ADDietCoach:
A Personalized Virtual Diet Coach for Alzheimer's Disease

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ABSTRACT

The aging population worldwide is expected to increase the prevalence of Alzheimer's disease. As there is no medical curative treatment for this disease to date, alternative treatments have been applied to improve the patient's brain and general health. One of these efforts includes providing Alzheimer's patients with proper food and nutrition. In this paper, the authors propose a knowledge-powered personalized virtual coach to provide diet and nutrition assistance to patients of Alzheimer's and/ or their informal caregivers. The virtual coach is built on top of an ontology-enhanced knowledge base containing knowledge about patients, Alzheimer's disease, food, and nutrition. Semantics-based searching and reasoning are performed on the knowledge base to get personalized context-aware recommendation and education about healthy eating for Alzheimer's patients. The proposed system has been implemented as a mobile application. Evaluation based on use cases has demonstrated the usefulness of this tool.

KEYWORDS

Alzheimer's Disease, Knowledge, Logic, Ontology, Personalization, Reasoning, Recommendation

INTRODUCTION

As people worldwide are living longer, the pace of population ageing around the world is also increasing dramatically. Aging is related to many risk factors of noninfectious diseases, including Alzheimer's disease (AD) (Xia et al., 2018). AD is defined by cognitive function progressively worsen. It starts gradually with early signs including patchy memory loss and subtle changes in behavior. The disease is progressively proceeding; the patient may need aid on all aspect of personal care including their daily diet care. AD is one of the best-known aging-linked diseases. According to Alzheimer's Association, approximately 5.8 million Americans of age 65 and above are living with dementia from Alzheimer's in 2020; 80% of them are 75 years of age or older.

The majority of AD caregivers are unprofessional family members or friends who do not have any experience in dealing with such disease. One of the most important life aspects that informal caregivers need assistance in is how to provide healthy daily diet for AD patients. Appropriate nutrition

is vital to maintain the body healthy and strong. For AD patients, poor nutrition can significantly raise the behavioral symptoms and cause weight loss (Pivi et al., 2012). Current epidemiological evidence suggests that an increase intake in saturated fatty acids (SFA) may have adverse impacts on mental functions, whereas increased polyunsaturated fatty acids (PUFA) and monounsaturated fatty acids (MUFA) may be protective against cognitive deterioration (Solfrlzzi et al., 2008). Present research on the effects of dietary components or food products on AD is inconsistent, mainly because people consume meals with complex combinations of nutrients; food items are likely to be synergistic causing difficulties in deciding which portion of the diet has a beneficial or adverse effect (Gardener et al., 2012).

There are lots of online websites and information about food and nutrition for AD care. However, it is not easy to find the most relevant and accurate information specifically to the patient's special need. AD patient themselves may have difficulty to read and understand the content. AD caregivers are mostly informal caregivers of family members who normally have very busy schedule and may not have the time to read and study these materials. Mobile applications are also available for nutrition coaching e.g., Myplate (*MyPlate Calorie Counter*, n.d.), diet tracking e.g., Calorific (*Calorific - What Do Calories Look Like?*, n.d.), and meal planning e.g., emeal (*Meal Planning Made Simple - EMeals*, n.d.).

Despite the large number of applications and tools (Sarwar & Javed, 2019) (Javed et al., n.d.), they do not target specifically for people living with AD; the education, coaching and recommendations given by these applications tend to be generic without considering the uniqueness of each patient including their preferences, other health conditions, culture, and traditions; these applications do not consider caregivers' conditions, such as their preference, their time limit to prepare a meal, and the economic status to afford the food items. To address the limitations in existing works, the authors propose a personalized AD diet coaching system. The system will respect the special socio-economic, cultural, ethnic, and geographical status, particularly to AD patients and their caregivers. By integrating the users' profile with general clinical AD care guidelines, the system can make useful recommendations that are more appropriate to AD users. The main contributions of this work can be summarized as follows:

1. Define and reuse a set of ontologies to provide computational knowledge about food, nutrition, and AD care; the ontologies also describe patient and caregiver's characteristics to provide evidence for personalization. Together the proposed ontologies provide knowledge foundation for personalized recommendation.
2. Collect, verify, and convert AD medical diet guidelines to logic rules which enable reasoning-based decision making and recommendation.
3. Implement a personalized virtual coach to provide context-aware and personalized diet education and recommendation to AD patients and their caregivers.

RELATED WORK

Mobile Apps For AD

Given the high prevalence of mobile phone use in the U.S., mobile applications (apps) have been proliferating in the market in recent years. They offer lots of potentials to improve the quality of life of people with AD and their informal caregivers. Based on our comprehensive survey on these apps, the authors categorize them into two main groups, namely apps for AD patients and apps for AD caregivers.

For patient's apps, they can be further categorized into seven subcategories:

1. AD self-diagnosis
2. Brain training
3. Movement monitoring and navigation.
4. Healthy lifestyle tips
5. Reminder
6. Entertainment
7. Communication with family members.

