Design and Development of Ontology for AI-based Software Systems to Manage the Food Intake and Energy Consumption of Obesity, Diabetes and Tube Feeding Patients

Diogo Martinho[1[0000-0003-1683-4950]], Vitor Crista[1[0000-0002-8794-6354]], Ziya Karakaya[2[0000-0003-0233-7312]], Zahra Gamechi[3], Alberto Freitas[4[0000-0003-2113-9653]], José Neves[5,6[0000-0002-8863-0351]], Paulo Novais[5,6[0000-0002-3549-0754]], Goreti Marreiros[1,6[0000-0003-4417-8401]]

[1] GECAD, Institute of Engineering, Polytechnic of Porto, Porto, Portugal
diepm, vvrpc, mgt @isep.ipp.pt

[2] Atılım Üniversity, Computer Engineering Department, Ankara, Turkey
ziya.karakaya@atilim.edu.tr

[3] Almende BV, Rotterdam, The Netherlands
zahra @almende.org

[4] CINTESIS@RISE, MEDCIDS, Faculty of Medicine, University of Porto, Porto, Portugal
alberto@med.up.pt

[5] ALGORITMI Centre, University of Minho, Guimarães, Portugal
jneves, pjon @di.uminho.pt

6 Intelligent Systems Associate Laboratory, Portugal

Abstract. Poor and sedentary lifestyles combined with bad dietary habits have a significant impact on our health. Nowadays, diet-related diseases have become a major public health concern, threatening the sustainability of healthcare systems, and new strategies to promote better food intake management are now being explored. In this context, the use of ontologies has gained significant impact over the past decade and become more prevalent. By incorporating ontologies in the healthcare domain, artificial intelligence (AI) can be enhanced to better support healthcare systems dealing with chronic diseases, such as obesity and diabetes requiring long-term progress and frequent monitoring. This is especially challenging with current resource inefficiency; however, recent research suggests that incorporating ontology into AI-based technological solutions can improve their accuracy and capabilities. Additionally, recommendation and expert systems can also benefit from incorporating ontologies for a better knowledge representation and processing and then increase their success rates. This study outlines the development of an ontology developed in the context of food intake to manage and monitor the progress of patients with obesity, diabetes, and those using tube feeding. As the main result, a standardized vocabulary for describing food and nutritional information was specified, which will enable the integration with different healthcare systems and provide personalized dietary recommendations that are tailored to the specific needs and preferences of each user.

Keywords: Ontology, Semantic Web, Food Recommendation, Personalized Healthcare

1 Introduction

Our dietary habits have a significant impact on our health, and diet-related diseases pose a major public health concern, threatening the sustainability of healthcare systems. Unbalanced food intake, in terms of both quantity and quality, can lead to various medical conditions, including metabolic disturbances, malnutrition, overweight, poor mental performance, and medical risk factors such as hypertension, osteoporosis, cardiovascular diseases, type 2 diabetes, hip fractures, liver pathologies, Alzheimer's disease, and even cancer [1]. These diet-related diseases continue to be a major public health concern and endanger the sustainability of healthcare systems [2, 3]. Therefore, it becomes necessary to study and develop effective tools to monitor and support users in either single or group contexts to make better decisions in their daily lives regarding the adoption of healthier behaviors [4-6] and to support achieving health related goals [7]. As a result, dietary habits will be improved to prevent and manage the aforementioned diseases. In this context the FoodFriend project[1] was established as a novel technology aimed at addressing these challenges in three different uses cases: prevention of malnutrition in nursing homes and patients using tube feeding (1); and nutritional transmural care of chronic diseases such as obesity (2) and type 2 diabetes (3). Traditional food intake monitoring methods can be labor-intensive and time-consuming [8], and feedback is not always absorbed correctly by the end-user. Therefore, the FoodFriend project focuses on developing a complete toolset that can automatically measure a person's food intake with minimal user-input and provide personalized, actionable feedback. The FoodFriend toolset consists of both hardware, such as sensors, and software, such as an application or web portal, that can automatically monitor a person's food intake, reducing the workload and problems associated with traditional food monitoring. Additionally, the FoodFriend toolset can benefit various groups of users, including dieticians, nutritionists, caterers, and individuals seeking to improve their dietary habits. For dieticians and nutritionists, the tool can provide insight into their clients' eating habits, while clients can benefit from a reduced workload during the monitoring process. Additionally, the comprehensive tool can lower the threshold for individuals not involved in dietary coaching to get involved in improving their nutritional habits. The FoodFriend project uses health behavior-change recommendation techniques, such as the transtheoretical model of health behavior change [9, 10] to provide personalized suggestions to end-users based on the collected data. The recommendation process is supported by visualization techniques, enabling dieticians to provide feedback and steer the recommendation process. Furthermore, FoodFriend platform also includes mobile device implementations to improve accessibility. Finally, the project delivers a research database and a nutrition-wise ontology for modeling nutritional behavior, providing semantic interoperability between heterogeneous data sources and enabling data integration between the three use cases of the project based on existing ontologies available in the literature that consider the same concepts and relationships shared with the proposed ontology for the FoodFriend project. In this work we present the methodological approach undertaken in the FoodFriend project to establish a common shared ontology

