An Integrated Approach for Preference based Diet and Exercise Recommendations to Diabetics

by

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APPROVAL

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To My Parents

Certificate of Originality

I hereby declare that the submitted thesis titled "**An Integrated Approach for Preference based Diet and Exercise Recommendations to Diabetics**" is my own work and to the best of my knowledge, it contains no materials previously published or written by another person, nor material which to a substantial extent has been accepted for the award of any degree or diploma at SEECS or any other education institute, except where due acknowledgment, is made in the thesis. Any contribution made to the research by others, with whom I have worked at SEECS or elsewhere, is explicitly acknowledged in the thesis.

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IRSHAD

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Abstract

Diabetes is among one of the fastest growing diseases all over the world. Controlled diet and regular exercise are considered as a treatment to control type 2 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. Moreover, existing conventional methods advices general recommendations those are not applicable to all variety of diabetes patients. Furthermore, the strong correlation between diet and exercise is ignored in current existing solutions. A single diet management scheme such as food pyramid, diet chart, carbohydrate counting and glycemic index doesn't gives customized, personalized and balanced diet. Our approach uses combination of these diet management techniques. 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 OWL (Web Ontology Language) based ontology along with SWRL (Semantic Web Rule Language) rules and then an integrated ontology combines these individual ontologies. Our prototype application is developed using Java, Jena and Pellet API. Based on data and rules, Pellet reasoning engine semantically recommends diet and exercise recommendations as inferences. The research work presents diet recommendations in the form of various alternative customized menus such that each menu is a personalized, healthy and balanced diet. Finally, exercise recommendations are generated in the form of various alternative and user's preferred physical activities along with duration and intensity.

Chapter 1 : INTRODUCTION

Diabetes is a disease due to deficiency or malfunction of a very important human hormone, insulin. Insulin functions as a key to open cell doors so that sugar can be entered into the cells. When either pancreas doesn't produce enough insulin or cells resist in absorbing the glucose, it builds up in the blood stream and the situation is considered as a disease named diabetes.

Among several types of diabetes major types are type 1 and type 2 diabetes. In type 1 diabetes, insulin generation by the body itself is eliminated; resulting to take the insulin either injected or via insulin pump as a treatment. That's why patients with type 1 are also known as insulin-dependent diabetes mellitus (IDDM). Most of the diabetes patients are type 2 diabetics i.e. about 90 to 95%. Type 2 diabetes is caused due to a special condition, called Insulin-resistance. Cells show resistance in absorbing sugar into the cell to get energy. Our research focus is on type 2 diabetes patients and type 1 is out of the scope of this thesis. The usual treatment for type 2 diabetes is to manage weight, diet and exercise, even in some cases without medications. Such diabetes management can be assisted using emerging technologies.

Current advancements in technologies results in using modern gadgets in everyday life. Use of latest technology is recommended to assist diabetics to control weight and for managing diet and exercise. Our work here is aimed to be a bridge between medical domain knowledge and emerging computer technology. We are going to combine diabetes domain knowledge with newly emerging technology, semantic web, to assist diabetes in managing diet and exercise.

Semantic web [1] is a collection of technologies with the aim that data can be accessed, understood and processed by machines. The idea of semantic web is enabling machines to understand the semantics of data and realizing the concepts and their relationships behind it. Ontology is being used for knowledge representation in the form of concepts and their relationships. For ontology expression RDF [2], RDFS [3] and OWL [4] are the supported technologies from semantic web side. SWRL [5] is the language to facilitate for defining domain knowledge based rules over the concepts and relationships. Reasoning engine is introduced so that machine itself can infer new/additional knowledge by using the rules over the concepts and relationships. Pellet [6], FaCT [7], FaCT++ [8] and HermiT [9] are various implementations of the semantic reasoning engine.

Using ontologies and semantics in the field of medical is very important and advantageous [10]. Ontology is the abstract conceptualization of real world concepts and OWL, as a semantic web technology, enables to explicitly define various medical terminologies, concepts and their interrelationships. We have domain rules in terms of clinical guidelines, fitness tips and useful health recommendations. Such rules can be defined to be implemented on the concepts and reasoning can be made to generate new information about the data as an inferences. So, an integrated ontology based rules and reasoning is a natural approach towards enabling machine for making intelligent decisions and leading the system towards automation.

1.1 Research Motivation

Diabetes patients increase rate is very alarming i.e. 70,000 per year worldwide. On average, two persons are diagnosed with diabetes and one person dies per 2 seconds, due to diabetes related complications [11]. Only in Pakistan more than seven million populations is diabetic which is expected to increase to 13.8 millions in 2030 [11]. Currently more than 88,000 deaths occur in a day due to diabetes and its related complications [12]. According to a survey report [13], looking at the number of diabetic patients, Pakistan is the 6th largest country in 2000 and it is estimated to secure number 5th in the list in 2030, if current increase rate prevails.

Table 1.1: Diabetes patients in Pakistan in 2000 and 2030

Table 3 —*List of countries with the highest numbers of estimated cases of diabetes for 2000 and 2030*

	2000		2030	
Ranking	Country	People with diabetes (millions)	Country	People with diabetes (millions)
1	India	31.7	India	79.4
2	China	20.8	China	42.3
3	U.S.	17.7	U.S.	30.3
4	Indonesia	8.4	Indonesia	21.3
5	Japan	6.8	Pakistan	13.9
6	Pakistan	5.2	Brazil	11.3
7	Russian Federation	4.6	Bangladesh	11.1
8	Brazil	4.6	Japan	8.9
9	Italy	4.3	Philippines	7.8
10	Bangladesh	3.2	Egypt	6.7

source: Wild S, Roglic G, Green A, Sicree R, King H (2004) Global prevalence of diabetes: Estimates for the year 2000 and projections for 2030. Diabetes Care 27: 1047–1053.

The topmost factors for controlling diabetes include controlled weight, healthy and balanced diet, proper exercise and regular blood glucose test [1]. These factors are considered as a treatment for diabetes control and to avoid its complications such as eye sight loss, kidney diseases, heart issues, bone problems, nerves damages and leg amputation etc [1]. Active lifestyle and healthy dietary habits are essential factors for diabetes management.

1.2 Problem Statement

Food and exercise suggestions in existing solutions don't consider user's preferences about food and exercise. Existing solutions suggests general diet and exercise recommendations for all variety of diabetes users. Such suggestions diet include food items that user may not like to intake or some exercise that are not practical to adopt for the user due to any personal circumstances. So, first of all user likeness about food items and willingness for exercise should be considered.

Food intake calorie requirement varies among diabetics, mainly depends upon gender, age, weight, height and current vital signs etc. Further, how much calories should be taken from which nutrients (carbohydrates, proteins and fats etc.) depends upon user's personal health profile data and disease situation. Additionally, calories distribution for different meals (breakfast, lunch, dinner and snacks etc.) in a day also needs to be managed. So, proper attention is required for diet management with respect to diet amount and nutrient values depending upon a person body structure, gender and age etc.

There is an association between food items and disease. For example, some food items cause in instant increase in blood sugar level while some food items are excellent in maintaining blood sugar level within a controlled range. So, when taking diet, such food must be avoided which increases the blood sugar level.

There is a strong correlation between diet and exercise. If person has taken more calories, then extra exercise is needed to burn more calories. Similarly, if person has performed extra physical activities, he/she may enjoy more calories. The rule is to balance intake and burned calories. Extra calories taken and not burned are saved in the form of fats inside the body while burning more calories than intake calories results in burning the body fats. Thus, if person is over weighted, he/she has any or both options to lose the weight, by either to reduce the per day intake calories or to do extra exercise to burn more calories and to melt the body's fats.

Knowing about restricted, forbidden and recommended food items, there is also a need to combine various food items along with portion size in the form of a menu such that overall the menu is comprises of a healthy diet (it takes food items from different food groups) and balanced (fulfill the constraints of satisfying that calories and nutrients values are in allowable range).

1.3 Thesis Objective

The objective of this thesis is to model, design and develop 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.

Although we propose the automatic monitoring and archival of diet and exercise activities performed by the user, but until the technology matures, manual entries will be done for taken diet, performed exercises and blood glucose level by the user which will be archived, processed and used by the system for further suggestions. Such archival is very useful for analysis and mining purpose and to produce new discoveries.

SHADE is modeled in Web Ontology Language (OWL) based ontology and includes OWL based semantic class definition for concepts; domain rules are defined in Semantic Web Rule Language (SWRL) and inference data is generated using Pellet 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.

1.4 Thesis Contribution

Our developed application assists diabetics in controlling weight and organizing diet and exercise for diabetes control. It generates recommendations based on integrated knowledge from various domains such as personal profile domain, food domain, disease domain and exercise or physical activity domain. Further, the recommendations are personalized and based on users preferences. The recommended diet intake and exercise calories are estimated to balance the consumed and burned calories on a particular day. Finally, generated diet menu satisfies the constraints of healthy and balance diet.

Semantic web is still an emerging technology and we have experienced first ever approach of using semantic web technologies in health domain to assist diabetics. The rules, reasoning and inference based approach not only assists diabetics, endocrinologists and nutritionists but also an effort towards the automation and enabling machines to make intelligent decisions for diet and exercise recommendations.

1.5 Thesis Organization/Structure

The rest of the thesis is organized into five chapters. Chapter 2 comprises of background work about diabetes, its types and current statistics about diabetes. Various diet management techniques, their comparison and our adopted methodology is discussed. Chapter 3 shows related work about various approaches towards food and exercise recommendation systems. Chapter 4 describes design and modeling of various ontologies and their integration. It also demonstrates our mechanism flow for food and exercise recommendations. Chapter 5 discusses our prototype implementation and its results. Finally, contribution, conclusion and future work is presented in section 6.

Chapter 2 : BACKGROUND WORK

2.1 About Diabetes

Diabetes is a disease in which a human body either i) don't produce insulin at all or ii) don't produce enough insulin or iii) cells don't respond properly to insulin. When we take diet, digestive system turns the diet into glucose or sugar which is mixed into the blood stream. The function of blood stream is to pass the glucose to cells of all over the body. The cells absorbed the glucose from the blood to get energy which is to be used for doing physical activity. Human body organ, pancreas, job is to produce very important hormone, called insulin. The role of insulin is to work as a lock key and opens the cells door so that sugar from blood can be absorbed into the cells. When there is no insulin or not enough insulin or insulin is not able to open the cells door, the sugar remains in the blood, causing to raise the blood sugar level. Such condition is considered as a disease, called diabetes.

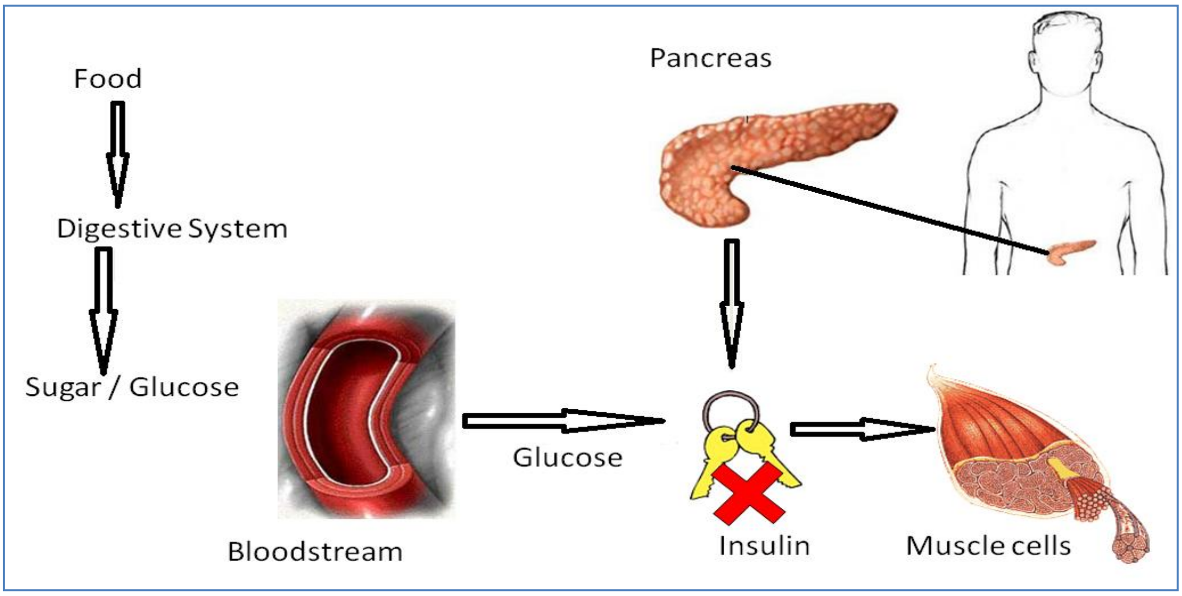


Figure 2.1: Role of Insulin in human body

In the first condition when human body don't produce insulin at all, is called insulin-dependent or type 1 diabetes. In type 1 diabetes, body's immune system mistakenly attacks and destroys the pancreas's beta cells, which are responsible to produce insulin. So, insulin production by the body itself is zero and patient is dependent on taken insulin externally via insulin injection or insulin pump. That's why type 1 diabetes is also called Insulin dependent diabetes mellitus (IDDM). Mostly children and young adults are affected with type 1 diabetes. A small fraction of about 5 to 10% of diabetes patients are type 1 diabetes patients.

Most of the diabetes patients are type 2 diabetics i.e. about 90 to 95%. Type 2 diabetes is mostly diagnosed in adults and older aged persons. In recent research, children have also been diagnosed with type 2 diabetes. Type 2 diabetes is caused due to a special condition, called Insulin-resistance. Cells show resistance in absorbing sugar into the cell to get energy. In order to fulfill the demand, pancreas releases more insulin so that sugar can be absorbed but over the time insulin secretion goes down and down and eventually the production becomes zero or too much low. The usual treatment for type 2 diabetes is to control weight, manage diet and perform exercise, even in some cases without medications.

Type 1 diabetes is insulin dependent and must be treated by taking insulin. However, type 2 diabetes is non insulin dependent and can be treated without taking insulin. Our research focus is on type 2 diabetes patients and type 1 is out of the scope of this thesis.

Major common symptoms of diabetes are excessive urination, too much thirst and hunger, weight loss, vision weakness, feeling fatigue etc. Main causes of type 2 diabetes include family diabetes history, obesity, physical inactivity and prior gestational diabetes history.

