WhatToMake: A Semantic Web Application for Recipe Recommendation

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Abstract

Semantic technology plays a significant role in the current Web development domain, and its collaboration with artificial intelligence techniques promotes the emergence of advanced query systems. These intelligent systems are able to provide more precise answers to users based on their queries. Food, as the essential substance to offer nutritional support to humans, is a frequently searched topic on the internet and many of the information related to food online is encoded through the semantically enriching markup in ontologies such as the FoodOn Ontology and BBC Food Ontology. However, most of these ontologies only focus on the food or recipes themselves without incorporating other dietary restriction information, such as food allergens and food glycemic indexes. And no ontology cares about the substitution of undesired food in recipes instead of simply ignoring them. In this paper, we will introduce a new system, WhatToMake, capable of recommending recipes to a user subject to the information about required ingredients, cooking time restrictions, recipe categories for meal and course, and various dietary needs of users. The most advanced feature of the system is to substitute one ingredient with another best-matched one through three different techniques that reduce the influence on taste of recipes caused by food restrictions.

1 Introduction/Motivation

The original motivation for this ontology came from our observation of the pains of using traditional cookbooks or even some online recipe archives to find recipes that fit a given person's requirements. There were a couple of places were this process was not ideal, which we felt could be improved. First, the ability to search for a recipe by a given set of ingredients. We saw that it was not easy for people to find recipes that contained ingredients that they already had if they were trying to search over the recipes with more than one ingredient in mind; i.e. searching for recipes with chicken was easy but searching for recipes with chicken, potatoes, and rosemary was hard. This same problem extends to other parameters as well such as cook time, course type, and meal type. Secondly, it was hard to restrict items from the search space. We saw that if a person had some form of allergy, health concern, or dietary restriction that it was hard for them to put those restrictions into their search so they would have manual sort through any recipes that were returned to them and reject them manually. This problem also demonstrated an interesting opportunity for the functionality of our application, which would be to help the user not only enter those restrictions but to help them find adequate substitutes for the ingredients that they have restricted in the event that was necessary. These two problems are the basis for the decision that we have made in the design and construction of this ontology.

2 Use Case

The system is designed to recommend recipes to users subject to the ingredients they have on hand and the total time they plan to spend cooking. The system can also recommend best-matched substitutions for ingredients where appropriate in order to meet the users taste preferences or diet restrictions. The users are allowed to specify the meal types (e.g. lunch) and course types (e.g. entree) for recipes in their request. If the users query for recipes without high Glycemic Index (GI) foods, the system will avoid offering any high glycemic recipes in the recommendation list.

The system requires sufficient recipe and food data to cover a wide number of parameters. The main stakeholders are individuals interested in cooking and leveraging their available ingredients and cook time. Other stakeholders include individuals with food allergies and dietary restrictions who are looking to explore cooking options that take their restrictions into consideration.

We will outline several specific use cases where our application can be employed.

Usage Scenario I: Jane finds some chicken that will expire soon in her fridge and plan to use it for a quick dinner. She accesses the system's interface and selects "chicken" and "pasta" in the ingredients field and also indicated a cook time less than 45 minutes. The system returns a list of the recipes that match her criteria. Jane selects a recipe she likes and prints it out.

Usage Scenario II: Karen is a picky eater. She has a hard time finding recipes without foods she dislikes online. Instead, she accesses the system and inputs some basic salad ingredients with "salad" as a course type. She picks one interesting recipe but finds a disliked ingredient "walnut" in it. So, she selects "walnut" as "dislikes" and the system presents for her almonds as an alternative for this recipe. Karen is now satisfied with the recipe and prints it out.

Usage Scenario III: John is allergic to tree nuts and wants some recipes that he can use. He accesses the system and specifies his allergy, as well as the ingredients "banana" and "all purpose flour" since he wants some banana-related baked goods. The system finds banana bread recipes with "walnut" but identifies this allergen and proactively substitutes it by "pumpkin seed". The system then returns recipes with banana and all purpose flour but not any tree nuts for John to select from.

Our use case can be found through the link https://tw.rpi.edu/web/Courses/Ontologies/2018/Project2/Use_case.