As an example of self-diagnosis, Geriatric Depression and Dementia Scale (GDDS) (*Stanford/ VA Alzheimer's Center*, n.d.) can help users evaluate their own cognitive ability. The app provides a series of 30 questions to test users' depression and dementia signs. After completion of the survey, it gives a numerical score suggesting if the user should go for a clinical check-up or not. Brain training applications such as Lumosity (*Lumosity Brain Training*, n.d.), Dakim (*Dakim BrainFitness*, n.d.), and Elevate - Brain Training (*Elevate - Brain Training and Brain Games*, n.d.) provide cognitive and scientific games to stimulate and improve brain function. Tracking apps such as AngelSense (*Angelsense*, n.d.) GPS SmartSole (*SmartSole®*, n.d.) use wearable technology to provide GPS monitoring of AD patients and notification service to notify their family members. Reminder applications are among the most popular ones for early-stage AD patients. Medisafe (*Medisafe - Medication Management Solutions*, n.d.) is one of such application. It allows a user setting reminding alarms to take medications and reminds a user when prescriptions are running low. It also alerts the user when they are taking medicines which are not supposed to be taken together. Users can add a "Medifriend" who will be notified when the user missed any dose of medication.

There are also apps developed for caregivers of AD patients. The authors classify these apps into four subcategories, namely:

1. Tips for caring.
2. Monitoring and tracking of their cared ones.
3. Coordinating and social networking.
4. Caring for the caregiver's health.

Alzheimer's Daily Companion (*Help For Alzheimers Families*, n.d.) focuses on providing educational information to caregivers on possible challenging situations that they may face on a daily basis. Care4Dementia (*Care4Dementia App - DCRC*, n.d.) aims at teaching caregivers about behavioral changes during dementia. The app helps caregivers to understand why it might be happening and what can be done as a remedy for the situation. Dementia Emergency (*Dementia Emergency on the App Store*, n.d.) is an application developed to help advise the caregivers on how to handle emergencies that may arise while caring for their loved ones. Similarly, the First Aid app (*Mobile Apps | American Red Cross*, n.d.) by the American Red Cross provides caregivers with guides on first aid basics such as CPR in case of emergency. CaringBridge app (*Personal Health Journals for Any Condition | CaringBridge*, n.d.) offers a cloud service for patients and caregivers to provide health updates, and for family and friends to respond with messages of emotional support. Lotsa Helping Hands (*Care Calendar Website | Lotsa Helping Hands*, n.d.) is an application that helps to create a community of people who want to help in caring for people with Dementia. It helps to maintain the coordination and communication among all for any required ride for appointments, any medication or food deliveries. This app helps to maintain coordination among everyone who wants to help in caring for a person. Besides the person with dementia, caregivers are equally affected, so some applications help caregivers to take care of their own health and maintain a balance. Sanvello (*Home - Sanvello*, n.d.) is an application focused on caregiver care by providing guided meditation and in-app exercises to help reduce the stress and anxiety they are going through.

Most tips and recommendations to caregivers provided by these apps are generic and text based. They lack interaction with users. Despite the existence of these AD caring apps, there are not many user-friendly tools about food and nutrition for healthy eating. The authors discuss the handful of available apps for healthy eating in the next section.

Mobile Apps for Healthy Eating

A multitude of mobile apps and online websites have been developed to make meal planning and food nutrition recommendations for maintaining a healthy lifestyle and losing weight. For example, MyFitnessPal (*MyFitnessPal | MyFitnessPal.Com*, n.d.) has a large food dataset and provides a calorie counter to help users to track their diet and exercise. FatSecret (*FatSecret - Calorie Counter and Diet Tracker for Weight Loss*, n.d.) gives users a food diary to track and plan their daily diet. Similarly, Lifesum (*Lifesum Health App – Get Healthy & Lose Weight - Lifesum*, n.d.) integrates diet with other habits such as exercise and sleep to help users reach their health and fitness goals. Fooducate (*Lose Weight & Improve Your Health with a Real Food Diet | Fooducate*, n.d.) includes a large number of articles and tips on nutrition and exercise. Lose It! (*Lose It! - Weight Loss That Fits*, n.d.) creates a plan including a recommended daily caloric intake based on the user's goals.

Besides diet apps for general wellbeing and losing weight, there are also diet apps for people with special health concerns. My Diet Diary Calorie Counter (*My Diet Diary: Calorie Counter Mobile Application for Weight Loss*, n.d.) works as a digital diary for users with diabetes to record their meals and physical activity. It helps users track carb intake and other nutrients and total calories. Our research team developed a personalized diet recommender for American Indian diabetes patients (Alian et al., 2018). There are many other similar apps (e.g. MySugr(*Diabetes App, Blood Sugar and Carbs Tracker | MySugr US | MySugr*, n.d.), Glucose Buddy (*Glucose Buddy*, n.d.)) to assist diabetes patients in maintaining their healthy eating lifestyle. My Food Coach (*My Food Coach | National Kidney Foundation – Serving Maryland and Delaware*, n.d.). Gives daily summaries of key nutrients for kidney health. Apps have been developed for pregnancy (e.g. Wholesome(*Wholesome - Micronutrient and Vitamin Tracker*, n.d.)), breastfeeding moms (e.g., Nursing mom's diet (*Nursing Mom's Diet - Apps on Google Play*, n.d.)). To the best of knowledge, there is no personalized diet management specifically designed for AD care.