Category	Fasting Value (mg/dl)		Post Prandial(mg/dl)
	Minimum Value	Maximum Value	Value 2 hours after consuming glucose
Normal	70	100	Less than 140
Early Diabetes	101	126	140 to 200
Established Diabetes	More than 126	----	More than 200

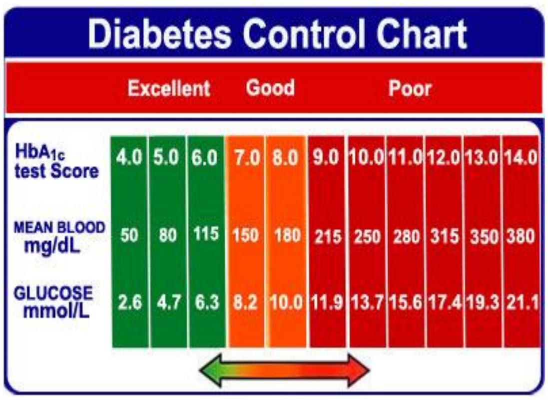


Figure 2.2: Glucose test reference value ranges [14]

Diabetes patients are advised to check regular blood glucose level, thrice a day. Normal blood glucose level measurements on pre-meal/fasting are in the range of 70 - 100 mg/dl, while post-meal glucose levels are 120 - 140 mg/dl. Hemoglobin A1C, also called, Glycosylated Hemoglobin *Test or* HbA1c or HA1c or A1C, is a measure, periodically every 2 - 3 months or at least after 6 months, to determine the average blood glucose level over the lifetime of the red blood cell. While normal glucose test before or after meal shows blood sugar information for a particular day, the HbA1c test shows how well blood glucose level has been maintained over the period of several months. A good recommended value of HbA1c levels should be at or below 8% for well controlled diabetes.

Diabetes leads towards serious complications such as eye sight loss, kidney diseases, heart issues, bone problems, nerves damages and leg amputation etc. Diabetes patients increase rate is very alarming i.e. 70,000 per year worldwide. On average, two persons are diagnosed with diabetes and one person dies per 2 seconds, due to diabetes related complications [11]. Only in Pakistan more than seven million populations is diabetic which is expected to increase to 13.8 millions in 2030 [11]. Currently more than 88,000 deaths occur in a day due to diabetes and its related complications [12]. According to a survey report [13], looking at the number of diabetic patients Pakistan is the 6th largest country in 2000 and it is estimated to secure number 5th in the list in 2030, if current increase rate prevails.

Active lifestyle and healthy dietary habits are essential factors for diabetes management. The top important factors for controlling diabetes include controlled weight, healthy and balanced diet, proper exercise and regular blood glucose test. These factors are considered as a treatment for diabetes control and to avoid its complication.

2.2 Diet Management for Diabetics

2.2.1 Diet Management techniques

There are several schemes of diet management for diabetes, some of commonly used are presented as follow:-

2.2.1.1 Food Pyramid

It is an interesting tool which consists of a pyramid having six food group layers. These food groups consist of carbohydrates, vegetables, fruits, Proteins, Milk and Dairy and fats. Food items in the bottom layer should be used in excess while food items in the peak should be restrictedly used. Each food group layer has a different size, showing the amount of usage in per day diet. Larger the layer size means more to use food items from that food group.

The food pyramid recommends food items, in general. It doesn’t consider user’s likeness or preferences about food items. Further, it considers the food group as a whole and doesn’t restrict any food item within the food group. For example, potato is from vegetable group but as it has large amount of carbohydrates, it usage should be restricted. No daily calorie count and nutrients management is being considered.

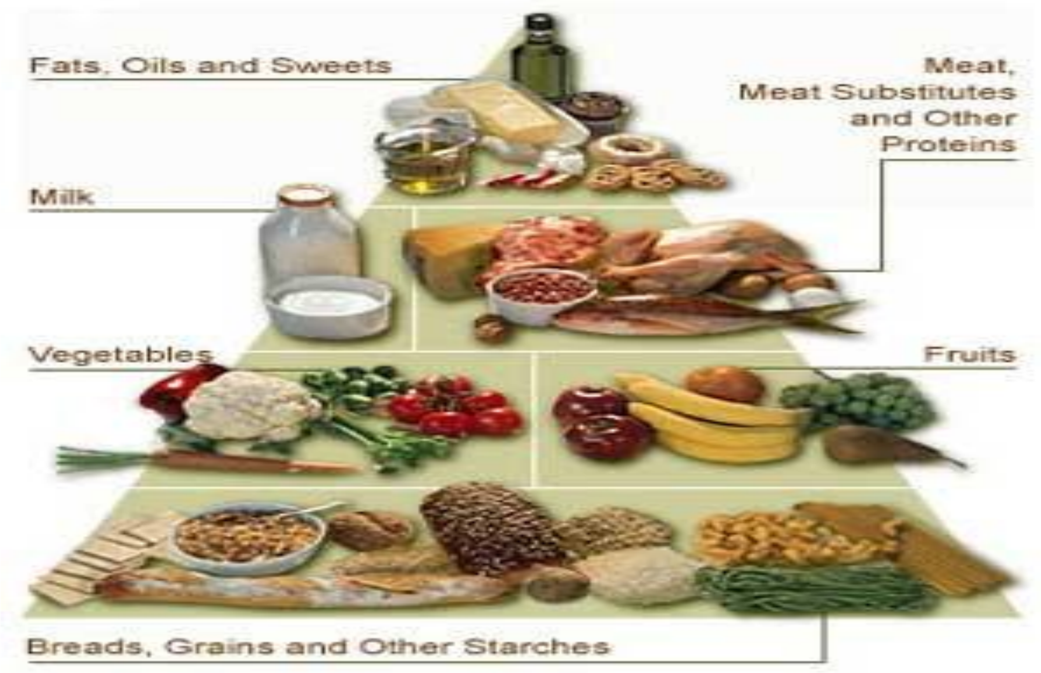


Figure 2.3: Food pyramid [15]

2.2.1.2 Food Charts

Under this scheme, whole day meal plan is presented in the form of a dietary chart, consists of three big and three small meals. Each meal plan consists of list of food items with their portion size.

The difficulty in using such food chart is to have limited variety of food items. User preferences are changed with time, season and context, so hard to usable. If such charts are user's personalized according to his/her gender, age, height, weight, physical life style etc. then it may be effective, but the practice is such charts are generalized, so not applicable and adoptable for all variety of users.

2.2.1.3 Food Exchange List

It is an extended version of food charts in which each meal plan consists of a list of alternative food items that can be replaced with one another. So, user can have the choice of using a variety of food items. Nutrition specialists define how many servings should be taken from each food group. There are multiple options/alternatives to replace a food item with another in the same food group. It is a complex and hard to do mechanism to follow. Another problem is it is not user's personalized.

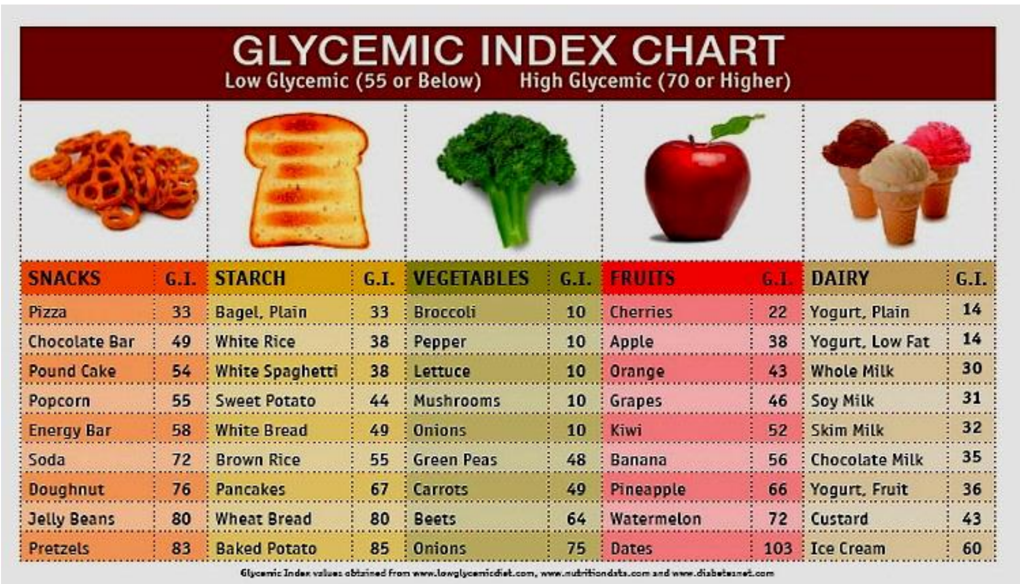
2.2.1.4 Carbohydrate counting

Carbohydrate counting technique facilitates in removing the hurdle of using any restricted food items. User can take any food item of his/her choice from any food group. The procedure is that dietician or nutritionist estimates the amount of daily intake carbohydrates according to user's gender, age, weight, height and life style. Then distribute the daily intake carbohydrates for each meal. User is advised the amount of intake carbohydrates for each meal and he/she has given a list of food items with portion size and contained amount of carbohydrates. User him/herself can create the meal plan according to amount of carbohydrates.

The problem with this method is it deals only the carbohydrates. Other nutrients such as fiber, proteins and fats are ignored. Some fatty food items such as cheese or butter have low carbohydrates but large amount of calories and fats which may be harmful. This method doesn't guarantee the meal plan to be healthy and balanced.

2.2.1.5 Glycemic Index (GI)

Glycemic index is the measure of how quickly an intake food item increases the blood sugar level. For example, juices are quickly digested and the produced carbohydrates are instantly builds up in the blood stream while milk takes a lot of time in digestion and the produced carbohydrates are builds up in the blood stream gradually. As low the glycemic index is, as useful it is for diabetes patient. Glycemic value range is zero to hundred. Food items having GI value less than 55 are considered as low GI food items while having GI value greater than 70 are called High GI food items.



SNACKS	G.I.	STARCH	G.I.	VEGETABLES	G.I.	FRUITS	G.I.	DAIRY	G.I.
Pizza	33	Bagel, Plain	33	Broccoli	10	Cherries	22	Yogurt, Plain	14
Chocolate Bar	49	White Rice	38	Pepper	10	Apple	38	Yogurt, Low Fat	14
Pound Cake	54	White Spaghetti	38	Lettuce	10	Orange	43	Whole Milk	30
Popcorn	55	Sweet Potato	44	Mushrooms	10	Grapes	46	Soy Milk	31
Energy Bar	58	White Bread	49	Onions	10	Kiwi	52	Skim Milk	32
Soda	72	Brown Rice	55	Green Peas	48	Banana	56	Chocolate Milk	35
Doughnut	76	Pancakes	67	Carrots	49	Pineapple	66	Yogurt, Fruit	36
Jelly Beans	80	Wheat Bread	80	Beets	64	Watermelon	72	Custard	43
Pretzels	83	Baked Potato	85	Onions	75	Dates	103	Ice Cream	60

Figure 2.4: Glycemic Index (GI) values for various food items [16]

2.2.2 A comparison of diet management techniques

A customized meal means user can change food items of his/her choice in an already planned meal. It allows user preferences about food items. A personalized meal refers to a meal that is according to user's gender, age, weight, height and physical life style etc. Daily intake calories and nutrients are estimated as per user requirement and distributed for each meal in a day. A balance meal is such a meal which takes food items from different food groups and verifies the calories and nutrients constraints as per user health profile data.

Table 2.1: Comparison of diet management techniques

Meal Planning Technique	Customized meal	Personalized meal	Balanced meal
Food pyramid	Yes	No	Yes
Food charts	No	No	Yes
Food Exchange list	Yes	No	Yes
Carbohydrate counting	Yes	Partially yes/no	No
Glycemic Index	Yes	No	No

2.2.3 Proposed technique for Diet Management

We are aiming to provide a solution that can provide alternative customized, personalized and balanced meal plan. To allow customization facilitates user in getting his/her choice preferred food items. Personalized menu let the user to estimate his calorie and nutrients need as per his/her profile data. Balance diet refers to a diet plan that covers food items from all food groups and verifies all needs and constraints of calorie and nutrients requirements.

2.2.4 Daily calorie estimates

Daily needed calories for each person is different depends upon his/her gender, age, height, weight and life style profile. There are various equations for such estimation, some of which are mentioned as follow:

2.2.4.1 Harris-Benedict Equation

Harris-Benedict principle is a method which gives mathematical equations in order to estimate a person's basal metabolic rate (BMR) and daily calorie requirements.

BMR: Basal Metabolic Rate is the amount of energy that the body needs at rest for 24 hours. Rest here means absolutely zero physical activity such as a patient on bed. The release and use of energy in this state is sufficient only for the functioning of the vital organs, nervous system, heart, lungs, liver, kidneys, , intestine, muscles, sex organs, and skin.

The estimated BMR value is multiplied by a number that corresponds to the individual's activity level. The resulting number is the recommended daily calorie intake to maintain current body weight.

Step 1 – calculating the BMR

The original Harris-Benedict equations as published in 1918 [17] and 1919 [18] are

$$BMR\ (for\ Men) = 66.4730 + (13.7516 * w) + (5.0033 * h) - (6.7550 * a) \quad (1)$$

$$BMR\ (for\ Women) = 655.0955 + (9.5634 * w) + (1.8496 * h) - (4.6756 * a) \quad (2)$$

Where 'w' is weight in kilograms, 'h' is height in centimeters and 'a' is age in years.

The Harris-Benedict equations revised by Roza and Shizgal in 1984 [19] are

$$BMR\ (Men) = 88.362 + (13.397 * w) + (4.799 * h) - (5.677 * a) \quad (3)$$

$$BMR\ (Women) = 447.593 + (9.247 * w) + (3.098 * h) - (4.330 * a) \quad (4)$$

Step 2 – Applying the Harris-Benedict Principle

The following table enables calculation of an individual's recommended daily calorie intake to maintain current weight [20]. It shows activity factor and calories needed/consumed for each physical activity level.

Table 2.2: Activity factor for different physical life style

Physical activity level	Activity Factor	Daily calories needed	Daily extra calories for exercise
Little to no exercise	1.2	BMR x 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	BMR x 1.375	(1.375 – 1.2) * BMR = 0.175 * BMR
Moderate exercise (3–5 days per week)	1.55	BMR x 1.55	(1.55 – 1.2) * BMR = 0.35 * BMR
Heavy exercise (6–7 days per week)	1.725	BMR x 1.725	(1.725 – 1.2) * BMR = 0.525 * BMR
Very heavy exercise (twice per day, extra heavy workouts)	1.9	BMR x 1.9	(1.9 * – 1.2) * BMR = 0.7 * BMR

Daily calorie need of a person can be estimated using the following formula

$$Daily\ calorie\ need = BMR * Activity\ Factor \quad (5)$$

Suppose we have following basic information about the user:

Gender = Male; Age = 33 years; Height = 5'10" inches = 178 cm = 1.78m; Weight = 99 kg;

Putting above parameter values in equation 1 estimates the BMR value for the person.

