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Towards a Collaborative Ontology-based Decision Support System to Foster Healthy and Tailored Diets

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Abstract. Nutrition-related diseases can considerably contribute to many different health-related problems and can impact on several segments of the population. Promoting balanced diet plans is therefore pivotal; however, this is not a trivial task as it requires different stakeholders (nutrition experts, agro-industrial businesses and consumers) to cooperate. This work introduces a prototypical ontology-based decision support system to enable such a cooperation, allowing nutrition experts to rely on a support tool when developing diet plans, consumers to receive tailored suggestions and to be informed regarding new food products that could have an effect on specific their health condition, and agro-industrial companies to divulge characteristics of novel food products and their expected effects. These stakeholders can also exchange comments, suggestions and observations. The decision support system relies on widely-adopted ontologies and its use is introduced by two scenarios.

Keywords: decision support system, ontology engineering, food ontology, nutrition ontology.

1 Introduction

Unhealthy nutrition can considerably contribute to many different health-related problems. Nutritional diseases – i.e. any nutrient-related condition that causes illness to humans – can range from obesity to eating disorders and include chronic diseases such as cardiovascular disease, cancer, diabetes mellitus hypertension; another branch of nutritional diseases encompasses metabolic disorders, food allergies and intolerances. Moreover, nutrition can play a pivotal role in influencing and/or preventing other conditions, such as stroke, osteoporosis and mental conditions (depression, anxiety) [1].

According to the World Health Organization (WHO) [2], Europe is facing an increase in overweight and obesity (especially in southern countries), with particular incidence among children and adolescents: the age-standardized prevalence of overweight in EU amount to 58%. Relevant noncommunicable and diet-related

diseases – diabetes, cardiovascular diseases, cancer, chronic respiratory diseases, mental disorders – account for more than 77% of deaths in EU [2]. With regard to ageing population, the EU reported that over 20 million elderly are at risk of undernutrition, a situation that – associated with other health conditions – can impact on social care costs up to 120 EUR billion per year and can potentially aggravate age-related conditions [3].

For these reasons, researches and clinical personnel stressed the importance of following a healthy and balanced diet to maintain or improve a healthy status. This recommendation is particularly relevant for those segments of the population that are more vulnerable to chronic conditions or suffer from allergies and intolerances, like the elderly, people with an impaired immune system, individuals characterized by frailty or neuromuscular conditions, etc. Promoting healthy and balanced diet plans can foster the prevention of the above-mentioned diseases and conditions, but the task of developing and implementing these diet plans is not easy. In the past ten years many mobile phone apps have been developed with the aim of supporting people in engaging themselves in a healthier nutrition, but the majority of them did not reach the goal of fostering the adoption of a balanced nutrition and failed in proving their effectiveness in both medium and long term [4].

Therefore, health professionals remain the most reliable and qualified option in creating healthy diets, while agro-industrial companies strengthen their efforts in developing novel and nutritionally-balanced food products – some of them specifically dedicated to certain segments of the population. In fact, as every person has his/her own health condition, each diet plan needs to be tailored on the individual's specific needs. This complex process could benefit enormously from the cooperation of both clinical and non-clinical professionals, who need to be provided with the means to exchange different data (health-related, food products' and nutrition-related data) in a collaborative effort involving different domains of knowledge. Reaching this goal could therefore enable the development of customized and well-balanced diet plans, specifically studied on the needs of the individuals.

A promising approach for cross-domains knowledge exchange is the ontology, a shared and formal logic-based description of the concepts composing a domain, and of the relationships that hold between them [5]. The ontology, cornerstone of the Semantic Web technologies, can be used to provide information interoperability among different stakeholders. Its adoption is well-established in different health-related domains, and it can be used as backbone for Decision Support Systems (DSSs), as it allows to elicit new pieces of information through semantic reasoning processes.

