An Integrated Approach of Diet and Exercise Recommendations for Diabetes Patients

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Abstract— **Diabetes is among one of the fastest growing disease all over the world. Controlled diet and proper exercise are considered as a treatment to control diabetes. However, food and exercise suggestions in existing solutions do not consider integrated knowledge from personal profile, preferences, current vital signs, diabetes domain, food domain and exercise domain. Furthermore, there is a strong correlation of diet and exercise. We have implemented an ontology based integrated approach to combine knowledge from various domains to generate diet and exercise suggestions for diabetics. The solution is developed as a Semantic Healthcare Assistant for Diet and Exercise (SHADE). For each domain (person, diabetes, food and exercise) we have defined separate ontology along with rules and then an integrated ontology combines these individual ontologies. Finally, diet recommendations are presented in the form of various alternative menus such that each menu is a healthy and balanced diet.**

Keywords—**Diabetes, ontology, semantics**

I. INTRODUCTION

Diabetes is among one of the fastest growing chronic diseases all over the world. Diabetes patients increase rate is 70,000 per year worldwide and more than seven million diabetics are in Pakistan which are expected to increase to 13.8 millions in 2030 [1]. Diabetes leads towards serious complications such as eye sight loss, kidney diseases, heart issues, bone problems, nerves damages etc. Besides medicine, healthy diet, regular exercise, weight control and proper blood test for glucose level are the main controlling factors for diabetes treatment and avoid the complications [1]. It is preferable that to treat young diabetics with controlled diet and proper exercise and avoid using drug treatment [2].

Diet and exercise advices in existing solutions are often found in general form that is not applicable for all variety of users, who have different age, gender, weight, height, life style activities, diet and exercise preferences etc. Further, diet and exercise are strongly correlated. To maintain blood glucose level controlled, it is necessary to balance number of intake and consumed calories. Moreover, diet and exercise suggestions involve knowledge from various domains like personal health profile, food, disease and physical activity.

We have proposed, modeled and implemented a Semantic Healthcare Assistant for Diet and Exercise (SHADE) that recommends diet and exercise suggestions, initially as a case study, for type 2 diabetes patients. SHADE's generated recommendations are based on individual's preferences, personal health profile factors, blood glucose level, disease restrictions, taken diet and performed exercise. SHADE is dynamic and interactive as diet and exercise suggestions are based on latest glucose level, taken diet and performed exercise.

SHADE is modeled in Web Ontology Language (OWL) [3] based ontology and includes OWL based semantic class definition for concepts; domain rules are defined in Semantic Web Rule Language (SWRL) [4] and inference data is generated using Pellet [5] reasoning engine. The suggestions mechanism needs concepts and information from various domains knowledge base, so a modular approach is used in which each domain (personal profile, food, disease and exercise) concepts and relationships are defined in a separate ontology and then these individual's domain ontologies are combined into an integrated Ontology to generate diet and exercise recommendations for diabetes patients. Recommended food items are actually inferences on the basis of reasoning and defined SWRL rules. Diet suggestions are generated in the form of meal menu with portion size and exercise suggestions are actually user's preferred and disease allowed exercises with duration and intensity.

The rest of the paper is organized as follow: Section II comprises of related work about various approaches towards food and exercise recommendation systems. SHADE architecture and domain ontologies modeling are described in section III. Section IV is about our approach of generating diet and exercise suggestions and Section V shows our prototype implementation and results. Our contribution has summarized in Section VI. Finally, conclusion and future work is described in section VII.

II. RELATED WORK

A personalized diet recommendation system is one that considers user's personal health profile and likeness about food items being suggested. If the user is patient of any disease, the suggested food items must not contribute for disease encouragement. The purpose is the recommendations are of user's interest as well as practical and adaptable. Following are some of the efforts that have been made for diet recommendations.

Lee *et al*. [6][7] developed IDRA which analyzes whole day taken meals before dinner and recommends food groups along with serving size for dinner menu to adjust calories and to make the diet balanced. Personal profile, diabetes and nutrition domains are integrated and fuzzy inference mechanism is used to generate recommendations. Current glucose level and exercise domain are totally handled by manual judgments of medical expert, which can be handled via some level of system automation.

