developing accurate interventions and providing services for improving their health status as well as maximizing their functional independence, to perform well daily activities and be healthy. Managing health is a complex challenge and often the health care system's scarce resources prevent providing adequate support and care especially to persons with chronic or disability conditions [2]. A patient's functional status is a snap-shot of a person's health status which is assessed by clinicians through interviews regarding their habits and standardized tests, however achieving behavior change for improving health is a long-term process. Consequently, there is a gap between people's health goals and the sparsely conducted health assessments, which is a limitation when aiming to achieve a good quality of care [3].

Physicians and researchers have studied the correlation between decline in functions and the insurgence of acute illness or an exacerbation of a chronic illness, and identified risk factors to

[1]The full ontology and its modules are available at https://w3id.org/helis

detect elderly most at risk of experiencing decline in functions [4, 5, 6]. However, the problem is that functional status information is not yet being fully embraced and thus is not used effectively to its full potential [3]. The usefulness and the development of interventions based on functional status measurements is still being studied and under development but many physicians do not appreciate the importance of this information yet [7, 8, 9, 10]. Indeed even if they were informed of patients' perceived health status only a few changed patient management accordingly [11].

Studies that are based on self-report of functional performance and early decline in functions, report that they successfully predict the actual performance and decline [12, 13]. Our investigation goes in this direction with the aim of designing an AI-enabled system able to assist the individual in monitoring their functional status and to prevent functional decline through the usage of a coaching mechanism providing motivational feedback supporting people in their goals to change lifestyle to improve health.

An example of a recent cooperative effort to create observable and replicable interventions to influence behavior and health is given by the taxonomy on behavioral change techniques presented in [14], which supports the aggregation of behavior and behavior change knowledge also sharing and reusing useful sources of behavior knowledge. Moreover, we observed that to our knowledge there currently exists no publicly available conceptual classification that models barriers to behavior change.

An important effort is the human behavior taxonomy from the World Health Organization [2] (WHO) [15], developed based on the knowledge of the WHO and the International Classification of Functioning (ICF), Disability, and Health, it includes a full definition of its classes, based heavily on the U.S. National Cancer Institute (NCI) Thesaurus and the Oxford English Dictionary [16].

The Health Behavior Change Ontology (HBCO) was built for a project aiming to establish an automated dialogue between a psychologist and a user to provide behavioral counseling [17], this ontology has strengthened the linkage between theoretical and practical parts, but few practical implementations exist [18], meaning there is currently no specific strategy providing a reusable behavior change ontology in practice.

As our conceptualization must refer to the model of the person for whom the behavioral change techniques need to apply, it is useful to explore the ontologies which explicitly model "users", in terms of their profile, characteristics, and sometimes also their behavior. One example of a user ontology is the General User Model Ontology (GUMO) [19], which is imported in our ontology. Also, there exist several other ontologies that encapsulate wider aspects of user (human) activities, like the User Navigation Ontology (UNO) [20] which is a GUMO extension, or OntoPIM (Ontology Personal Information Management) which describes various users' dimensions and shares a lot of concepts with GUMO [21].

3. Building Personal Health Knowledge Graph

The creation of the FuS-KG presented in this paper started from HeLiS [1] (briefly presented in Section 3.1), an existing ontology modeling the healthy lifestyle domain. The HeLiS ontology has been created by applying the METHONTOLOGY [22] ontology engineering methodology.

[2]https://www.who.int/classifications/drafticfpracticalmanual.pdf

Hence, the modeling of the three modules described below followed the same process involving four knowledge engineers and seven domain experts from the Trentino Healthcare Department for achieving our goal. More precisely, three knowledge engineers and four domain experts participated in the ontology modeling stages (hereafter, the modeling team), while the remaining knowledge engineer and three domain experts were in charge of evaluating the ontology (hereafter, the evaluation team). Since the development of the HeLiS ontology required the involvement of the experts in-situ, the adoption of METHONTOLOGY was driven by the necessity of adopting a methodology with a clear definition of the tasks to perform. Other methodologies, like DILIGENT [23] and NeOn [24], were also considered, however the characteristics of such methodologies, like the emphasis on the decentralized engineering, did not fit our scenario well.