[1] https://itea4.org/project/food-friend.html

between the three different use cases and we provide a representation of this ontology including the main concepts and relationships identified.

In the next section, all the related works presenting different ontologies in the context of food representation are described with a discussion of their application and relatedness to the FoodFriend project. In section 3, the methodology undertaken for each use case is specified describing the associated concepts and relations in the context of each use case. In section 4, the architecture of the common shared ontology for the FoodFriend project is presented. A discussion regarding the results achieved in this work is presented in section 5 and the main conclusions are drawn in the last section of this work.

2 Related Works

This section summarizes the current State of the Art regarding existing ontologies in the context of Food representation. Each relevant ontology will be described in terms of structure and main concepts and relationships as well as associated limitations in the context of the FoodFriend project.

2.1 FoodOn Ontology

Perhaps the most well-known food ontology, FoodOn [11, 12] is an open-source, comprehensive ontology structured with several term hierarchy facets that cover basic raw food source ingredients, process terms for packaging, cooking and preservation, and an upper-level variety of product type schemes under which food products can be categorized. FoodOn has been initially designed with several terms retrieved from LanguaL, a library science and ontology friendly food classification system that is composed by 14 food product description facets including plant or animal food source, chemical additive, preservation or cooking process, packaging, and standard national and international upper-level product type schemes. Currently, at least 3400 terms are used in FoodOn to describe “the individual plant, animal, or chemical food source from which the food product or its major ingredient is derived”. Furthermore, FoodOn describes the organism's food source terms using intermediate groups like “stem or spear vegetable” but separates chemicals (mainly additives) into a “food component class” to differentiate whole organism references (see Fig. 1).
Additionally, FoodOn works in partnership with other OBOFoundry related ontologies which together represent the Joint Food Ontology Workgroup (JFOW). JFOW is an informal group of ontology stakeholders and has the main goal of standardizing the content of food products and research related ontologies. As such, this group aims to simplify the annotation of datasets to meet interoperable FAIR data standards[13], as well as to enhance plug-and-play, queryable knowledge graph search and provide vocabularies for nutritional analysis, including chemical food components which are factors in diet, health and plant and animal agricultural rearing research.

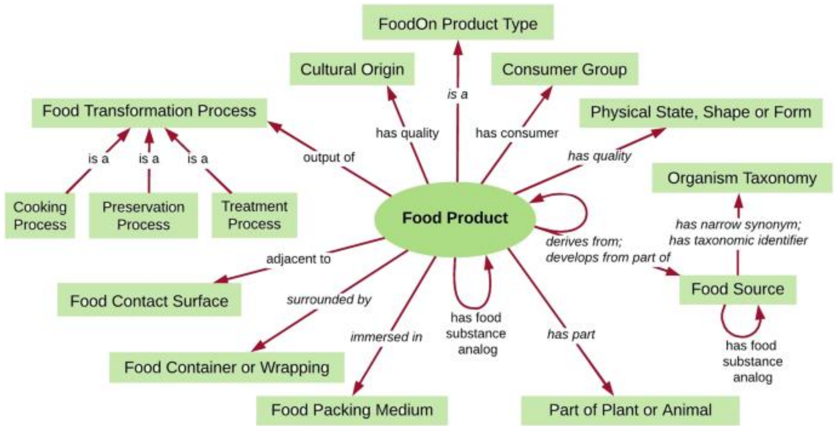

Fig. 1. FoodOn Ontology – adapted from [12].

