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Expert System for Nutrition Care Process of Older Adults

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Abstract. This paper presents an expert system for a nutrition care process tailored for the specific needs of elders. Dietary knowledge is defined by nutritionists and encoded as Nutrition Care Process Ontology, and then used as underlining base and standardized model for the nutrition care planning. An inference engine is developed on top of the ontology, providing semantic reasoning infrastructure and mechanisms for evaluating the rules defined for assessing short and long term elders' self-feeding behaviors, to identify unhealthy dietary patterns and detect the early instauration of malnutrition. Our expert system provides personalized intervention plans covering nutrition education, diet prescription and food ordering adapted to the older adult's specific nutritional needs, health conditions and food preferences. In-lab evaluation results are presented proving the usefulness and quality of the expert system as well as the computational efficiency, coupling and cohesion of the defined ontology.

Keywords: Expert system, Nutrition care, Inference engine, Malnutrition, Ontology

1. Introduction

Over the past decade, healthcare systems have under-gone a paradigm shift from being a solely treatment-based focus towards a more personalized, person-centred, and prevention-oriented approach. Such change is driven by the increasing health cost burden to non-sustainable limits, of treatment-based systems, due to the overall ageing of the population, sedentary life-styles and poor nutrition habits, which has led to the increased proliferation of chronic illnesses (e.g. diabetes) (Antos et al., 2013).

Studies have shown that in Europe more than 15% of the older population is affected by poor nutrition including malnutrition caused by age-related risk factors such as sensory changes (taste, smell, eye sight), poor dental health, lack of transportation, physical difficulties, forgetfulness and other issues (Sieber, 2010). Malnutrition is defined as a state of nutrition in which a deficiency, excess or imbalance of energy, protein, and other nutrients causes measurable adverse effects on body form (body shape, size and composition), function, and clinical outcome (Elia, 2001). According to the British Association for Parenteral and Enteral Nutrition (Elia&Russell, 2008), malnutrition affects over 3 million people in the UK alone, and of these, about 1.3 million are over the age of 65. If unman-aged, malnutrition may significantly impact on the older person's health (such as exacerbation of chronic conditions, delayed recovery from illness, etc.), thus causing significant increases in related healthcare costs. In fact, the cost associated with malnutrition in Europe is estimated to amount to a staggering 170 billion Euro each year (Ljungqvist and Man, 2009). The rapid identification of malnutrition and early prevention through the provision of nutritional assistance to the elderly would thus help to avoid such high public health costs, and enhance both the mental and physical conditions of older adults including their quality of life. It is generally agreed that the best strategy for malnutrition prevention is to lead a healthy lifestyle which can be enacted through a personalized nutrition care process. In Europe, it has been estimated that 77% of the disease burden can be ac-counted for disorders related to unhealthy lifestyle and furthermore, 70% of stroke and colon cancer, 80% of coronary heart disease, and 90% of type II diabetes could be prevented and managed through nutrition care (Brown, 2013). Lifestyle behavioural factors (poor nutrition habits, physical inactivity, tobacco and alcohol use) are classified as modifiable indirect risk factors which can be influenced by individuals and if not managed, could lead to metabolic and physiological changes including high blood pressure, high blood glucose, overweight, obesity and high cholesterol, which all represent direct factors for the development of chronic diseases (Willett et al., 2006). At the same time targeting obesity and overweight, promoting healthy eating, physical activity, smoking/alcohol cessation have been shown to reduce the incidence of "type 2" diabetes (Knowler, et al., 2002).

In this context, advances in the ICT (Information and Communication Technology) sector have made feasible the development of solutions for nutrition care through prevention and self-management. Most contemporary nutrition

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management solutions aim at offering nutritional information and advice for popular commercial products. Their healthy lifestyle plans are targeting weight loss and do not consider the specific nutritional and physiological problems of the older adults, or the detection and prevention of malnutrition.

This paper contributes towards achieving these goals by proposing an expert system for nutrition care process tailored for the specific needs of older adults. Led by nutritionists, we first investigate benchmarks and nutritional guidelines to evaluate diets based on published recommendations suitable for elders, as well as identify suitable nutrition problems and interventions for the elders. The older adults nutrition related information (provided by nutritionists) is utilized to construct a semantic dietary knowledge encoded as ontology, named the Nutrition Care Process Ontology. It is composed of four sub-ontologies: Nutrition Monitoring Ontology, Nutrition Assessment Ontology, Nutrition Problem Identification Ontology, and Nutrition Intervention Ontology. The Nutrition Monitoring Ontology defines and semantically represents information regarding the older adult relevant information for assessing their nutrition and self-feeding behaviour. The Nutrition Assessment Ontology covers information facilitating the assessment of older adult's food intake and converts these to associated nutrient values. The Nutrition Problem Identification Ontology captures potential nutrition related problems and associated symptoms. Finally, the Nutrition Intervention Ontology models suitable intervention actions for identified nutrition problems and unhealthy behaviour. A nutrition inference engine is developed on top of the Nutrition Care Process Ontology, to provide a semantic reasoning infrastructure for evaluating the rules defined for assessing short term and long term older adult's self-feeding behaviours, for identifying un-healthy dietary patterns and proactively detecting the early instauration of malnutrition and for helping nutritionists to define personalized intervention plans.

The rest of the paper is organized as follows. Section 2 discusses related work. The proposed Nutrition Care Process Ontology and the rules for assessing unhealthy behaviours are detailed in Section 3, while Section 4 presents a corresponding use case validation. Finally, Section 5 concludes the paper.

2. Related work

Most of the state of the art of diet management models and services aim to provide nutrients information for popular products and to define customized weight loss and healthy lifestyle plans (see CaloriesCount web applications). Although these models are intended to be used by all kinds of people regardless of age, the specific problems of older adults regarding nutrition and self-feeding behaviour are not specifically considered. Sensory changes, side effects of medication, physical difficulty or forgetfulness can cause nutrition problems for older adults which cannot be solved by using simple weight loss plans. Main challenges addressed by existing research efforts focus on monitoring food intake and nutritional habits, definition of appropriate knowledge to assess unhealthy behaviours and the development of expert systems which may take nutrition intervention decisions based on the monitored nutrition data and knowledge base.

Defining and representing nutrition related knowledge diet is fundamental for allowing ICT systems to reason about it, and to provide personalized diet intervention and feedback. As the knowledge base become more structured rule based reasoning can be employed to assess the nutrition related behaviour of a person (Vassányi et al., 2014). While the use of ontologies has proven to be effective in establishing standard models, taxonomies, vocabularies and domain terminology (Valencia-García et al., 2008; Rivero et al., 2013) few approaches use the ontologies for evaluating nutrition related behaviour, and the provision of intervention plans is mostly limited to the management of some chronic conditions such as diabetes (Quinn et al., 2015; Lee et al., 2008). In (Tumnark et al., 2013) ontology-based personalized dietary recommendation for weightlifting to assist athletes in meeting their nutritional requirements is developed and used to provide personalized daily menus. The provided ontology is limited to weightlifting nutritional knowledge while the inference engine is not suitable for complex reasoning processes considering various age related factors. In (Quinn et al., 2015) the authors present a conceptual architecture for web-based personalized patient education experience having as central element the patient ontological model which captures knowledge related to medical conditions, physical activities and educational background. Ontology based daily menu assistance system for suggesting daily menus based on reference values of daily calories of a person is the subject of (Fudholi et al., 2009). However, the developed fuzzy ontology is limited to some food related criteria such as price, rate, vote and taste but the use of daily calories benchmark values makes it suitable for losing weight based on low calories intervention plans. In (Lee et al., 2008) an ontology model for diabetic food recommendation is proposed containing Taiwanese food ontology and a set of personal food ontologies. An intelligent agent based on a fuzzy inference engine is developed and used to create a meal plan according to a person's lifestyle and health needs for diabetes as a chronic condition. The results show great potential in supporting the dietician efforts but the main disadvantage is that the ontology focuses on Taiwanese food only and lacks the reliability of fuzzy reasoning. In (Snae and Brückner, 2008) a counselling system for menu planning in a restaurant is developed. The system is based on a food ontology which contains specifications of ingredients, substances, nutrition facts and recommended daily intakes, an inference system based on the defined ontology, and a web interface for dieticians. The system's disadvantage is its static nature in not being able to adapt the provided menus and recipes for specific nutritional profiles, for diabetics for example, and the lack of an automated assessment of dietary plans. The PIPS (Personalized Information Platform for Health and Life Services) food ontology (Dominguez et al., 2006) is a food taxonomy that uses the Eurocode food coding used by software agents to generate personalized advice for people with type II diabetes. Our approach for nutritional assessment uses PIPS ontology for assessing the behaviour of older adults focusing on factors relevant to nutrition.