BMR = 66.4730 + (13.7516 * 99) + (5.0033 * 178) – (6.7550 * 33) = 2096

Suppose physical life style is 'Little exercise' then daily calories is estimated using equation 5 as following

Daily calories need = 2096 * 1.375 = 2882 KCal

Table 3 shows the amount of burned energy for each classification of physical life style and mathematically defined as follow. If 'e' is the amount of energy, burned per day by the person during physical exercise then column 4 of Table 3 can be used to determine a person physical life style and transformed as a function as following

$$f(lifestyle) = \begin{cases} Sedentary, & e = 0 \\ Little\ Active, & 0 < e \leq 0.175 * BMR \\ Moderate\ Active, & 0.175 * BMR < e \leq 0.35 * BMR \\ High\ Active, & 0.35 * BMR < e \leq 0.525 * BMR \\ Very\ High\ Active, & 0.525 * BMR < e \leq 0.7 * BMR \end{cases} \quad (6)$$

2.2.4.2 Miffin-St Jeor Formula

Miffin-St Jeor equation [21] can also be used to estimate BMR and subsequently daily calorie need. American Dietetic Association (ADA) has published a comparison of various equations to estimate daily calorie need and Mifflin-St Jeor was found to be the most accurate [22].

$$BMR\ (Men) = 10 * weight\ (kg) + 6.25 * height\ (cm) - 5 * age\ (y) + 5 \quad (7)$$

$$BMR\ (Women) = 10 * weight\ (kg) + 6.25 * height\ (cm) - 5 * age\ (y) - 161 \quad (8)$$

Multiply above calculated BMR with activity factor, as mentioned in Table 3, to get daily calorie need.

These are the per day calories to maintain the current weight. In case, the person is overweight and need to lose weight by reduction in intake calories, some calories must be subtracted from daily calorie need and to get burn the body fats. It is notable that there is a "rock bottom" figure that equates to 8 calories per pound of body weight – the extreme fat loss will never be less than this amount.

2.2.4.3 Katch-McAdle calculations

The Katch-McArdle formula differs from the Harris-Benedict formula in that Katch-McArdle takes lean body mass (LBM) into consideration. This calculation is therefore only possible if you know your percentage body fat. LBM is calculated by subtracting body fat weight from total body weight

Generally speaking, this is a better measure of caloric need for the obese than Harris-Benedict because it represents your actual body composition and is not based on assumptions about what one "should" weigh.

The formula is as follows:

$$BMR = 370 + (9.79759519 * \text{Lean Body Mass in pounds}) \quad \text{OR} \quad BMR = 370 + (21.6 * \text{Lean Body Mass in kg}) \tag{9}$$

$$\text{Lean body Mass} = (\text{Weight in kg})\ x\ \left(1 - \frac{body\ fat}{100}\right) \tag{10}$$

Healthy Body Fat Guidelines*:

Table 2.3: Body fat ranges

Age	Women	Men
20 – 39	21% - 32%	8% - 19%
40 – 59	23% - 33%	11% - 21%
60 – 79	24% - 35%	13% - 24%

*Adapted from: Gallagher et al., "Healthy percentage body fat ranges: an approach for developing guidelines based on body mass index." *American Journal of Clinical Nutrition*, 72 (3): 694.

LBM can also be estimated using mathematical formulas based on body weight and height [23].

$$LBM\ (Men) = (0.32810 * W) + (0.33929 * H) - 29.5336 \tag{11}$$

$$LBM\ (Women) = (0.29569 * W) + (0.41813 * H) - 43.2933 \tag{12}$$

where W is body weight in kilograms and H is body height in centimeters.

2.2.4.4 Comparison of daily calorie estimates equations

Suppose we have a user with basic health information as Gender = Male; Age = 33 years; Height = 5'10" inches = 178 cm = 1.78m; Weight = 99 kg; Then its BMR can be calculated with different formulas, as shown in Table 2.4.

Table 2.4: Sample BMR and per day calorie estimates

Formula	BMR	Daily calorie need
Harris-Benedict	= 66.4730 + (13.7516 * 99) + (5.0033 * 178) – (6.7550 * 33) = **2096**	= 2096 * 1.375 = 2882 Kcal
Miffin-St Jeor	= (10 x 99) + (6.25 x 178) – (5 *33) + 5 = **1942**	= 1942 * 1.375 = 2670 kCal
Katch-McAdle	LBM = (0.32810 * 99) + (0.33929 * 178) - 29.5336 = 63.34 kg BMR = 370 + (21.6 x 63.34) = **1738**	= 1738 * 1.375 = 2390 Kcal

2.2.5 Calorie distribution for each meal in a day

Among the top most important nutrients that must be considered for diabetic patients are carbohydrates, proteins, fats and number of calories [24].The standard recommended daily Intake nutrients measure is defined as following [25] by equation 13. This distribution is updated when value of daily needed calories changes. The reaction of each meal on blood glucose level is different for different individuals. So, it is different for each individual depends on disease situation and assumed to be defined and updated by dietician or nutritionist.

$$\begin{gathered} \textit{Daily carbohydrates percentage} = 50\%\text{-}60\% \textit{ of daily calories,} \\ \textit{Daily protein percentage} = 10\%\text{-}20\% \textit{ of daily calories and} \\ \textit{Daily fat percentage} = 25\text{-}35\% \textit{ of daily calories.} \end{gathered} \tag{13}$$

Common recommendation is 45 to 60 grams of carbohydrates for lunch/dinner and 15 to 30 grams of carbohydrates for snacks. The goal is post-meal glucose level (after 90 minutes of meal) shouldn't exceed 30-40 mg/dL.

The relation between calories and nutrients transformation, defined as follow, can be used to find out daily nutrients value in grams [25]:

$$\textit{1 Gram Carbohydrate} = \textit{1 Gram Protein} = \textit{4 Calories} \tag{14}$$

$$\textit{1 Gram Fat} = \textit{9 Calories} \tag{15}$$

Thus

$$\begin{gathered} \textit{Daily carbohydrate need (in grams)} = (50\text{-}60\ \%\ \textit{of daily calorie}) / 4 \\ \textit{Daily protein need (in grams)} = (10\text{-}20\ \%\ \textit{of daily calorie}) / 4 \\ \textit{Daily carbohydrate need (in grams)} = (25\text{-}35\ \%\ \textit{of daily calorie}) / 9 \end{gathered} \tag{16}$$

Normal or common 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)

2.3 Exercise Management for Diabetics

The top most factor of consideration for exercise suggestion is Person's intension for exercise. Whether the user willing or not for doing exercise. Many persons control their weight/BMI only by controlling or reducing the number of daily intake calories/carbohydrates in their diet. If the user's intension is positive towards exercise, plan should be made for the number of calories per days burned by the user via exercise. Such a plan making process must consider user's weight and age variables.

If person is over weighted and willing to lose weight via exercise then daily exercise should also take into account extra calories to be burned due to overweight condition.

2.3.1 Estimate burned calories during exercise/activities

The calories burned during exercise/activities can be calculated using following formula [26] [27], as defined by equation 17:

$$\text{Calories burned (CB)} = \text{duration (in minutes)} * MET * 3.5 * \text{weight in Kg} / 200 \quad (17)$$

The variables defined in above equation 17, are described as follow:

1. **Weight of the individual:** Calories burned during exercise by two different individual is different. Two individuals doing same exercise for the same period burn different number of calories, which depends upon their weight.
2. **Duration:** The amount of time (in minutes) taken in doing exercise.
3. **MET:** is metabolic equivalent, and is defined as the amount of oxygen consumed while sitting at rest and is equal to 3.5 ml O2 per kg body weight per minute [28]. 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 [29] and [30].
4. **Intensity of exercise/activity:** It is how hard the body is working during aerobic activity.
    a. Light: when the activity results in only minimal perspiration and only a slight increase in breathing above normal; activities demanding only 1-4 MET value are generally considered to be of low intensity.
    b. Moderate: when the activity results in definite perspiration and above normal breathing; Activities in the 5-8 METS range are considered to be of moderate intensity.
    c. Heavy: when the activity results in heavy perspiration and heavy breathing. Activities requiring an energy expenditure of 8 METS and above are considered to be of high intensity

Example: A person having weight of 68 kg did aerobic exercise with low intensity for 30 minutes. How much energy burned during this activity?

We can estimate burned calories using equation 17, as follow:

Calories burned = 30 * 5.04 * 3.5 *68 / 200 = 179.9 ~= 180 calories

2.3.2 Define person's life style using burned calories

Sedentary or Inactive: Following three definitions have been found from different literature for inactive life style:

1) The definition of being sedentary or physically inactive is expending less than 1.5 kcal/kg/day in leisure physical activities, according to the National Population Health Surveys of Canada.

2) This is the equivalent of walking a little over two kilometers or 1.3 miles, or approximately 3000 steps. For most people, that is a walk of 25 minutes or less.

3) Adults are classified as inactive if they did not report any sessions of leisure-time physical activity of at least 10 minutes a day.

The question arises in mind that how we can define or estimate the life style of a person on the basis of his/her physical activities. We take help from the table 3. Column 4 of the table 3 shows the number of burned calories per day for corresponding life style group. For example, if a person has BMR value equal to 1820 then calculated form of Table 3 can be represented with Table 6, as follow:

Table 2.5: Estimate for per day burned calories for different life style

Activity life style	Factor	Daily calories needed (BMR * factor)	Daily calories burned by exercise
Little or no exercise	1.2	2184 = (2184 + 0)	0
Light exercise	1.375	2502 = (2184 + 318)	318
Moderate exercise	1.55	2821 = (2184 + 637)	637
Heavy exercise	1.725	3140 = (2184 + 956)	956
Very heavy exercise	1.9	3458 = (2184 + 1274)	1274

From above table, it is evident that if the person burns on average per day up to 318 calories, it lies in the category of 'Little exercise'. Similarly, if the burn calorie per day average falls in the range of 318-637, the person is said to be doing 'Moderate exercise'.

Alternatively, if a person initially declares himself/herself as a ‘Little exercise’ physical life style, then he should have to burn up to 318 calories per day. If the person is over weighted too then

$$\begin{aligned} &planCaloriesToBurn = Daily\ Calories\ burned\ by\ exercise\ (Column\ 4\ of\ above\ table) \\ &+ Calories\ adjusted\ for\ overweight \end{aligned} \tag{18}$$

The planCaloriesToBurn variable is created at registration time when user defines his/her activity life style and will be updated monthly on the basis of reported data of activities.

Chapter 3 : LITERATURE REVIEW

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

3.1 Existing Portals and Applications

A number of online websites are available for diet management and a few of which also supports exercise management. Myfitnesspal [31] is a web portal where a user can register himself/herself for the purpose of weight lose. A user gives his/her health profile variables such as gender, age, weight, etc. and daily intake calories and nutrient (carbohydrate, protein and fat) values are estimated for him/her by considering his/her goals of maintaining/losing weight. Basically, the top most features is to maintain a record keeping diary for all taken food items and performed exercises as well as facilitates in entry procedure. To maintain exercise diary, a user selects a physical activity along with duration and system estimates the calories burned in performing the physical activity; the activity is recorded into the diary. For diet entry, a user selects, meal type, food item and portion size and it is entered into the diary with estimated calories for the taken diet.

It is just a diary keeping system where the difference of overall taken and burned calories are recorded and matched with goal calories per day. Database archival approach is used. System doesn't recommend any food, diet plan or exercise. No relationship between food item and disease is considered.

Similar to myfitnessPal, there are several other online web portals which are using the technique of calorie counting and diary keeping. A long list of such systems is surveyed by US health news [32], as shown in Table 3.1. All of 13 web portals are evaluated by a panel of experts on a scale of 1 to 5 according to different factors including diabetes patient's perspective.

The different systems, as shown in Table 3.1, evaluate the taken diet in general perspective using only calorie counting methodology while ignoring the carbohydrate counting. Carbohydrate counting is a very important factor from diabetes point of view, as carbohydrate is a main nutrient in a diet which effects blood glucose level. So, a general diet evaluation is not very effective for diabetes patients.

Table 3.1: Evaluation survey of various diet management solutions

Rank	Diet	Overall	Short-Term Weight Loss	Long-Term Weight Loss	Easy to Follow	Nutrition	Safety	For Diabetes	For Heart Health
#1	Weight Watchers Gold Medal	3.9	4.0	3.5	3.7	4.1	4.6	3.1	3.4
#2	Jenny Craig Gold Medal	3.7	3.8	3.2	3.6	4.0	4.4	3.0	3.2
#3	Biggest Loser Diet	3.6	4.1	2.9	2.9	3.8	4.1	3.6	3.5
#4	Slim-Fast	3.3	3.4	3.2	3.2	3.4	3.6	3.2	2.8
#4	Spark Solution Diet	3.3	3.6	2.9	2.3	3.6	4.0	3.1	3.1
#6	Flat Belly Diet	3.2	3.1	2.3	2.7	3.5	4.0	2.8	3.2
#6	Nutrisystem	3.2	3.2	2.3	3.1	3.7	4.0	2.7	2.4
#8	Abs Diet	3.0	3.1	2.1	2.6	3.4	3.5	2.7	2.7
#8	South Beach Diet	3.0	3.7	2.3	2.8	3.2	3.4	2.5	2.9
#10	Zone Diet	2.9	3.0	2.3	2.2	3.2	3.7	2.3	2.8
#11	Medifast	2.7	3.5	2.0	2.4	3.1	3.0	2.6	2.7
#12	Atkins	2.3	4.0	2.5	2.3	1.8	2.2	2.5	2.1
#13	Dukan Diet	2.0	3.0	2.0	1.5	1.9	2.3	2.0	1.7

3.2 Mobile based Solutions

Computerized Automated Reminder Diabetes System (CARDS) [33] is an alert generating application that sends a reminder via email or SMS to diabetes patient mobile, if blood glucose level report is not received from the patient at a particular pre-defined time. The system receives the blood glucose level reports at different times, analyzes it and generates an overall diabetes control evaluation of the patient.

Text4Health [34] developed another solution for diabetes self management. It sends customized diabetes control tips as a message to a user depending upon health profile data and eating habits. Different users can share knowledge, tips and questions with other users as well as diabetes experts.