Despite the existence of a multitude of mobile apps for AD care and healthy eating, there are no effective tools designed for personalized diet management for AD patients and their caregivers.
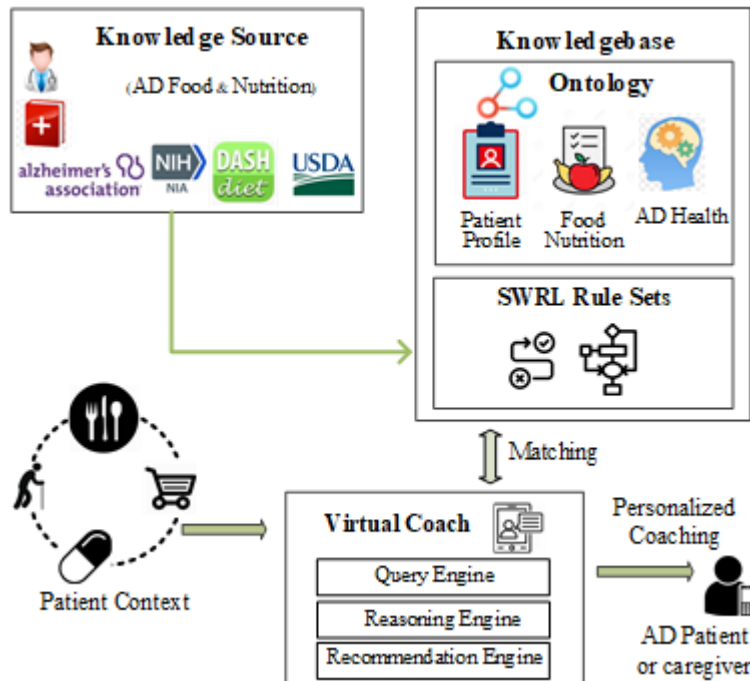
METHODOLOGY

The authors propose an ontology-enhanced virtual diet coach, ADDietCoach, to provide personalized education, planning, and recommendation on food and nutrition for AD patients and their caregivers. As shown in Figure 1, the system is built on top of an ontology-based knowledgebase and a set of semantic logic rules. The ontology knowledgebase contains three ontology components: patient's profile, food and nutrition, and AD health. It also contains semantic rules that were converted from medical guidelines/recommendations. The knowledgebase is the brain of our virtual coach. It provides knowledge foundation for all the recommendation and education.

KNOWLEDGE PREPARATION

Ontology

Because of the complexity of a healthcare application and the ever-increasing size of information to collect, represent, and analyze, the knowledge need to be stored in an extendable and computable format. The authors propose to adopt an ontology to generate formal representations of entities and relationships between them to improve manageability and machine-executability. The ontology set

Figure 1. The Framework of the Personalized Virtual Coach

is composed of three sub-ontologies: The User Profile Ontology (UPO), the AD Health Ontology (AHO), and the Food and Nutrition Ontology (FNO).

UPO defines various characteristics of the user including both the AD patients and their caregivers. UPO is composed of several directions including basic profile, social profile, health profile, preference profile and capability profile. With UPO, the system can integrate each user's unique characteristics to the intelligent recommendation and education. Therefore, UPO is the foundation of personalization of the system. AHO provides the high-level logical structure of the AD, its symptom, treatment, and their relationships to one another. AHO provides the system with knowledge about the disease and its treatment. FNO provides an extensive taxonomy for foods, nutrition and other properties related to food, such as source organism, region of origin, and so forth. This provides much-needed connections between related concepts.
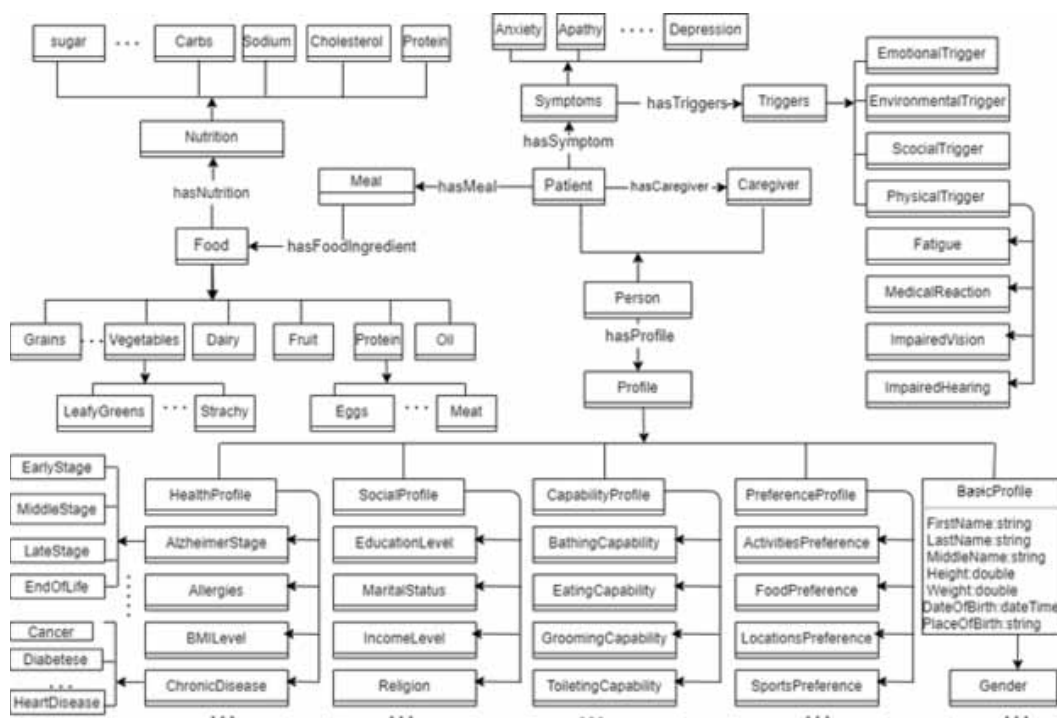
Figure 2 shows part of the top-level ontology. As can be seen from Figure 2, this part of the ontology includes some important concepts (classes) such as person, food, profile, and triggers. Concepts can be subspecialized or refined by subclasses. For example, a person class can be specialized into patient and caregiver; a profile class can be refined to basic, health, preferences, social, and capability profiles; while a symptom trigger can be classified as emotional trigger, environmental trigger, physical trigger, etc. Subclasses can be further subclassed as needed. For example, the physical trigger can be further divided into fatigue, impaired vision, etc.