Nutrition expert systems have proven to be effective for offering advice and menu planning out of nutritional knowledge for preventing malnutrition (Quinn et al., 2015; Lee et al., 2008; Tumnark et al., 2013; Snae and Brückner, 2008; Vassányi et al., 2014). In (Espín et al., 2015) the authors describe a nutritional recommender system, for helping older adults to follow dietary plans that are based on nutritionists' guidelines. The proposed system uses a reasoning process based on SWRL (Semantic Web Rule Language) rules upon nutritional and user profile ontologies to generate recommendations through semantic similarity measures. Similarly in (Quinn et al., 2015) semantic rules are used to infer associations between ontology concepts in order to create educational content for health education. (Al-

Dhuhli et al., 2013) propose an expert system for evaluating nutrition conditions and for suggesting a specific type of food or the required time to exercise each day. The knowledge used as input to the system is based on if-then statements and decision tables and is represented using the e2go freeware rule-based shell. Although the system is evaluated using experts and different user groups, it does not involve complex reasoning processes, being limited to generating simple outputs such as body mass index values, nutrient values or weight information. In (Vassányi et al., 2014), a system which analyses dietary logs to assess the diet of an individual and to construct a personalized menu is developed. The system is based on predefined rules for foods and dishes employing genetic algorithms to calculate the fitness of candidate solutions using personalized target values of various nutrients. The solution was developed for mobile devices, collects nutrition information only through user interaction which is not very accurate and does not represent the knowledge in computer interpretable manner thus no advanced reasoning and inference is possible. In (van der Merwe et al., 2014) the authors propose an expert system based on a rule-based inference engine and multi-objective linear programming models for dietary recommendations. The system generates an eating-plan that conforms to the nutritionist specifications, considering end-users' preferences and food item costs. A knowledge base was developed consisting of predefined foods grouped according to the proportions of carbohydrate, protein and fat. The inference engine uses if-then production rules while linear programming is applied to select foods from the knowledge base and construct the overall personalized diet. The system does not involve monitoring the patient following an intervention plan nor does allow defining complex inference rules due to the if-then approach. In (Arens-Volland et al., 2009) an ICT based system for the detection and prevention of food allergies as well as for diet management is proposed. The authors propose an expert system for mobile devices for analysis of nutrition-based allergies based on end-user food diaries filled using a barcode scanner, electronic patient records for identifying the specific allergies and food product databases. The system helps the end-users to avoid stressful and time consuming blood and skin tests but cannot take into consideration the food that is not labelled in a specific way, particularly cooked food. The opportunities offered by an ICT based learning environment to deliver nutrition health learning and education for children are investigated in (Raiha, 2013). The end-user eating habits and nutrition knowledge are recorded by means of questionnaires. The study revealed that the use of the ICT-based learning environment developed the pupils' critical reading skills for nutrition and health information that can be found on the Internet. In (Atienza et al., 2008) 27 healthy adults aged over 50 were involved in an 8-week nutrition intervention study using mobile devices. They used PDAs to monitor their vegetable and whole-grain intake levels twice per day and to provide daily individualized age-appropriate feedback, goal-setting, and support. The results have shown that the participants reported a significantly greater increases in vegetable servings (1.5-2.5 servings/day), as well as a trend toward greater intake of dietary fibre from grains (3.7-4.5 servings/day). A prototype expert system for human nutritional diagnosis based on service oriented architecture was proposed in (Quesada and Jenkins, 2013). The system performs a nutrition diagnosis using Body Mass Index (BMI) evaluation of the end-users and sends notifications to the end-users regarding the meal time and suggest healthy food places nearby.

Our proposed solution takes a different approach and is the first (to the best of our knowledge) that attempts semantic modelling of nutrition related knowledge covering all phases of the older adult's nutrition care process. In addition, the proposed inference engine allows the automatic assessment of early instauration of nutrition related problems, and of older adults' short and long term unhealthy behaviours, which may lead to malnutrition. Unlike other approaches our expert system will not provide only menu planning but it will go one step further to provide personalized intervention plans that includes nutrition education, diet recommendations and food ordering adapted to the older adult's specific nutrition needs, health and preferences.

3. Nutrition care process ontology

There are a number of standardized models of the nutrition care planning process (see the Academy of Nutrition and Dietetics' Nutrition Care Process and Model). The British Dietetic Association has a similar version (see the Model and Process for Nutrition and Dietetic Care), and the same applies to countries such as US, Canada and Australia. The international dietetics community is working to develop a standardized language for documenting the nutrition care process. Within Europe, take up by the profession has been slower, but there is a vision for the adoption of a standardized care process to be used by all dietitians, and in the training of dietitians, by 2020 (see FAD Professional Practice Committee report).

Nutrition care planning is a cyclical and systematic process, with each stage dependent on those preceding it. The four stages are: (i) monitoring, (ii) assessment, (iii) nutrition problem identification and finally (iv) intervention implementation. The first stage (monitoring) feeds new data into the second stage (assessment), i.e. it triggers a re-assessment to determine if the previous plan is still relevant or if changes need to be made to reflect the progression of previously identified, or the development of new, nutritional problems. Factors influencing the implementation of the intervention (e.g. social and financial changes) are also identified during the monitoring stage. In practice, screening in the community or by non-nutrition specialists triggers a referral to a nutritionist or dietitian for more in depth assessment and a 'nutrition care plan' is then developed. Hence screening is almost a 'pre-step' of nutrition care process, which we have decided to incorporate in the monitoring phase, but does not need to be executed each time the nutrition care process runs.

Our aim is to provide an appropriate computational representation for the clinically informed diet knowledge and to construct a knowledge base on which reasoning and query processes can be executed for dietary assessment of older adults. This will enact the development of a nutrition expert system which will automate the nutrition care process by providing nutrition assistance, advices, explanations, nutrition evaluation and intervention and rational decision support without emotional overhead. Also interactions of nutritionists with the older adults are minimized making the nutrition care process more efficient and less invasive. A common contemporary approach to represent knowledge of a specific domain (in this case the older adult's nutrition care process domain) is in the form of ontologies (Rodríguez et al., 2014). The main idea is to establish standard models, taxonomies, vocabularies and domain terminology.

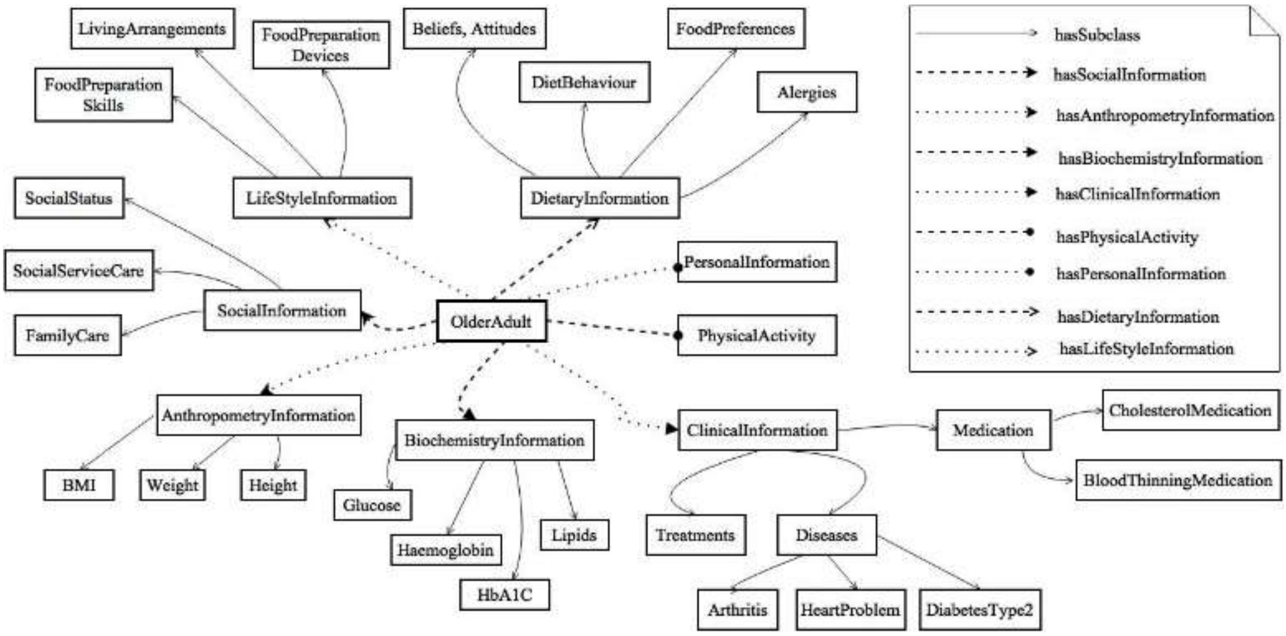

Figure 1: *Nutrition Monitoring Ontology*

These can be further used to infer new knowledge and relationships in the modelled domain. Here, ontologies are used to capture nutrition related knowledge resulting in the Nutrition Care Process Ontology, composed from four sub-ontologies: Nutrition Monitoring Ontology, Nutrition Assessment Ontology, Nutrition Problem Identification Ontology and Nutrition Intervention Ontology. These sub-ontologies are detailed next.

3.1. Nutrition Monitoring Ontology

Nutrition Monitoring Ontology (see Fig. 1) semantically annotate data describing the older adult self-feeding behaviour such as **personal information** (such as age and gender), **lifestyle information** (including living arrangements, financial context, and skills and equipment for food preparation), **social information** (e.g. supports already in place including family and wider social network), and **physical activity information.** The rest of the assessment is based on the “ABCD approach” (Knox et al., 2013) (which includes collection of anthropometry, biochemistry, clinical and dietary information) as outlined below.

Anthropometry is the measurement of different aspects of the human body. For older adults, the most relevant data to collect will be their *measured* weight and height, although proxy or estimated measures can be used particularly for height in case where it may be more difficult to measure due to specific health conditions. These include ulna length and demi span as measures that can be used where measured height is not possible. This information needs to be interpreted to inform the assessment; commonly body mass index (BMI, weight/ height^2) and any percentage change in weight (previous – current weight/ previous weight x 100) in the preceding 6 months are calculated.

Biochemistry information is collected to identify those individuals requiring intensive follow up (individualised care by a nutrition professional) and flag up where dietary modification might be targeted. It is unlikely that older people living in the community will be able to provide blood chemistry results for this assessment factor. However, those being seen by a nutritionist or dietitian with a referral from a doctor may require the system to record this information. Typically in the older age group blood chemistry results may include blood lipids (cholesterol, triglycerides), blood glucose, or full blood counts (which include white cell count, red blood cell count, and haemoglobin levels), and if diabetes is present, glycosylated haemoglobin (HbA1C). These tests must be ordered by a doctor but are useful adjuncts to the nutritional assessment; an evaluation of whether dietary modification might help to address values outside of the normal range can be then made (dietary modification may be instead of or in conjunction with medication). They are also very useful outcome indicators to evaluate nutrition and dietary care. The absence of biochemistry data does not preclude further assessment.