Villarreal *et al.* [8] combined ubiquitous computing with ontologies for its use in health system. Framework architecture is designed for mobile monitoring, medical treatment and diet specifications for the patients. Diet specifications classify food items into restricted, forbidden and recommended categories from only disease perspective and personal profile while user's preferences and exercise domain are ignored.

J. Cantais *et al.* [9] developed food ontology that includes different types of foods along with their nutritional ingredients. The developed ontology was designed to be incorporated in PIPS project, which aims to integrate and facilitate different types of healthcare professionals and users. After food ontology development, no further work is in our knowledge. The project lacks in taking care of patients preferences about their diet and exercise domain is totally ignored.

Jong *et al.* [10] designed a personalized diet recommendation system for heart patients. The effort lacks in describing food portion size and food menu. For diabetics, diet and exercise are very strongly correlated and considering diet without exercise is something incomplete.

Gergely *et al.* [11] focus is on suggesting prohibited, not recommended, recommended and highly recommended categories for nutrients from user's profile and disease perspective. It lacks in considering user's preferences and suggesting food items with proportion size.

Abdus Salam *et al.* [12] proposed a case-based approach for diet recommendation. Although, menu construction using incremental knowledge acquisition system (MIKAS) suggests food menu for different disease patients, but it lacks exercise recommendation which are very useful and effective for diabetes management and blood glucose control. Knowledge sharing and integration among various domains is not standardized.

In En-Yu Lin *et al.* [13] approach, diet and exercise recommendations are generated on weekly basis to facilitate nutritionists. Customer's profile based diet menu and exercise recommendations produced but preferences and disease perspective is not covered for the recommendations.

Maiyaporn *et al.* [14] used clustering approach to group food items based on their different nutrients values definition. For diabetics, food items are categorized into normal, limited and avoidable classifications. Food items can be checked from disease perspective but personal profile and exercise life style in not considered for food recommendations.

Hierarchical grouping technique is devised [15] for food items depending upon their nutrients values. Seven top important nutrients are selected and automated ontology construction mechanism categorizes a food item as Low, Medium and high according to each nutrient values. The study focuses only on food and nutrition domain.

Consider the related work it is evident that managing healthy diet and proper exercise in the life of a diabetic is a hectic job. Such management needs to consider various factors from different knowledge domains. Further, it requires making reasoning and following healthy recommendations in the form of rules. An integrated approach for food and exercise recommendation is proposed and described in the next section.

III. SHADE ARCHITECTURE AND MODELLING

Diet and exercise suggestions for diabetics needs to share and combine information from various domains. These domains include foods, exercise, personal information, diabetes domain, physical activity or exercise domain and then integration of these domains. Ontology based system is best suitable for various reasons including knowledge base creation, separation of knowledge with rules, reasoning capability and knowledge sharing situation. Using modular approach and to develop separate OWL based ontology for each domain enables to work with each domain independently. Then individual ontologies are imported into an integrated ontology which combines and defines relations among the objects from various ontologies. The reasoner, in our case Pellet, uses semantic ontological (OWL) description logic based class definition and rules defined in semantic web rule language (SWRL) to suggest food items as inferences. SHADE's main architecture is shown in Fig. 1.

A. The Domain Ontologies

Personal Health Profile Domain Ontology: Person domain ontology is shown in Fig. 2. It is developed to model a person's basic health profile information and to derive further information such as body mass index (BMI), basal metabolic rate (BMR), per day estimated energy need etc. Rules, defined in SWRL, are used to estimate the derived parameters. User is classified and inferred on age, gender, weight and life style variables by Pellet reasoner using ontological (OWL) description logic based class definition and SWRL rules. For example, "an old person is defined as a person having age in the range of between 30 and 50". In SWRL form, it is defined as:

Old_Age = Person some and (has Age decimal[>30, ≤50])