3 Technical Approach

Our ontology contains two main structures of interest, the food class and the recipe class, along with several supporting structures. The food class describes different types of food and categorizes them into different subclasses. An instance of something in the food class that is also used in a recipe is multiclassed into the ingredients class as well. This allows us to make the distinction that not all food is an ingredient, which is important so that we accurately reflect world knowledge. We classified the different food ingredients by leveraging an existing classification in the EBI Food Ontology, FoodOn [4]. This classification was detailed enough that we didnt need to create our own classification, but also allowed us to make some additions. This classification scheme is illustrated in the figure below, where the imported classes from FoodOn are in blue and the classes that we added are in green.

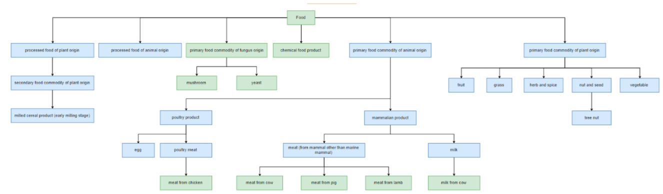

Figure 1: The food class conceptual model.

An individual that represents some food ingredient has several different data properties that can be defined in order to either further aide in classification or to aide in enhancing the knowledge we have about the food to help our user search. Two such properties are hasGluten and hasGlycemicIndex, which encode whether or not this food item contains gluten and what its glycemic index is. This allows our ontology to infer things about gluten-free and low-glycemic recipes.

The recipe class contains instances of recipes, which establish a relationship with its respective ingredients though the hasIngredient property, as well as a few other properties including hasCookTime, hasCookTemperature, serves, isRecommendedForCourse, and isRecommenedForMeal. These properties are all parameters that the user can search by making our recipe search customization comprehensive and highly adjustable. The following piece of the conceptual model shows the relationship between recipes, ingredients, courses and meals, where the boxes in red are object relationships, the boxes in yellow are data properties, the boxes in green are classes, and the circles in purple are individuals. Note that for meals and courses, we have a predefined set of individuals that represent the meals and courses that a recipe can be recommended for.

In order to present a user with different substitutions for ingredients, the ontology encodes certain information about a foods characteristics through the characteristic class and its respective subclasses. Currently, the subclasses flavor and texture are used to represent the different flavors and textures that are commonly used to describe foods. These characteristics can then be leveraged by the ontology when trying to infer about substitutes. For example, if a user wanted a substitute for a kind of cheese, then the ontology would attempt to return a valid substitute by matching as many of these characteristics as possible. There is plenty of room for expansion here, seeing as each food item can be described in much more detail with additional characteristics. Since the characteristic class is defined with multiple subclasses, each containing an enumeration of possible characteristics, adding characteristics and individuals is very simple.

Finally, our ontology has the notion of a user, where each unique user is represented as an individual in our on-

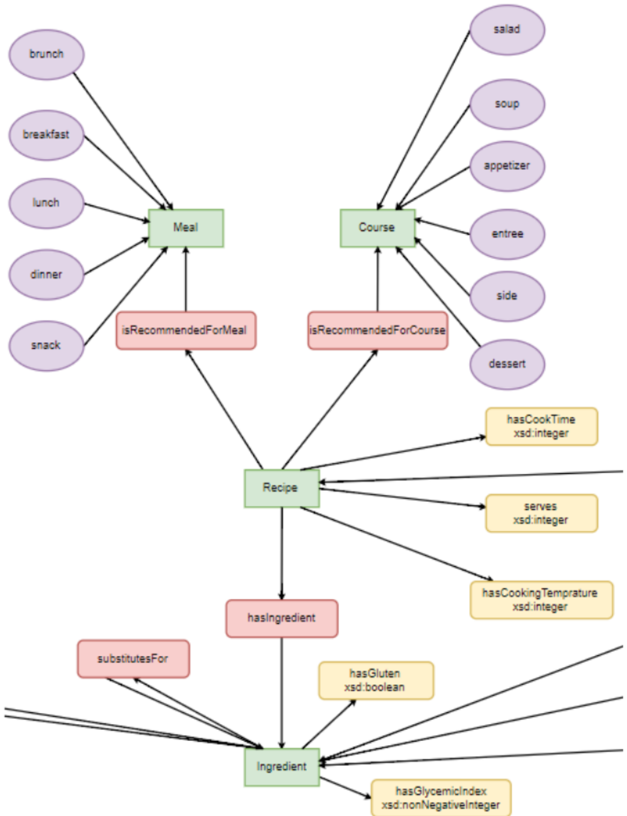

Figure 2: The recipe, ingredient, meal, and course conceptual model.