Besides the subclass and superclass relationship, concepts are connected by other relationships/ properties between them. For example, the patient class is linked to the symptom class through "*hasSymptom*" relation; and person and profile are connected with "*hasProfile*" property.

Semantic Rules

The knowledgebase uses ontology to represent specific facts in an instance of the domain of AD diet care. It contains general set of facts to be shared. The knowledgebase also needs to embrace

Figure 2. Part of the High-Level Ontology

clinical guidelines and recommendations of diet management for AD care. For example, a guide about food to avoid for AD patients may help the virtual coach to determine recipe ingredients when it recommends recipe to an AD user. These guidelines are the basic principles for the virtual coach's action. Rules and ontologies represent two main components in knowledgebase. They are expected to tightly interplay for making automatic and intelligent operations.

The authors have collected medical guidelines from multiple reliable sources, including AD general caring guidelines, food and nutrition guidelines, such as guidelines defined in National Institute on Aging (NIA) (*National Institute on Aging*, n.d.), Alzheimer's Association (*Alzheimer's Association | Alzheimer's Disease & Dementia Help*, n.d.), Mayo clinic (*Mayo Clinic - Mayo Clinic*, n.d.), alzheimers.net(*Get Alzheimer's Information and Find Dementia Care*, n.d.), Guideline for Alzheimer's Disease Management (Los Angeles, 2008), and Dietary Guidelines for Americans (USDA, 2015). For example, a diet recommendation, Mediterranean and dash diets (MIND), is incorporated in the system. The MIND diet focuses on reducing dementia and the decline of brain health that often takes place as people age. It incorporates elements of two very common diets, the Mediterranean diet and the Stop Hypertension Approaches (DASH) diet. Based on many recent studies (e.g., (Morris, Tangney, Wang, Sacks, Barnes, et al., 2015)(Tangney et al., 2014)(Morris, Tangney, Wang, Sacks, Bennett, et al., 2015)(Van Den Brink et al., 2019)), there is plenty of evidence supporting the connection between this dietary approach and preventing the disease.

The collected rules were further verified by two experienced clinicians on our research team who specialized in the diagnosis and management of cognitive disorders including AD. Then these rules were converted to rules that computers can "understand". The authors use the Semantic Web Rule Language (SWRL) (*SWRL: A Semantic Web Rule Language Combining OWL and RuleML*, n.d.), an expressive W3C standard OWL-based rule language to present the generated rules. SWRL aims to combine Horn-Like rules with OWL knowledge base. Every SWRL rule includes an antecedent

Table 1.

```
    Patient(?user) ^
    hasMeal(?user,?meal) ^
    hasCal(?meal,?mealTotalCal) ^
    hasSatFat(?meal,?satfat) ^
    swrl:Multiply(?satFatLimit,0.10,?mealTotlaCal) ^
    swrlb:greaterThan(?satfat,?satFatLimit) ->
    isRecommended(?meal,false)
```

(body) and a consequent (head). The rules are taking the form of an implication between an antecedent (body) and consequent (head). The meaning can be read as follows: If the conditions stated in the antecedent are met, then the action stated in the consequent will be performed (Zhai et al., 2018). Both the antecedent (body) and consequent (head) contain zero or more atoms which are OWL classes and properties. Antecedent with zero atoms is true by every interpretation so the consequent must be satisfied by every interpretation. On the other hand, an empty consequent is treated as false so the antecedent must not be satisfied by any interpretation. Multiple atoms in the head or the body are treated as a conjunction. SWRL rule can be transformed into multiple rules if it consists of conjunctive consequent.(*SWRL: A Semantic Web Rule Language Combining OWL and RuleML*, n.d.).