METHONTOLOGY is composed by seven stages, namely *Specification*, *Knowledge Acquisition*, *Conceptualization*, *Integration*, *Implementation*, *Evaluation*, and *Documentation*. We summarize the activities performed in each stage within the following paragraphs.

Specification. The purpose of FuS-KG is two-fold: (i) providing a set of conceptual modules detailing several aspects connected to the representation of users' FSI; (ii) fostering the design and development of AI-enabled systems towards the implementation of behavior change strategies in patients affected by specific barriers.

Knowledge Acquisition. The knowledge was acquired in two ways: (i) we organized a set of focus groups with the domain experts for acquiring the main concepts and for building the first version of the graph; and, (ii) we analyzed the literature on behavior change strategies and techniques for detailing our model and for disambiguating possible inconsistencies that came to light during the focus group.

Concerning enablers and barriers, the modeling team defined which are the main types of both enablers and barriers, presented in the state of the art, relevant for supporting the development of third-party behavior change applications. The conceptualization of barriers and of the different states of change has been created by extracting knowledge from domain-specific unstructured resources [25, 26]. During this step, the main challenges were related to the creation of the *enablers* module where we had (i) to distinguish between strategies and techniques and (ii) to detect duplicate knowledge. Indeed, several notions defined within the behavior change area present conceptual overlaps that, from the ontological perspective have to be removed.

Concerning argumentation, we defined which are the main concepts that can drive the creation of motivational dialogues for obtaining FSI from users, or for generating motivational messages tailored to users for supporting them to overcome specific barriers in order to achieve their goals to improve their health. With the involvement of domain experts, we defined which is the role of each argument type within a motivational dialogue and how such arguments are semantically linked with enablers or barriers.

Conceptualization. The conceptualization of the three ontology modules was split into two steps: (i) covered by the knowledge acquisition stage, concerned the modeling as concepts or properties of most of the terminology collected into the ontology; (ii) consisted of deciding how to represent, as classes or as individuals, the information collected from unstructured resources. The latter activity has been done, in particular, on the enablers where the distinction between concepts and individuals is, sometimes, very small. Then, we modeled the properties representing the different relationships between the defined concepts.

During this stage, we relied on several ontology design patterns (ODP) [27], sometimes renaming some properties upon the request of domain experts. In particular, we exploited the logical patterns *Tree* and *N-Ary Relation*, the alignment pattern *Class Equivalence*, and the content patterns *Parameter*, *Time Interval*, *Action* and *Classification*.

Integration. The integration of the ontology has two objectives: (i) to align them with a foundational ontology, which was satisfied by aligning the root concepts of both extensions with the ones defined within the DOLCE [28] top-level ontology; and (ii) to link it with the Linked Open Data (LOD) cloud, satisfied by aligning our ontology with the UMLS Knowledge Base [3] that has been recently included within the LOD cloud thus working as a bridge between the latter and the three ontology modules.

Implementation. The created FuS-KG is represented by means of several ontological modules 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 [29], while the exposure of the ontology is granted by the services available from the HeLiS ontology website.

Evaluation. The evaluation procedure was conducted by the evaluation team.To evaluate our FuS-KG we adopted the metrics described in [30, 31, 32, 33, 34]: *Accuracy*, *Adaptability*, *Clarity*, *Completeness*, *Computational Efficiency*, *Conciseness*, *Consistency/Coherence*, and *Organizational fitness*. All the evaluation criteria obtained positive scores. Then, we also performed a further qualitative check by using the OOPS! pitfall scanner [4] in order to fix all minor issues.