This work introduces a prototypical ontology-based DSS to enable the cooperation between health professionals, food and nutrition experts and agro-industrial businesses. The DSS is one of the expected results of the Lombardy Region research project sPATIALS³, started in 2020 and aimed at enhancing agro-industrial productions for a safer, healthier and sustainable nutrition. The ontology behind the DSS allows health professionals, nutrition experts and agro-industrial businesses to exchange knowledge related to both existing and innovative food products' characteristics and their expected effects on health. The knowledge formalized in the DSS serves as a supporting tool for nutrition professionals – as they can have more information related to food products and their effects – and for the consumers, who

can benefit from tailored dietary recommendations. Moreover, thanks to the contribution of food companies, the DSS can also encompass the characteristics of novel food products, specifying the segments of the population who could benefit most from them. All the above-mentioned stakeholders can exchange comments, suggestions and observation among them.

The remainder of this paper is organized as follows: Section 2 delves into the ontology – backbone of the DSS and named Nutrition and Health Ontology (NutrHe) –, describing its modules in detail (the standards they rely on and the long-standing ontologies it reuses). Section 3 provides two scenarios that help clarifying how the DSS works with health professionals, consumers and agro-industrial businesses. Finally, the Conclusions summarize the main outcomes of this paper and sketch the future directions of this research.

2 Related Work

Domain ontology is widely adopted in DSSs, since it allows to formalize knowledge and enables semantic reasoning. There exist many examples of ontology-based DSS in healthcare, and some of them are focused on nutrition-related problems – both for general and specific target users. Bianchini et al. [6] designed a recommender system to provide users with personalized and healthy menus, taking into account user's preferences and medical prescriptions. An ontology is used to combine people's profile (health and cultural constraints) with recipes. In the context of a semantic-based platform for supporting healthy lifestyles, Dragoni et al. [7] leveraged ontology to provide a description of foods and their macronutrients components (carbohydrate, protein, lipids, etc.). Similarly, NutElCare [8] provides a representation of foods' macronutrients into an ontology with the aim of providing healthy recommendations to elderlies.

Ontology-based technologies cover a relevant role also in many other food-related research fields. Subramaniaswamy et al. [9] developed a food recommendation system within tourism activities that leverages on ontological representations of users' profile; by comparing different users and adopting filtering mechanisms, the system is able to provide each user with a list of tailored food recommendation. In the field of agriculture, [10] described a DSS aimed at help farmers to plan intercropping, while [11] proposed a DSS to evaluate food quality in agri-food chains.

NutrHe tries to link users' health condition and foods' characterization recurring to widely-adopted ontologies, with the aim of creating a DSS that can be used by different stakeholders. While nutrition professionals can use NutrHe as a support tool in decision making, agro-industrial companies can add their products and consumers can take advantage of tailored suggestions.

3 Development of NutrHe

NutrHe is developed by following the NeOn Methodology for ontology engineering [12]. As many methodologies for ontology development, NeOn fosters the reuse of already existing and long-standing models, which are already adopted in many other projects. NutrHe is divided into four main modules: the first dedicated to the Person, the second dedicated to Food description and the third describing the effects of foods on human health; a fourth module provides a set of rules to trigger some inferences (as further illustrated in Sect. 2.4). The ontology is developed using the editor Protégé [13] and exploits Resource Description Framework (RDF) [14] and Ontology Web Language (OWL) [15] – W3C recommendation languages – with Semantic Web Rule Languages (SWRL) [16].

3.1 Persons and Health Conditions Module

The description of the consumers – persons characterized by a specific health condition – relies on the Friend Of A Friend (FOAF) vocabulary [17] to represent personal data (age, place of birth, contacts, tax identification number, etc.): FOAF is widely adopted due to its simplicity and it allows to formalize the most relevant pieces of information related to a person. NutrHe reuses a limited number of FOAF entities (the `foaf:Person` class and the properties `foaf:age`, `foaf:givenName`, `foaf:familyName`, `foaf:gender`) and adds a few properties to complete a consumer's description (`nutrhe:TINnum`, `nutrhe:address`, `nutrhe:email`, `nutrhe:phone`). Each person is represented with an individual (belonging to `foaf:Person` class) and is linked to an individual representing a health condition via the `nutrhe:healthCondition`.