A new idea [35] is put up in which user has given the facility of diet data entry and glucose logging in terms of capturing images. The captured images are then analyzed by the team and actual diet information in the form of food item and portion size is entered into the system by care taker team on behalf of the user. In accordance with the received data, diet or diabetes control suggestion are passed to the user.

3.3 Research Efforts

A diabetes patient needs personalized diet recommendation according to his/her preferences, calorie needs and nutrients requirements. A personalized food and exercise recommendation system can assist a diabetic in controlling blood glucose level and to prevent the complications. Following articles have made efforts in this direction.

Lee et al. [36] [37] developed IDRA which the analyzes whole day taken meals before dinner and recommends food groups along with serving size for dinner menu 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 expert, which canbe handled via some level of system automation.

Villarreal *et al*. [38] 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*. [39] 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*. [40] 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*. [41] 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*. [42] 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*. [43] 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*. [24] 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 [44] 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.

3.4 Critical Analysis

Considering the above it is evident that our effort differs from existing work done towards diet and exercise recommendations for diabetics. Some of the above related either consider only diet or exercise management but neither has considered both diet and exercise recommendations altogether. Further, our semantic web technologies based work is the first attempt of using it for diabetes recommendations. Our work is unique, also in the sense that we have produced a solution from start to final output as alternative diet menu plans.

Chapter 4 : SHADE DESIGN AND MODELING

4.1 SHADE Architecture

Semantic Healthcare Assistant for Diet and Exercise (SHADE) needs an integration mechanism or technology to combine information from various domains. Further, it also requires an automated procedure which can generate the recommendations. SHADE main architecture is shown in Fig.4.1. OWL based individual ontologies are developed and then integrated. Each individual ontology contains its own knowledge base in terms of classes, properties, instances, rules and inference data. The integrated model defines relationship between concepts of individual ontologies in its own separate ontology and individual model entities are pointed out by using references. Diet and exercise recommendations are generated as outputs. It also generates alert or reminders if blood glucose level entry is not received at a particular time. SHADE inputs are user's preferences about food items and exercise activities, data of all taken diet and performed exercises and entries for blood glucose level thrice a day. The output recommendations are analyzed and evaluated by nutritionist or dieticians.

The top most rationale for using OWL based ontology is to enable reasoning capability over schema and data by applying domain based rules. 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.

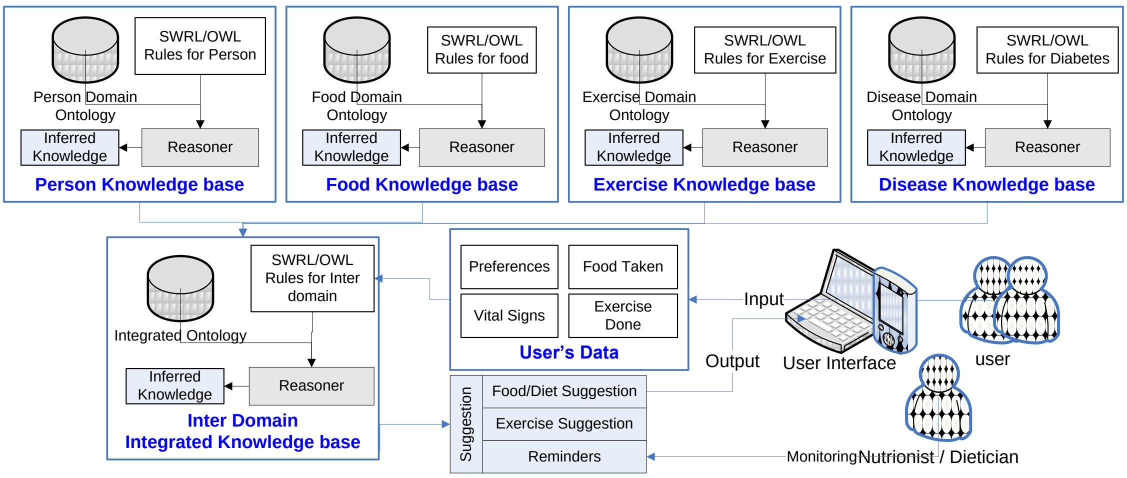


Figure 4.1: SHADE architecture

4.2 SHADE Modeling

Diet and exercise management in the life of a diabetic is a cumbersome job. It involves information and knowledge from various domains. For example, first of all it needs to estimate the number of daily intake calories which depends on health profile variables like gender, age, weight, height and life style etc. This requires to include and to study detail knowledge from personal health profile domain. BMI estimation and on the basis of its value, several situation are arises and needs to be handled.

Diet suggestion refers to a list of food items along with portion size. Each food item has different calories, carbohydrates, proteins, fats and other macro nutrients. Further, this information varies according to cooking method, portion size, meal time and other numerous factors. Moreover, each person has different calories and nutrients necessity, so, customized meal plans need to be generated for each person, taking into consideration the food science. Thus, diet suggestion without being involving detail study of food domain is impossible.

Diseases are diagnosed with the help of observing vital signs of laboratory tests. This requires domain knowledge and relationships between vital signs and disease. The disease domain knowledge includes normal and critical value ranges for various lab tests and depends on the value of lab test, infers or confirms the status or level of disease. Disease status is also main factor in deciding meal menu. Some food items have positive while some has negative effects on current disease level. For example, low glycemic index value food items helps in maintaining blood glucose level while high glycemic index value food item may further increase the blood glucose level of the patient. So, there is an association between disease knowledge base and food domain.

For controlling overweight and maintain blood glucose level, regular exercise is one of important key factor. Exercise management requires knowledge from physical exercise domain. This includes types of various physical activities along with their effects and relationships on diseases. Further, it involves how much calories need to be burned, which physical activity burns how much calories. How activity duration and person’s weight effect the number of burned calories, how age factor is relevant with physical activity etc. So, physical activity is key important knowledge base or domain knowledge which never can be ignored or skipped.

From above discussion, it reveals that 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 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.

We are using here World Wide Web consortium motivated semantic web based technologies. Web Ontology Language (OWL) is a semantic web supported language for defining ontologies. In OWL based ontology, a class represents the objects of similar properties. A class can be defined using explicitly description logic based class definition or in terms of SWRL rule. In order to define relationship between classes or concepts, there are two types of properties. An object type property defines relationship between two entities or classes while data type properties are used to define primitive properties of entities. The legend for the figures in this chapter is classes or entities are represented with sky blue color while objects or class instances are showed as pink color. Azure color ovals shows object type properties while data type properties are represented as green ovals. Data type properties are further classified as system input and system calculated data type properties. The data type properties which values are estimated by the system are represented by yellow ovals.

4.2.1 The Domain Ontologies

4.2.1.1 Personal Profile Domain Ontologies

Person domain ontology is shown in Fig. 4.2. It has been 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. The class description of these variables and their classifications is shown in following table. The SWRL based rules for these classes has described in next chapter.

Table 4.1: Class descriptions of personal health profile variables

Variables	Classification	Description
Age (In years)	Very_Young	All Persons having age value in the range between 14 and 18
	Young	All Persons having age value in the range between 18 and 30
	Old	All Persons having age value in the range between 30 and 50

	Very_Old	All Persons having age value greater than 50
Weight	Underweight	All Persons having BMI value less than or equal to 18.5
	NormalWeight	All Persons having BMI value in the range between 18.5 and 25
	OverWeight	All Persons having BMI value greater than or equal to 25
Life Style	Sedentary	No exercise (calorie burned per day) reported except little routine work
	Little_Active	In addition to little routine work, 0.175 * BMR calories burned per day
	Moderate_Active	In addition to little routine work, 0.35 * BMR calories burned per day
	High_Active	In addition to little routine work, 0.525 * BMR calories burned per day
	Very_High_Active	In addition to little routine work, 0.7 * BMR calories burned per day
Gender	Male	All persons whose gender data type property value equals to 'Male'
	Female	All persons whose gender data type property value equals to 'Female'

Person is classified in terms of weight as underweight, normal weight and overweight, depends upon the value of Body Mass Index (BMI). BMI [45] is the ratio of person's mass and square of height in meters, mathematically expressed as follow:

$$\textit{Body Mass Index (BMI)} = \frac{mass\ (in\ Kg)}{(height\ (in\ meter))^2} \tag{19}$$

If BMI value is less than 18.5, the person is classified as underweight. If BMI value lies in the range of 18.5 and 25, he/she is considered as normal weight while BMI value above 25 evaluate the person as overweight.

$$f(weight) = \begin{cases} Underweight, & BMI \leq 18.5 \\ Normal\ weight, & 18.5 < BMI < 25 \\ Overweight\ , & BMI \geq 25 \end{cases} \tag{20}$$

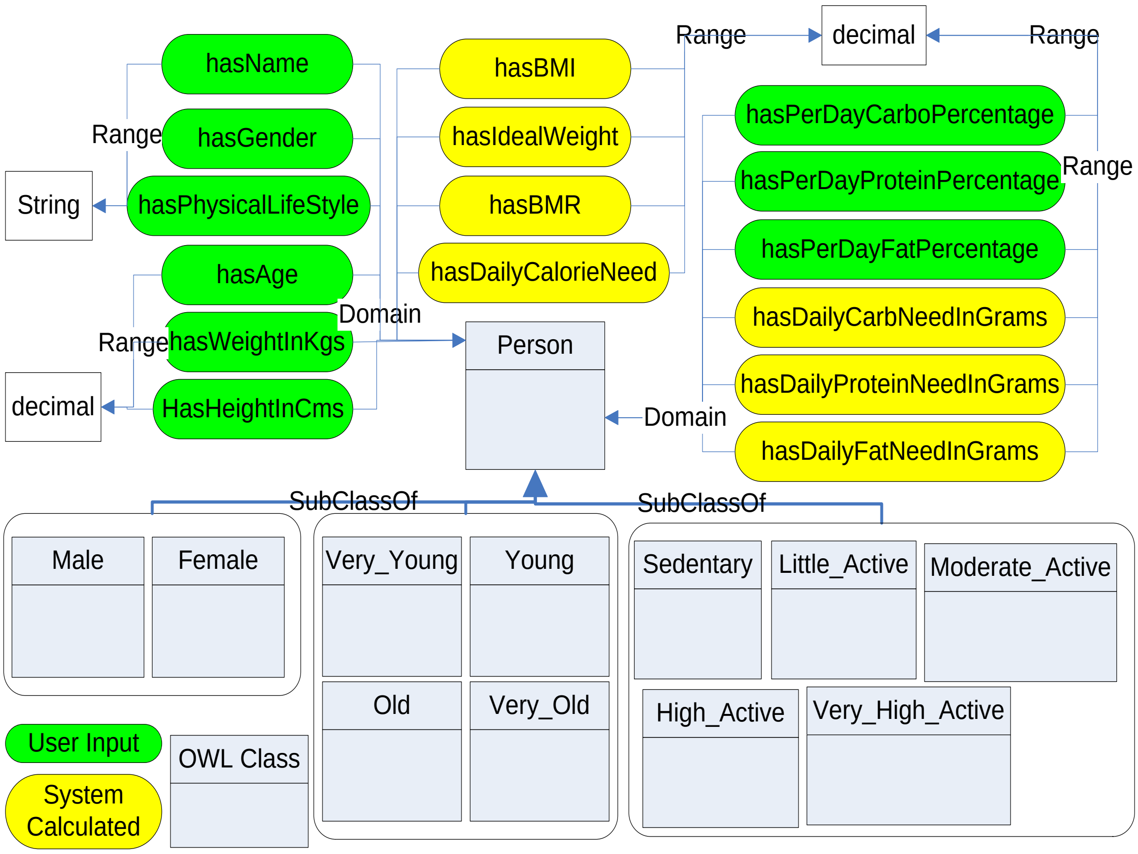


Figure 4.2: Personal health profile ontology model

In order to estimate person's BMR, we use Harris-Benedict equations, as defined in chapter 2 by equation 1 (for male) and equation 2 (for female), with slight modification. The limitation of Harris-Benedict equation is that it considers the whole body weight as lean body mass and ignores the fat percentage of the body. It estimates the energy requirement for the body to maintain current weight as well as fats. If body is underweight, the actual energy requirements is some more so that to gain the weight. In other case, if person is overweight, there is a need to reduce the intake calories per day. So, we use modified form of Harris Benedict formula in the sense to use ideal weight instead of actual weight in case of person's underweight or overweight situation. The ideal weight is calculated using Body Mass Index (BMI) formula. We use only three categories of BMI: Underweight, Normal and Overweight. If a patient is underweight, we assume BMI value 18.5 and calculate ideal weight. If a patient is overweight, we consider 25 as BMI value to estimate ideal weight. In case of a patient BMI value is normal, the actual weight is used. Mathematical equation to define ideal weight is defined by equation 21 as follow:

$$f(IdealWeight) = \begin{cases} 18.5 * \ (height\ (in\ meter))^2, & BMI \leq 18.5\ (Underweight) \\ BMI * \ (height\ (in\ meter))^2, 18.5 < & BMI < 25\ \ (Normal\ weight) \\ 25 * \ (height\ (in\ meter))^2\ , & BMI \geq 25\ (Overweight) \end{cases} \quad (21)$$

So, BMR is calculated by replacing actual weight in equation 1 and 2 with ideal weight of the person as calculated using equation 21.

Daily calorie need of a person is estimated using equation 5. Default values for per day nutrient (carbohydrate, protein, fat) percentage is considered using equation 13, if not defined by nutritionist. Nutrient values in grams for each meal are calculated with the help of equation 16.

Person is categorized into one of life style category on the basis of amount of energy he/she burned per day during the exercise. If person does, more exercise then more energy is burned and achieve higher level of physical life style category. Burned calories per day infer person's physical life style or physical activity level which determines Activity factor. Using table 3, get the respective activity factor coefficient and then multiply with BMR to estimate daily intake needed calorie for the person. At the time of a person registration into the system, he/she is initially asked to input his/her life style status. Later on, for the purpose of evaluating person's life style we use BMR to estimate physical life style using the function defined by equation 6. Person is categorized into one of life style category on the basis of amount of energy he/she has burned per day during the exercise using equation 6.

4.2.1.2 Food Domain Ontologies

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. Food domain ontology model, as shown in Fig. 4.3, describes various relationships among food items, food groups, nutrients and their subclasses. Meal is a super class of Breakfast, Lunch and Dinner and defined as a collection of food items along with their portion size. Number of calories, nutrients values of a meal and status of balanced / Non-balanced can calculated using SWRL rules. On the basis of reasoning and rules, it can be inferred which nutrients are found in which food items. 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 [46] and myfitnesspal [31]. Although [31] nutrient database is not public and may provide the nutrients database information on request, we have collected nutrients of some food items using single food item based retrieval.