Clinical information collected includes details of: (i) health problems including normal ageing processes likely to affect food intake e.g. poor dentition, problems with digestion and information on mobility/function (activities of daily life if available); (ii) medical diagnoses and/or information on treatment from other health professionals such as physiotherapists, speech and language therapists (who may prescribe food and drink texture modifications), home care nurses etc.; (iii) use of prescribed and over the counter medications and supplements (if available from the general practitioner).

Dietary and food preference information collected includes likes and dislikes of individual, unsuitable foods (due to texture modification needs, allergies, intolerances, personal or religious and cultural exclusions) and details of texture modification prescriptions (e.g. soft foods, pureed food, thickened drinks). This information ensures tailoring to the individual in the planning and implementation of the intervention.

3.2. Nutrition Assessment Ontology

The objective of the Nutrition Assessment Ontology is to semantically represent food and nutritional information and to enact the assessment of older adult food intake and associated nutritional values. To achieve this objective the nutritionists are interested in nutrients intake as well as at food consumption data, thus the ontology stores data about different types of foods

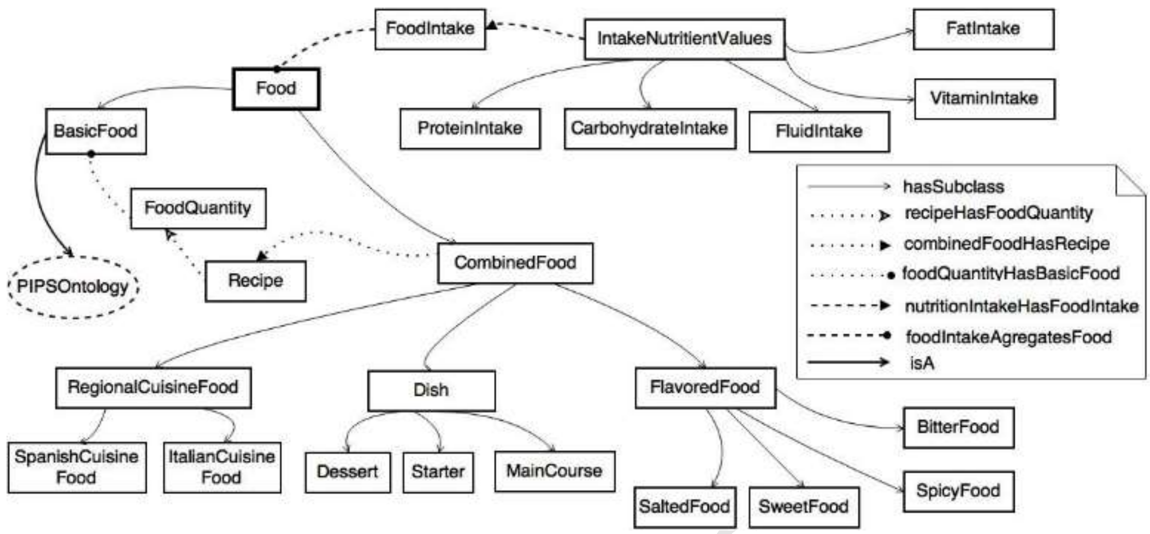

Figure 2: *The Nutrition Assessment sub-Ontology*

and their associated nutritional values.

The *Food* concept is at the root of this ontology, and all the other concepts inherit its properties, allowing the description of an aliment in terms of its nutrients. There are two types of foods modelled in the ontology: basic food and combined food.

The *basic food taxonomy* classifies food items according to the PIPS (Personalized Information Platform for Health and Life Services) food ontology (Dominguez et al., 2006), which has been imported and used in our assessment ontology. The PIPS ontology constructs the food taxonomy using the Eurocode 2 food coding which provides a mono-hierarchical classification of foods according to groups and subgroups that are useful in dietary studies. Specifically, the PIPS ontology defines 14 major food groups: 1) Milk, milk products and dishes, 2) Eggs, 3) Meat, 4) Poultry, 5) Fish, molluscs, reptiles and crustaceans, 6) Oils and fats, 7) Grains, 8) Pulses, seeds, nuts and kernels, 9) Vegetables, 10) Fruits, 11) Sugar, 12) Beverages (except milk), 13) Miscellaneous, soups, sauces and 14) Foods for special nutritional use.

The *combined foods* are prepared foods which are based on a recipe of basic foods (see Fig. 2). The recipe concept represents a collection of basic foods in different proportions or quantities and each recipe is associated with a combined food. There are different types of combined food: flavoured food, regional cuisine food and dish, and each of them has different subtypes. For example, flavoured food has the following subtypes: sour food, bitter food, spicy food, salted food and sweet food. Regional cuisine food can be further classified into: Italian cuisine food, Spanish cuisine food, etc. Finally, a dish could be a starter dish, a main course dish, or a dessert dish. Another important part of this ontology, for assessing the nutritional values of the older adult food intake, is represented by food quantities. There are different types of food quantities such as slice, cup, bowl, dish, pound, piece, box, bag, carton, jar, etc.

We have defined the *FoodQuantity* concept and associated relation for modelling their conversion in grams. Nutritional intake will be calculated from the food the older consumes during the day and will include the nutrient values such as: energy (kcal or kJ), fat (g), carbohydrates (g), fatty acids (g), protein (g), potassium (mg), calcium (mg), sodium (mg), vitamin D (ug), alcohol (g), and water (g). These values are important because malnutrition is prevented by maintaining them within ideal limits.

The nutrient values for each type of food are extracted from the McCance and Widdowson's food composition tables, which provide the description of around 3400 food items. Based on these nutritional values, the ontology individuals that represent specific food items are created and classified in the food ontology. For each food item, the main properties extracted are: the food code (Eurocode format), name and description, number of kilocalories, the amount of water, protein, fat, and other nutrients per 100 g. Three tables from McCance and Widdowson are important for creating the ontology instances: inorganics, proximates and vitamins. The inorganics table contains information on inorganic nutrients per 100 g such as the quantity of sodium (mg), potassium (mg), calcium (mg), magnesium (mg), phosphorus (mg), iron (mg), copper (mg), zinc (mg), chloride (mg), manganese (mg), selenium (ug), and iodine (ug). The proximates table contains information about the macro nutrients and their sub-components per 100 g such as: water (g), total nitrogen (g), protein (g), fat (g), carbohydrate (g), energy (kcal), energy (kJ), starch (g), oligosaccharide (g), total sugars (g), glucose (g), galactose (g), fructose (g), sucrose (g), maltose (g), lactose (g), alcohol (g), cholesterol (mg), etc.. Finally, the vitamins table contains information per 100 g on the content of vitamins including retinol (ug), carotene (ug), retinol equivalent (ug), vitamin D, vitamin E, vitamin K1, thiamine, riboflavin, niacin, and vitamin C.

3.3. Nutrition Problem Identification Ontology

The objective of this ontology is to define, classify and semantically represent potential nutrition related problems and the associated symptoms. Based on the values obtained from nutrition monitoring and nutrition assessment, this ontology provides the nutritionist with the ability to detect and evaluate nutrition related problems early in older adults, thus enabling proactive definition of nutrition intervention schemes that will allow the prevention of a problem before its actual instauration. We have defined this ontology by adapting the Nutrition Diagnosis step in the Academy of Nutrition and Dietetic Nutrition Care Process and Model, which specifies a problem as an alteration in the person’s nutritional status. Whilst the model proposes 60 approved standardized language terms, we have selected smaller number of problems and defined their associated symptoms for older adults using SWRL rules, which

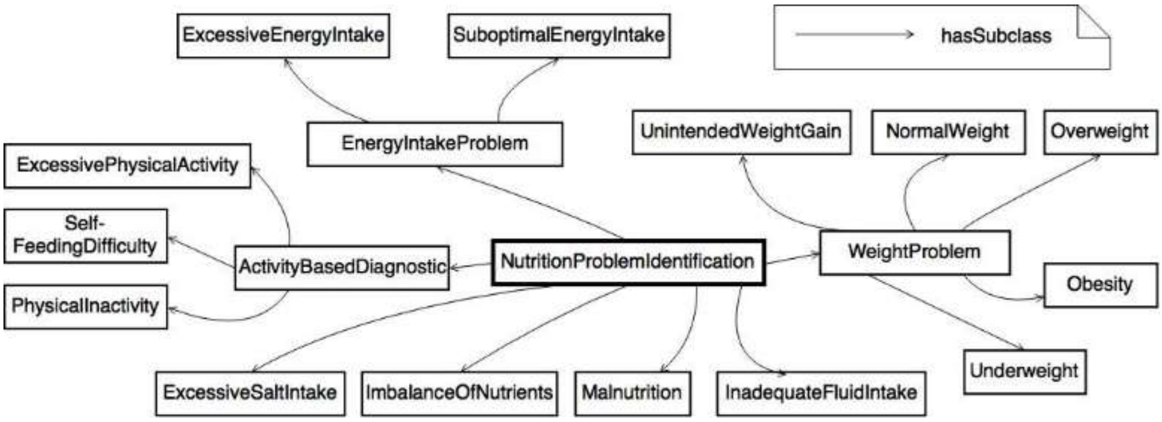

Figure 3: *Nutrition Problem Identification Ontology*

are then evaluated by reasoning on the defined ontologies.

The rules to proactively detect the early instauration of specific nutrition related problems in older adults as provided by nutritionists are defined in Table 1, while the Nutrition Problem Identification Ontology is depicted in Fig. 3. For example, to detect the nutrition problem related to inadequate fluid intake, 3rd SWRL rule from Table 1 is used. We have chosen this rule due to the fact that dehydration has a high occurrence rate in older adults and the assessment of this problem is quite complex due to the fact that daily water needs are strongly dependent on various factors like ambient temperature, fluid losses and dietary composition (see Hydration in the Aging). liquid, and so on are consumed). In the case of inadequate fluid intake, the reasoning works as follows: given the monitored intake of an older adult during a whole day, if the amount of water consumed is less than or equal to 1.5 litters (equivalent of six glasses), the older adult's fluid intake for that day is deemed suboptimal. Besides the nutrition problems included in Table 1, we have defined rules for assessing short term and long term unhealthy behaviours which may lead to the development and instauration of malnutrition. As previously noted, the impact of malnutrition on the elderly population includes the exacerbation of chronic and acute diseases, acceleration in the development of degenerative diseases, delayed recovery from illness and, in very extreme cases, even death so identifying behaviours which allow the early identification and prevention of malnutrition is paramount (see Time to recognise malnutrition in EU). Addressing malnutrition is not exclusively addressing insufficient nutrition intake and starvation but also addressing obesity due to the fact that older adults may eat an abundance of calories that do not deliver all the nutrients their body needs.