Documentation. The documentation of the FuS-KG has been done from two perspectives: (i) a document prepared during the whole modeling process by the people involved in the construction process; (ii) a document created to ease the readiness of the FuS-KG for users, which was generated by using the LODE [5] system and available on the FuS-KG website.

3.1. The HeLiS Ontology

The personal health knowledge graph described in this paper and used within our virtual coaching platform has been built by starting from the HeLiS [1][6] ontology, a state-of-the-art conceptual model for supporting healthy lifestyles, defining the dietary and physical activity domains together with entities that model concepts concerning users' profiles and the monitoring of their activities. [1] provides details about the conceptual model and the methodology for building the model. Here, we provide an overview of the HeLiS ontology by introducing the concepts modeling users, meals and physical activities, monitoring rules, and detected violations that are referred in this paper. Moreover, we briefly recap the main concepts involved into the core module of HeLiS in order to better link them with the ones defined in the extensions presented below.
Figure 1 shows the main concepts defined within the core module of the HeLiS ontology.

Food is responsible for modeling the instances macro-grouped under *BasicFood*, which includes also *Nutrient*s' information (carbohydrates, lipids, proteins, minerals, and vitamins) and *Recipe*,

[3]https://www.nlm.nih.gov/research/umls/
[4]https://oops.linkeddata.es/
[5]http://www.essepuntato.it/lode
[6]http://w3id.org/helis

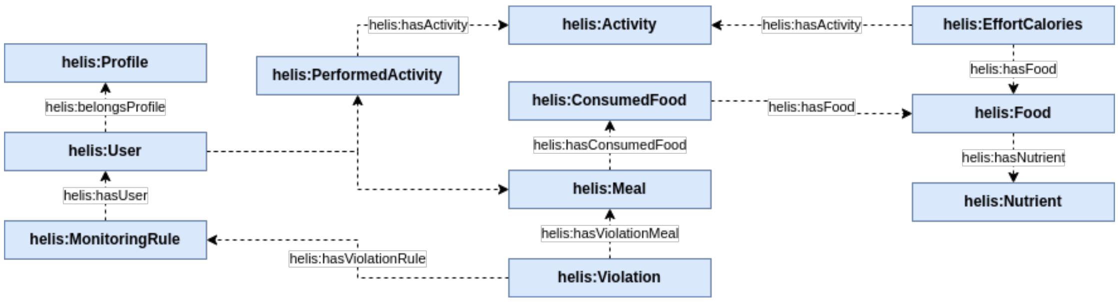

Figure 1: The main concepts of the HeLiS core ontology.

which describes complex dishes (such as *Lasagna*) through a list of ⟨*BasicFood*, quantity⟩ pairs.

Activity contains *PhysicalActivity* with 856 activities sorted in categories. For each activity, we provide the amount of calories consumed per minute for each kilogram of user's weight and the MET (Metabolic Equivalent of Task) value expressing the energy cost of the activity.

MonitoringRule describes the parameters defining how users should behave if adhering to health goals (aka "rules"), and *Violation* contains the results of reasoning activities exploited for generating users' advises and recommendations.

User branch contains the conceptualization of user information and it enables the representation of all users' events (consumed foods and performed physical activities) and the linking of each violation to the corresponding user. Users' events are represented via the *Meal*, *ConsumedFood* and the *PerformedActivity* concepts. The last two concepts are reified relations enriched with attributes for representing the facts that a user consumed a specific quantity of a food or performed an activity for a specific amount of time.

3.2. The Enablers Module

The *Enablers* module contains the main concepts enabling a user to start a behavior change process, namely *Intervention*, *Treatment*, *Strategy*, and *Technique*. This module has been built by starting from two of main references available in the field indicated by the domain experts [25, 26]. Figure 2 shows the main concepts defined within the enablers module of FuS-KG.