Other members of JFOW include:

- Food-Biomarker Ontology (FOBI) – An ontology with two interconnected sub-ontologies: one to describe raw foods and multi-component foods terms and a Biomarker Ontology to describe chemical classes.
- Ontology for Nutritional Studies (ONS) – Developed within the ENPADASI European project, has the main goal to represent a comprehensive resource for the description of concepts in the broader human nutrition domain covering classes necessary for describing and querying for nutritional studies.
- Animal Health Surveillance Ontology (AHSO) – An ontology to describe animal health data which can promote the secondary use of these data for surveillance (data-driven surveillance, or syndromic surveillance).
- Crop Nutritional Data Ontology (CDNO) – An ontology structured with terminologies to describe nutritional attributes of material entities that contribute to human diet.
- Ontology for Nutritional Epidemiology (ONE) – An ontology to describe nutritional epidemiologic studies accurately.
- Medical Actions Ontology (MAxO) – An ontology that provides a structured vocabulary for medical procedures, interventions, therapies, and treatments, including nutrition based medical interventions.
- Environmental Conditions, Treatments, and Exposures Ontology (ECTO) – An ontology to describe experimental treatments of plants and model organisms, exposures of humans or any other organisms to stressors through a variety of routes, stimuli, any kind of environmental condition or change in condition that can be experienced by an organism or population of organisms on earth.

Although FoodOn, and the associated ontologies part of the JFOW group already cover a wide spectrum of elements associated to the Food variable these are still lacking in terms of describing and modelling the human variable and associated characteristics which including dietary and health issues (such as diabetes and obesity) leading to the scope of FoodFriend project and the necessity to model this concept.

2.2 Quisper Ontology

Eftimov and colleagues proposed in 2018 [14] a food ontology named Quisper ontology that has been developed in a semi-automatic way and can be used for the harmonization and enable research in the domain of personalized dietary web services. Additionally, the proposed ontology combines aggregated data from different sources to provide new knowledge to contribute for healthier lifestyles. The defined ontology (see Fig. 2)has been initially designed to include 5 main groups (Component, Food, FoodGroup, Personal and SNP) and 7 main classes (Component, Food, FoodGroup, Personal, SNP, Unit, and WebService).

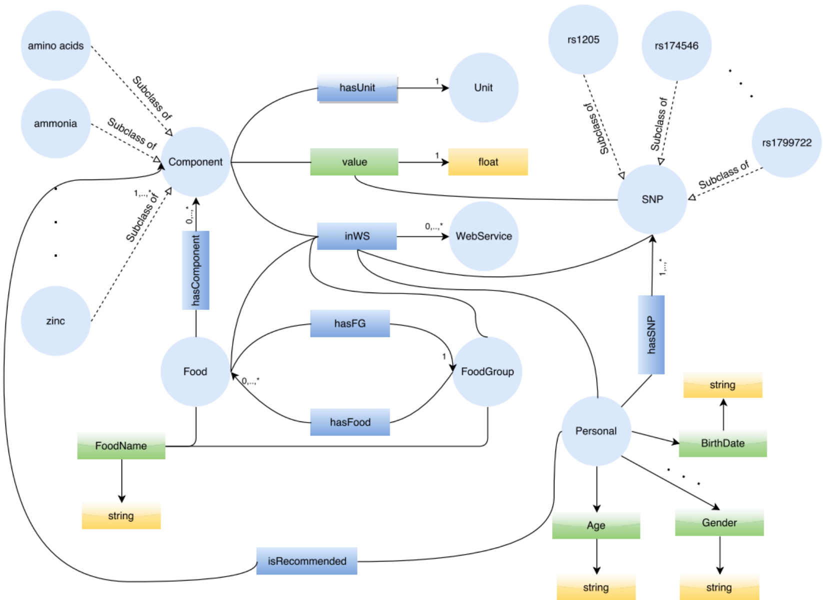

Fig. 2. Quisper Ontology – adapted from [14].