Table 1: *SWRL rules for detecting the early instauration of nutrition related problems*

Nutrition Problem	Rule definition	SWRL Rule Implementation	Dietary Plan for Intervention
Suboptimal Energy Intake	Weight loss > 3kg in the past month	*AnthropometryInformation (?a) ∧ hasWeightChange(?a, ?w) ∧ lessThanOrEqual(?w, -3.0) → hasNutritionProblem(?a, SuboptimalEnergyIntake)*	High Calories Diet, Provide Additional Snacks
Excessive Energy Intake	Weight gain > 3kg in the past month	*AnthropometryInformation (?a) ∧ hasWeightChange(?a, ?w) ∧ greaterThanOrEqual(?w, 3.0) → hasNutritionProblem(?a, ExcessiveEnergyIntake)*	Low Calories Diet
Suboptimal fluid intake	Less than 6 glasses of fluid (~1.5 L) per day	*IntakeNutrientValues (?i) ∧ hasWaterIntakeValue (?i, ?w) ∧ lessThanOrEqual(?w, 1.5) → hasFluidIntakeProblem(?i, SuboptimalFluidIntake)*	Increase Fluid Intake Plan
Excessive Salt Intake	Over 6 g per day for elders with heart problems	*IntakeNutrientValues (?i) ∧ hasSaltIntakeValue(?i, ?v) ∧ greaterThan(?v, 6) → hasNutritionProblem(?a, ExcesiveSaltIntake)*	Low Salt Diet
Underweight	BMI < 18.5 kg/m2	*AnthropometryInformation (?a) ∧ hasBMI(?a, ?bmi) ∧ lessThan(?bmi, 18.5) → hasWeightProblem(?a, Underweight)*	High Calories Diet, Provide Additional Snacks
Overweight	BMI between 25.0 and 29.9 kg/m2	*AnthropometryInformation (?a) ∧ hasBMI(?a, ?bmi) ∧ greaterThanOrEqual(?bmi, 25.0) ∧ lessThan (?bmi, 30.0) → hasWeightProblem(?a, Overweight)*	Low Calories Diet
Obesity	BMI > 30.0 kg/m2	*AnthropometryInformation (?a) ∧ hasBMI(?a, ?bmi) ∧ greaterThanOrEqual(?bmi, 25.0) → hasWeightProblem(?a, Obesity)*	

In our approach each older adult consumes different amounts of food and drinks during the day, which are monitored, with the information being stored in the nutrition monitoring and assessment ontologies. Using the McCance and Widdowson's tables, the nutrient values associated with the older adult's intake are computed (i.e. amount of protein, carbohydrates,

Table 2: *SWRL rules for detecting older adult's short term nutrition related un-healthy behaviors*

Evaluation Criteria	Nutrition Assessment Rule	SWRL Rule Implementation
Energy	Men: ~ 9.8 MJ/day Women: ~ 8.0 MJ/day	*AnthropometryInformation (?z) ∧ IntakeNutrientValues (?x) ∧ PersonalData (?p) ∧ PhysicalActivity (?ph) ∧ hasGender (?p, "male"^^string) ∧ hasHeight (?z, ?h) ∧ hasPAF (?ph, ?f) ∧ hasWeight (?z, ?w) ∧ add (?s1, ?r1, ?r2) ∧ multiply (?r1, ?h, 2.57) ∧ multiply(?r2, ?w, 0.0478) ∧ subtract(?s2, ?s1, 1.07) ∧ multiply(?rez, ?s2, ?f) → hasEstimatedEnergyValue(?x, ?rez)*
Total fat	~ 20-35% energy	*IntakeNutrientValues (?x) ∧ hasEstimatedEnergyValue(?x, ?e) ∧ divide(?r, ?m, 100.0) ∧ divide(?rez, ?r, 9.0) ∧ multiply(?m, ?e, 35.0) → hasEstimatedFatValueUpperLimit(?x, ?rez)*
Saturated fatty acids	< 11% energy	*IntakeNutrientValues (?x) ∧ hasEstimatedEnergyValue(?x, ?e) ∧ divide(?r, ?m, 100.0) ∧ divide(?rez, ?r, 9.0) ∧ multiply(?m, ?e, 11.0) → hasEstimatedSatFatAcidValueUpperLimit(?x, ?rez)*
Trans fatty acids	< 1% energy	*IntakeNutrientValues (?x) ∧ hasEstimatedEnergyValue(?x, ?e) ∧ divide(?r, ?m, 100.0) ∧ divide(?rez, ?r, 9.0) ∧ multiply(?m, ?e, 1.0) → hasEstimatedTransFatAcidValueUpperLimit(?x, ?rez)*
Protein	> 0.75g/kg body weight / day	*AnthropometryInformation (?z) ∧ IntakeNutrientValues (?x) ∧ hasWeight(?z, ?w) ∧ multiply(?r, ?w, 0.75) → hasEstimatedProteinValueLowerLimit(?x, ?r)*
Potassium	> 3.5g/d	*FoodIntake(?x) → hasEstimatedPotassiumValueLowerLimit (?x, 3.5)*
Calcium	> 700 mg/ day	*FoodIntake(?x) → hasEstimatedCalciumValueLowerLimit (?x, 700.0)*
Vitamin D	~10 micrograms/day	*FoodIntake(?x) → hasEstimatedVitaminDValue (?x, 10.0)*
Salt	< 6 g / day	*FoodIntake(?x) → hasEstimatedSaltValueUpperLimit (?x, 6.0)*
Alcohol	Men: < 28 units / week Women: < 21 units/ week	*IntakeNutrientValues (?x) ∧ PersonalData(?p) ∧ hasGender(?p, "male"^^string) → hasEstimatedAlcoholValueUpperLimit(?x, 21.0)*

To assess the older adult's short term behaviours which may lead to malnutrition, the older adult's self-feeding process is evaluated against the benchmarks and dietary recommendations for older adults (regarding daily nutrients intake) as defined by nutritionists.

As before, these recommendations are represented using SWRL (see Table 2) and evaluated by means of a reasoning engine on the defined ontologies. If the conjunctions specified in the SWRL rule's antecedent are false for a specific older adult, the rule's consequent classifies the corresponding unhealthy behaviour. If unhealthy behaviours are observed over several days, nutrition interventions are triggered in the form of notifying the older adult or the associated carer and also recommending and delivering food to the older adult to rebalance the nutrients intake (see Nutrition Intervention Ontology). In addition to short term behaviours to assess the older adult's long term unhealthy behaviours which may lead to malnutrition, the older adult's level of adherence to the

Table 3: *14-item Mediterranean diet adherence score questionnaire*

Questions	Criteria for 1 point
Do you use olive oil as main culinary fat?	Yes
How much olive oil do you consume in a given day (i.e. oil used for frying, salads, out-of-house meals, etc.)?	≥ 4 tablespoons
How many vegetable servings do you consume per day (1 serving: 200g; consider side dishes as half a serving)	≥ 2
How many fruit units (portions) (including natural fruit juices) do you consume per day?	≥ 3
How many servings of red meat, hamburger, or meat products (ham, sausage, etc.) do you consume per day (1 serving: 100 – 150g).	< 1
How many servings of butter, margarine or cream do you consumer per day (1 serving: 12 g)	< 1
How many sweet or carbonated beverages do you drink per day?	< 1
How much wine do you drink per week?	≥ 7 glasses
How many servings of legumes do you consume per week? (1 serving: 150g)	≥ 3
How many servings of fish or shellfish do you consume per week? (1 serving 100-150g fish or 4-5 units (pieces) or 200g of shellfish)	≥ 3
How many times per week do you consume commercial sweets or pastries (not homemade), such as cakes, cookies, biscuits, or custard?	< 3
How many servings of nuts (including peanuts) do you consume per week? (1 serving 30g)	≥ 3
Do you preferentially consume chicken, turkey, or rabbit meat instead of veal, pork, hamburger or sausage?	Yes
How many times per week do you consume vegetables, pasta, rice, or other dishes seasoned with sofrito (sauce made with tomato and onion, leek, or garlic and simmered with olive oil)?	≥ 2

Mediterranean diet assessed using a previously published (Martinez-Gonzalez et al., 2012) Mediterranean Diet Adherence Score Questionnaire (see Table 3).

The effectiveness of the Mediterranean diet in reducing the prevalence of cardiovascular and chronic diseases has been largely evidenced in the state of the art literature (Féart et al., 2010). Also it has been shown that there is a 13 percent lower risk of cognitive impairment in Mediterranean diet adherents, and that following a Mediterranean diet may help prevent diabetes in people who are at risk of heart disease (Preidt, 2014). The Mediterranean diet is based on few principles such as (see Table 3): eating primarily plant-based foods such as fruits and vegetables, whole grains, legumes and nuts; replacing butter with healthy fats, such as olive oil; using less salt to flavor foods; limiting red meat to no more than a few times a month and eating other kind of low fat meat such as chicken or turkey; eating fish and poultry at least twice a week; and finally an optional principle is drinking red wine in moderation due to the anti-oxidants it contains. To assess the adherence of a person to the Mediterranean diet, the nutritionist uses the Mediterranean Diet Adherence Score questionnaire presented in Table 3. It is well known that the use of questionnaires is not always effective for older adults due to the effect of age on memory recall.