As an example, the following statement is taken from to the Dietary Guidelines for Americans (USDA, 2015) that provides the recommended intake of saturated fat: "Intake of saturated fats should be limited to less than 10 percent of calories per day". This is a rule that can be understood, but it need to be converted it into logical rules that are understood by the computers. The provided example can be represented using SWRL rule as follows:

SWRL adds rule capabilities to OWL-based Ontologies. SWRL enhances OWL expressiveness and makes it possible to model more domain knowledge than OWL alone. Adding SWRL rules allows users to set user-defined rules which in turn will allow performing inferences over OWL individuals, so new data about these individuals can be gained.

Knowledge-Powered Personalized Coaching

A logic-based virtual coach is designed based on the ontological knowledgebase. The core of the virtual coach includes three engines: the query engine, the reasoning engine, and the recommendation engine. A semantics-based query engine is designed to locate relevant data from the knowledgebase. A reasoning engine is proposed to derive additional truths about data in the knowledgebase and to answer queries and solve problems regarding the domain. The recommendation engine works on top of the result of the query and the reasoning engine to provide personalized recommendations to users.

The authors designed a semantics-based query engine that supports query of both explicitly and implicitly derived data in the knowledgebase according to syntactic, semantic, and structural information contained in the data. Besides the ontology the authors designed, external datasets were also used, such as USDA dataset and Freebase. Therefore, our knowledgebase is a complex federated datastore with named graphs, linked data, triples, and relational data. Consequently, our query engine should be able to search over these different data formats. The authors use SPARQL (*SPARQL Query Language for RDF*, n.d.), the W3C recommended semantic web query language, to formulate semantic queries in a syntax similar to SQL. SPARQL is applied directly to search ontological data in triple and graph format. SPARQL query is translated to SQL format to search relational data over relational database.

The authors built a rule-based reasoner to infer new data and provide extended query services. The reasoner is based on the facts in the ontology and the rules that are provided by the SWRL ruleset. The reasoning algorithm the authors applied is forward chaining (Russell & Norvig, 2016). It starts with the available atomic facts in the knowledge base. Then it searches the inference rules

until it finds one where the antecedent is true. Then it applies the rule in a forward direction to infer new facts (consequences). The generated facts will be used as new facts to trigger other rules. This process repeats until the goal is reached or no more rules can be triggered (Ricci et al., 2011). The user's (including patient's and caregiver's) comprehensive profile is utilized to provide personalization in the inference.

Now assume a user needs the virtual coach to recommend a meal for the AD patient she is taking care of. As shown in Figure 1, when the user sends a request to the virtual coach via her smart phone application. The request is first passed to the query engine where it is processed and forwarded to the reasoning engine. The reasoning engine will look for all the rules that have the facts in the request as a premise. Then if other premises in the rule are already held, the system will generate new consequences. The new inferred knowledge will be added to the knowledgebase, triggering further inference. The reasoner will generate the meal recommendation as its final goal. During this process, the SWRL rules in the rule set will be applied on the ontology data including UPO, AHO, and FNO. In this way, a meal recommendation will be made based on the medical guidelines defined in the rule set, user's characteristics defined in UPO, AD disease properties defined in AHO, and food and nutrition knowledge defined in FON.

RESULTS AND DISCUSSION

Implementation

As shown in Figure 3, the prototype system, ADDietCoach, is built using a modular cloud-based client/ server architecture. The server in the cloud contains five components: the database, the knowledgebase, the query engine, the reasoning engine, and the recommendation engine.

The database component is built on top of MySQL(*MySQL*, n.d.) database server. The JOOQ(*JOOQ: The Easiest Way to Write SQL in Java*, n.d.) framework is used as the API for other components to communicate with the database module. The system utilizes the database module to store the detailed information on user's meals, some of user's profile information, and food

information. The authors choose a relational database to store these data instead of using an ontology-based graph or triple store, because the processing speed of relational database is much faster.

The knowledge base component synchronizes changes made on the ontology with the filesystem. The ontology is loaded into memory using a graph data structure for faster access from a file where it is stored using the RDF format. The rules are embedded into the ontology in SWRL format and loaded with the ontology. The Query Engine employs the OWL API (*OWL API by Owlcs*, n.d.) framework to perform the create, read, update, and delete (CRUD) operations on the knowledge base. The Reasoning Enginees uses the Openllet OWL DL (Zhai et al., 2018) as its reasoner. The system utilizes Openllet to trigger inferencing new knowledge based on the ontology and rules. The Openllet OWL2 (*GitHub - Galigator/Openllet: Openllet*, n.d.) reasoner supports the SWRL rule language and the OWL DL (Description logic) which is best suited for application-based ontologies.