With this structure, the authors express the advantage of the ontology not being focused only on food-related data, but also to include information for everyone from his/her user profile, biomarker analysis, dietary reference intakes and recommendations.

This ontology goes in line with the goals of the FoodFriend project, however the current description of the person/human variable is still very limited in terms of understanding characteristics which include dietary and health issues as well to understand and describe the person's meal intake over the days.

2.3 Ontology Based Food Recommendation

More recently, in 2022 [15], Chivukula and colleagues proposed a new food ontology, named Ontology Based Food Recommendation to model in the food domain to help people in getting the right recommendation about the food, based on their health condition. Some of the key concepts that were considered are related to the food domain and include types of food, flavors and textures, and different kinds of food courses and meals (see Fig. 3). Additionally, information on recipes and corresponding ingredients together with their nutritional values is also described. Finally, the user variable with the details of physical attributes such as age, weight with health history is also maintained. The authors explain how the proposed ontology could be used in different food and dietary domains, for example, by people with culinary interests, nutritionists, restaurants, and chefs.

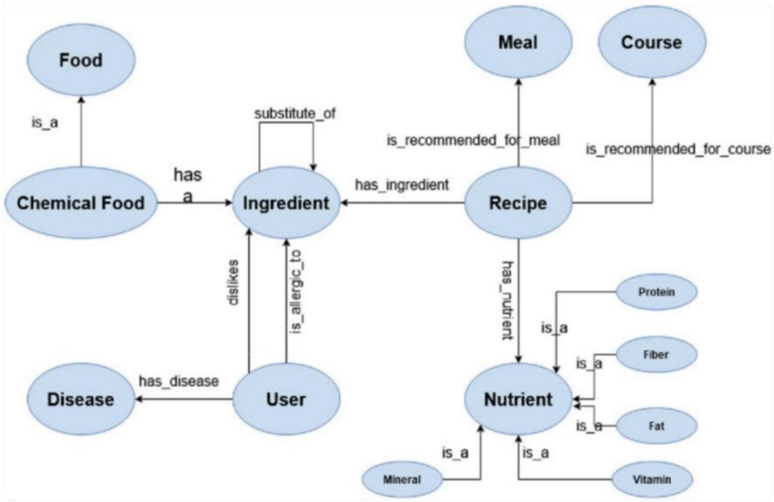

Fig. 3. Ontology Based Food Recommendation – adapted from [15].

The proposed ontology is the closest to meet the goals of the FoodFriend project as it considers both food, human and even meals variables. However, additional concepts must still be considered to correctly describe the user Meal Intake and additional components are also necessary. For example, the Food variable should also include information which is relevant to manage dietary and food issues such as Diabetes by considering information on the associated glycemic index of each food.

3 Methodology

This section describes the different concepts and corresponding relationships associated with each Use Case of the FoodFriend project. These concepts will be then combined into a common FoodFriend Ontology which is described in the following section of this document.

3.1 Diabetes Use Case

Diabetes use case focuses on the creation and validation of technologies for objective self-monitoring and management of patients with diabetes type 2. The major outcome will be a quantified self, evidence-based coaching solution for self-monitoring and management of diabetes type II disease based on food intake and lifestyle monitoring. The transparent integration of this type of technology in the daily routine of patients will improve self-monitoring of disease, increase treatment adherence and the promotion of healthy behaviors, having as consequence diminishing the acute complications of diabetes. By specifying an ontology in the context of the management of diabetes disease, it is possible to develop a recommendation system using a structured and standardized representation of knowledge, enabling efficient information retrieval and inference. In this context, ontologies can be used to organize and categorize food-related data, such as nutritional information and personal preferences to deliver personalized and accurate dietary suggestions based on individual needs and constraints. Currently, a recommendation system has been developed regarding the type 2 diabetes use case. The rules composing this system were generated based on the guidelines from the WHO (World Health Organization), related to the consumption of the main macronutrients. The application daily sends users' macronutrient intake, and recommendations are subsequently generated if the macronutrients exceed the specified levels or fall below the recommended levels [16].