The problem can be addressed by defining SPARQL rules (see SPARQL recommendation) for each corresponding question and using them on the defined nutrition monitoring and assessment ontologies to calculate the older adult adherence to the Mediterranean diet score. If the calculated score is less than 3 points there is poor adherence, if the calculated score is between 4 and 7 points there is medium adherence, and if the score is higher than 8 points there is good adherence. For example, Fig. 4 presents the SPARQL query rule equivalent to question 3 of Table 3, i.e. "How many vegetable servings do you consume per day (1 serving: 200g; consider side dishes as half a serving)".

The query starts with the declaration of prefixes to the ontologies defined above: PIPS food, nutrition assessment and nutrition monitoring. The query retrieves the food intake and the quantity of vegetables consumed during a day for an older adult by searching the food taxonomy defined in the PIPS ontology. For each type of food intake that is classified as of type *Vegetables* in this ontology, the *foodQuantitiesInFoodIntake* data Property is considered. The sum of these data values is the overall quantity of vegetables consumed during the day.

```
"PREFIX foods: <http://www.semanticweb.org/foodsontology/food/#>"
+ "PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>"
+ "PREFIX food: <http://www.semanticweb.org/dorin/ontologies/food#>"
+ "PREFIX nutritionassessment: <http://www.semanticweb.org/ ontologies/nutritionassessment#>"
+ "PREFIX nutritionmonitoring: <http://www.semanticweb.org/ ontologies/nutritionmonitoring#>"
+ "SELECT ?foodIntake (SUM(xsd:double(?coefficient) * xsd:double(?grams)) AS ?Grams) "
+ " WHERE {"
        + "   ?foodIntake nutritionmonitoring:hasUsername \"" + username + "\" . "
        + "   ?foodIntake nutritionmonitoring:hasDate \"" + dateString + "\"^^xsd:dateTime . "
        + "   ?foodQuantityInFoodIntake nutritionassessment:foodQuantityHasFoodIntake ?foodIntake . "
        + "   ?foodQuantityInFoodIntake nutritionassessment:foodIntakeHasFoodQuantity ?foodQuantity . "
        + "   ?foodQuantityInFoodIntake nutritionassessment:foodQuantityInFoodIntakeHasCoefficient ?coefficient . "
        + "   ?foodQuantity nutritionassessment:hasGramsValue ?grams . "
        + "   ?foodQuantity nutritionassessment:hasBasicFood ?basicFood . "
        + "   ?basicFood rdf:type food:Vegetables . "
        + " } GROUP BY ?foodIntake ";
```

Figure 4: *SPARQL rule equivalent to question 3 of Table 3 "How many vegetable servings do you consume per day"*

3.4. *Nutrition Intervention Ontology*

The Nutrition Intervention Ontology (see Fig. 5) models knowledge regarding the type of actions that may be taken in case a nutrition problem or unhealthy behaviour is identified for an older adult. The nutrition intervention process consists of two steps consisting of different actions modelled in our ontology:

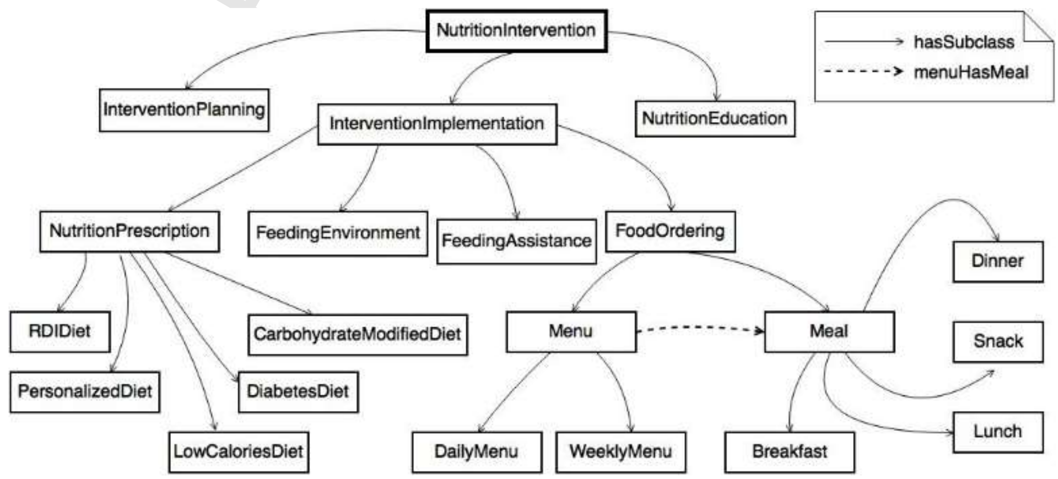

Figure 5: *Nutrition Intervention Ontology*

planning the intervention and implementing it.

In **the first step**, the recommendation of a new diet is performed by a nutritionist aiming to change an identified unhealthy behaviour by setting goals and expected outcomes in form of a recommendation that needs to be followed by the older adult. The recommendation will be defined in close correlation with the nutrition problems identified and nutrition-related monitored information. Ideally the plan should be developed in conjunction with or by the older person (and carers or family) and should reflect clinical guidelines. For goals or intervention planning, the following factors are considered: changing nutrients or food provided to affect intake, influencing nutrition related knowledge or behaviour, change to environment and access to supportive care and services.

Table 4: *Generic nutrition intervention plan for elders*

	Energy	Protein
BREAKFAST: E.g. fruit juice, cereal and semi-skimmed milk, bread and spread, preserves;	400 kcal	5.0g
MAIN MEALS AND DESSERTS: Two main courses and desserts offered each day should average out to meet energy and protein values;	1050 kcal	29.0 g
HIGHER ENERGY SNACKS INCLUDING A SUPPER SNACK: Two to three daily; total nutrients provided should average out to meet the energy and protein values.	400 kcal	3.0g
MILK FOR DRINKS 400ml semi-skimmed/skimmed milk. Minimum of Fluid intake 6-8 glasses of water, juice and milky drinks. A small portion (15g or half a matchbox) (OR additional 150ml milk)	190 kcal 60 kcal	14g 4.0g
For practical purposes the total to be provided is rounded to 2100 kcal and 55g protein. These are minimum values and not targets.		

Table 4 presents a generic nutrition intervention plan for an older adult incorporating minimum nutritional standards with no chronic condition (adapted from (Cartz, M. et al., 2012) and NACC Nutritional Standards for Adults).

In **the second step**, the intervention plan is implemented by means of defined intervention alternatives presented in Table 5.

Table 5: *Nutrition intervention implementation options*

Intervention	Automated goals	Example of actions
Food ordering	Implement the nutrition prescription plan: • regular meals and/or regular snacks • modify distribution, type or amount of food within meals or snacks; • encourage / provide specific foods, beverages or food groups.	Provide additional snack foods that are high in energy and protein (and in line with older person's preferences) e.g. cheese with biscuits, yoghurt, custard, scones or pancakes.
Feeding assistance	Assistance with eating: • special equipment; • feeding position recommendation; • meal set up.	Involve carers and family. Incorporate some of the strategies recommended by the Dementia Mealtime Assistance Tool or similar.
Feeding environment	Improvement to eating environment: • lighting, temperature distractions, table set up adjustment, etc.	
Nutrition education	Brief Nutrition Education: • build or reinforce basic nutrition related knowledge	Video clips with tips, recipes, skills education; highlighting foods on the menu that meet goals set.

Regarding food ordering, different foods may be suggested to comply with the nutritionist's recommendation and nutrition-

```
SELECT ?foodIntake "
   + "(SUM(xsd:double(?coefficient) * xsd:double(?grams) * xsd:double(?energy) / 100) AS ?Energy) "
   + "(SUM(xsd:double(?coefficient) * xsd:double(?grams) * xsd:double(?fat) / 100) AS ?Fat) "
   + "(SUM(xsd:double(?coefficient) * xsd:double(?grams) * xsd:double(?carb) / 100) AS ?Carb) "
   + "(SUM(xsd:double(?coefficient) * xsd:double(?grams) * xsd:double(?satFatAcid) / 100) AS ?SatFatAcid) "
   + "(SUM(xsd:double(?coefficient) * xsd:double(?grams) * xsd:double(?transFatAcid) / 100) AS ?TransFatAcid) "
   + "(SUM(xsd:double(?coefficient) * xsd:double(?grams) * xsd:double(?potassium) / 100) AS ?Potassium) "
   + "(SUM(xsd:double(?coefficient) * xsd:double(?grams) * xsd:double(?calcium) / 100) AS ?Calcium) "
   + "(SUM(xsd:double(?coefficient) * xsd:double(?grams) * xsd:double(?sodium) / 100) AS ?Sodium) "
   + "(SUM(xsd:double(?coefficient) * xsd:double(?grams) * xsd:double(?vitaminD) / 100) AS ?VitaminD) "
   + "(SUM(xsd:double(?coefficient) * xsd:double(?grams) * xsd:double(?alcohol) / 100) AS ?Alcohol) "
   + "(SUM(xsd:double(?coefficient) * xsd:double(?grams) * xsd:double(?water) / 100) AS ?Water) "
   + " WHERE {"
      + "?foodIntake rdf:type nutritionmonitoring:FoodIntake . ?foodIntake nutritionmonitoring:foodIntakeHasId " + foodIntakeId
      + ". ?foodQuantityInFoodIntake nutritionassessment:foodQuantityHasFoodIntake ?foodIntake"
      + ". ?foodQuantityInFoodIntake nutritionassessment:foodIntakeHasFoodQuantity ?foodQuantity "
      + ". ?foodQuantityInFoodIntake nutritionassessment:foodQuantityInFoodIntakeHasCoefficient ?coefficient"
      + ". ?foodQuantity nutritionassessment:hasGramsValue ?grams . ?foodQuantity nutritionassessment:hasBasicFood ?basicFood"
      + ". ?basicFood nutritionassessment:hasEnergyValue ?energy . ?basicFood nutritionassessment:hasFatValue ?fat"
      + ". ?basicFood nutritionassessment:hasCarbValue ?carb . ?basicFood nutritionassessment:hasSatFatAcidValue ?satFatAcid"
      + ". ?basicFood nutritionassessment:hasTransFatAcidValue ?transFatAcid . ?basicFood nutritionassessment:hasProteinValue ?protein"
      + ". ?basicFood nutritionassessment:hasPotassiumValue ?potassium . ?basicFood nutritionassessment:hasCalciumValue ?calcium"
      + ". ?basicFood nutritionassessment:hasSodiumValue ?sodium . ?basicFood nutritionassessment:hasVitaminDValue ?vitaminD"
      + ". ?basicFood nutritionassessment:hasAlcoholValue ?alcohol . ?basicFood nutritionassessment:hasWaterValue ?water"
               + " } " + " GROUP BY ?foodIntake ";
```

Figure 6: *Evaluating the nutritional information of older adult's daily food intake*

related monitored information. If it is inferred that using food ordering can no longer balance the daily intake (i.e. there is severe violation of the dietary plan), alarms are generated for the older adult, associated carer and nutritionist.