A person's health condition is described by recurring to two WHO's standard classifications: in fact, to increase health information interoperability and to enhance the cooperation between medical and non-medical professionals, NutrHe adopts the International Classification of Diseases and Related Health Problems (ICD-11) [18] and the International Classification of Functioning, Disability and Health (ICF) [19]. The ICD enables a classification of diseases for diagnostic purposes and can also provide the means to record and analyze the general health situations of populations groups (monitoring the incidence of diseases and other health problems). The ICF focuses instead on the formalization of the functional description of an individual, conceptualizing the interactions between a person's health condition and the environment. The classifications present a similar taxonomical structure: they divide their respective domains of knowledge into Chapters (24 for the stem codes of ICD, and 30 for all the four components constituting the ICF), which are further deepened by subcategories (as exemplified by the excerpts of ICD and ICF reproduced in Figure 1). The deeper is the subcategory, the more detailed is the information provided by the code.

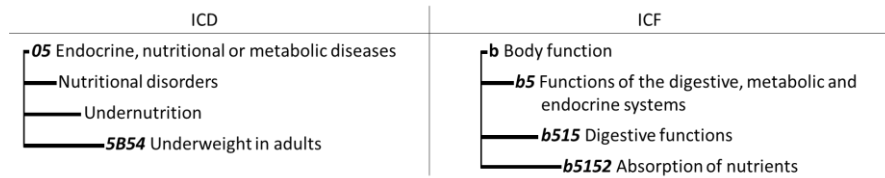


Fig. 1. Two excerpts of the ICD (left) and ICF (right) classifications; both the WHO standards organize the domains of knowledge into a hierarchical taxonomy, starting from the most general category (the “chapters”) to the most specific. In this figure, “05 Endocrine, nutritional or metabolic diseases” and “b5 Functions of the digestive, metabolic and endocrine systems” are chapters of – respectively – ICD and ICF; “b Body functions” represents one of the four ICF components.

The ICD stem codes comprised in the 24 chapters (for a total of more than 10.000 codes) can be used alone to represent diseases and conditions, while the 1400 ICF codes can provide a description of the functioning of a person – even within a specific context. Due to their structure, degree of diffusion among health and non-health professionals, and granularity in representing knowledge, both the classifications have been modelled into two ontologies, which are used in the development of ontology-based DSSs involving the management of health-related information [20, 21]. NutrHe prototype reuses parts of these classifications, specifically: for the ICD, the first 15 chapters, for the ICF the whole Body functions component.

Each ICD and ICF code is represented in NutrHe with a class and the hierarchical relationships among classes are described using the `rdfs:subclassOf` property. The bottommost classes – those representing 4- and 5-digits ICF codes and 4-character codes in ICF – are populated with one individual, named after the class.

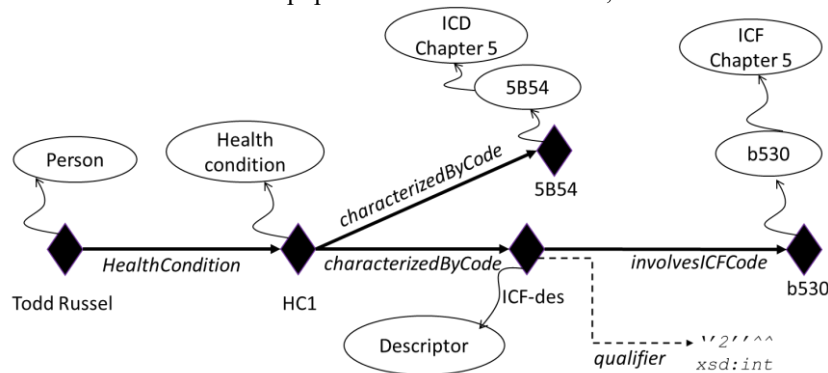


Fig. 2. A graphical representation of a person and his health condition; since in NutrHe it is possible to specify a qualifier for ICF codes, to avoid reification (following an ontology design pattern presented in [22]) a descriptor individual is adopted. Concepts are represented with ellipses, individuals with diamonds, and roles with arrows (dashed arrows indicate datatype properties, full-line arrows indicate object properties); the type of an individual is stated with a curved arrow.