In the context of Diabetes Use case the following concepts and corresponding relationships have been identified:

- ***User – Food*** - The person (user) has interests regarding each food available/inserted in the system. These interests can cover aspects such as preferences and allergies.
- ***User – Meals Intake*** - Each person keeps track of all the meals intake, which corresponds to any ingested food information provided to the system. These meals usually refer to breakfast, lunch, dinner, and snacks.
- ***Meal – Food*** - As mentioned previously, each meal taken by the person will include one or more foods. Additionally, each food (and its information) will also be related to the types of meal for which that food is most recommended. For example, a bowl of milk and cereal could be recommended for breakfast while a roast chicken could be recommended for either lunch or dinner.
- ***Food – Nutritional Values*** - Foods have nutrients and therefore, each food available in the system must also contain nutritional information regarding key nutrients to manage a healthy diet. These nutrients correspond to proteins, carbohydrates, fibers, fats, minerals (such as salt and sugar) and vitamins.

3.2 Obesity Use Case

Obesity use case focuses on people with desk jobs having a higher risk on obesity due to their limited physical activity in daily life. The major idea is to detect every food consumption of the user depending on the data collected via their mobile devices like location of the user, movement of the user, social media sharing, mail sending activity, incoming/outgoing calls, etc. In addition to concepts and corresponding relationship described in Diabetes Use Case, we have identified the followings valuable for Obesity Use Case:

- ***User – Energy Consumption Activity*** - While food intake behavior of the user has significant impact on weighing, the energy consumption during “Physical Activities”, “Resting”, and “Sleeping” has as much impact as the level of food intake. In addition to the duration of these activities, the energy consumption rate is also affected by the attributes of the user, such as basal metabolism.
- ***User – Goal – Dietary Plan*** - Users have goals to achieve. The goals can be assigned by the user itself or by professionals either as distinct goals or by combining with their dietary plan.
- ***User – Disabilities*** - Physical activities suitable for the user will naturally depend on their disabilities if they exist.
- ***User – Allergenics*** - Having allergies will affect the recommendation of food and ingredients. Users may be allergic to some foods or constituents. This information must be taken into account by professionals and AI based food recommendations.
- ***User – Disease*** - Users may have comorbidities which should be regarded in recommendation operation. Some foods may seem good for persons having obesity conditions but may also threaten other disease treatment. The FoodFriend system should not create any threat to patients.

3.3 Tube Feeding Use Case

Food intake of patients on tube feeding is performed by gathering data from the tube feeding pump and determine the energy expenditure of the patient with indirect calorimetry and accelerometers. Based on the obtained data and insights into the nutritional status of the patient, personalized feedback can be provided through an easy-to-use platform and incorporated into the treatment plans of dietitians. Also, by giving the patient more insight into his/her nutritional status, compliance with the therapy will increase. The concepts and relationships regarding the Tube Feeding use case are as follows:

- ***User – Feeding Pack*** - The user takes available/recommended feeding packages. The recommended feeding package can be based on the users medical and health status.
- ***User – Food Intake*** - The feeding pump tracks the food intake of the user. For any food intake (meals or beverages) the user utilizes the feeding pump. The food intake can be a feeding pack, water, or coffee.
- ***Feeding Pack – Intake Status (Feeding Pump)*** - For each user based on the medical status, a special intake status is recommended. The intake volume, flow rate, dose, as well as the intake duration can be adjusted to the user's demand. Each of these elements have an influence on the health status of the user. These elements can be adjusted and recorded automatically by the feeding pump.
- ***Feeding Pack – Nutritional Values*** - Each feeding package has nutrients and energy produced by that. This information can be accessed by scanning the barcode of each

feeding package. The factsheet provided for each feeding package reveals the amount of energy, protein, carbohydrate, fat, fiber, water, minerals, Vitamins, and other trace elements.