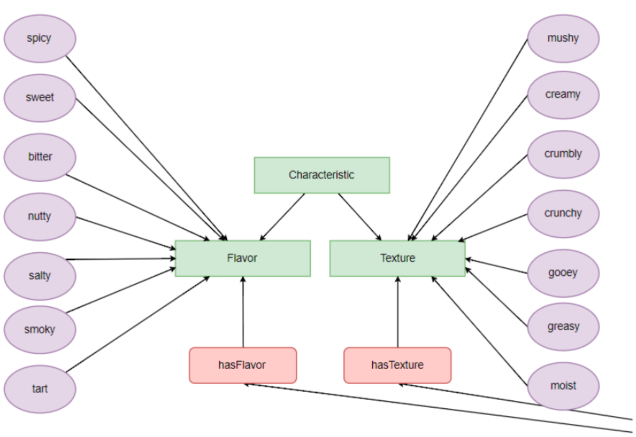

Figure 3: The characteristic conceptual model.

tology. These individual users can have relationships with different recipes and ingredients, which encode information about allergies, dislikes, forbidden ingredients, and saved recipes. What this allows us to do is reason on these parameters on a per-user basis without needing the user to input this additional information every time. The diagram below shows us these relationships.

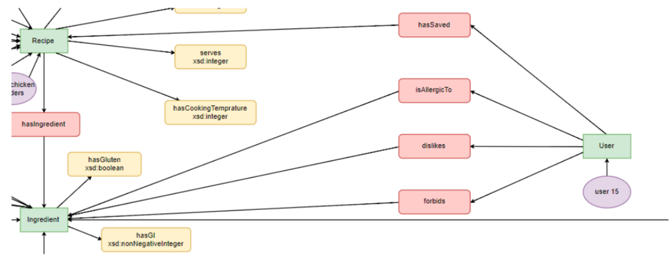

Figure 4: The user conceptual model.

The full conceptual model for our ontology can be found through the following link: https://tw.rpi.edu/web/Courses/Ontologies/2018/Project2/Conceptual_models.

Our ontology itself is broken up into three components: the base file, the food classification file, and the individuals file. All three of these files can be found at https://tw.rpi.edu/web/Courses/Ontologies/2018/Project2/Ontology. The food classification ontology file contains all of the imported classes from the FoodOn ontology [4]. This file is then imported into the base ontology, which is where we define all of our additional classes. The individuals file then imports the base file and adds to it all of the recipe and ingredient individuals present in our ontology. Adding recipes and ingredients would thus only require editing the individuals file to add new individuals and classify them using the existing classes and relationships present in the base file.

4 Related Work

Due to the rapid development of semantic technologies and a human desire for higher quality of life, many ontologies and applications related to food and dietary needs have emerged. These related works are broken down by category in Table 1 below.

Many existing and comprehensive food ontologies have been developed that can be reused by importing and mapping existing terms. These ontologies are designed for various purposes and should be carefully selected to import based on the applications goals. For example, the FoodOn

Table 1: Related Work Grouped by Contents

Related Work Categories		
Category	Work Content	Reference Number
Food Ontologies	Food Product Ontology FoodOn	[22] [10]
Recipe Ontologies	BBC Food Ontology Classroom-Developed Ontology Cooking Ontology	[3] [23] [11]
Human Disease and Nutrient Ontologies	Disease Ontology Ontology for Nutritional Studies Substance Intolerance Ontology	[31] [12] [35]
Food Ontologies and Health	Diabetes Control Ontology Hypertensive Diet Ontology Personalized Information Retrieval	[16] [17] [33]
Substitution Techniques	Named-Entity Substitution Mining Substitution Rules Synonym Substitution Method	[5] [30] [24]
Applications	FoodWiki PerKApp Ontology Personalized Dietary Recommendation Diet-Aid	[8] [32] [28] [6]

ontology[10] is a very broadly scoped and widely used ontology that describes the commonly known foods that exist in nature as well as various food categorizations based on different standards. It is ideal for use in applications that involve food-related ontologies since the terms within it cover a broad range of domains in the field of food. Some other food ontologies such as the Food Product Ontology described by M. Kolchin, and D. Zamula [22] are designed for business purposes. It includes concepts such as price and brand, which are more suitable for food suppliers than a recipe lookup.

Other ontologies exist that concentrate more closely to the cooking domain. For example, the BBC Food Ontology[3] is a well-known recipe ontology that offers a small set of concepts related to recipes, ingredients, menus and diets. However, it only focuses on the top-level classes related to a meal and does not categorize information about food or dietary needs thus limiting its use.