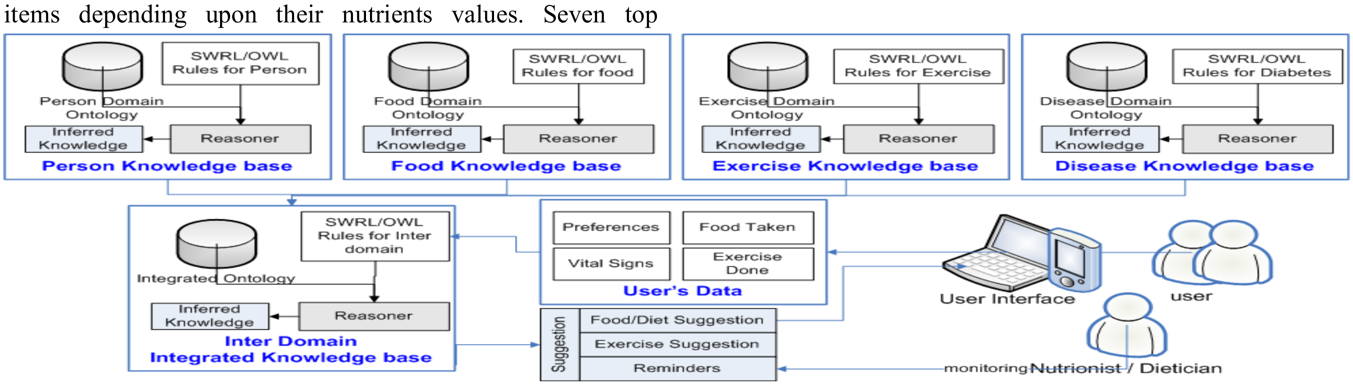

Fig. 1. SHADE Architecture

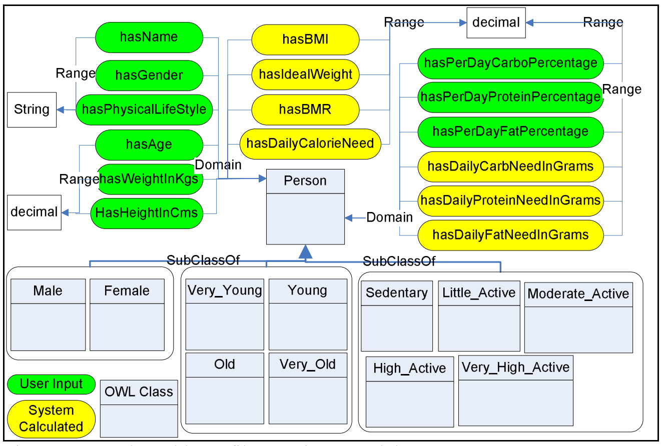

Fig. 2. Personal Health Profile Ontology Model

Food Domain Ontology: OWL based food domain ontology is developed containing various food items with proportion size, calorie values and their nutrients values such as amount of carbohydrates, proteins, fats, vitamins etc. Besides western food items, the ontology is enriched with various Pakistani and Indian food dishes and compatible with their food culture. These nutrients values have been collected from standard and well known resources such as USDA [16] and myfitnesspal [17]. Although [17] nutrient database is not public and may be available on request, we have collected nutrients of some food items using single food item based retrieval. Food domain ontology model is shown in Fig. 3. Reasoning and rule base approach is used to classify food items according to constraints of nutrients values such as LowProteinFoodItem, HighFatFoodItem etc. For example, Low calorie food item is defined as "a food item that has some calorie value which is less than 50". In SWRL format, it is defined as:

FoodItem(?f), Calorie(?c), hasCalories(?f, ?c), hasValue(?c, ?v), lessThanOrEqual(?v 50) → LowCalorieFoodItem(?f)

Disease Domain Ontology: Disease ontology is modeled which defines concepts, relationships and properties for disease domain. We have used OWL semantic class definition and SWRL based rules for diagnosis and conformation of disease, depending on vital sign values. For example "a diabetes patient is defined as a person who has some vital sign and that vital sign type is glucose level and value of that glucose level is greater than 180". Its SWRL form is:

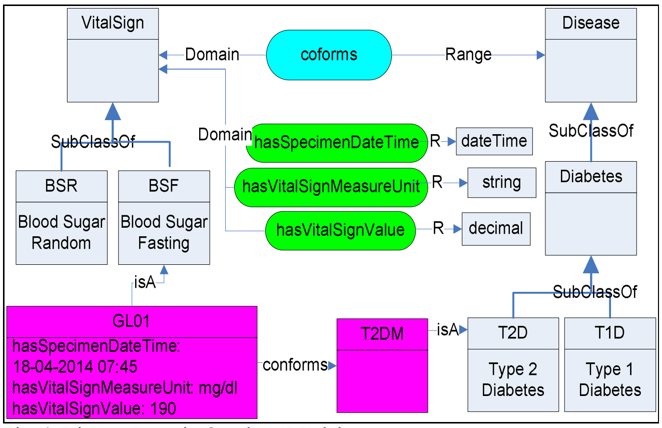

Fig. 4. Disease Domain Ontology Model

Person(?p), hasVitalSign(?p, ?g), GlucoseLevel(?g), hasVitalSignValue(?g, ?v), greaterThan(?v, 180) → DiabeticPatient(?p)

Further, concepts between disease ontology and food ontology are defined as there are various food items that should be restrictedly used, allowed and prohibited in case of a particular disease. Additionally, in case of a particular disease, some food items works as a treatment and some exercises may be harmful to do. Disease ontology model is shown in Fig. 4.

Exercise Domain Ontology: Exercise domain ontology is modeled to describe various activities with their possible intensities and metabolic equivalent (MET) values. Knowing the numbers of calories to be burn, ontology infers the possible activities along with duration and intensity. Some context-aware variables like time, location etc. are also modeled in the ontology for our future plan to incorporate context variables while suggesting exercise. Exercise domain ontology is shown in Fig. 5.

B. The integrated Ontology

Several solutions exist towards food recommendation for diabetes patients but none of the effort has considered the integration of various domains knowledge, all together into one system, for food and exercise recommendations. In fact, each of the domains has its own complexities and business rules; and they are extremely interrelated for diet and exercise recommendations for diabetes patients.

An integrated ontology model that imports the domain ontologies and defines relationships among them is shown in Fig. 6