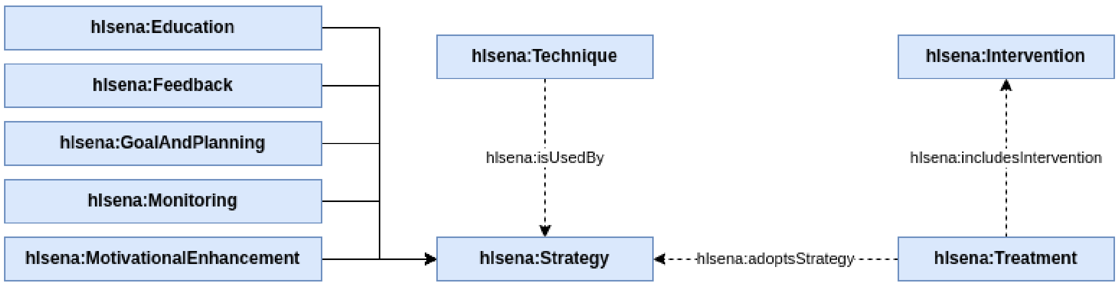

Figure 2: The main concepts of the FuS-KG enablers module.

The *Intervention* concept follows the definition provided in [26] and it refers to a single action performed during a *Treatment*. As example, in behavior change scenario where a patient affected by diabetes has to monitor their glycemic index after each meal and provide the observed value into a mobile application, the reminder to do this action is an instance of the *Intervention* concept.

The *Treatment* concept is defined as the unfolding of all *Intervention*s performed to allow users achieving their aim. An example of *Treatment* is the set of *Intervention*s performed by an AI-enabled system to persuade a patient about following the Mediterranean Diet.

The *Strategy* concept subsumes the five main strategies that can be implemented during a behavior change process: (i) *Education* models the aim to increase the user's understanding of their past and current state, and of the steps required to achieve the future state (e.g., to provide information and/or instruction for behaving in a proper way); (ii) *GoalAndPlanning* refers to future planning to achieve desired future states (e.g., activity scheduling and/or setting tasks of progressively greater difficulty); (iii) *Feedback* models the information on current and past states provided to the users about their condition and/or actions; (iv) *Monitoring* defines the action of recording past or current user's states (e.g., current nutritional behaviors and/or activity events); and, (v) *MotivationalEnhancement* refers to interventions that increase the likelihood that the user will engage in specific behaviors related to treatment goals or use the application in the future. Each instance of the *Strategy* concept has to be associated with the instance of the *Treatment* concept adopting it, that can be done by instantiating the *adoptsStrategy* object property.

Finally, the *Technique* concept indicates an observable, replicable and irreducible component of a *Strategy* used within a *Treatment* designed to alter or redirect causal processes that regulate behavior. A *Technique* is an "active ingredient" (e.g., feedback, self-monitoring, reinforcement) of a *Strategy* and it can be used alone or in combination and in a variety of formats. Within FuS-KG, we defined 19 types of techniques subsuming the *Technique* concept. Moreover, each instance of the *Technique* concept has to be associated with the instance of the *Strategy* concept adopting it, done by instantiating the *isUsedBy* object property.

3.3. The Barriers Module

The Barriers ontology module is composed of four main branches: (i) the classification of the barriers, (ii) the representation of the different states of changes, (iii) a new taxonomy for classifying the list of physical activities defined within barriers and (iv) the representation of the patients.
Figure 3 shows the main concepts defined within the barriers module of FuS-KG.