4 Proposed Ontology

This section describes the FoodFriend Ontology according to the scope of each Use Case and how the knowledge representation is structured according to the different concepts and relationships previously identified. All ontological structures from each use case have been merged into a single ontology as is presented in Fig. 4. Furthermore, the proposed ontology has also been inspired by the literature reach made in the context of this Task and deliverable to consider essential concepts and relationships also like the scope of the FoodFriend project.

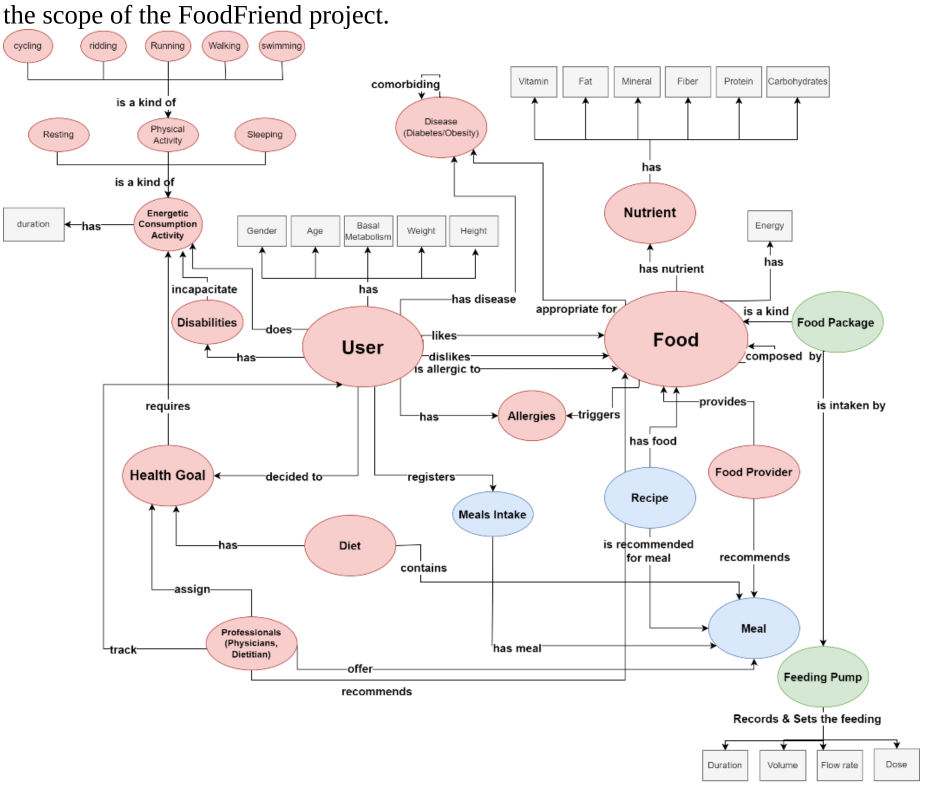

Fig. 4. FoodFriend Ontology

The two main classes of the FoodFriend Ontology are the User and Food. A user will contain demographic information such as age, gender, weight and height, and other characteristics such as the recommended daily energetic consumption and food-related diseases and may also have disabilities which incapacitate daily energetic consumption. The user will be given different health goals that can be included in a diet (which is created by a health professional). The user will also register his/her meals intake for each meal taken throughout the day (breakfast, lunch, dinner, snacks, etc.). These meals are part of a diet which is necessary to correctly accomplish an established health goal. Additionally, certain meals have recommended recipes that can be provided by a food provider. The user will relate to food in terms of preferences and allergies to certain types of food. Each food has its own nutritional information associated in terms of total number of fats, vitamins, fibers, carbohydrates, etc. Certain foods can also be stored in the feeding packages with the means of a feeding pump. The intake status is a crucial element in tube feeding which is managed by the feeding pump. Foods are also part of recipes and relate to food diseases as appropriate/inappropriate and can be recommended by health professionals.