A health condition, represented as an individual of the class `nutrhe:HealthCondition`, can therefore be specified using the

`nutrhe:characterizedByCode` followed by the individuals representing the ICD or ICF codes – the latter specified by a qualifier ranging from 0 (no impairment) to 4 (complete impairment). Figure 2 provides a graphical representation of a person's health condition in NutrHe.

3.2 Foods and their Characteristics Module

Formalization of foods reuses the Food Ontology (FoodOn) [23], a large and comprehensive model formalizing more than 9.600 food products in a formal hierarchy. FoodOn is compatible with the Basic Formal Ontology and formalizes classes and properties for the description of food products, their transformation processes and their packaging or containers. NutrHe reuses FoodOn since it allows to describe multiple points of view related to food products: for instance, crisps – potato chips derived from slicing and frying potatoes – can be classified as a `foodon:40370` – potato crisps from potato slice (following the Foodex2 classification of the European Food Safety Authority modelled in FoodOn), and also as a fried product (`foodon:food(fried)`) to represent it as a `foodon:food_product_by_process`, or as a `foodon:potato_crisps` product (subclass of `foodon:snack_` (potato-based)).

3.3 Food and Health Module

NutrHe's third module links foods from `foodon:food_product_type` to the diseases and conditions represented with ICD and to the impairments of the body described with ICF. NutrHe captures the relationships between food products and health conditions adopting two object property, `nutrhe:canHarm` (and its inverse property `nutrhe:worsenedBy`) and `nutrhe:hasBenefitsOn` (and its inverse property `nutrhe:benefitsFrom`). The first property links those foods that are known to worsen a specific disease, while the second is used to link products whose effects can be good for a specific condition. For instance, a salty food product, like a `foodon:hungarian-type_salami`, or a fat product, like `foodon:butter`, are linked to the ICD code BA00 (Essential hypertension) via the `nutrhe:canHarm` property (and, therefore, the same ICD code is linked to the same food product via `nutrhe:worsenedBy`). On the contrary, `foodon:beet(whole, raw)` and `foodon:tomato(whole, raw)` are linked to the same ICD code via `nutrhe:hasBenefitsOn`. Thanks to FoodOn's structure, it is also possible to state to account for the same food being prepared differently – and, therefore, having different effects on a certain health condition. For example, a dish (represented as an individual) composed of a piece of `foodon:salmon(frozen)` which is `foodon:output_of` a `foodon:steaming_without_pressure` (a subclass of `foodon:food_cooking_process`) can be linked to ICD BA00 via the

`nutrhe:hasBenefitsOn` property. Instead, a dish made of `foodon:salmon(frozen)` undergone a `foodon:deep-frying_process` can be linked to ICD BA00 via the `nutrhe:canHarm` property. In this way, NutrHe can account also for complex foods and their cooking methods, which can deeply modify foods' effects on health.

The aim of this module is to represent a “map” of the relationships between food products and specific health conditions. This task requires expertise from nutrition professionals and food product-related knowledge from agro-industrial companies – especially for complex food products which undergo to several different transformation processes. NutrHe prototype represents the relationships between osteoporosis (ICD code FB83.1), hypertension (ICD code BA00), IBS syndromes (ICD codes DD91.00, DD91.01), gastritis (DA42).

3.4 SWRL Rules

A set of SWRL rules is designed to help clinical personnel to determine food products that can be suggested to persons whose health condition is characterized by specific diseases or conditions. Simple rules like:

```
food_material(?dish), has_ingredient (?dish, ?ing),
foodon_product_type (?ing), hasBenefitsOn (?ing, ?code),
not (canHarm(?ing, ?code)) ICD_Code (?code), Person (?p),
healthCondition (?p, ?hc), characterizedByCode (?hc,
?code) -> potentialSuggestionFor (?dish, ?p)
```

can detect those food products containing any ingredient healthy for a person with a healthy effect on the same ICD (or ICF) code. The product is therefore suggested for a specific person, after medical personnel. A similar rule identifies food products containing any ingredient that could harm a health condition characterized by a specific ICD (or ICF) code.