Our semantic based approach enables the dynamic selection based on the prescribed diet, of suitable food service providers, potentially enabling automated shopping. In addition, it allows the assistance of older adults and their informal carers during daily self-feeding activities to enable the detection and prevention of malnutrition. The nutrition education actions aim to educate the older adult to eat healthier food by building or reinforcing basic nutrition or diet related knowledge in strict alignment with the assessed nutrition related problems. In this step the nutritionist will also use the system for process evaluation purposes, i.e. to check that the plan has been carried out (for example, that a meal with additional snack items has been delivered as agreed), and that any existing problems are identified and rectified. This is done by means of continuously evaluating the food intake by calculating the nutritional intake on daily basis using SPARQL rules such the one presented in Fig. 6 and by food ordering to balance the intake. In this phase, it is important that the elder can provide feedback on the acceptability of the intervention, as well as communicate any practical issues with its implementation.

4. Use case validation

The validation process aims to ensure that the defined nutrition expert system satisfies the requirements of its users, which are in our case the nutritionists. In the state of the art literature, there is a general agreement on two main classes of expert system validation (Preece, 1990): laboratory validation and field validation. Field validation for evaluating our approach in depth will require large scale deployment and data gathering over a long period which may be costly in terms of time and money and may primarily discover and address problems with front-end interface aspects of the system rather than the underlying technical contributions as described in the above paper. Moreover, prior to that, a preliminary evaluation is required to ensure that the idea is feasible, as determined by expert nutritionists. This is why our evaluation process is based on laboratory validation, which measures the usefulness and quality of the system, aiming to expose problems regarding the defined nutrition knowledge base and inference system. The validation process will consist of comparing the nutrition expert's assessment with that of the expert system for a test case (an older adult), with the system being accepted if it is as competent as the nutritionist (Grogono, et al., 1993). This process requires the definition and generation of older adult patients' situations describing unhealthy self-feeding behaviours, the execution of the expert system to assess the nutrition related problems, and the comparison of the results provided with the ones given by the nutritionist. In addition, the cohesion and computational efficiency of the knowledge base are assessed.

4.1. Nutrition Expert System in-lab Prototype

Fig. 7 presents the architecture of the nutrition expert system developed and used for the in-lab validation process. The core part of the system is the nutrition related knowledge represented by means of the Nutrition Care Process Ontology and associated nutrition diagnosis SWRL and SPARQL rules. The Nutrition Monitoring module generates data describing older adult unhealthy self-feeding behaviours in accordance with the foreseen validation scenarios. Examples of the data generated are the older adult's food and beverage intake, weight, physical activity levels, etc. The Nutrition Assessment and Problem Identification modules implement the nutrition expert system's inference engine, which evaluates the defined nutrition related rules on elder's food intake. The inference engine is based on semantic reasoning tools and techniques. The Nutrition Intervention module selects the appropriate intervention option according to the assessed nutrition problem (i.e. it associates dietary goals with specific conditions and behaviours identified).

We have designed a semantic inference engine consisting of the following tools (see Fig. 8): (i) Protégé (Fudholi et al., 2009) for implementing the concepts and properties of the Nutrition Care Process Ontology, (ii) Jena framework which provides the API to process RDF data, (iii) D2RQ for mapping individuals from the ontology with entries from an SQL database and (iv) Pellet reasoned for evaluating the defined nutrition rules on the ontology.

Due to the large number of ontology concepts describing food items that need to be instantiated and classified in the defined taxonomy, this process cannot be done manually. On the other hand, there is an evident need for ensuring a semantic validation

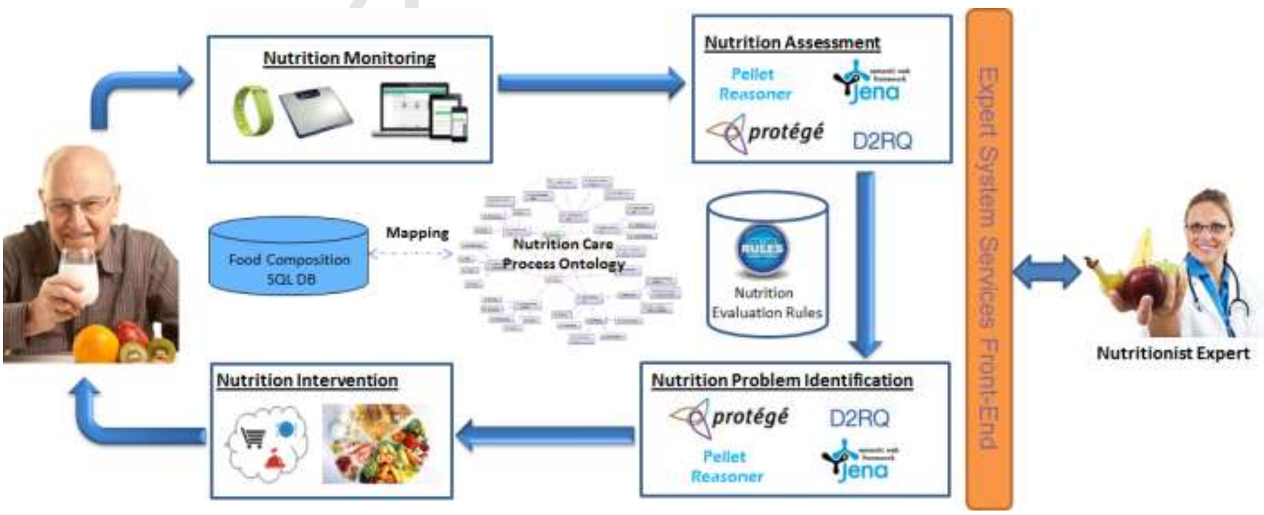

Figure 7: *Architecture of the nutrition expert system's in-lab prototype*

and automated reasoning on the data provided which cannot be achieved using the relational database representation of data. Our solution is to store data regarding food items and their nutritional information in a relational database and to map the ontology concepts onto the database tables to obtain concept instances. Different alternatives to connect and map ontology to a relational database are reported in the literature (Konstantinou et al., 2008). When choosing the solution we have considered the following criteria: how the individuals will be persisted in the relational database, whether the ontology will be written in a specialized tool, whether a reasoner will be used to infer new knowledge from the already existing data, and whether data will be queried by using a specialized language. We chose to use D2RQ due to the fact that classes, object properties and data properties can be managed in the form of database tables, there is a clear separation between the ontology data (individuals) and ontology structure, and D2RQ can be easily integrated with Jena which is a powerful tool for reasoning on ontologies. A simplified architecture of how the ontology is mapped to the database using D2RQ and how this mapping can be used in order to get information is presented in Fig. 8

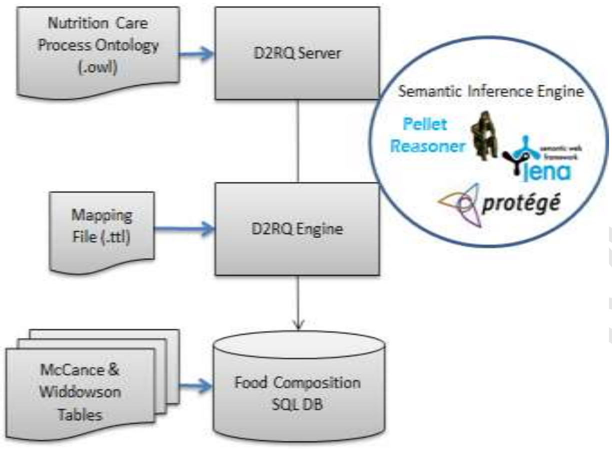

Figure 8: *Food Ontology mapping onto the Food Composition DB and Inference Engine*

Data about individuals is persisted in a database. A mapping file is used to define the relation between the ontology specific elements (i.e. ontology classes, data properties, object properties, and subclass relations) and the database tables. Reasoning and query rules are expressed using the concepts provided by the food ontology and the mapping defined data from the database.

The steps followed by the in-lab prototype to make decisions are: firstly the nutrition monitoring module generates data describing the older adult's nutrition related situation by creating the corresponding individual in the Nutrition Care Process ontology; secondly the data regarding the nutrient composition of the older adult's consumed food items is queried by the D2RQ platform and passed to Jena; thirdly the defined nutrition related rules are loaded by Jena and evaluated by Pellet on the ontology; and finally the inference result is queried to extract and process the nutrition assessments and decisions.

4.2. Ontology usefulness evaluation

The usefulness of the Nutrition Care Process ontology and inference engine is evaluated by using the developed in-lab system prototype for nutrition knowledge management to assess the self-feeding behaviour of one individual (called Miguel). Two nutrition experts who provided the initial nutrition related knowledge had interacted with the in-lab prototype and conducted independent assessment processes on the patient to evaluate the outcome.