The *Barrier* concept is the root concept of the first branch and it subsumes six macro-categories of barriers: (i) *EnvironmentBarrier* refers to the hinders related to performing an action due to obstacles connected to the circumstances in which the action takes place, examples could relate to the weather, (like unfavorable climatic conditions), to money (like the cost of the equipment need), to security issues (e.g. the lack of safety), etc.; (ii) *HealthBarrier* concerns the presence of some disease preventing to perform or complete a specific action, it enables the possibility of importing external medical knowledge bases (e.g. the UMLS) thus connecting barriers with medical knowledge that can be exploited at reasoning time (such as asthma, chest pain, etc.); (iii) *PersonalBarrier* represents barriers associated with real-life situations (e.g. job conditions) that obstruct the performance of specific actions; (iv) *PhysicalBarrier* and (v) *PsychologicalBarrier*

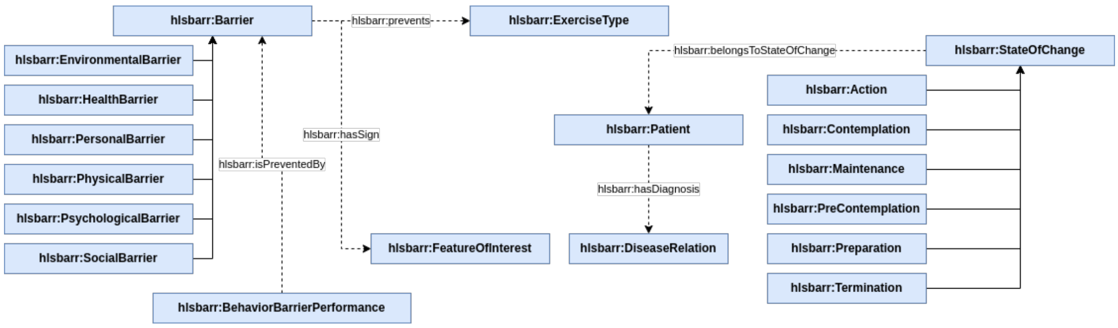

Figure 3: The main concepts of the FuS-KG barriers module.

are related to hindrances given by physical pain (e.g. knee injury) or emotional status (e.g. fear) that block a person from performing specific actions; and, (vi) *SocialBarrier* mainly refers to the possible lack of support from people close to patients (parents, friends, etc.).

The second branch consists of the abstract representation of the Transtheoretical Model of change (TTM) [35]. TTM describes the different stages of change that an individual can be in, and is used by clinicians for supporting the behavior change process. The main concepts we defined are *StateOfChange* that is the root concept of this branch, and then the six stages in which a *Patient* can be: *PreContemplation*, *Contemplation*, *Preparation*, *Action*, *Maintenance*, and *Termination*. Moreover, we defined the property *hasBehavior* that is used as a reification of the status in which a *Patient* is during a specific *Timespan*.

The third branch provides a new taxonomy of physical activities defined in the core of barriers. This extension provides physical activities rooted in the *ExerciseType* concept which are classified following different perspectives: the energetic system generally used for performing the action (e.g. aerobic or anaerobic), if the activity required flexibility abilities, if the activity corresponds to an athletic sport, and whether the activity is performed indoors or outdoors. Additionally, the intensity (or effort) level of each activity can be specified by the property *hasIntensity* that associates an activity to an *IntensityLevel* (i.e. light, moderate or vigorous). The rationale of this classification is given by the necessity of defining the relationships between barriers and physical activities. For instance, in case a user suffers from asthma, such a *HealthBarrier* may obstruct the performance of some *OutdoorActivity*.

Finally, the fourth branch consists in the representation of the user as a *Patient*, which helps to identify the characteristics of each user and specify whether they suffer from a certain disease which could influence the behavior of the user.

3.4. The Arguments Module

The arguments module aims at supporting efficient and effective dialogues for motivating behavior change. It has been developed following the model described in [36], and it is structured to help the formulation of persuasive dialogues [37] aiming at motivating a user/patient toward a healthier lifestyle (or a particular lifestyle goal). The module collects various arguments, i.e. different types of sentences, that are used to model dialogues providing beliefs a person may have concerning healthcare issues and the appropriate responses motivating behavior change.

Therefore, each argument can have various properties that help to define its type, function, topic, context, utility and the healthcare problem or solution it refers to.
Figure 4 shows the main concepts defined within the arguments module of FuS-KG.