A second set of rules checks for specific ICD (or ICF) codes (like, for example, the code describing hypertension) checks whether or not among food products suggested for a person (having the condition described by the code) the ingredients are processed with an unsuitable method, which may hinder the person's diet and health (as described in Sect. 2.3).

4 Scenarios

This Section introduces two scenarios with the aim of illustrating the use of NutrHe by different stakeholders.

Scenario 1: medical personnel and consumers. A nutritionist adopts an application based on NutrHe to understand whether some (complex) food products can harm or be benefic for one of his patient's health condition. Through automatic reasoning process, each food product modelled in the ontology is suggested (or advised against) for a specific individual, whose health condition is provided as an input and is

characterized by ICD and ICF codes. The nutritionist is also informed that new food products specifically designed for helping consumers characterized by the same health condition of his patient are now available. Through the DSS, the nutritionist can therefore evaluate them and insert them into his patients' diet plans. Moreover, the nutritionist can annotate other effects – not explicit in NutrHe – he observed and inform the food company of his findings. Consumers can receive tailored suggestions based on their health status, including the offer of new food products. Suggestions can be received through an application, which also shows consumers only the lists of harmful and benefic foods – thus hiding from them the complexity of the health condition modelling. Also consumers can annotate effects they observed and believe to be connected with a specific food consumption; in this way, the nutritionist could be informed of the alleged effects and evaluate them. NutrHe can facilitate the communication between patients and nutrition professionals, by letting the former aware of which foods can harm them and which can have a positive effect on their health; NutrHe – via application – can inform both consumers and clinical personnel whenever a new product is added to the ontology.

Scenario 2: agro-industrial companies and new products. Companies developing new food products can model them inside NutrHe. For example, if a company develops a new probiotic dietary supplement for consumers suffering from IBS syndrome, it can add the new product in NutrHe (using FoodOn classes) and can indicate the benefits the product is expected to have on the specific health conditions. Following the same pattern, a company producing nutraceutical prepared foods for elderly, can add its products (`foodon:prepare_food_product`) and model the expected benefits in the ontology. The products added in this way can be retrieved by nutrition professionals and consumers, as described in Scenario 1. The same company can also receive comments, suggestions and clinical observation by other stakeholders (consumers and nutrition professionals) regarding the effects linked to the consumption of their products.

5 Conclusions and Further Work

This paper described a prototypical ontology-based DSS designed for helping nutritionists in taking nutrition-related decisions, providing consumers with suggestions tailored on their health condition, and supporting agro-industrial companies in divulging novel food products specifically developed for target users. The main modules composing NutrHe and the decision behind its engineering are exposed, also taking advantage of explanatory scenarios.

Although the main components of the NutrHe ontology are identified, there are some further steps that need to be tackled before the DSS is fully developed. A first important step foresees the further development of the relationships between ICD and ICF codes describing diseases and conditions and food products: several other conditions (such as food allergies or food intolerances, kidney diseases, diabetes, etc.) can be modelled in NutrHe and the effects of foods (benefits and harms) on these conditions can be specified in the ontology as well. This would lead to a larger

number of consumers being able to find tailored information and could support nutrition professionals more efficiently.

With regard to adding information to NutrHe, the sPATIALS³ research project foresees the participation of three agro-industrial companies operating in the Lombardy Region; these companies are expected to develop novel nutraceutical food products (ready meals, food products prepared through new processes) and can test NutrHe's ability to properly represent products' characteristics. In this way, it is possible to test NutrHe in enhancing the cooperation among companies, nutrition professionals and consumers.

Information retrieval from NutrHe also covers a pivotal role and is expected to be conducted using the W3C recommendation language SPARQL [24]; this language can efficiently filter RDF data by combining several triple patterns, thus providing in-depth views of the ontology and the relationships among its entities. Data filtering with SPARQL can also help the retrieval of tailored products for consumers suffering from comorbidities.

Finally, as depicted in Section 4, the DSS should be used via applications (dedicated to clinical personnel, consumers and companies), each of which should be tested by the respective targets.

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