5 Discussion

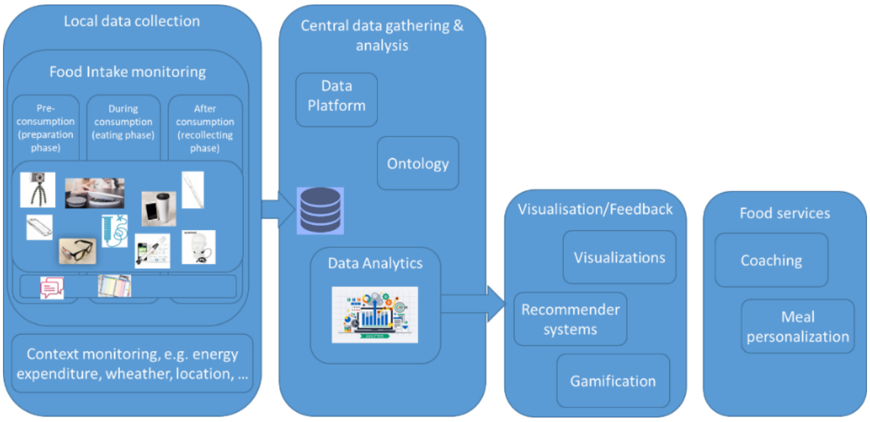

Fig. 5. FoodFriend technical value chain

The use of common shared ontology in the context of the FoodFriend project is essential for several reasons (see Fig. 5). First, the use of this ontology can help to integrate data from different sources, such as food composition databases, nutrition tracking apps, and clinical studies related to each specific use case. By using a common vocabulary and structure, data can be more easily shared and compared across the different systems developed in the FoodFriend project. Second, ontologies can help to support decision-making related to food and nutrition. For example, the proposed ontology could be used to classify foods based on their nutritional content or allergenic properties. This information could then be used to make personalized dietary recommendations adequate to all the use cases depending on the data collected from users. Finally, the proposed ontology can be used to advance our understanding of the complex relationships between diet, health, daily activity, and diseases. By representing knowledge in a structured and explicit way, the proposed ontology can facilitate the discovery of new associations and hypotheses such as to explore relationship amongst different use case related concepts. Overall, the use of a common ontology in the context of food, eating, and nutrition has the potential to support a wide range of applications, from personalized nutrition to public health policy. As more data becomes available in the context of the FoodFriend project and the different use cases, the ontology here proposed will more likely play an important role in organizing and making sense of this information.

6 Conclusions

Ontologies play a crucial role in many areas of knowledge representation and data management, including the domain of food intake and nutrition. An ontology is a formal representation of knowledge in a particular domain, defining a set of concepts and the relationships between them. In the context of food intake and nutrition, an ontology can provide a standardized vocabulary for describing food, nutrients, and dietary recommendations, allowing for more accurate and consistent data analysis and decision-making. The use of ontologies in the context of food intake and nutrition has become increasingly important in recent years, as more and more data is being generated by various sources such as wearable devices, mobile applications, and electronic health records. These data sources often use different terminologies and standards for representing food and nutritional information, making it difficult to compare and integrate data from different sources. By using an ontology, it becomes possible to reconcile these different terminologies and create a unified representation of food and nutritional data that can be easily shared and integrated with other systems. This can lead to improved decision-making in areas such as personalized nutrition, clinical research, and public health policy. The FoodFriend project is presented in this work leveraging the use of ontologies in the context of food intake and nutrition to develop a personalized nutrition platform that considers individual preferences, nutritional needs, and health goals. As such, the use of ontologies in this project is essential to create a standardized vocabulary for describing food and nutritional information, which will enable the integration of data from various sources such as food diaries, wearable devices, and clinical records. As a result, the FoodFriend platform will be able to provide personalized dietary recommendations that are tailored to the specific needs and preferences of each user. In this work we have presented the methodological approach undertaken to define a common shared ontology for food intake in the context of the FoodFriend project. By using ontologies to standardize the representation of food and nutritional data, the FoodFriend project is paving the way for a more personalized and effective approach to nutrition and health management.