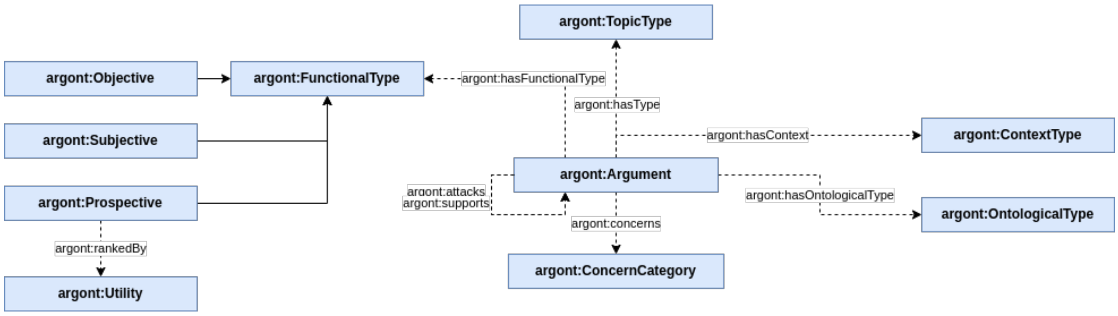

Figure 4: The main concepts of the FuS-KG arguments module.

More in detail, the concepts defined in the arguments module are *Argument*, *Concern_category*, *Context_type*, *Functional_type*, *Ontological_type*, *Topic_type* and *Utility*. The *Argument* concept represents the argumentations that are used in the generation of the dialogues, these sentences are properly characterized by properties that specify the role of each argument in a dialogue and how they relate to each other. For example, *do physical activity regularly*, *an active lifestyle and a balanced diet are the best medicine to live longer and better* or *not having time to exercise*.

The *Concern_category* represents healthcare problems (such as *Stress* and *Heart Problems*) and solutions (like *Healthy diet* and *Physical Activity*) which are useful to indicate which problem and/or solution an argument relates to, in fact the property *concerns* connects arguments to the associated healthcare category. It is important to notice that some arguments can concern more than one problem or solution and in some cases they could refer to both problems and solutions. For example, the *do physical activity regularly* '*concerns*' *Stress*, because doing regular activity helps to reduce stress, while *not having time to exercise* '*concerns*' *Physical Activity* because its an obstacle to be active.

The *Context_type* concept represents specific contexts that can refer to location, age or status of the user; these are used to contextualize arguments limiting the domain in which an argument is true and can be used. For example, in healthcare a solution for a problem for some people can be damaging for others (e.g. people having a particular health status or age). It's thus important to be able to define the context of an argument and the property *hasContext* has been defined for that purpose.

The *Functional_type* concept specifies the role an argument can have in the dialogue (for example, whether the argument is a goal a person may have, some kind of evidence regarding a healthcare problem, an opinion of the user, etc.). *Functional_type* is then subdivided in *Objective* (undeniable information that could be based on well-established medical or scientific knowledge or current healthcare guidelines), *Prospective* (goals a person might have for themselves or for the welfare of others) and *Subjective* (controvertible or false information, opinions and beliefs). The property *has_functional_type* connects the arguments to their functional type. For example, *do physical activity regularly* has the function of a persuasion goal, while *not having time to* *exercise* is a subjective argument that expresses an opinion of a possible user.