Nutrient and calorie clustering such as LowCarbFoodItem, HighFatFoodItem and LowProteinFoodItem are formed according to constraints of nutrients values by defining SWRL rules which enables reasoner automatically classify a food item into a particular cluster. For example, following function defines the clustering of food items on the basis of amount of calories per serving. If n is number of calories in per serving of a food item then

$$f(foodItem) = \begin{cases} LowCalorieFoodItem, & n \leq 50 \\ MediumCalorieFoodItem, & 50 < \ n < 120 \\ HighCalorieFoodItem\,, & n \geq 120 \end{cases} \qquad (22)$$

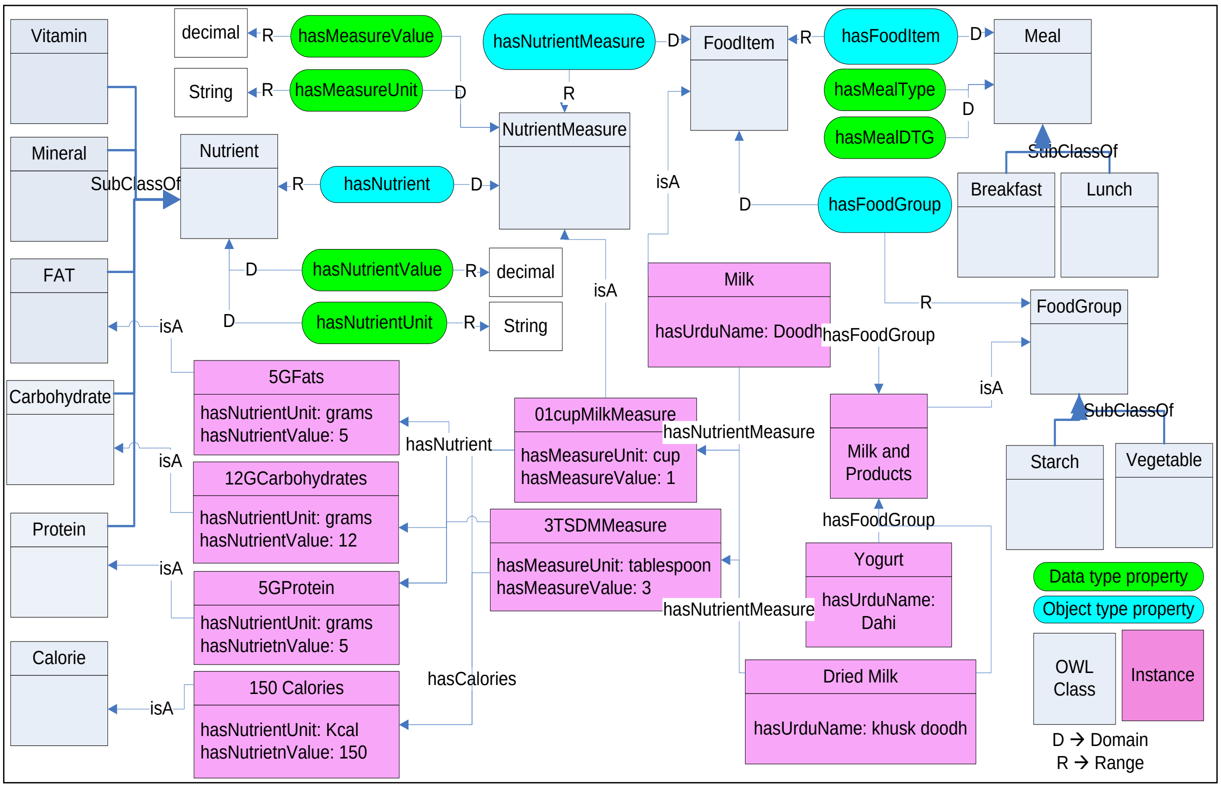


Figure 4.3: Food domain ontology model

A sample list of food items are selected for generating breakfast menu plan and their nutrient values are extracted from USDA [46] database, as shown as in Table 8.

Table 4.2: Breakfast food items with calories and nutrient values

S. No	Food Item	Calories	Carb	Protein	Fat
1	Chapati (100 gram)	170	33	6	2
2	Paratha	230	37	2	8
3	Paratha stuffed with potato	265	41	5	9
4	Naan (100 gram)	311	43	9	11
5	Poore		30		
6	Brown bread (2 slices)	148	27	5	3
7	Brown Rusk (2 Number)	82	15	3	1.5
8	Bun	110	18	5	2
9	Corn flakes (1 cup)	101	25	2	0
10	Apple (1 medium, 3 per lb)	72	19	11	1

11	Apricot (100 grams)	48	11	2	0
12	Guava	68	14	3	1
13	Pear (1 medium, 2.5 per lb)	96	26	1	0
14	Cooked pulses (1 oz, 28 gram)	46	8	2	0
15	Cooked meat	250	5	24	15
16	Cooked green vegetable (1/2 cup)	73	11	3	2
17	Curry (Peas and potato) (233 gram)	245	33	5	11
18	Hareesa 100 gram (Curry made from porridge and meat)	52	3	3	3
19	Curry (Peas) (3/4 cup)	191	33	11	6
20	Yogurt (100 gram)	63	7	6	2
21	Yogurt / Raita (25 gram)	16	2	2	0
22	Lassi (1 glass 200 ml)	150	20	11	4
23	Milk (1 cup)	146	11	8	8
24	Doodh patti (1 cup)	178	19	8	8
25	Tea (1/3 milk, 2/3 water sugar free)	30	5	1	1
26	Cream (1 tbsp)	15	2	0	1
27	Butter (1 tbsp)	102	0	0	9
28	Jam/Jelly Sugar free (1 tbsp)	55	14	0	0
29	Chicken Spread (1/4 cup, 56 grams)	88	10	2	10
30	Halva (1 small bowl)	360	33	5	23
31	Pickle (100 gram)	18	5	0	0

Following are some sample rules for making meal planning

- Total number of calories for breakfast shouldn't exceed from the value of allowCaloriesForBreakFast
- Total number of carbohydrates for breakfast shouldn't exceed from allowCarbForBreakFast value
- Total number of fats for breakfast shouldn't exceed from allowFatsForBreakFast value
- If there is cooked food item in the menu, there must be chappati or Naan or rice in the menu
- There should be maximum one cooked food Item in breakfast menu

4.2.1.3 Disease Domain Ontologies

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 we have multiple definitions for declaring a person as diabetic, one of the definition is “a diabetes patient is defined as a person who has some vital sign and that vital sign type is blood sugar random (BSR) and value of that BSR is greater than 180”.

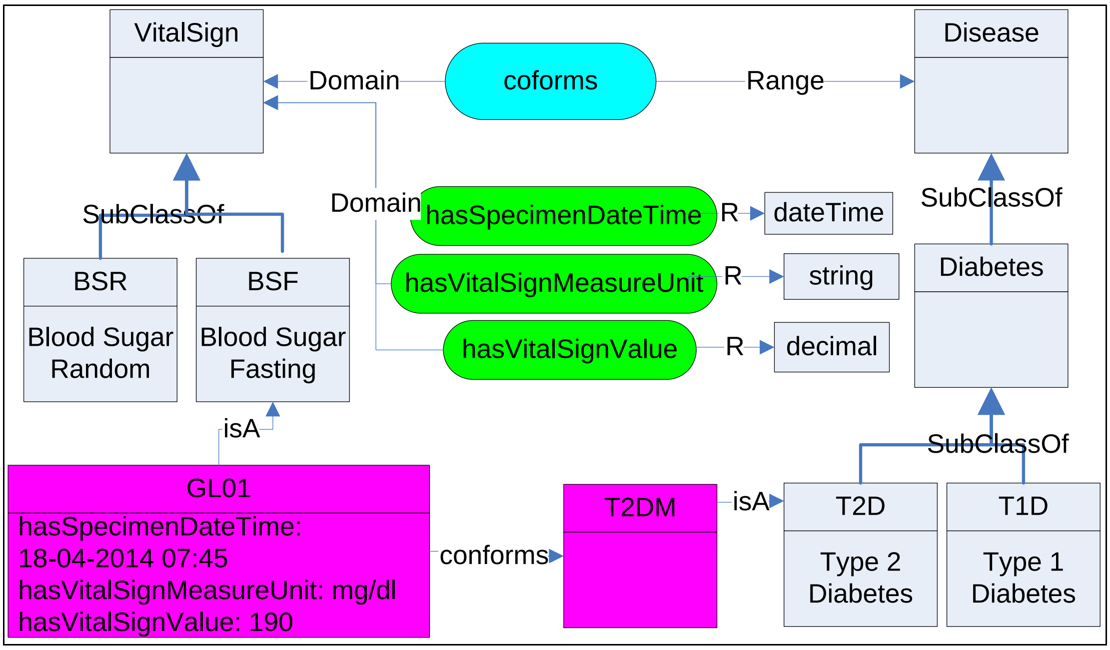


Figure 4.4: Disease domain ontology model

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. 4.4.

4.2.1.4 Exercise Domain Ontologies

Exercise domain ontology is modeled to describe various physical activities with their possible intensities and metabolic equivalent (MET) values. It describes the hierarchical classification of various physical activities. 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. 4.5. There is a specific MET value for each combination of Physical activity and intensity. Classification of activities on the basis of intensity is expressed as Low Intensity, Moderate Intensity and heavy Intensity activities, which can be transformed in the form of a function as equation 23.

$$f(ActivityIntensity) = \begin{cases} Low\ Intensity, & 1 < \ MET\ value\ \leq 4 \\ Moderate\ Intensity, & 4 < \ MET\ value\ \leq 8 \\ High\ Intensity, & 8 < \ MET\ value \end{cases} \qquad (23)$$

For example, Walk with 3 miles per hour has MET value 3.2 and it is inferred as low intensity activity whereas walk with 8 miles per hour has MET value 10.5 and is considered as high intensity activity. The purpose of intensity level classification is to use it in rules. For example, old age person should be recommended only activities which are of low intensity.

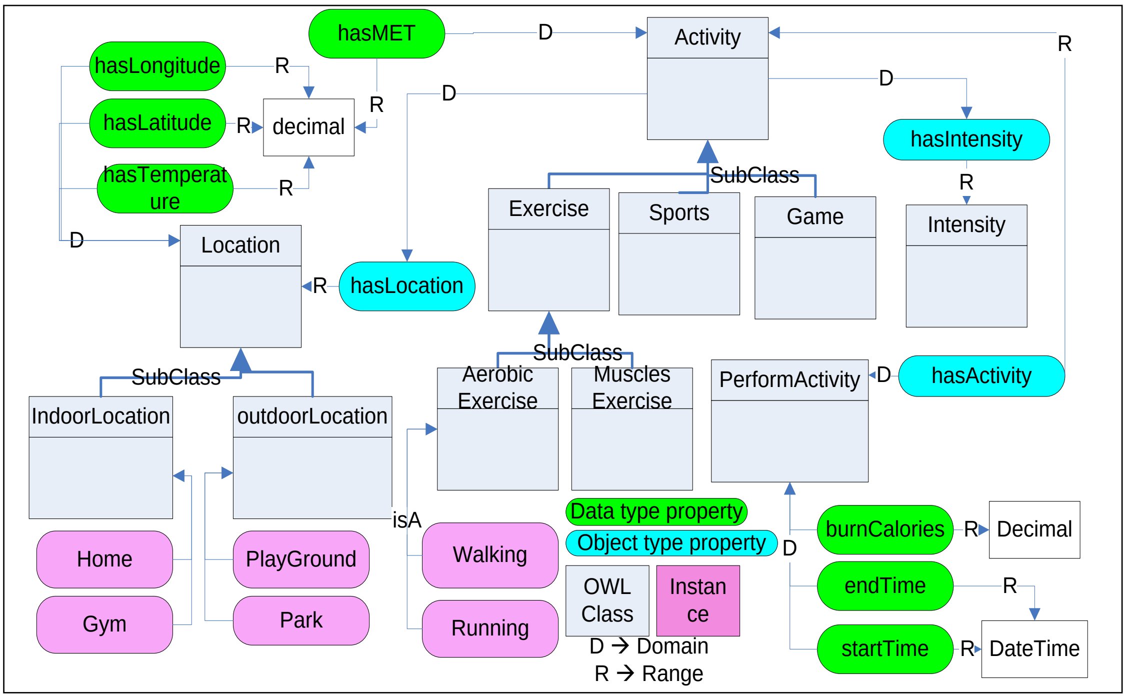


Figure 4.5: Exercise domain ontology model

4.2.2 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. 4.6.

Personal health profile has association with food ontology, exercise ontology and disease ontology because person has some preferred / liked food items and exercises as well as person has some vital signs and disease status. Food ontology has relationships with disease ontology as some food items are forbidden while some other are recommended for a particular disease. Exercise ontology is related with disease ontology as some exercise may be forbidden while others are good for controlling disease situation. The integrated ontology has the properties and rules among concepts from different domain ontologies. The diet and exercise recommendations are actually inferences on the basis of rules and combination of knowledge of different domains.