M. Sam et al. [23] introduce two cooking recipe ontology patterns developed in a classroom setting. The purpose of the ontology is to integrate data about recipes from different websites. The two ontology structures are simple and cover basic components for recipes. Even though they are not implemented, these structures can serve as great initial points to develop a recipe ontology that includes more details than the BBC one.

A more comprehensive recipe ontology is created by F. Batista et al [11]. The designers include four main classes- actions, food, recipes, and utensils- with supplementary classes units, measures, and equivalencies in the ontology and eventually integrated it into a dialogue system to answer the questions. With an increasing demand for health information, researchers have tried to combine knowledge about recipes, nutrients, and chronic diseases and have developed various ontologies on human diseases and nutrients. For example, the Disease Ontology (DO) database[31] covers a wide range of disease and is designed to use a graph database to improve its speed, efficiency and robustness. It is employed by major biomedical databases such as the Neuroscience Information Framework (NIF) and the Immune Epitope Database (IEDB) and ontologies such as the Neuroscience Information Framework Standard (NIFSTD) ontology. The Substance Intolerance Ontology (SIO)[35] was developed for substance intolerance and hypersensitivity. For nutrients, the solid and extensible nutritional ontology called the Ontology for Nutritional Studies (ONS) [12], which integrates carefully selected pre-existing ontologies to the novel health and nutritional information, can be imported.

Many scholars and researchers have already started to design ontologies that integrate food and health related information together. An information retrieval system that incorporates knowledge from the domains of food, health, and nutrition to recommend food based on the users conditions and preferences was developed by T. Helmy et al. [33]. To control diabetes, a food ontology was designed for some novel healthcare delivery models to help healthcare professionals obtain updated medical knowledge and empower European citizens to live healthier [16]. It involves multi-domain knowledge such as medical practice and food. The main purpose of the ontology is to guide diabetic patients into choosing food intelligently and reduce their health risks caused by food. The authors integrate eight different ontologies together and evaluate the ontology by using 453 queries from various sources. A more complicated and comprehensive ontology to manage hypertensive individuals was created by J. Clunis[17]. This ontology includes four main models - food, drug, person, and recipe. By using various semantic technologies, the designers plan to manage chronic diseases, specifically hypertension, and generate warnings and recommendations for hypertensive individuals based on the potential interactions that exist among foods, recipes, and drugs.

Several applications have been designed to recommend personalized diets to users according to their environments and health conditions. First–based on the Food Ontology Knowledge Base (FOKB) which includes person, disease, product, and food ingredients/compounds classes–the smart e-health system FoodWiki [8] is able to recommend diets that will reduce the probability of health risks such as diabetes and allergens. Second, the PerKApp Ontology [32] is designed for the PerKApp project which aims to achieve remote lifestyle monitoring by giving users appropriate real-time feedback on their diet and physical activity. The main component of the project is its persuasive component which can customize the messages according to the users needs, attitudes, and preferences. Furthermore, based on the health screening data provided by the Health Level Seven International (HL7), the authors make a system called Diet-Aid [6] that can recommend a personalized diet by filtering unsuitable foods from the given recipe data. In addition to reducing health risks, these types ontologies can be applied to recommend meals for specific type of users such as sport athletes. A system that involves the food and nutrient ontologies, user profiles, and specific dietary needs for athletes was created by P. Tumnark, et al. [28] for weightlifting athletes. This rule-based knowledge framework can recommend diets to athletes based on different times of the day, the nutritional needs, training phases, and preferences.

To our knowledge, there are currently no ontologies that apply the substitution techniques that we propose in these food-related applications. However, some substitution algorithms do exist in ontologies for natural language tasks. For example, a supervised machine learning approach called instance-based ontology population (IBOP) [5] based on the lexical substitution technique is designed for NLP. It competes many other existing algorithms and is evaluated through various mathematical benchmarks. Some researchers work on the knowledge-based mining of substitution rules through the novel approach based on the Expected-Actual Substitution Framework and Affordance-Based Substitution (ABS) algorithm [30]. Their unique interestingness measure can lead to more effective knowledge discovery. Another interesting paper that focuses on substitution methods introduces an automated synonym-substitution method, which is constructed based on the lexical information of concepts and the hierarchical structure of the Human Phenotype Ontology [24]. For this method, the annotation of terms is very important. The techniques to identify lexical overlaps and create new synonyms recursively are interesting.