The Recommendation Engine is built using the Javalin framework (*Javalin - A Lightweight Java and Kotlin Web Framework*, n.d.), which is used to provide the REST-API for the mobile clients to interact with the server. The benefits of using such technology are to use a unified interface between the server and different types of clients and abstract all the complex logic on the server side. The Javalin framework provides all the needed components to build the REST-API (Authentication and Authorization, Socket API for push notifications, Validations, Exception handling, Caching, logging and more).

The mobile client is built using Ionic framework (*Ionic - Cross-Platform Mobile App Development*, n.d.). Ionic framework is a cross platform framework where a single code base that runs on multiple platforms (Android, IOS and web) can be used. Ionic provides native components and ready to use UI components that helps in simplifying the user experience without scarifying performance. The

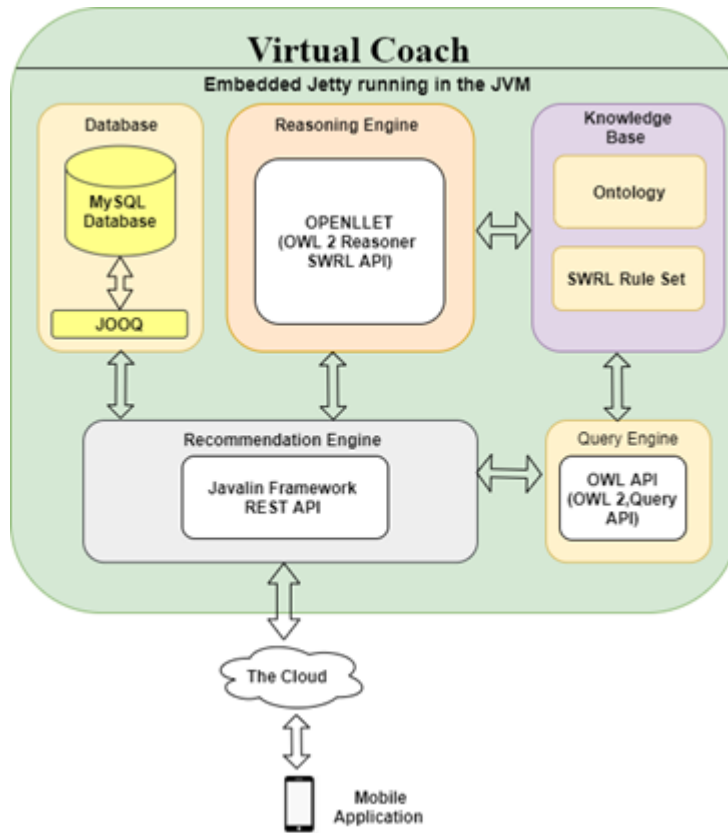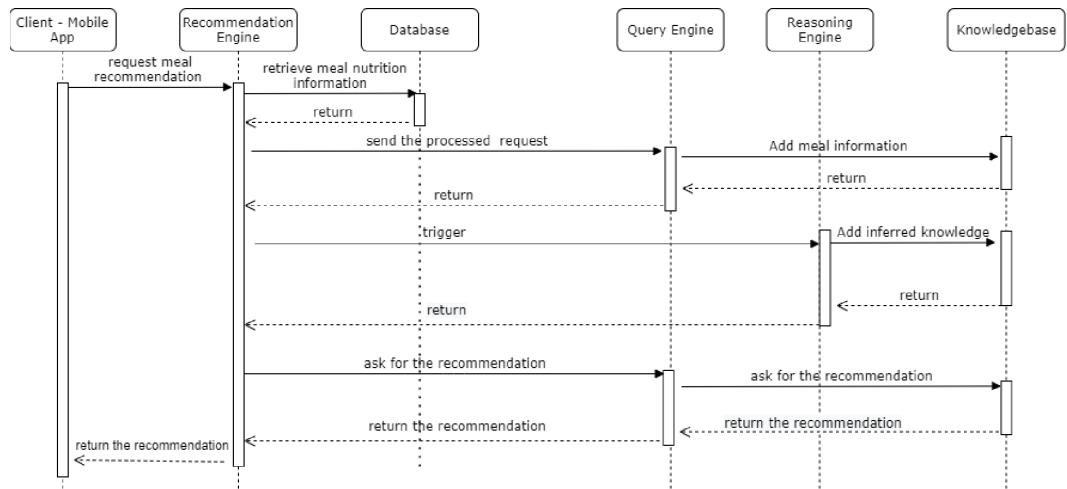**Figure 3. Framework of the Personalized Virtual Coach**

Figure 4. Sequence Diagram of the Recommendation Request.

client is built using web standard languages (HTML, CSS and JavaScript). The authors used the MVC (Model-View-Controller) architectural Pattern. The view is represented in the HTML and CSS pages to build visual components. The Model is represented in JavaScript classes built to provide Views with the logic needed. The Model is represented in JSON objects the client app received from the server.

Use Case Studies

Use cases in various scenarios allow us to explore the key characteristics, meanings, and implications of the case before the system can be deployed to large-scale real-world testing. Therefore, the authors performed use case studies to gain concrete, contextual, in-depth knowledge about using the ADDietCoach app in real life.