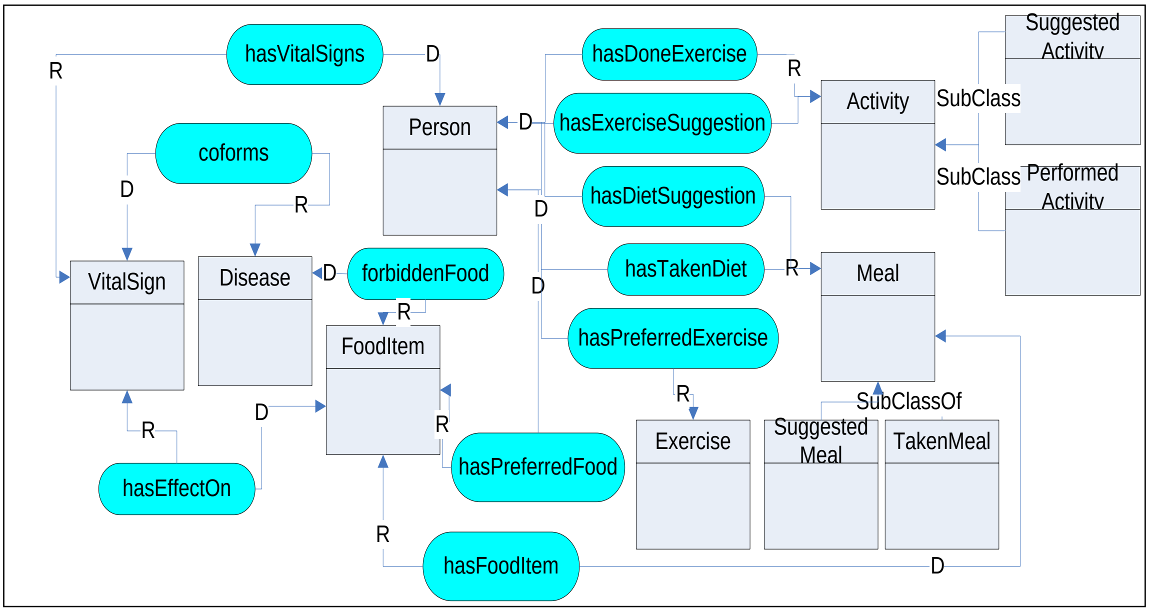


Figure 4.6: Integrated ontology model

4.3 SHADE Recommendations

SHADE recommends diet and exercise suggestion to a 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. Otherwise the user may ask the system to generate diet or exercise recommendations at any time. A nutritionist or dietician can monitors the recommendations so that rules can be improved or redefined in case of abnormal suggestion is generated.

4.3.1 SHADE Diet Recommendations

Diabetes is a complex disease and managing diet is a difficult task. Diabetes patients have to keep record of taken diet, medicine and blood glucose reading so that to consult with endocrinologist in a better way. While talking about diet, it is a complete science of calories, nutrients, food groups, healthy eating tips and balanced diet etc. Today in the era of modern technology and ubiquitous computing, small gadgets are being facilitating the user in daily routine tasks. Our focus is in using modern gadgets and tools to assist diabetics in managing diet, exercise, record archival without being involved him/her complexities of technical domain knowledge. Our solution recommends diet in a systematic way. 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. 4.7. 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. 4.8. Details of these tasks are as follow:

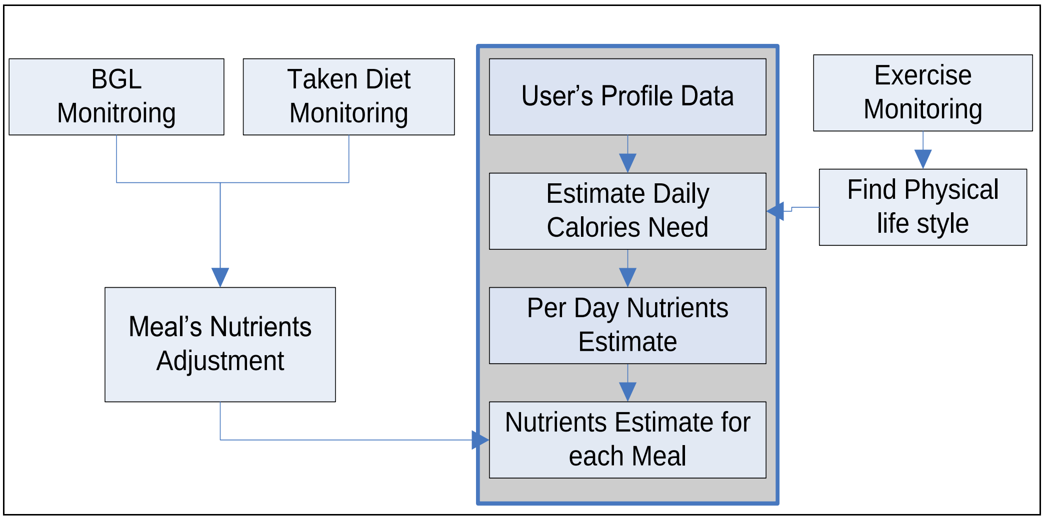


Figure 4.7: Long term activities for profile update

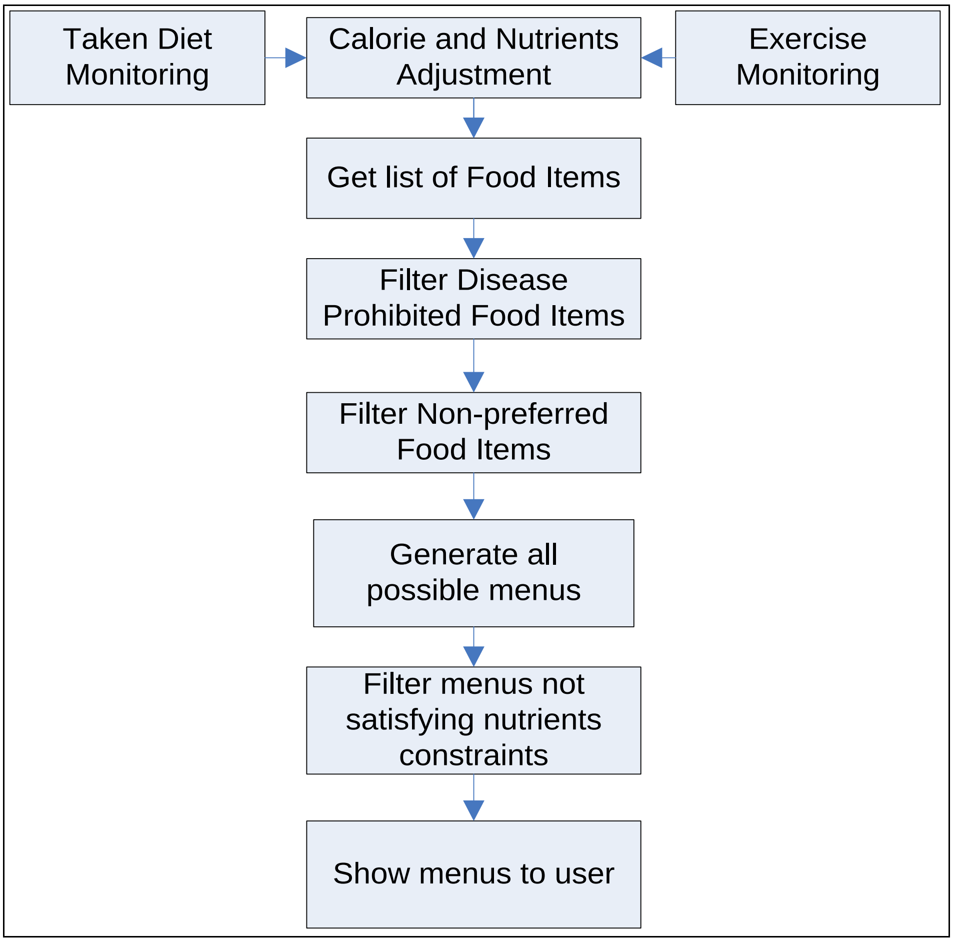


Figure 4.8: Diet suggestion steps/activities

Estimate Daily Calories Need: Harris-Benedict equation [17] [18], as defined by equation 1 and 2, are used with slight modification to estimate basal metabolic rate (BMR) and then multiply it with activity factor (AF) to estimate daily calorie need with the help of equation 5. The modification in BMR calculation is to use ideal weight (equation 21) instead of actual weight.

Per Day Nutrients Estimate: Among the top most important nutrients that must be considered for diabetic patients are carbohydrates, proteins and fats [24].The standard recommended daily Intake nutrients measure values as defined in equation 13 are considered as default values. 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 defined and updated 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, so it is initially defined and later updated by nutritionist or dietician. Based on taken 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. The purpose is to control post meal BGL by analyzing served food menu and BGL.

Calories 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 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 all available food items is retrieved and then filtered for disease prohibited food items. In case of person is suffering from diabetes, food items having high glycemic index are excluded. Then user’s non-preferred food items are removed. The remaining food items are allowable, preferred and recommended food items. Finally, list of possible menus generated such that satisfying the calorie values, nutrients constraints and fulfill the requirements of balanced diet. 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.

4.3.2 SHADE Exercise Recommendations

Exercise recommendations needs to consider person's willingness for exercise, age, weight, extra taken calories, preferences and disease profile. Our algorithm calculates the number of calories needed to be burn for current exercise suggestion. For this purpose, following factors need to be considered:

1. **Plan calories to burn:** The value of this variable is estimated at registration time and updated monthly. We use it into the algorithm as it defines Person's willingness for exercise, weight and activity life style etc. On the basis of physical activity life style, total number of daily calories to be burned is estimated, as shown in Table 3. Further, if a user is over weighted and wants to lose weight via exercise, we further add a number of calories to be burned in order to reduce weight.

2. **Age of the Person**: Exercise suggestion should be according to person's age that he/she can do the suggested exercise. For example, an old age person should not be suggested for heavy or vigorous exercise.

3. **Person taken calories on that day**: If a person has taken extra calories, he/she can control blood glucose level (BGL) by doing more exercise activities on that day.

4. **Person's already burned calories on that day:** If person has performed some activities due to which extra calories has already burned, these need to be adjusted for later exercise on same day. By default a person is sedentary. If he/she has reported any leisure-time physical activity then we estimate the energy burned during that physical activity using calories burned equation, as defined in upcoming text. Such reported leisure-time activity and energy is caloriesAlreadyBurn.

5. **Glucose level**: Patient glucose at start of physical exercise should be noted and used. If glucose level is high, more calories need to be burn.

Calculate the number of burned calories during a physical activity

The calories burned during an exercise/activity can be calculated using equation 17.It shows burned calories depends on weight of the person and duration of physical activity. Two persons having different weights consume different number of calories by doing same physical activity. The person who has more weight, consume more energy during a physical activity.

Exercise recommendations mechanism also follows two steps. The first step estimates the needed calories to be burned and second step recommends various alternative user's preferred activities with duration and intensity that burn the required number of calories.

Step 1: Calculate the number of calories to be burned:

This algorithm is triggered when user's exercise time occurs or a user requests for getting exercise suggestion. Our simple algorithm or formula to find the number of calories to be burned is as follow:-

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

Example: Let's suppose a user has to burn 1000 calories per day, then plannedCaloriesForExercise = 1000;

Scenario 01: Today morning the user has already burned 200 calories and taken no extra calories then exercise suggestion at evening time is estimated as

1000 (planned) + 0 (extra calories) – 200 (alreadyBurnCalories) = 800

Scenario 2: Today morning the user has taken 150 extra calories in breakfast then estimated calories for exercise is

1000 (planned) + 150 (extraCaloriesTaken) – 0 (alreadyBurnCalories) = 1150

Step 2: Suggest preferred exercises

While recommending exercise, first of all user's preferred and disease allowed activities are filtered. Then, using above equation, duration of all filtered exercises are calculated. The equation is used in reverse format such that knowing the exercise/activity, adjust the time/intensity so that the result is equal to the number of calories estimated in step 1.

Chapter 5 : SHADE 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.

The purpose and use of OWL language is to

- formalize a domain by defining classes and properties of those classes,
- define individuals and assert properties about them, and
- Reason about these classes and individuals to the degree permitted by the formal semantics of the OWL language.

OWL has some inherent and general advantages of ontologies such as knowledge sharing, easy integration etc. Besides that following are main points of our focus:

- As per our knowledge, no work has been done in healthcare systems using OWL based ontologies. Our claim is OWL based ontologies can be used in developing health care systems. We will prove it by giving an application of diet recommendation system for diabetes patients.
- We want to generate new knowledge through automated reasoning. There are automated reasoners available such as Pellet [6], FaCT [7], FaCT++ [8] and HermiT [9] which work on OWL based ontologies and apply rules, defined in SWRL, on instances to infer new knowledge.

On the basis of expressiveness, OWL can be categorized into following three sub-languages:

1) OWL Lite:
    a. The least expressive
    b. Used only when simple class hierarchy and simple constraints are needed.
2) OWL DL

   a. More expressive than OWL Lite
   b. Based on description logic
   c. Super-class and sub-class relationships (subsumption relationships) are automatically computed by the reasoner
   d. Can be check/verified for ontology inconsistencies.
3) OWL FULL
   a. Most expressive OWL sub-language
   b. Not possible to perform automated reasoning.

The choice between OWL-Full and OWL-DL may be based upon choosing whether expressiveness or automated reasoning is preferred. If it is important to carry out automated reasoning OWL-DL is the choice whereas if highly expressiveness and powerful modeling facilities are desired then OWL-Full is the right option. As our aim is to have automated reasoning, we are using OWL-DL with as much expressivity as OWL-DL allows.

There are a number of OWL based reasoners like Fact [7], FaCT++ [8], Pellet [6] and HermiT [9] etc. In order to get comparison and differences among them we need to go to each reasoners website and collect the facts/characteristics from there. The problem is such information/characteristics are the part of internal implementation of the reasoner and it is not mentioned on the web portal for end user. A comparison is studied from the research paper “Comparison of Reasoners for large Ontologies in the OWL 2 EL Profile”. Although this paper has published in 2011 but it is also outdated. From the paper it is evident that there is no significant different among reasoners in terms of completeness and decidability. A comparison of various reasoners given by [47] is shown in Table 5.1.

We are going to choose a reasoner that is Protégé as well as Jena compatible and open source. With up-to-date knowledge Pellet, FaCT, FaCT++, Hermit etc. are protégé compatible i. e. they can be integrated or plug-in with protégé. The only reasoner that comes with its own Java based API and can function with Jena API is, Pellet. From implementation point of view, we need a reasoner that can infer new knowledge programmatically or dynamically on runtime. So, we are going to choose Pellet.