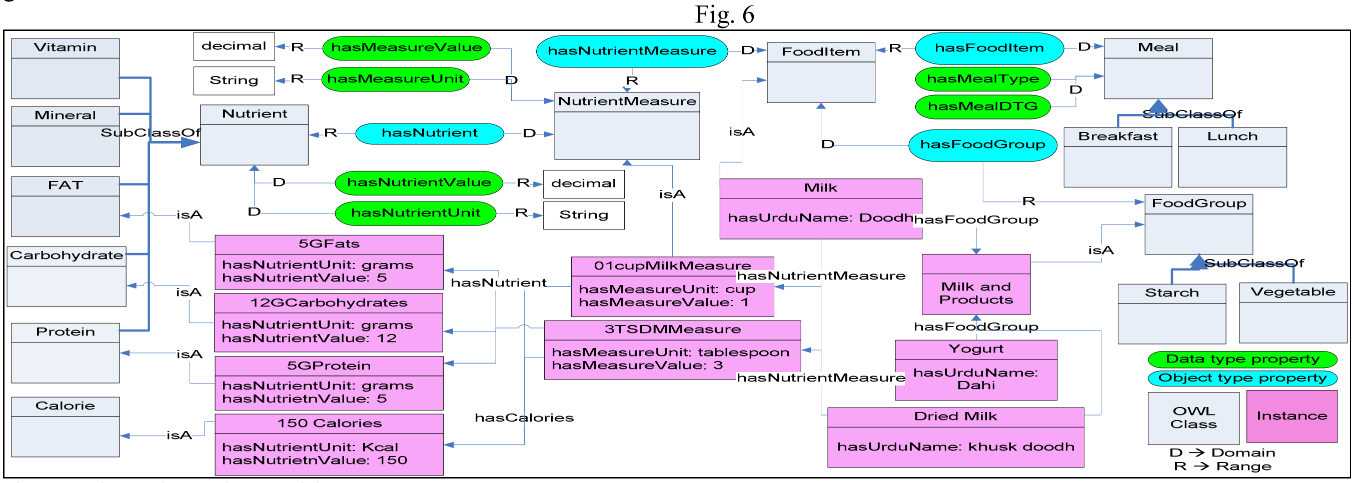

Fig. 3. Food Domain Ontology Model

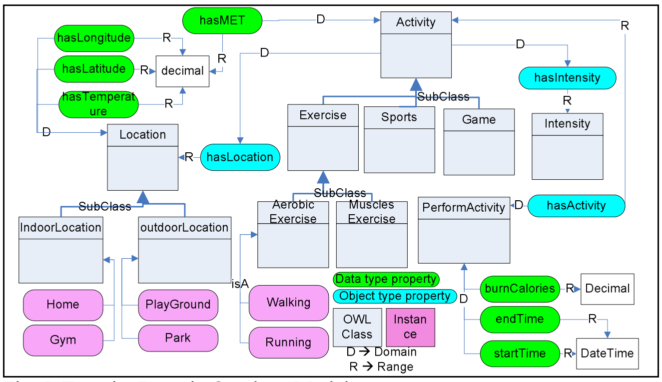

Fig. 5: Exercise Domain Ontology Model

C. *The Rules*

Each domain has its own knowledge base, which can be precisely represented in the format of rules. For example, general health recommendations, clinical guidelines, food tips can be explicitly defined terms of rules for diet and exercise recommendations. Some basic examples and rules are described here as follow:

Example 1: Suggestion of low calorie food items for diabetics

Rule 1: Low calorie food item is defined as a food item that has some calorie value which is less than 50. In SWRL format, it is defined as:

FoodItem(?f), Calorie(?c), hasCalories(?f, ?c), hasValue(?c, ?v), lessThanOrEqual(?v 50) → LowCalorieFoodItem(?f)

Rule 2: Diabetes patient is defined as a person who has some vital sign and that vital sign type is glucose level and value of that glucose level is greater than 180.

Person(?p), hasVitalSign(?p, ?g), GlucoseLevel(?g), hasVitalSignValue(?g, ?v), greaterThan(?v, 180) → DiabeticPatient(?p)

Rule 3: Low calorie food items are suggested for diabetics

DiabeticPatient(?p), LowCaloriePreferredFoodItems(?f), hasPreferredFood(?p, ?f) → hasFoodSuggestion(?p, ?f)

Rule 1 classifies all low calorie food items, rule 2 infers if the person is diabetic then rule 3 suggests those low calorie food items to diabetics which are preferred by him/her.

Example 2: Low intensity exercise suggestion for old person

Rule 4. Low intensity exercise is "an activity that has MET value less than or equal to 3". Its SWRL rule is defined as:

Activity(?a), hasMET(?a, ?m), lessThanOrEqual(?m, 3) → LowIntensityActivity(?a), hasIntensityValue(?a, "Low")

Rule 5. Suggested exercise for an old person is low intensity exercise. It is written in SWRL format as:

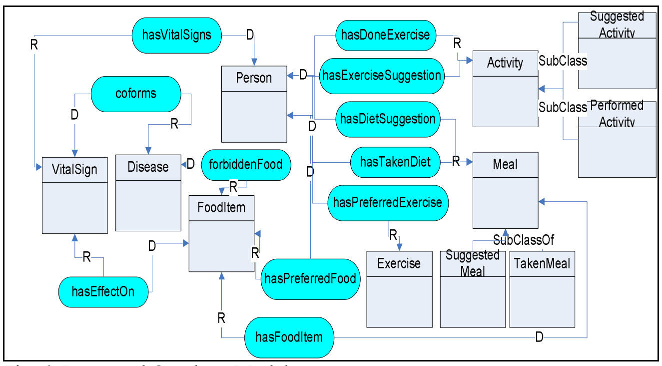

Fig. 6. Integrated Ontology Model

Old_Age(?p), LowIntensityActivity(?a), hasPreferredExercise(?p, ?a) → hasExerciseSuggestion(?p, ?a)

Rule 4 categorizes all low intensity exercises. Rule 5 suggests low intensity and preferred exercises to old age person.