The *Ontological_type* defines the kind of the belief expressed in an argument. The types defined in the module are: *attitude* that concerns opinions on the attitude of a person toward a healthcare problem and/or solution; *background* that specifies additional facts or opinions on some healthcare problems or solutions; *benefit* that describes events having a positive payoff in relation to solving a healthcare problem; *capacity* that concerns the ability of a person of addressing a healthcare problem; *cause* that gives facts or opinions regarding the cause of a healthcare problem; *commitment* that describes a pledge a user may take in order to solve a healthcare problem; *community* that concerns beliefs on the user's community; *cost* that gives facts or opinions regarding the possible costs for a healthcare solution; *motivation* that gives an opinion on the user's motivation for addressing a healthcare problem; *myth* that concerns beliefs that are commonly thought true regarding a problem or solution but that are in fact false; *obstacle* that concerns barriers a user may face trying to achieve a healthcare solution; *opportunity* that concerns facts or opinions related to the opportunity of achieving a healthcare solution; *risk* that describes possible negative events that can occur from a healthcare problem; and *side-effect* that concerns facts or opinions on possible side-effects to a healthcare solution. Then, the property *has_ontological_type* is used to connect an argument to its type. For example, *an active lifestyle and a balanced diet are the best medicine to live longer and better* is a *benefit*, while *not having time to exercise* is defined as an *obstacle*.

The *Topic_type* concept represents the topic and subject matter used to classify the content of the arguments. In fact, knowing the topic of an argument is helpful in choosing arguments that may interest some users better then others, thus supporting the creation of more effective and persuasive dialogues.

Finally, the *Utility* concept refers to the usefulness of a certain goal, it specifies how beneficial a goal may be for the user and it could also be used for ranking goals. The *ranked_by* property is used to connect a goal-argument to the measure of its utility.

After defining the concepts used to characterize the arguments and in order to facilitate the creation of a persuasive dialogue we modeled two properties (i.e. *support* and *attack*) that connect two arguments. The *support* property specifies that an argument helps to support another, for example *an active lifestyle and a balanced diet are the best medicine to live longer and better* '*supports*' *do physical activity regularly*.Instead, the *attack* property is used to define that an argument challenges or attacks another argument. For example, *not having time to exercise* '*attacks*' *do physical activity regularly*.

In order to be able to create effective dialogues it's very important to have numerous arguments in fact, after having constructed the structure of the argument module, we instantiated the argumentations in the healthcare domain, collecting material from various sources both from domain experts and online (concerning the physical activity [7] and healthy diet [8] domains).

[7]https://www.physio-pedia.com/Barriers_to_Physical_Activity
[8]https://www.sanihelp.it/

4. Scenarios Integrating The Personal Health Knowledge Graph

In this Section, we describe two real-world scenarios that adopted FuS-KG: (i) FuS-KG has been used for performing real-time reasoning to support behavior monitoring; (ii) FuS-KG is integrated into a chatbot aiming to populate the argument module with knowledge harvested from real users through interviews.

4.1. The Integration Within The HORUS.AI Platform

The ontology modules described in Section 3 are exploited for monitoring the functional status of a user through their integration into a SPARQL-based reasoner used for detecting undesired situations within users' behaviors. When inconsistencies with respect to the encode guidelines are detected, the knowledge base is populated with individuals of type *UndesiredEvent* that, in turn, can be used for providing feedback to users. The integrated reasoner relies on the architecture implemented in RDFPro [38] and reasoning can be triggered in two ways: (i) each time a new data packages is acquired, or an existing one is modified in the knowledge base, the reasoner is invoked for processing the new, or updated, information;(ii) at the end of a specific timespan, such as the end of a day or of a week, with the aim of checking the overall user's behavior in such timespan, and it works on a collection of data labeled with a timestamp valid within the considered timespan. RDFPro has been chosen for two main reasons: (i) its architecture allows the integration of custom methods into reasoning operations for performing mathematical calculations on users' data, and for exploiting real-time information acquired from external sources without materializing them within the knowledge repository; and (ii) efficient analysis performed on RDFPro demonstrated the suitability of this reasoner with respect to other state-of-the-art reasoners into a real-time scenario [1].