5.1 Implementation of Domain Ontologies

We have initially modeled the system as defined in the previous chapter. Then each model is transformed into OWL based ontology using Protégé 4.1. Protégé enables to save each individual domain model along with rules into a separate .owl file. The integrated model is independently saved in separate .owl file which imports individual ontologies, having references of individual ontologies and defines rules and relationships among concepts of individual domain ontologies. We have transformed personal profile, food, disease and exercise ontologies into OWL based ontologies. We will discuss the modeling implementations of domain ontologies one by one in this section

Table 5.1: Comparison of various reasoners

		Pellet	RACER	FACT++	Snorocket	SWRL-IQ	HermiT	CEL	TrOWL	ELK
Methodology		Tableau based	Tableaux based	tableau based	Completion rules	SWRL rules	Hypertableau based	Completion rules	Completion rules	Consequence based
Soundness		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Completeness		Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes
Expressivity		SROIQ(D	SHIQ	SROIQ(D	EL+	-	SROIQ(D)	EL+	SROIQ	EL
Native Profile		DL, EL	DL	DL	EL	-	DL	EL	DL, EL	EL
Incremental Classification	**Additio**	Yes	No	No	Yes	Y/N	No	Yes	No	Yes
	Remova	Yes	No	No	No	Y/N	No	No	No	Yes
Rule Support		Yes (SWRL)	Yes (SWRL)	No	No	Yes (SWRL)	Yes (SWRL)	No	No	Yes (Own rule format)
Platforms		all	all	all	all	all	all	Linux	all	all
Justifications		Yes	Yes	No	No	Yes	No	Yes	No	No
ABOX Reasoning		Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	No
OWL API		Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes
OWL Link API		Yes	Yes	Yes	No	No	Yes	Yes	No	Y/N
Protégé Support		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
NeOn Support		Yes	No	No	No	No	Yes	No	No	No
License		DULI: AGPL	own	GLGPL	own	Y/N	GLGPL	Apache License 2.0	DULI: AGPL	Apache License 2.0
Jena Support		Yes	No	No	No	No	No	No	Yes	Y/N
Impl. Language		Java	LISP	C++	Java	Prolog	Java	LISP	Java	Java
Availability		Open source	Commercial	Open Source	Commercial	Y/N	Open source	Open source	Commercial	Open source

5.1.1 Personal health profile domain ontology

Person domain ontology is implemented in the form of OWL based ontology using protégé 4.1. Classes are defined in description logic based semantic class definition and properties are defined. All properties in this ontology are data type properties, some of which values are defined by the user while other are calculated using SWRL rules. Fig. 5.1 shows protégé implementation of personal profile domain ontology.

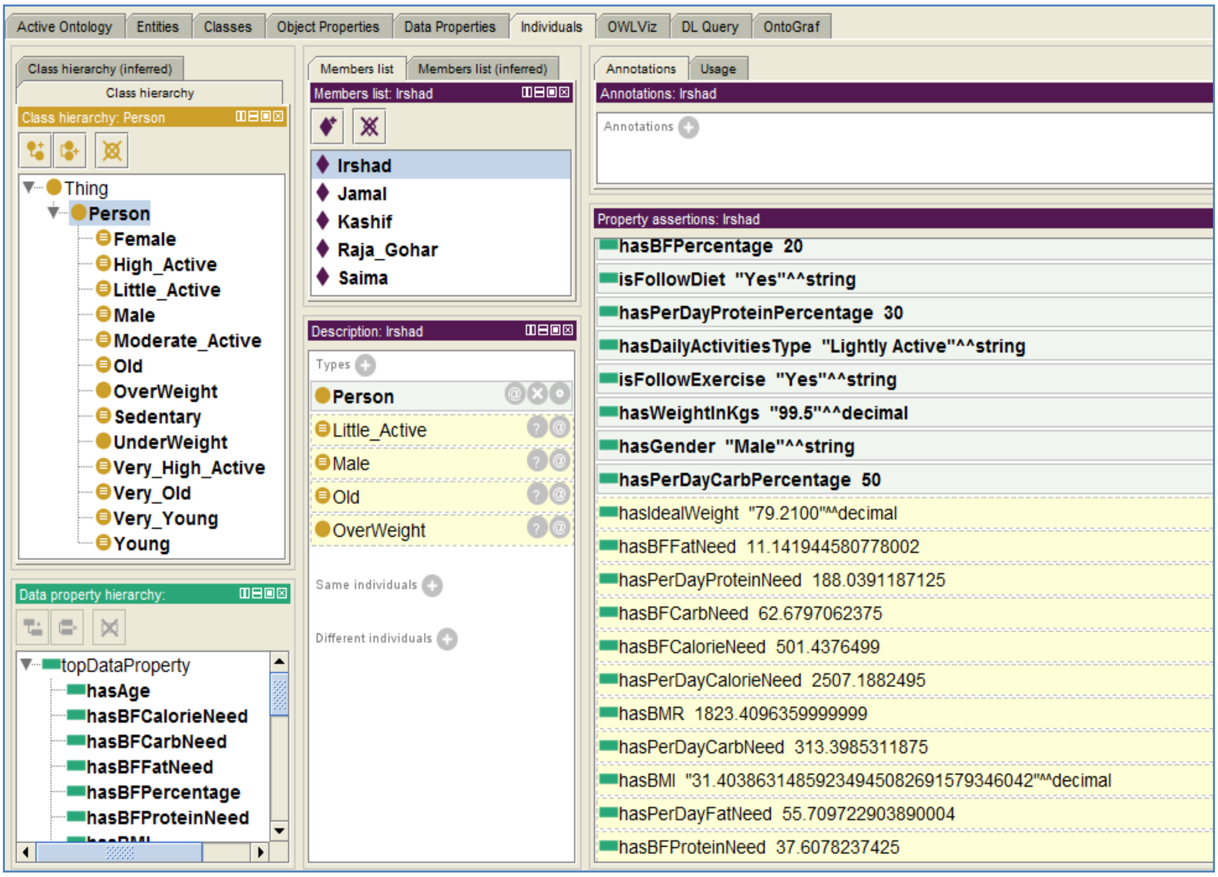


Figure 5.1: Protégé implementation of personal health profile model

Table 5.2 shows class definition of some classes in person profile ontology

Table 5.2: Semantic class definitions and descriptions

Class	Definition	Meaning
Female	Person and (hasGender value "Female")	All those persons whose hasGender data type property value equals to 'Female'
Young	Person and (hasAge some decimal[> 18 , <= 30])	All those Persons having age value in the range between 18 and 30, are Young
Very_Old	Person and (hasAge some decimal[> 50])	All those Persons having age value above 50, are Very_Old
Sedentary	Person and (hasDailyActivitiesType value "Sedentary")	All those persons whose hasDailyActivitiesType data type property value equals to 'Sedentary'
Little_Active	Person and (hasDailyActivitiesType value "Lightly Active")	All those persons whose hasDailyActivitiesType data type property value equals to 'Little Active'

Two classes are said to be disjoint if they are mutually exclusive, means that an instance is belong to exactly from one of the class. There must be no such instance which can belong to more than one disjoint class. 'Male' and 'Female' are disjoint classes. We can make classes Very_Young, Young, Old and Very_Old are disjoint but problem is that a person may be currently Young and after some time get Old. So, the person belongs to Young and Old classes during different time periods. To overcome this problem, we declare hasAge property as Functional Property. A functional property means we can define, as an axiom, maximum one value for that property. So, we have defined hasAge and hasDailyActivitiesType properties as functional which restricts to define only one value for that property which is current value. Thus, following are the set of classes which are disjoint or mutually exclusive. In case, an instance is belong to more than one disjoint class or define more than one value for functional property, the ontology becomes inconsistent and we can't make reasoning over the ontology until all inconsistencies are eliminated.

- Male and Female are disjoint classes
- Very_Young, Young, Old and Very_Old are disjoint classes
- Sedentary, Little_Active, Moderate_Active, High_Active and Very_High_Active are disjoint classes
- UnderWeigtht, NormalWeight and OverWeight are disjoint classes.

As discussed in previous chapter, Little_Active person is defined as a person who in addition to little daily routine work burns 0.175 * BMR calories per day. Actually, these two definitions don't conflicts with each other. Using SWRL rule, we set value of hasDailyActivitiesType property to 'Little_Active' for all those persons who burns 0.175*BMR calories per day.

The problem in using protégé for OWL based ontology modeling is having no support for doing basic arithmetic calculation and condition checking on the value of a data type property. In order to overcome this problem, the only way is to use SWRL rules and utilize SWRL built-in functions for basic arithmetic calculations and other mathematical support.

Table 5.2 show classes defined using description logic based class definition. We can also define class definition using SWRL rule. As an example, SWRL rules for categorizing a person in terms of weight, as defined by equation 20, can be expressed an follow:

Person(?p), hasBMI(?p, ?bmi), lessThanOrEqual(?bmi, 18.5) -> UnderWeight(?p)
Person(?p), hasBMI(?p, ?bmi), greaterThan(?bmi, 18.5), lessThan(?bmi, 25) -> NormalWeight(?p)
Person(?p), hasBMI(?p, ?bmi), greaterThanOrEqual(?bmi, 25) -> OverWeight(?p)

Last row of above table is explained as if ‘p’ is a person and ‘p’ has BMI value equals to ‘bmi’ and if ‘bmi’ is greater than or equal to 25 the person ‘p’ is said to be OverWeight.

We use SWRL rule where we need mathematical calculation to estimate the property value. For example, BMI estimation as demonstrated via equation 19, can be transformed in terms of SWRL rule as follow:

Person(?p), hasHeightInCms(?p, ?h), hasWeightInKgs(?p, ?w), divide(?hm, ?h, 100), multiply(?hms, ?hm, ?hm), divide(?bmi, ?w, ?hms) -> hasBMI(?p, ?bmi)

Above rule is explained as ‘p’ is a person; h= height in centimeters; w = weight in kgs; hm= height in meters = h/100; hms=square of hm = hm * hm; bmi = w / hms = w / (hm * hm)

Following are the SWRL rule for calculation of respective property values

$$f(Idealweight) = \begin{cases} 18.5 * \ (height\ (in\ meter))^2, & BMI \leq 18.5\ (Underweight) \\ BMI * \ (height\ (in\ meter))^2, 8.5 < & BMI < 25\ \ (Normal\ weight) \\ 25 * \ (height\ (in\ meter))^2\ , & BMI \geq 25\ (Overweight) \end{cases}$$

Person(?p), hasBMI(?p, ?bmi), lessThanOrEqual(?bmi, 18.5), hasHeightInCms(?p, ?hcm), divide(?hm, ?hcm, 100), multiply(?iw, 18.5, ?hm, ?hm) -> hasIdealWeight(?p, ?iw)
Person(?p), hasBMI(?p, ?bmi), greaterThan(?bmi, 18.5), lessThan(?bmi, 25), hasWeightInKgs(?p, ?w) -> hasIdealWeight(?p, ?w)
Person(?p), hasBMI(?p, ?bmi), greaterThanOrEqual(?bmi, 25), hasHeightInCms(?p, ?hcm), divide(?hm, ?hcm, 100), multiply(?iw, 25, ?hm, ?hm) -> hasIdealWeight(?p, ?iw)

BMR (for Men) = 66.4730 + (13.7516 x w) + (5.0033 x h) – (6.7550 x a)

BMR (for Women) = 655.0955 + (9.5634 x w) + (1.8496 x h) – (4.6756 x a)

Where ‘w’ is weight in kilograms, ‘h’ is height in centimeters and ‘a’ is age in years

Male(?m), hasAge(?m, ?a), hasHeightInCms(?m, ?h), hasIdealWeight(?m, ?w), multiply(?wf, ?w, 13.7516), multiply(?hf, ?h, 5.0033), add(?x, ?hf, ?wf, 66.473), multiply(?af, ?a, 6.755), subtract(?bmr, ?x, ?af) -> hasBMR(?m, ?bmr)
Female(?f), hasAge(?f, ?a), hasHeightInCms(?f, ?h), hasIdealWeight(?f, ?w), multiply(?wf, ?w, 9.5634), multiply(?hf, ?h, 1.8496), add(?x, ?hf, ?wf, 655.0955), multiply(?af, ?a, 4.6756), subtract(?bmr, ?x, ?af) -> hasBMR(?m, ?bmr)

There is an AND condition among the constructs of a SWRL rule which are separated by a comma. Above rule for calculating BMR for men is splitted into parts and explained with the help of Table 5.3.

Table 5.3: Detail explanation of SWRL rule for calculating BMR

Rule	Meaning	Mathematical calculations

Male(?m)	Only for those instances who are male	
hasAge(?m, ?a)	if the male has some age=a	a= male's age in years
hasHeightInCms(?m, ?h)	if the male has some height value h	H= male's height in cms
hasIdealWeight(?m, ?w)	If the male has some ideal weight value w	w= male's ideal weight in kg
multiply(?wf, ?w, 13.7516)	multiply ideal weight with coefficient 13.7516 and store result in variable wf	wf (weight factor)=w*13.7516
multiply(?hf, ?h, 5.0033)	multiply height with coefficient 5.0033 and store result in variable hf	hf (height factor)=h*5.0033
add(?x, ?hf, ?wf, 66.4730)	Add hf, wf and 66.4730 and store result in variable x	x=66.4730+hf+wf x=66.4730+(h*5.0033)+(w*13.7516)
multiply(?af, ?a, 6.7550)	multiply age with coefficient 6.7550 and store result in variable af	af (age factor)=a*6.7550
subtract(?bmr, ?x, ?af)	Subtract af from x and store result in bmr	bmr=x-af bmr=(66.4730+h*5.0033+ w*13.7516) – (a*6.7550)
➔ *hasBMR(?m, ?bmr)*	Assign hasBMR value of male as hasBMR=bmr	hasBMR = bmr where bmr=(66.4730+ h*5.0033+ w*13.7516) – (a*6.7550)

Similarly, daily needed calories are calculated using SWRL rule in following format:

Person(?p), Sedentary(?p), hasBMR(?p, ?bmr), multiply(?c, ?bmr, 1.2) -> hasPerDayCalorieNeed(?p, ?c)
Person(?p), Little_Active(?p), hasBMR(?p, ?bmr), multiply(?c, ?bmr, 1.375) -> hasPerDayCalorieNeed(?p, ?c)
Person(?p), Moderate_Active(?p), hasBMR(?p, ?bmr), multiply(?c, ?bmr, 1.55) -> hasPerDayCalorieNeed(?p, ?c)
Person(?p), High_Active(?p), hasBMR(?p, ?bmr), multiply(?c, ?bmr, 1.72) -> hasPerDayCalorieNeed(?p, ?c)
Person(?p), Very_High_Active(?p), hasBMR(?p, ?bmr), multiply(?c, ?bmr, 1.9) -> hasPerDayCalorieNeed(?p, ?c)

1 Gram Carbohydrate = 1 Gram Protein = 4 Calories whereas, 1 Gram Fat = 9 Calories

Thus Daily carbohydrate need (in grams) = (50-60 % of daily calorie) / 4

Daily protein need (in grams) = (10-20 % of daily calorie) / 4

Daily carbohydrate need (in grams) = (25-35 % of daily calorie) / 9

Person(?p), hasPerDayCalorieNeed(?p, ?c), hasPerDayCarbPercentage(?p, ?cp), multiply(?x, ?c, ?cp, 0.01, 0.25) -> hasPerDayCarbNeed(?p, ?x)
Person(?p), hasPerDayCalorieNeed(?p, ?c), hasPerDayProteinPercentage(?p, ?pp), multiply(?x, ?c, ?pp, 0.01, 0.25) -> hasPerDayProteinNeed(?p, ?x)
Person(?p), hasPerDayCalorieNeed(?p, ?c), hasPerDayFatPercentage(?p, ?fp), multiply(?x, ?c, ?fp, 0.01, 0.1111) -> hasPerDayFatNeed(?p, ?x)

Calories distribution for breakfast is calculated as follow

Person(?p), hasPerDayCalorieNeed(?p, ?dcal), hasBFPercentage(?p, ?bfcalp), divide(?bfcal, ?bfcalp, 100), multiply(?x, ?dcal, ?bfcal) -> hasBFCalorieNeed(?p, ?x)

5.1.2 Food Domain Ontology

Food ontology has designed and then defined in OWL using protégé. Objects properties are defined for relationships between concepts such as Food_Item, Food_group, Nutrients and MealMenu etc. The ontology has enriched with numerous instances of food items along with portion sizes, different nutrients and calorie values. Using rules and reasoning approach, food items are automatically categorized on the basis of different food groups, cooking methods and various nutrient values clustering. Fig. 5.2 shows modeling of food ontology in protégé. The instance ‘Apple’ is inferred as Fruit, RawFoodItem and MediumCalorieFoodItem on the basis of SWRL rules and semantic class definition.