IV. SHADE RECOMMENDATIONS

SHADE recommends diet and exercise suggestion to the user at user's predefined time. A user may be asked for preferred meal time and on that specific time, trigger occurs to generate personalized food items. A nutritionist or dietician can monitors the recommendations so that rules can be improved or redefined in case of abnormal suggestion is generated.

A. *Diet Recommendations*

It consists of two steps: First step estimates the amount of calories and nutrients (carbohydrates, proteins and fats) that needed to intake for the current meal and in second step satisfying the constraints of calories and nutrient values, disease restrictions, preferences and current vital signs, food menus are suggested. Step 1 activities are shown in Fig. 7(a). with gray background, these tasks are performed after long term specified duration and step 2 tasks performed each time, when meal time occurs, as shown in Fig.7 (b). Details of these tasks are as follow:

Estimate Daily Calories Need: Harris-Benedict equation [18, 19] is used, with slight modification to estimate basal metabolic rate (BMR) and then multiply it with activity factor (AF) to estimate daily calorie need. The modification in BMR calculation is to use ideal weight instead of actual weight.

$$\text{BMR (Male)} = 66.47 + (13.75 * w) + (5.0 * h) - (6.75 * a) \quad (1)$$

$$\text{BMR (Female)} = 655.09 + (9.56 * w) + (1.85 * h) - (4.67 * a) \quad (2)$$

where 'w' is the ideal weight in kg, 'h' is height in cm and 'a' is age in years.

$$\text{Daily calorie estimate} = \text{BMR} * \text{AF} \quad (3)$$

where AF can be determined from Table I.

Per Day Nutrients Estimate: Among the top most important nutrients that must be considered for diabetic patients are carbohydrates, proteins and fats [11].The standard recommended daily Intake nutrients measure is carbohydrates 50%-60% of daily calories, protein 10%-20% of daily calories and fat 25-35% of daily calories [20]. This distribution is updated when value of daily needed calories changes. It is different for each individual depends on disease situation and assumed to be initially defined by dietician or nutritionist.

Nutrients Estimate for the meal: Default distribution of daily calories for each meal type is: Breakfast: 20%, lunch: 25%, dinner: 25%, snacks: 30% (10 mid breakfast + 10 evening snacks + 10 bed tea). Such distribution varies on individual basis and defined by nutritionist in the beginning. Based on diet and blood glucose level (BGL) monitoring, the distribution is changed as it is possible that some diabetes patients BGL increases after having breakfast or other may have high BGL on fasting.

Calorie and Nutrients Adjustment: Diet and exercise are strongly correlated. Diabetes patient with doing more exercise can enjoy more calories and in the absence of exercise they

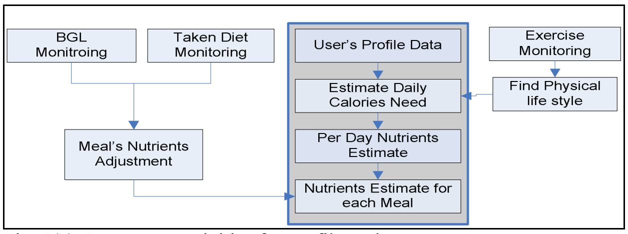

Fig. 7(a). Long term activities for profile update

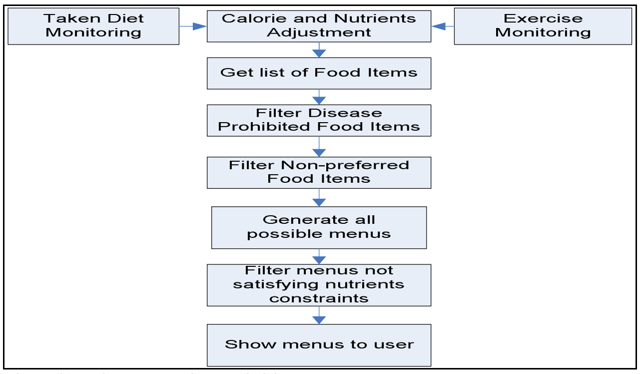

Fig. 7(b). Diet suggestion activities

need to be very careful about calories intake, so we have devised an algorithm that dynamically allow change in number of calories for meal on a specific day, depending upon the physical activities of the patient on that day and number of calories already taken in prior meal on that day.