The authors assume that the registered user is a person with AD or his/her caregiver. Say Mike is a 75-year-old male cared by his daughter Samantha. Mike has early-stage AD and suffers from type 2 diabetes and high blood pressure. Mike's body mass index (BMI) is normal; his physical activity level is sedentary. All other profile information, such as his height, weight, age, cholesterol level, are stored in the system. Samantha does not have any chronic disease or allergy.

In the first case, Samantha consults the virtual coach to choose healthy meals for her dad and herself. One evening Samantha thinks about an IHOP entrée for diner. The entrée includes buttermilk crispy chicken, one potato pancake and a buttered corn. She checks this meal with ADDietCoach to see whether it is good for Mike.

ADDietCoach analyzes the meal's ingredients and screen them with various requirements and constraints, such as preference, religion requirements, medical limitation etc. This is realized by applying reasoning over the facts (including the meal's information, food and nutrition information, and user profile information) and rules (medical guidelines). It finds that this meal violates many medical guidelines and the MIND diet recommendation as listed below:

1. The estimated calorie needs per day for males aged 71 to 75 with a sedentary activity level is around 2000 (USDA, 2015).
2. Saturated fat should not exceed 6% of daily calories for AD patients (*High Blood Pressure and Diet: MedlinePlus Medical Encyclopedia*, n.d.).
3. A diabetic male should get about 50% of their total calories from carbs (*Carb Counting | Eat Well with Diabetes | CDC*, n.d.).
4. Fiber should be more than 14g/1000 kcals/day (*Dietary Reference Intake*, 2002).
5. Cholesterol daily intake should range from approximately 250 to 325 mg/d for men (*Dietary Reference Intake*, 2002).
6. Sodium should not exceed 1500 mg per day for people with high blood pressure (*Lower High Blood Pressure | American Heart Association*, n.d.).
7. Total fat should be less than 27% of daily calories for AD patients (*High Blood Pressure and Diet: MedlinePlus Medical Encyclopedia*, n.d.).
8. Protein should be between 20% and 30% of the meal energy (*American Diabetes Association Standards of Medical Care in Diabetes-2018*, n.d.).
9. Fried food should be avoided for AD patients (Gabb et al., 2016).

Each of these guidelines has a corresponding SWRL rule that is stored in the knowledgebase. As an example, medical guideline 7) about fat can be translated into the following SWRL rules.

When applying this rule on Mike's profile, through reasoning the system finds that the fat in this meal goes beyond the recommended fat limit. Similarly, when applying other rules, the system finds that the meal also passes the limit of saturated fat, cholesterol, and sodium, etc. Therefore, it is not recommended for Mike.

Figure 5 and Figure 6 demonstrate how the virtual coach gives detailed nutrition and recommendation information to the user.

Table 2.

```
Patient(?ptnt) ^
hasChronicDisease(?ptnt,?disease) ^
Alzheimers(?disease) ^
hasMeal(?ptnt,?meal) ^
hasFat(?meal, ?fat) ^
consumedTotalCalories(?ptnt, ?totalCalories) ^
swrl:Multiply(?limit,0.27,?totlaCalories) ^
swrlb:greaterThan(?fat,?limit) ->
isRecommended(?meal,false)
```
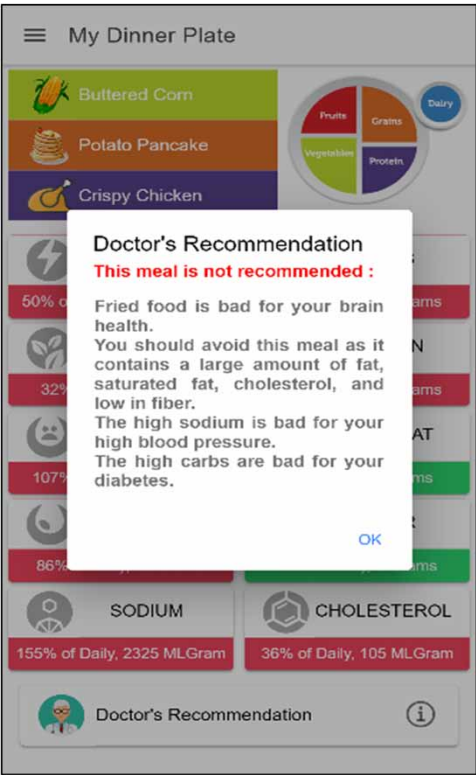
A personalized recommendation in text is shown in Figure 6. The recommendation is given based on Mike's profile and his daily diet record for that day. For each food ingredient, red color represents a warning limit and green color represents a safe amount.

In the second case, Samantha uses the food item search function of ADDietCoach to get personalized educational information about food product. ADDietCoach provides users two different interfaces (Barcode Scanner and manual input) to extract information of food items and food products. One day, Samantha is grocery shopping in a supermarket. She finds a pack of broiled sirloin steak. She wants to know if this is a good food choice for her dad. She scans the steak using ADDietCoach. As can be seen in Figure 7, the system shows all the nutrition's facts of the sirloin steak. An educational recommendation is listed at the bottom. As sirloin steak is a kind of beef, which is considered as red meat (*Beef and Veal Nutrition Facts*, n.d.). MIND diet regulations suggest limiting red meat

Figure 5. Screenshot of the meal evaluation with detailed nutrition information.