We organized the reasoning in two phases: (i) the *offline* phase consists in an one-time processing of the *static* part of the ontology (i.e. monitoring guidelines, barriers, arguments, activities) when the system starts to materialize the ontology deductive closure, is based on OWL 2 RL and some additional pre-processing rules that identify the most specific types of each individual defined in the static part of the HeLiS ontology ABox which also greatly helps in performing the aggregation operations during the online reasoning phase; (ii) the *online* phase concerns each time the reasoning is triggered by a user event (e.g., a new data package is entered by a user) or by a time event (e.g., a specific timespan ended) where the user data is merged with the closed ontology and the deductive closure of the rules is computed, the resulting *UndesiredEvent* individuals and their RDF descriptions are then stored back in the knowledge base.

4.2. The Integration within an Argument Collection Chat-bot

The argument module can be easily populated with instances of arguments harvested with the use of a chatbot, an effective tool in argument mining as it explicitly asks users for (counter) arguments about a topic. In addition, in some cases chatbots are a necessary choice, as open textual discussions about a very specific topic are not always available. For example, in the healthy lifestyle domain, the (counter) arguments related to users' barriers, capacities and suggestions from experts (such as, nutritionists and psychologists) can be found in forums, social networks or in specialized journals. Therefore, the argument mining is difficult to perform and a chatbot is a more effective solution [39, 40, 41]. Here, we show how we used a chatbot for populating the argument module with arguments regarding the Mediterranean Diet and the physical activity.

The Healthy Lifestyles Domain. We harvested arguments regarding barriers and enablers of specific prescriptions of the Mediterranean Diet [42] and of a regular physical activity[9] which regard (i) the number of daily portions of fruit, vegetable, fish, milk, evo; (ii) the number of weekly portions of red meat, cured meat, sweets and sugary drinks; and, (iii) the time (minutes) of daily and weekly physical activity.

The Involved Users. The users were Computer Science students of the local university who voluntary participated in the collection of the arguments. This sample of population presents some bias (similar age, sex and school degree) that do not affect our goal as we aim at an initial population of the argument module with the use of a bot without covering all the representative arguments about healthy lifestyles.

The Chatbot. The chatbot is inspired by [39] and starts by asking some profiling questions (age, gender and school title). Then, the users were asked whether they respect each of the above prescriptions about healthy lifestyles with a simple yes/no click button. Positive cases are then asked about textual suggestions (i.e., arguments) they would give to friends that would like to respect such prescription but fail. Negative cases are deepened by asking (open-text format): (i) why they do not follow that particular prescription; (ii) suggestions for friends that want to follow such a prescription; (iii) whether such suggestions would hold for them; and, (iv) if the previous point is false, what would they consider a valid suggestion. With this dialogue procedure we collected arguments from both positive and negative cases.

Processing the Arguments. A manual checking of the arguments has been performed to discard duplicate arguments (i.e., arguments with the same meaning). This operation can be performed by checking the semantic similarity of arguments with a universal sentence encoder [43]. The arguments were then manually tagged with their functional and ontological types.

The Gathered Arguments. The chatbot provided 270 (counter) argument instances for the argument module each one with his own functional and ontological types. Examples of arguments are the barriers to following a particular prescription, such as, lack of time, forgetting about the prescription, too much effort or dislike of some food.

5. Conclusion and Future Directions

In this work, we presented three modules extending the HeLiS ontology providing a conceptualization of *Enablers*, *Barriers* and *Arguments*. These modules aim to enhance the AI capabilities of coaching systems designed for supporting the monitoring of users' functional status. Beside the description of the three modules, we shown how such modules have been integrated into a couple of simple but relevant use cases. As mentioned in Section 1, this work represents a first step toward the long-term achievement of having a full-fledged AI coaching system. Future efforts will be focused on three main directions: (i) to expand the knowledge base involving

[9]https://sites.google.com/site/compendiumofphysicalactivities/home and http://www.hhs.gov/

domain experts and exploring techniques that leverage data mining to detect hidden information from large textual data; (ii) to integrate the ontology with natural language understanding (NLU) and natural language generation (NLG) components to be able to automatically transform natural language texts into their equivalent semantic argument-based representation; and, (iii) to evaluate the system into a real-world coaching scenario.

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