Our work is to integrate various domain knowledge that involves main classes of food, recipes, ingredients, and user profiles for food recommendations based on the users dietary needs and food preference with several auxiliary classes - characteristics of ingredients for food substitution, time measurement of recipes for cooking time restriction, and meal and course classes to improve the recipe classification.

5 Evaluation

Our ontology is evaluated through various approaches on aspects involving data sources, domain coverage, quality of automated reasoning, efficiency, and performance. The data sources were proven to be trustworthy before being applied to the ontology based on the information offered on their official websites and their widely application in multiple projects. We also checked our system by running various reasoners such as Pellets and HermiT, developing a carefully designed regression testing set of individuals, and applying OOPS!, an ontology correctness tool which can return potential errors that exist in the ontology. The testing results from all of these evaluation tools prove that the ontology in our system is consistent, coherent, and with no syntax or logical errors.

Competency questions are crucial to evaluate the completeness and validity of an ontology. The WhatToMake system is evaluated through various competency questions from different domains covered by the ontology, which represent the various demands of users. Based on the accuracy of answers returned by SPARQL queries applied on the ontology, the performance of our ontology can be tested. The following example questions cover almost every topic (Table 2) that can be answered by the WhatToMake system.

Question 1: What can I cook with beef, potatoes and carrots?
This question is the most basic one that should be answered by the system. Through the basic flow of events, this simple question can be correctly answered by returning a list

of recipes that use all three ingredients requested by the user. Beef stew is an example recommendation.

Question 2: What can I cook with kamut, salt and baking powder?
It seems to be the same as the last question but since insufficient recipes use kamut, ingredient constraints have to be relaxed and substitution information contained in the ontology should be extracted to fulfill the recommendation list. By activating an alternative flow of events on individual substitutions, the system replaces the main ingredient kamut by other food such as all purpose flour and returns the recipes in alphabetical order. So, the recipes contain those exactly matched the criteria like kamut muffin and those with substitutions like brownies.

Question 3: I dont like almonds. What substitute can I use for almonds in this recipe?
This competency question involves the food preference and substitution information. The system, according to the implemented property-based substitution method, finds walnuts and pecans as substitutes for almonds that have the same texture as almonds and also belong to the tree nut class.

Question 4: I am allergic to tree nuts. What can I make with bananas that does not contain tree nuts?
This query is the most complicated one since it involves multiple queries to get the answer correctly. According to the alternative flow on food allergens, the system first finds recipes with banana, then identify the tree nuts in each recipe, and eventually provides the best matched replacement through the cross-class substitution method. The desired answers are returned.

Question 5: What can I cook with chicken that will take less than 45 minutes to finish?
Compared to question 1, this request include two parameters: ingredient and cook time constraints. Based on the basic workflow, the system successfully return a list of recipes that contain chicken and have a cook time less than 45 minutes in an increasing time order.

Question 6: What can I cook with chicken that is a dinner entree for a guest who has type II diabetes?
Question 6 includes the most comprehensive knowledge compared to other questions and employs various properties in the ontology. For a question about dietary restriction, the alternative flow of events is applied to provide the solution. The returned recipes by the system contain chicken and are recommended as entrees and dinner items. Also, no ingredients with a glycemic index equal to or greater than 50 exist in these recipes. Therefore, all the criteria in the query are satisfied.

All of the competency questions are correctly answered in the application.

Since a good quality ontology should be checked on accuracy, completeness, conciseness, adaptability, clarity, computational efficiency and consistency [18], we plan to apply some other evaluation tools mentioned in the class lectures and readings to make our ontology more trustworthy and reusable. For example, OntoClean is able to clean the ontology taxonomies based on rigidity, identity, and unity. Also, some more complicated queries that cover a wide range of knowledge should be designed to test the systems efficacy.