Figure 6. Screenshot of a Meal Evaluation with Detailed Recommendation

consumptions within 4 servings per week (*Improve Brain Health with the MIND Diet - Mayo Clinic*, n.d.). Similarly, in Figure 8 the educational recommendation is shown for spinach. Spinach, as a green leafy vegetable, is encouraged by the MIND diet.

The rules triggered to infer the recommendation shown in Figure 6 can be represented as shown in Table 3.
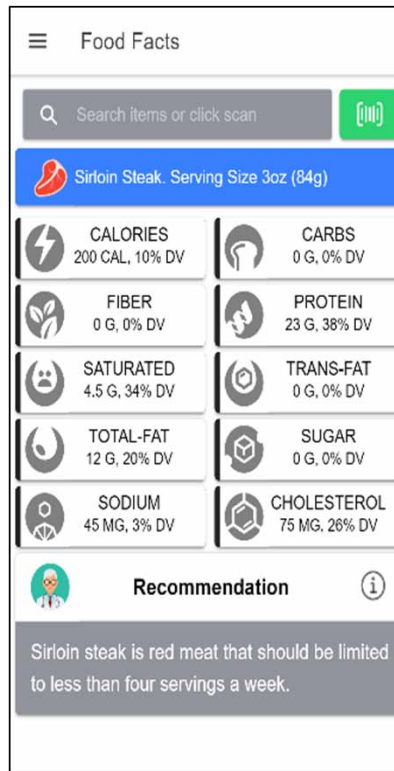
Manual Verification

The authors verified the recommendations generated by the system manually. Totally 78 recommendations were generated for different categories including food evaluation, shopping recommendation, food and nutrition education, and meal recommendation. Based on the user records containing detailed personal profile, scenarios, and corresponding recommendations provided by the

Table 3.

```
Patient(?ptnt) ^
hasChoronicDisease(?ptnt,?disease) ^
Alzheimer(?disease) ^
foodItemForPatient((?item, ?ptnt) ^
RedMeat(?item) ^
WeeklyLimit(?limit) ^
swrlb:lessThan(?limit, 4) ->
foodItemLimitation(?item, ?limit)
```

Figure 7. Screenshot of Food Items Nutrition Facts and General Recommendation-Sirloin Steak
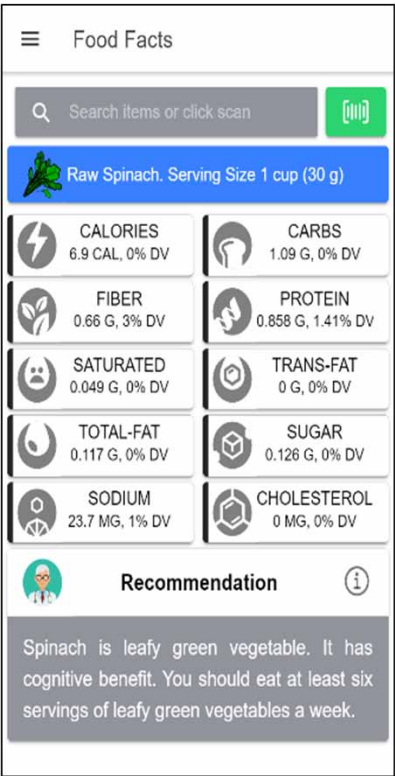

system. The authors turn to medical literatures to identify if the recommendations are correct. The authors got 100% accuracy, which have confirmed the correctness of the recommendations.

In the future, the authors plan to deploy ADDietCoach in a real setting with AD caregivers and early-stage AD patients as users. More comprehensive user studies will be performed to evaluate the virtual coach's usability, the satisfaction rate of the users, and the health and quality of life improvement outcomes.

CONCLUSION

Healthy eating is beneficial to the brain and general health of AD patients. However, it is not easy for unprofessional caregivers of AD to make appropriate diet plans based on the patient's unique needs. In this paper, the authors propose ADDietCoach, a personalized smart virtual diet coach to assist informal caregivers of AD in diet management and education. ADDietCoach is built on top of an ontological knowledgebase that includes concepts and relationships about patient's profile, AD, and food and nutrition. Diet-related medical guidelines and recommendations are also included in the knowledgebase. Diet coaching services are provided through ontological query and reasoning over the comprehensive knowledge. Personalization and context-awareness are realized through integrating user's profile and context information into the reasoning process. The proposed system has been implemented as a mobile application and tested with use cases in real life scenarios. This is an ongoing project; the authors plan to deploy ADDietCoach to real AD patients and their caregivers to enhance caregivers' engagement in AD diet care, thus sustainably improving care for patients as well as caregivers' own health and wellbeing. After successful testing, the authors plan to publish the

Figure 8. Screenshot of Food Items Nutrition Facts and General Recommendation - Spinach

proposed system as open source and release free mobile applications in Apple and Android stores. In this way, AD patients and their caregivers can use the software freely.

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