Acknowledgements

This research work was developed under the project Food Friend – “Autonomous and easy-to-use tool for monitoring of personal food intake and personalised feedback” (ITEA 18032), co-financed by the North Regional Operational Program (NORTE 2020) under the Portugal 2020 and the European Regional Development Fund (ERDF), with the reference NORTE-01-0247-FEDER-047381 and by National Funds through

FCT (Fundação para a Ciência e a Tecnologia) under the project UI/DB/00760/2020. The work of Paulo Novais has been supported by FCT–Fundação para a Ciência e Tecnologia within the R&D Units Project Scope: UIDB/0031/2020.

References

1. Bidlack, W.R.: Interrelationships of food, nutrition, diet and health: the National Association of State Universities and Land Grant Colleges White Paper. Journal of the American College of Nutrition 15, 422-433 (1996)
2. Seely, S., Freed, D.L., Silverstone, G.A., Rippere, V.: Diet-related diseases: the modern epidemic. Routledge (2022)
3. Jacobson, M.F., Krieger, J., Brownell, K.D.: Potential policy approaches to address diet-related diseases. Jama 320, 341-342 (2018)
4. Marreiros, M.G.C.: Agentes de Apoio à Argumentação e Decisão em Grupo. Universidade do Minho (2007)
5. Carneiro, J., Martinho, D., Marreiros, G., Novais, P.: Arguing with behavior influence: a model for web-based group decision support systems. International Journal of Information Technology Decision Making 18, 517-553 (2019)
6. Carneiro, J., Martinho, D., Alves, P., Conceição, L., Marreiros, G., Novais, P.: A multiple criteria decision analysis framework for dispersed group decision-making contexts. Applied Sciences 10, 4614 (2020)
7. Martinho, D., Carneiro, J., Neves, J., Novais, P., Corchado, J., Marreiros, G.: A Reinforcement Learning Approach to Improve User Achievement of Health-Related Goals. In: EPIA Conference on Artificial Intelligence, pp. 266-277. Springer, (2021)
8. Rutishauser, I.H.: Dietary intake measurements. Public health nutrition 8, 1100-1107 (2005)
9. Prochaska, J.O., DiClemente, C.C.: Transtheoretical therapy: Toward a more integrative model of change. Psychotherapy: theory, research & practice 19, 276 (1982)
10. Prochaska, J.O., Velicer, W.F.: The transtheoretical model of health behavior change. American journal of health promotion 12, 38-48 (1997)
11. Griffiths, E.J., Dooley, D.M., Buttigieg, P.L., Hoehndorf, R., Brinkman, F.S., Hsiao, W.W.: FoodON: A Global Farm-to-Fork Food Ontology. In: ICBO/BioCreative, pp. 1-2. (2016)
12. Dooley, D.M., Griffiths, E.J., Gosal, G.S., Buttigieg, P.L., Hoehndorf, R., Lange, M.C., Schriml, L.M., Brinkman, F.S., Hsiao, W.W.: FoodOn: a harmonized food ontology to increase global food traceability, quality control and data integration. npj Science of Food 2, 1-10 (2018)
13. Bezuidenhout, L.: Being fair about the design of FAIR data standards. Digital Government: Research Practice 1, 1-7 (2020)
14. Eftimov, T., Ispirova, G., Finglas, P., Korosec, P., Korousic-Seljak, B.: Quisper Ontology Learning from Personalized Dietary Web Services. In: KEOD, pp. 277-284. (2018)
15. Chivukula, R., Lakshmi, T.J., Sumalatha, S., Reddy, K.L.R.: Ontology Based Food Recommendation. In: IOT with Smart Systems: Proceedings of ICTIS 2021, Volume 2, pp. 751-759. Springer, (2022)
16. Martinho, D., Crista, V., Pinto, A., Diniz, J., Freitas, A., Carneiro, J., Marreiros, G.: An Architecture for a Coaching System to Support Type 2 Diabetic Patients. In: International Symposium on Ambient Intelligence, pp. 167-178. Springer, (2022)