6 Discussion

We have talked about how our ontology is different from others in that it takes into consideration the dietary needs and preference of the user in order to make a more informed decisions about what kinds of recipes it should return to the user. We are going to go through each of our claims and talk about how we address it in the ontology. First, our claim that we use user preferences to search over the recipe space. We are able to do this because recipes have all the ingredients that they contain attached directly to them, the same is true for the cooking time and the meal/course type. These are just relations attached to every recipe. It is slightly trickier when considering dietary needs. If the dietary need is one having to do with the gluten content or the recipe of whether or not it is diabetic safe, this will mean that the recipe individuals need to be examined to see what values they have for their GI and their gluten status. Allergies are a case where we can leverage some of the semantic power of the ontology. Give a food allergy we know that we should restrict anything that is a hyponym of that food/food type. This means that food instances do not need to be marked with an allergen type, but that their allergen type can be inferred by their inheritance. Another place where we can leverage the semantics of the ontology is when we start to introduce substitution suggestions. Our first method of substitution is direct substitution, we call it that because ingredients can have a property substitutesFor that is a direct link between an ingredient and something that substitutes for it. While this method does not leverage semantics it is the most straightforward and arguably the most reliable. The next two methods do rely on the semantic abilities of the ontology. The next method is property-based substitution, this method leverages the fact that from an ingredient we can discover ingredient's siblings. To further refine this process we look for siblings that share certain characteristics with the ingredient that we are trying to substitute. This is the first method where we rely on the semantics of the ontology to help us reason what might be a good substitute for any given ingredient, because of the nature of this method it is less reliable than substitutesFor relations

Table 2: Competency Questions Based Performance Evaluation Result

Query Categories	Questions	Accuracy (%)
Required ingredients	1,2,3,4,5,6	100
Time restriction	5	100
Food allergy	4	100
Food preference	3	100
Meal type	6	100
Course type	6	100
High glycemic recipes	6	100
Gluten-free recipes	NA	NA
Food substitution	2,3,4	100

that were put in by hand. Finally we have the cross-class substitution, this method allows us to make two classes synonyms meaning that they anything in one class is interchangeable with anything in the second class. This is the least accurate of the three methods but it provides wide general coverage that could be useful to the user.

This ontology is one of the first that has classified and grouped various foods let alone ingredients. The WhatToMake ontology is a great jumping off point for those that are looking for foods that have been categorized, or for those that are looking for certain metadata about food such as Glycemic Index or gluten content. Because of the groundwork that the WhatToMake ontology has laid, it would be easy for practically anyone to lay a strong application layer on top of the ontology if they wanted to get into more specific problems in the field. Say for example that someone wants to make a gluten free cooking website. Those developers could leverage the general framework that we have built and expand upon the areas that they feel need to be covered as well as tailoring the individuals in the ontology to meet their criteria. Also due to the nature of how the substitution system functions, application specific substitutions could be injected extremely easily on the individual level making the ontology highly customizable. The approach that we are using for substitutions can thus be improved for much more granular situations, for example when generating substitutions for baking.

The link to the WhatToMake project website is https://tw.rpi.edu/web/Courses/Ontologies/2018/whattomake.

7 Future Work

Since the project is a class exercise accomplished within a limited time period, some features were not implemented as originally designed and left for future development.

Clearly, the ontology currently only contains a very limited subset of recipes and ingredients. For a more usable system, a wide range of recipes and ingredients would need to be imported. Also, the recipes currently do not contain the quantity information of the ingredients (for example, there is no notion for 2 cups of flour in the ontology). The Quantity, Unit, Dimension and Type (QUDT) Ontology can be imported to facilitate the operation on the quantitative terms. Furthermore, more allergen categories other than tree nut and gluten need to be coded in the ontology. The concepts of allergens exist in ontologies such as FoodOn and the methods to work on food allergy can be explored in the FoodWiki paper [8].

Our ontology could also be improved through the following ideas. Ideally, adding more recipes and ingredients into the ontology would be done in a more automated way. Currently, the recipe and food data are manually coded in the ontology so it is hard to include sufficient data by hand. However, since most recipe data exists online, a better practice would be to collect the data across the Web and automatically parse it into a knowledge graph. We can borrow the ideas from the Good Relations (GR) Ontology, which is a lightweight Web Ontology designed to deal with e-commerce information online. Second, nutritional information such as the amount of fibers and calories in a recipe could be be collected and stored. This information could help to satisfy more dietary needs of users to improve their health outcomes. Finally, the system could collect recipes described in different languages. The Universal Networking Language (UNL) can be used appropriately to achieve this process.

8 Conclusion

Through the discussion of the project, it is clear that semantic technologies can help answer the questions more precisely and improve users qualities of life in various aspects. Through the construction of domain ontology, design of inference rules, application of different reasoners, representation of queries, and justification of answers, the WhatToMake system is able to recommend desired recipes to users, which gives cooking guidance to users and facilitates their searching process on recipes.

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