List of food items satisfying the nutrients and calorie values constraints is retrieved and then filtered for disease prohibited food items and user's non-preferred food items. The remaining food items are allowable, preferred and recommended food items. SHADE recommends a number of alternative meal menus such that each menu comprises of a list of food items having sum of nutrient and calorie values remains in allowable range and the diet is healthy and balanced.

B. *Exercise Recommendations*

Exercise recommendations needs to consider person's willingness for exercise, age, weight, extra taken calories, preferences and disease profile. Exercise recommendations mechanism also follows two steps. First step estimates the needed calories to burn and second step recommends activities with duration and intensity that burn the required number of calories.

TABLE I. CATEGORIES AND ACTIVITY FACTOR FOR PERSON EXERCISE

Person's life style for exercise	***Activity Factor***	***Daily extra calories for exercise***
Little or no exercise	1.2	Nil (BMR is resting energy and 1.2 factor consume in little daily routine work)
Light exercise (1–3 days per week)	1.375	(1.375 – 1.2) * BMR = 0.175 * BMR
Moderate exercise (3–5 days per week)	1.55	(1.55 – 1.2) * BMR = 0.35 * BMR
Heavy exercise (6–7 days per week)	1.725	(1.725 – 1.2) * BMR = 0.525 * BMR
Very heavy exercise (twice per day, extra heavy workouts)	1.9	(1.9 * – 1.2) * BMR = 0.7 * BMR

planCaloriesToBurn = Daily Calories burned by exercise (Column 3 of table 1) + Calories adjusted for overweight + extraIntakeCalories - caloriesAlreadyBurned *(4)*

The calories burned during exercise/activities can be calculated using following formula:

Calories burned (CB) = duration (in minutes) *MET * 3.5 * weight (in Kg) / 200 (5)

where MET is metabolic equivalent, and it is per minute consumption of oxygen in the body at the state of sitting at rest. The value 3.5 is amount of oxygen per kg body weight per minute [21]. There is a specific value of MET for each combination of activity type and intensity level. For example, if aerobic exercise is done with low intensity then its MET value is 5.04. A long list of such MET values has been defined in various literatures, for example [22, 23].

While recommending exercise, first of all user's preferred and disease allowed activities are filtered. Then, using (5) duration of all filtered exercises are calculated. Its SWRL rule is as follow:

Person(?p), hasPreferredExercise(?p, ?a), hasDisease(?p, ?d), recommendedActivity(?d, ?b), owl:sameAs(?a, ?b), todayCaloriesToBurn(?p, ?cb), hasWeightInKgs(?p, ?w), hasMET(?a, ?m), multiply(?n, ?m, ?w, 0.0175), divide(?d, ?cb, ?n) → ExerciseSuggestion(?a), hasExerciseSuggestion(?p, ?a), hasDuration(?a, ?d)

V. PROTOTYPE IMPLEMENTATION

Our prototype implementation approach is semantic based in which ontology is defined using OWL, rules are defined in SWRL and inferred knowledge is produced using Pellet reasoning engine. The main ground for using OWL based ontology is to enable reasoning on the data on the basis of semantic class definitions and rules to infer knowledge. Ontology is the explicit description of the concept and their relationships while rules are proper definitions of health recommendations and clinical guidelines, so it's a natural approach towards enabling machine for making decision and leading the system towards automation.

We have initially modeled the system using Protégé 4.1 and each of the ontology is saved in a text file in the form of tuples. In our prototype application, the ontology is retrieved and loaded in the form of a model object using Jena API. Pellet API is used to make inferences dynamically on the basis of current and latest data instances. User Interface is developed in Java which enables to register new user, add user's health profile data, include new food items and their calories and nutrient values with portion size, insert new exercise along with MET values etc. The application allows the user to enter data of taken meal, performed exercise and blood glucose level so that this data is processed and considered while next recommendation is generated.