Miguel is a 78 year old retired man who lives alone in his home in a small town of the North of Spain. He was diagnosed with type II diabetes 7 years ago and was later also diagnosed with cardiovascular disease after he experienced a Myocardial Infarction two years ago. He wakes up every day at 8.00AM and prepares himself a simple breakfast, coffee with some toast. After that, Miguel takes a walk towards a newspaper kiosk located in the town's main square, which is 15 minutes' walk from his home. Miguel buys the newspaper and then sits in one of the main square benches. He reads the news for around one hour and gets distracted with the bustle of the place for some more time. On his way back home, Miguel stops at a supermarket, close to his place, and buys some food including precooked meals. Miguel is able to prepare simple meals, but not complex ones, so he prefers to consume precooked food which makes his life easier. Also every weekend Miguel's friends come to visit, often bringing some sweets or treats. Being diagnosed with type II diabetes and cardiovascular disease, the diet that Miguel is actually following is not suitable for his condition as he is consuming too many calories, too much salt and saturated fat, and does not have balance among the main food groups. He gained 4 kg in weight over the last 12 months, so his local doctor has referred him to a nutritionist. Table 6 presents Miguel's profile after the screening conducted by the nutritionist.

Table 6: *Miguel's nutrition related screening*

Monitored Data	Measured Values
Anthropometry	Height: 178 cm (measured using stadiometer)
	Current weight: 88 kg
	BMI: 27.8 kg/m^2
	Weight history: 82 kg (2 year ago), 84 kg (1 years ago)
	Physical activity factor (PAF): 1.2
Biochemistry	HbA1C: 7.5%
	Random blood glucose: 9.8 mmol/L
	Blood pressure: 140/90 mm Hg
Clinical	Medical history: Myocardial Infarction, Arthritis
	Medications: Metformin 1 g bd, Simvastatin 20 mg od
Dietary	Texture: Normal
	Requires diabetic meals
	Average Meal: 550 kcal; 18g protein
	Preferences: Spanish Cuisine
	Current Mediterranean diet assessment score: 5

The data resulting from Miguel's screening and nutrition monitoring as well as his profile are inserted as individuals in the Nutrition Care Process ontology. Using this information, the inference engine of the prototype is able to calculate the following parameters regarding Miguel's condition:

- The estimated basal metabolic rate (BMR). The value of BMR is computed using the Henry equation (Henry, 2005) where 0.0478, 2.57 and 1.07 are constants for male elders aged over 60 years:

$$BMR = (0.0478 \times weight) + (2.57 \times height) - 1.07 = 7.711\ MJ/day\ (1842\ kcal/day) \quad (1)$$

- The estimated daily energy requirement. The value of the estimated daily energy requirement is the estimated BMR multiplied by a physical activity factor (PAF):

$$BMR \times PAF = 9.25\ MJ/day\ (2211\ kcal/day) \tag{2}$$

- The body mass index:

$$BMI = weight(kg)/(height(m) \times height(m)) = 27.8\ kg/m^2 \tag{3}$$

Next we determine our prototype's ability to evaluate the nutrition problem identification rules defined in SWRL in Section 3.3 (see Table 2) considering Miguel's screening, profile and the above assessment, to infer the Recommended Daily Intake values for different nutrients personalized for Miguel's condition. Table 7 presents the Recommended Daily Intake values for Miguel's daily menu calculated by our prototype and benchmark values provided by nutritionists.

Table 7: *Miguel inferred recommended daily nutrient intake*

Nutrient	Miguel's Inferred Daily Values	Nutritionist Benchmark for Men
Energy	9.25 MJ/day	~ 9.8 MJ/day
Total fat	~ 49 - 86 g/day (~19.6-34.4% energy)	~ 20-35% energy
Saturated fatty acids	~ 27 g/day (~10.8% energy)	< 11% energy
Trans fatty acids	~ 2.5 g/day (~1% energy)	< 1% energy
Protein	~ 66 g/day (~11.4% energy)	> 0.75g/ kg body weight / day (>11% energy)
Potassium	~ 3.5 g/day	> 3.5 g/day
Calcium	~ 700 mg/day	> 700 mg/ day
Vitamin D	~ 10 micrograms /day	~10 micrograms/day
Salt	~ 2.4 g/day	< 6 g / day
Alcohol	~ 32 g/day	< 28 units / week
Water	~ 2.5 L/day	~2.5 L/day

One can notice that all calculated values fall between the limits traced by nutritionists. At the same time the prototype inference engine makes a nutrition diagnosis assessment to identify the symptoms of nutrition related problems defined in Table 1 by evaluating the associated SWRL rules on Miguel's specific situation. For example due to the fact that Miguel's BMI is between 25 and 30 (i.e. 27.8) our prototype classifies him as **overweight**.

For nutrition intervention the system first tries to associate the proper intervention plans from the ones already defined by nutritionists and formalized in our ontology for Miguel's condition and profile. Being previously assessed as overweight our prototype successfully selects a **low calorie based diet** (see Table 1) as appropriate intervention plan suggesting a daily menu with ~836 kJ lower than his estimated daily energy requirements (~ 9.25 MJ). Also because he suffers from diabetes and cardiovascular diseases, our prototype infers that in addition to the low calories diet, Miguel should also follow specific dietary plans defined for those diseases.

For cardiovascular diseases the system recommends a personalized **low salt diet** (see Table 1) with a moderate restriction estimated based on Miguel's daily energy requirements. It is likely that potassium intakes, at a higher intake of fruit and vegetables than recommended to the general population, will have an effect on blood pressure. The association of blood pressure with alcohol is particularly strong at intakes above 2 drinks per day so it is carefully evaluated.

For diabetes, the system's dietary plan is based on a reduction in calorie intake in those who are overweight, coupled with an improvement in physical activity to improve the action of insulin. However for diabetes patients requiring insulin as Miguel's case, the system recommends eating carbohydrate containing foods at regular intervals and/or matched to their insulin dose. More slowly absorbed carbohydrate foods (i.e. those with a lower glycaemic index) should be emphasized for improved glycaemic control.

Once the intervention plan is developed for Miguel's individual conditions, the system prototype will continuously evaluate the nutritional adequacy of Miguel's daily food intake using the SWRL rules. Table 8 presents different simulated situations of Miguel's daily intake, for which the prototype was used to evaluate the intake adequacy and the degree of violation of Miguel's dietary goals. The same situations were presented to the nutrition experts who conduct their own independent assessment, and in the end the results are compared. As it can be seen our prototype manages to successfully determine the daily menus that are inadequate for Miguel assessing the adherence to the goals defined by nutritionists.

Table 8: *Miguel nutrition assessment for daily food intake*

Miguel's Daily Intake	Nutrient Analysis	
	Our prototype results	Nutritionist results
Day 1: **Breakfast** – Mug of coffee with 60ml whole milk and 1 teaspoon sugar; 2 slices white bread spread thickly with butter **Lunch** – 250ml orange juice; 1 x 400g packs of macaroni cheese; 2 tablespoons canned sweet corn, 2 slices tomato, 200g rice pudding **Dinner** – 1 x 400g pack chicken curry with rice. Half-pint glass of mango juice. **Snack** – Banana (1 medium)	Energy: 2169.8 kcal Exceeds recommendation: *Salt: 7.4g* *% en from fat: 37.29%* *% en from SFA: 18.9%* Below recommendation: *Fluid: 1645.32 ml* *Potassium: 2.9g*	Energy: 2144 kcal Exceeds recommendation: *Salt: 7.5g* *% en from fat: 37%* *% en from SFA: 19%* Below recommendation: *Fluid: 1620 ml* *Potassium: 2.8g*
Day 2: **Breakfast** – Mug of coffee with 60ml whole milk and 1 teaspoon sugar; 2 slices white bread spread thickly with butter **Lunch** – 1 x 440g pack of Beef curry with rice. 200g rice pudding, 330ml can of lemonade **Dinner** -Turkey pie– 1 medium slice; 2 x 65g Ice lollies with real fruit juice **Snack:** 1 x 40g bags peanuts, raisins and chocolate chips. 1 pint lager, 1 x 37g bag potato crisps	Energy: 2145.0 kcal Exceeds recommendation: *Salt: 8.3 g* *% en from fat: 39.12%* *% en from SFA: 18.47%* Below recommendation: *Fluid: 1218.67 ml* *Potassium: 3.4 g*	Energy: 2098 kcal Exceeds recommendation: *Salt: 6.3 g* *% en from SFA: 16%* Below recommendation: *Potassium: 2.8 g*
Day 3: **Breakfast** – Mug of coffee with 60ml whole milk and 1 teaspoon sugar; 2 slices white bread spread thickly with butter **Lunch** – 1 x 400g pack chicken curry with rice, 2 dessertspoons plain yoghurt, granary bread 1 slice spread thickly with butter, half-pint glass mango juice. **Dinner** – 1 x 300g packet of sausages and mash, 1 medium slice apple pie (1 crust) with ready-made custard (1 pot). **Snack** – 1 medium nectarine, 1 medium banana	Energy: 2255.1 kcal Exceeds recommendation: *Salt: 8.3 g* *% en from fat: 39.37%* *% en from SFA: 18.07 %* Below recommendation: *Fluid: 1495.31 ml* *Potassium: 2.9 g*	Energy: 2239 kcal Exceeds recommendation: *Salt: 8.4 g* *% en from fat: 39%* *% en from SFA: 17%* Below recommendation: *Potassium: 3.0 g*

Miguel's Daily Intake	Nutrient Analysis	
	Our prototype results	**Nutritionist results**
Day 4: **Breakfast** – Mug of coffee with 60ml whole milk and 1 teaspoon sugar; 2 slices white bread spread thickly with butter **Lunch:** 400g pack vegetable lasagne, garlic bread – half of 150g stick, fruit salad 1 cup with 2 scoops vanilla ice cream **Dinner:** 1 x 450g pack cottage pie, 1 half-pint glass mango juice **Snack:** 2 glasses tomato juice, 1 portion camembert cheese with 5 water biscuits	Energy: 2401.8 kcal Exceeding recommendation: *Salt: 15 g* *% en from fat: 41.57%* *% en from SFA: 17.41%* Below recommendation: *Fluid: 1694.40 ml*	Energy: 2379 kcal Exceeding recommendation: *Salt: 14.3 g* *% en from fat: 41%* *% en from SFA: 17%* Below recommendation: -

Legend: % en from fat = proportion of energy derived from total fat;
% en from SFA = proportion of energy derived from saturated fatty acids;
kcal = kilocalories

4.3. *Ontology quality evaluation*

To assess the quality of the ontology, the *computational efficiency*, *coupling* and *cohesion* metrics were used (Burton-Jones et al., 2005; Hlomani and Stacey, 2014). We have simulated an increasing number of older adults (up to 210) by generating and inserting the corresponding individuals in the ontology, and evaluated the nutrition knowledge and knowledge management using metrics reported in literature.