Suggested food items are actually inferences as a result of reasoning by pellet reasoning engine on the basis of pre define rules. Using suggested food items, various alternative menu options are generated, where each menu is a combination or list of suggested food items with the restriction of having nutrient and calorie values in an acceptable range. Finally eliminate those combinations or menus which are invalid. Example of an invalid menu is a combination of pasta with rice. Fig. 8 (a) shows the recommended suggestion for diet. Fig. 8 (b) shows exercise suggestions for the user with duration and intensity. The exercise suggestions are as per user's preferences and non-risky to the disease, so adaptable and usable.

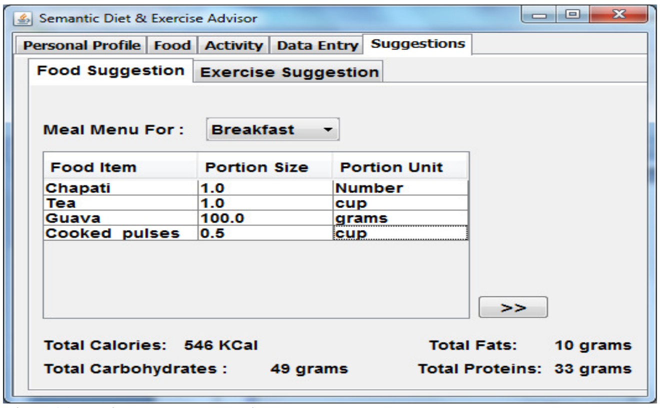

Fig. 8(a). Diet menu suggestion

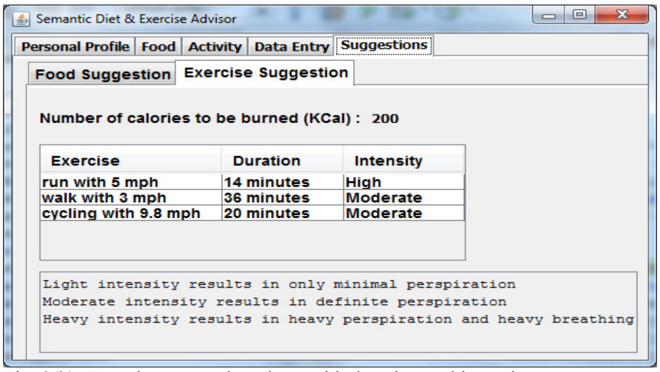

Fig. 8(b): Exercise suggestion along with duration and intensity

VI. CONTRIBUTION

We have used first ever approach of OWL base ontology, semantic ontological domain concepts definitions and SWRL based rules to generate diet and exercise suggestions. Previously, no reasoning and inference based technique has been used for diet and exercise assistance for diabetics.

Furthermore, our implementation integrates knowledge from various domains for diet and exercise suggestions. No such consideration has been done previously. Our integration approach shows the real benefit of using ontologies i. e. integration and sharing of concepts from various domains knowledge base, defines new relationships among these domains concepts and integrated it into one system.

Diet and exercise are strongly correlated and we have focused on this relationship. If patient has taken more calories, he/she can adjust it by doing extra exercise. Up to our knowledge, no efforts have been made in which the generated suggestions involves both diet and exercise suggestions simultaneously.

Our generated food recommendations are in a menu format which makes our effort to be used in real and practical life.

VII. CONCLUSION AND FUTURE WORK

Managing balanced diet and proper exercise by a diabetic is a complex task. Food and exercise recommendations for diabetics need to consider various knowledge base domains. In our current work we developed person, food, disease and exercise ontologies and then an integrated ontology combined these ontologies. Using semantic ontology based rules and reasoning food and exercise recommendations for diabetics are generated. SHADE evaluation is to be done by diabetes patients, endocrinologists and nutritionists for its validation and further improvements.

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