The ontology *computational efficiency* refers to the time overhead for running SPARQL queries and SWRL reasoning rules and its variation with the number of older adults stored in the ontology. First we have evaluated the time needed to run and assess the Mediterranean Diet adherence questions, with the average time values obtained being reported in Fig. 9. Even though the relation between time overhead and number of elders is exponential, reasonable time results are obtained for 210 elders (~ 27 seconds). Second we have determined the Pellet's incremental reasoning performance on the Nutrition Care Process ontology by evaluating the variation of the incremental classification time with the number of older adults stored in the ontology. The incremental classification is used to update the ontology classification results when the class hierarchy changes (new concepts are defined).

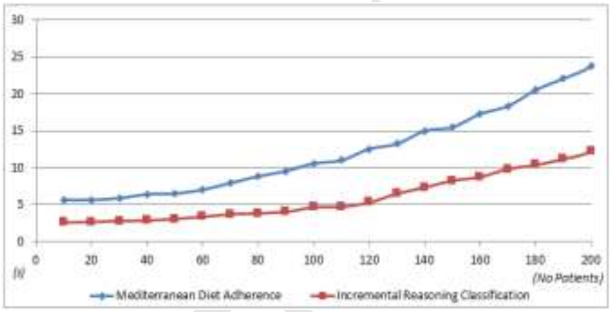

Figure 9: *Computational time overhead results*

The *coupling metric* evaluates the number of classes from external ontologies imported and used in the Nutrition Care Process ontology. We have reused only the PIPS food ontology for classifying the food items so the coupling value is given by the number of concepts used from this ontology (i.e. 176 out of 277 named classes). The *cohesion metric* measures the modularity and the degree of relatedness of concepts from our ontology in terms of number of root concepts, number of leaf concepts, and depth of inheritance tree, etc. For computing cohesion we have used an ontology evaluation tab for Protégé (see Ontology evaluation in Protégé) and the obtained results are summarized in Table 9.

Regarding ontology *consistency*, besides the evaluation done by nutrition experts regarding ontology concepts definition, taxonomy and relation among them, we have used Pellet (Incremental) reasoner to check the ontology's hierarchies, domains, ranges, conflicting disjoint assertions, etc. No Inconsistent Ontology Exception was generated.

4.4. *Discussion and Limitations*

In this section we discuss our findings and potential limitations form the perspective of our system's end users: older adults,

Table 9: *Nutrition care process ontology metrics results*

Evaluation Metric	Monitoring Ontology	Assessment Ontology	Problem Identification Ontology	Intervention Ontology	PIPS Food Ontology
No. Named Classes	43	34	7	7	176
Average No. Parents	0.8	0.82	0.85	0.94	0.92
Average No. Siblings	3.4	4.7	6	3.2	12.5
Max Depth	2	3	1	5	1
Total No. Nodes	44	35	8	18	177
Total No. Roots	9	6	1	1	13
Total No. Internal Nodes	10	6	1	5	13
Total No. Children	34	28	6	16	163
Total No. External Nodes	33	28	6	12	163
No. Properties	53	48	4	6	0
No. Object Properties	8	10	0	1	0
No. Data Type Properties	45	38	2	5	0
Properties with Domain	100%	93.75%	100%	100%	0%
Properties with Range	39.60%	62.50%	100%	100%	0%

nutritionists and food providers.

Effective older adults' nutrition monitoring is crucial for our system to capture nutrition problems, tracking trends and later for intervention decision-making. The nutritional assessment of food intake done by nutritionists during elderly regular visits using questionnaires implies great memory effort from elderly and may lead to imprecise results due to elderly memory impairment. We had approach this problem allowing the elders to provide information regarding their food intake directly right after they had eaten the meals using semantic concepts from the food ontology familiar to them and the interfaces provided by our system. This requires some minor technical knowledge from elders making the accessibility and usability features our system of high priority. Before commercializing such product great focus should be put on making the user experience positive with people in general and for those with age related impairments in particular and understanding the type of barriers they have when interacting and understanding the system. At the same time the ontology based inference system proposed is open for integrating sensor based intake monitoring (when available) for providing a definitive answer to the question of "what is the actual food intake?".

We innovatively use ontologies, databases and interference systems for the analysis of non-medical, nutrition data to identify patterns and relations between lifestyle behavior, self-feeding process and adherence to a prescribed diet. A challenge in this case is the way in which the large amount of data collected is stored considering system scalability, performance and usability. Even though the databases provide great scalability and are used widely, there are some limitations: they store only data that is explicitly known, the performance of the system is reduced significantly if the number of tables is very large, and the extraction of semantic meaning from data is slow. Our data representation approach which uses both an ontology and a relational database presents as advantages the fact that reasoning capabilities may be used, in order to infer new knowledge from information which is already represented in the ontology, while new information can be inserted easily using Object/Relational Mapping tools that are not specific to ontologies. The computational efficiency evaluations show reasonable processing time results even for complex inference processes such that the long term unhealthy behaviours and Mediterranean diet assessments.

As from nutritionists point of view their main benefit for using the system is the automatic identification of older adults' behavioural patterns that are usually associated with unhealthy eating and the deviations from prescribed diets especially in the case of pre-existing health problems such as diabetes and cardiovascular dieses. Our inference system is able to correctly assess the total nutrient values from daily food intake and more over it is successful in selecting the appropriate diet and food suggestions to compensate potential self-feeding problems. The nutrition assessment rules defined with the help of nutritionists and implemented in SWRL are generic enough to allow the nutritionists to define more specialized self-feeding problems and to associate and monitor the adherence to a wide variety of diets (see Table 10) which are usually prescribed to older adults.

From food providers perspective our system provides the opportunity of new revenue streams from delivery of personalized meals packages, potentially enabling automated shopping. Following a healthy diet plan that meets an older adult's nutritional needs, while accommodating their medical conditions and food preferences, is essential for addressing the malnutrition problem. Whilst those living on their own may wish (and are encouraged) to remain independent, their ability to cook and prepare food may be affected by various aging-related diseases, making it difficult for them to maintain a well-balanced diet. Utilizing external food providers offers an opportunity for such older adults to obtain the quality, nutritious meals they are no longer capable of cooking at home. Moreover, meal delivery services can also bring other benefits for older adults including cost-efficiency and social interaction.

Table 10: *Main Classes of diets and their variations*

Clases	Sub-clases
BASAL DIET	Normal diet, Without salt added, Soft diet with/without salt added, Puree diet with/without salt added
DIABETIC DIET	Normal diabetic diet, Diabetic diet without salt added, Soft diabetic diet with/without salt added, Puree diabetic diet with/without salt added.
WEIGHT CONTROL DIET	Weight control diet with/without salt added, Soft weight control diet with/without salt added, Puree weight control diet with/without salt added
DIET FOR ANTI-COUAGULANT THEREAPY	Normal sintrom diet, Sintrom diabetic diet with/without salt added, Sintrom weight control diet with/without salt added, Soft sintrom diet with/without salt added, Puree sintrom diet with /without salt added
SPECIAL DIET	Vegetarian diet, Gastric protection diet, Astringent diet, Intolerance diets, Allergy diets, Uric Acid diet, Purine restricted diet, Dialysis patient diet, Renal patient's diet, Low protein diet.

Such reliance on external food providers, however, also imposes challenges for our system. Although a range of food services supporting older adults in achieving a healthy diet may be available, potential clients (older adults, their carers, or software applications acting on their behalf) might not be aware of these services, thus demanding a means to increase their visibility. Additionally, such food services need to be sufficiently described in order to enable an appropriate selection (e.g. to ensure the meals selected are both appealing and comply with specific dietary criteria).

5. Conclusion

In this paper we have presented an expert system for older adults' nutrition care process. We have defined a semantic dietary knowledge base capturing various aspects that are relevant to older adults and their nutrition and a suitable inference system based on reasoning and query techniques (against such knowledge base) to assess the elderly's short term and long term self-feeding behaviours, to identify potential nutrition associated problems and to help nutritionists in defining a corresponding personalized intervention plan. The semantic dietary knowledge is encoded as the Nutrition Care Process Ontology, consisting of four sub-ontologies: Nutrition Monitoring, Nutrition Assessment, Nutrition Problem Identification, and Nutrition Intervention. The evaluation is carried out in-lab and assesses the usefulness and quality of the system aiming to expose problems regarding the defined nutrition knowledge base and inference system. We have compared the nutritionist assessment with the expert system for a test case older adult diagnosed with cardiovascular disease and diabetes, with our system proving to be as competent as the nutritionist. The computational efficiency tests show that even though the relation between the ontology processing time overhead and number of elders is exponential, reasonable time results are obtained for 210 elders. Also it is shown that the defined ontology features strong coupling, cohesion and consistency.

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Expert System for Nutrition Care Process of Older Adults

Research Highlights

- expert system for a nutrition care process tailored for the specific needs of elders
- An inference engine is developed on top of the ontology, providing semantic reasoning infrastructure and mechanisms for evaluating the rules defined for assessing short and long term elders' self-feeding behaviors
- Define and semantically represent information
- Performance evaluation