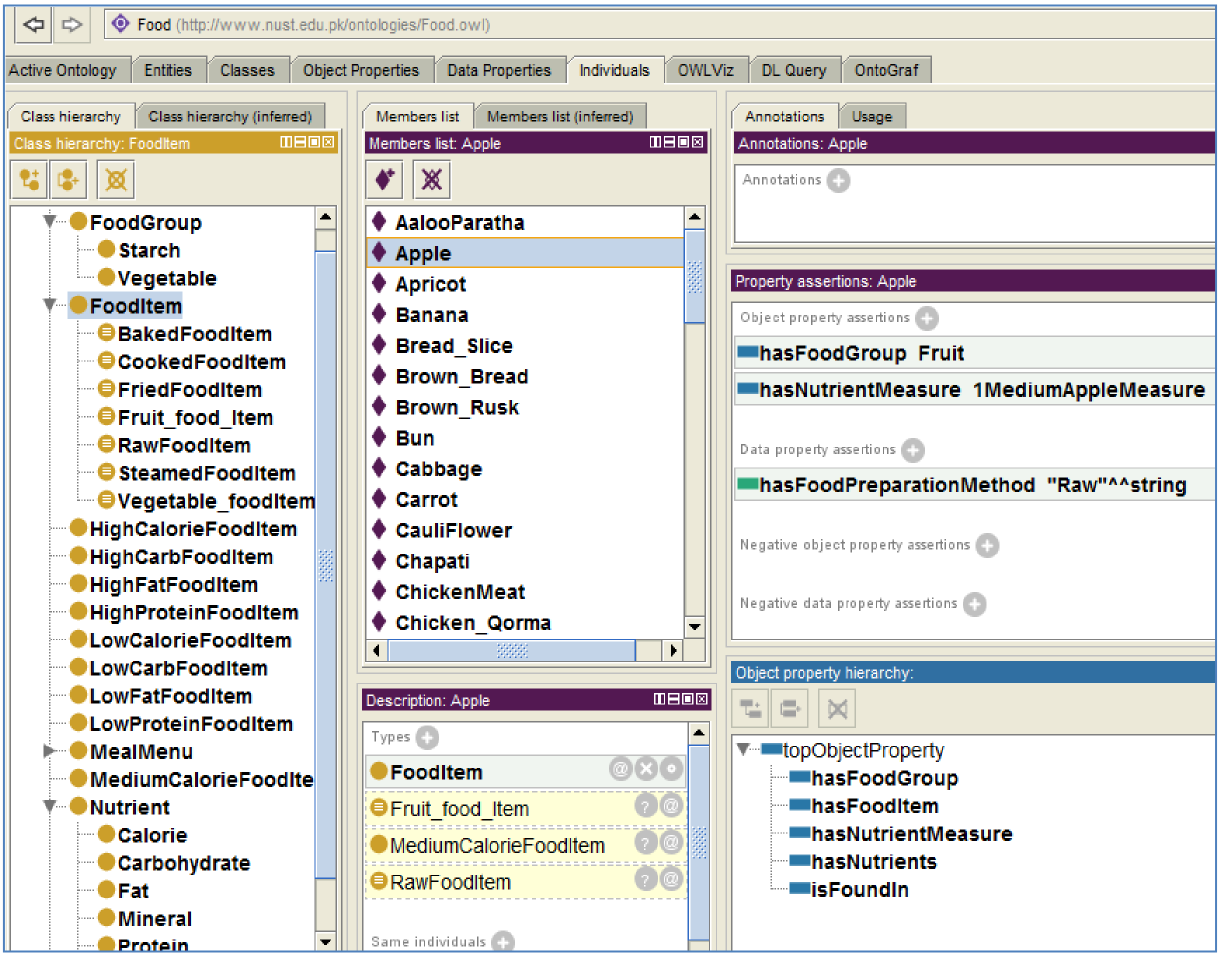


Figure 5.2: Protégé implementation of food ontology

In order to find out various alternative food items having the same nutrient values, we have defined following SWRL rule. As an example of this rule, Fig. 5.3 presents inference of all food items having 7 grams of proteins.

FoodItem(?f), hasNutrientMeasure(?f, ?nm), hasNutrients(?nm, ?n) -> isFoundIn(?n, ?f)

Nutrient and calorie clustering such as LowCarbFoodItem, HighFatFoodItem and LowProteinFoodItem are formed by defining SWRL rules which enables reasoner automatically classify a food item into a particular cluster. For example, following function defines the clustering of food items on the basis of amount of calories per serving. If n is number of calories in per serving of a food item then

$$f(foodItem) = \begin{cases} LowCalorieFoodItem, & n \leq 50 \\ MediumCalorieFoodItem, & 50 < \; n < 120 \\ HighCalorieFoodItem\,, & n \geq 120 \end{cases}$$

The above function is transformed into SWRL rules as follow:

FoodItem(?f), hasNutrientMeasure(?f, ?nm), hasNutrients(?nm, ?n), Calorie(?n), hasNutrientValue(?n, ?nv), lessThanOrEqual(?nv, 50) -> LowCalorieFoodItem(?f)

FoodItem(?f), hasNutrientMeasure(?f, ?nm), hasNutrients(?nm, ?n), Calorie(?n), hasNutrientValue(?n, ?nv), greaterThan(?nv, 50), lessThanOrEqual(?nv, 120) -> MediumCalorieFoodItem(?f)

FoodItem(?f), hasNutrientMeasure(?f, ?nm), hasNutrients(?nm, ?n), Calorie(?n), hasNutrientValue(?n, ?nv), greaterThan(?nv, 120) -> HighCalorieFoodItem(?f)

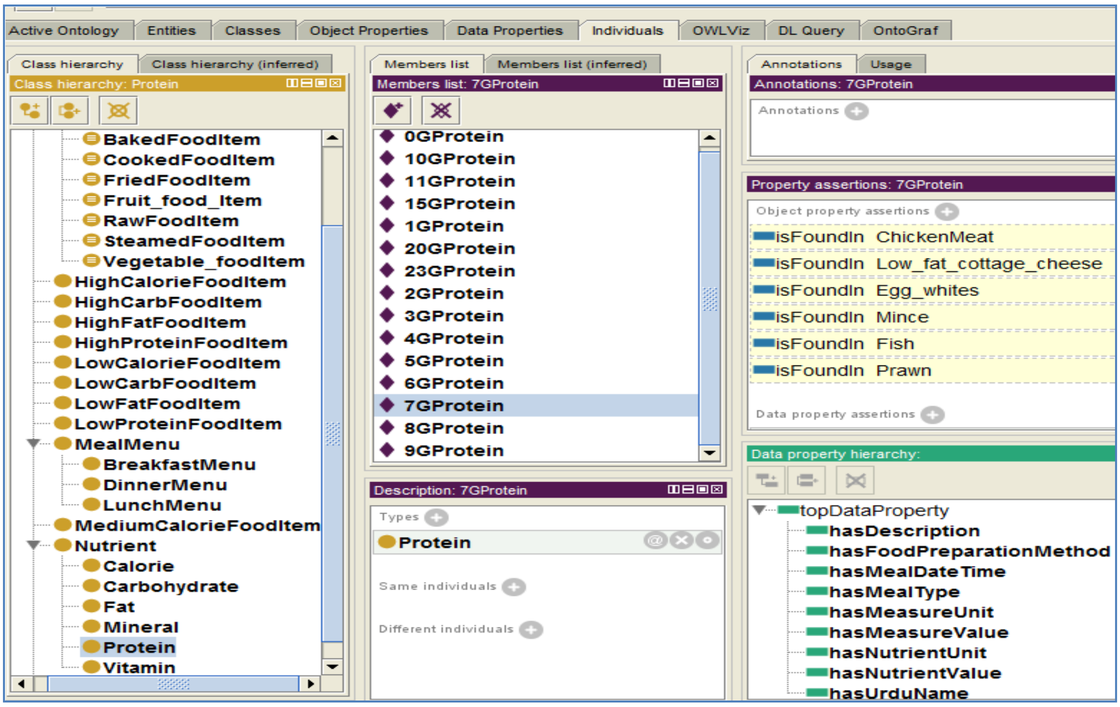


Figure 5.3: Inference of different food items having same nutrient values

5.1.3 Disease domain ontology

It is a general disease domain ontology which is designed to model disease knowledge base, concepts and relationships. Protégé modeled version of disease ontology is shown in Fig. 5.4. It includes hierarchical representation of various diseases and relationships of different diseases with particular vital signs. Clinical guidelines of disease diagnosis and verification are transformed into SWRL rules and automatically inferences are generated as disease diagnose on the basis of values of vital signs. For example, following rule shows diagnosis of diabetes patient, if he/she has glucose level value higher than 180.

GlucoseLevel(?gl), Person(?p), hasVitalSign(?p, ?gl), hasVitalSignValue(?gl, ?gv), greaterThan(?gv, 180) -> DiabeticPatient(?p)

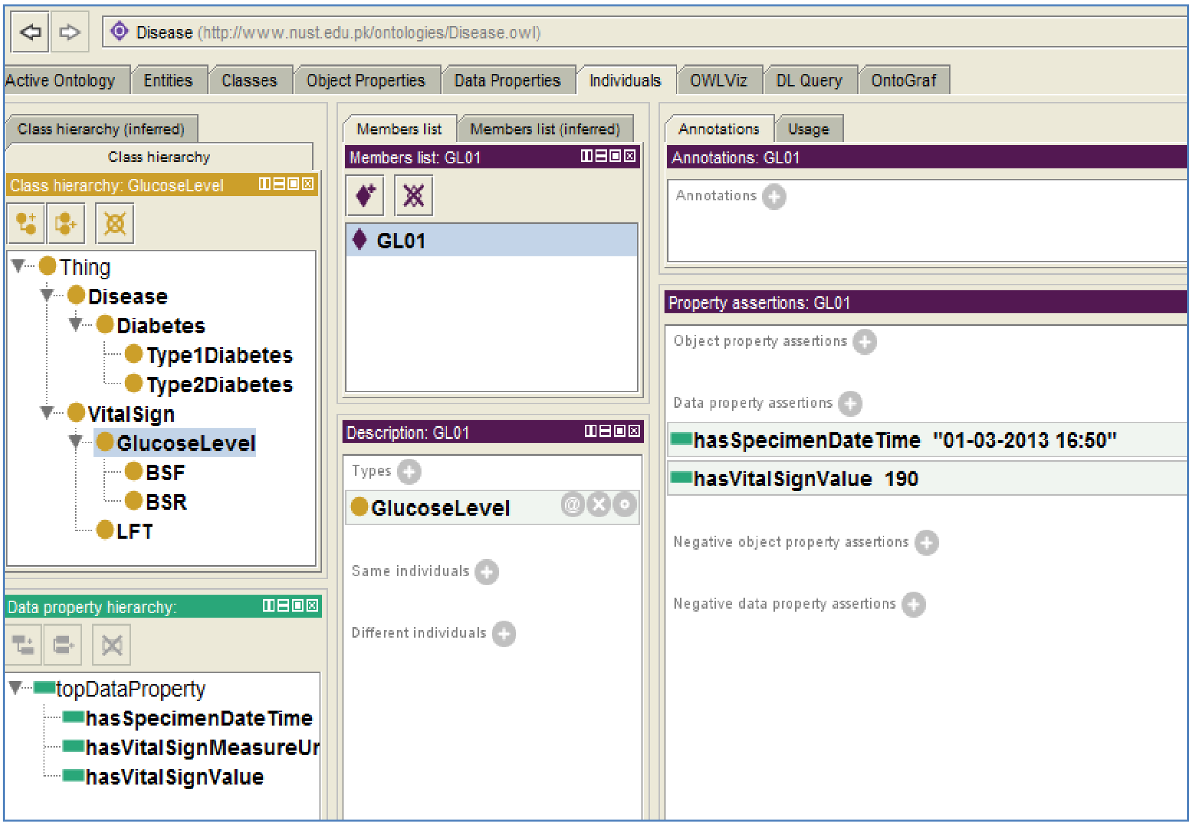


Figure 5.4: Protégé implementation of disease ontology

5.1.4 Exercise domain ontology

Exercise or physical activity domain ontology is designed and developed to model its domain knowledge. Hierarchy of various physical activities is structured, object type properties are defined and instances are generated. Physical activity domain protégé implementation is shown in Fig. 5.5. Activities are classified on the basis of MET value and respective SWRL rules are formed as follow:

$$f(ActivityIntensity) = \begin{cases} Low\ Intensity, & 1 < MET\ value \leq 4 \\ Moderate\ Intensity, & 4 < MET\ value \leq 8 \\ High\ Intensity, & 8 < MET\ value \end{cases}$$

Activity(?a), hasMET(?a, ?m), lessThanOrEqual(?m, 4), greaterThan(?m, 1) -> LowIntensityActivity(?a), hasIntensityValue(?a, "Low")
Activity(?a), hasMET(?a, ?m), greaterThan(?m, 4), lessThanOrEqual(?m, 8) -> ModerateIntensityActivity(?a), hasIntensityValue(?a, "Moderate")
Activity(?a), hasMET(?a, ?m), greaterThan(?m, 8) -> HighIntensityActivity(?a), hasIntensityValue(?a, "High")

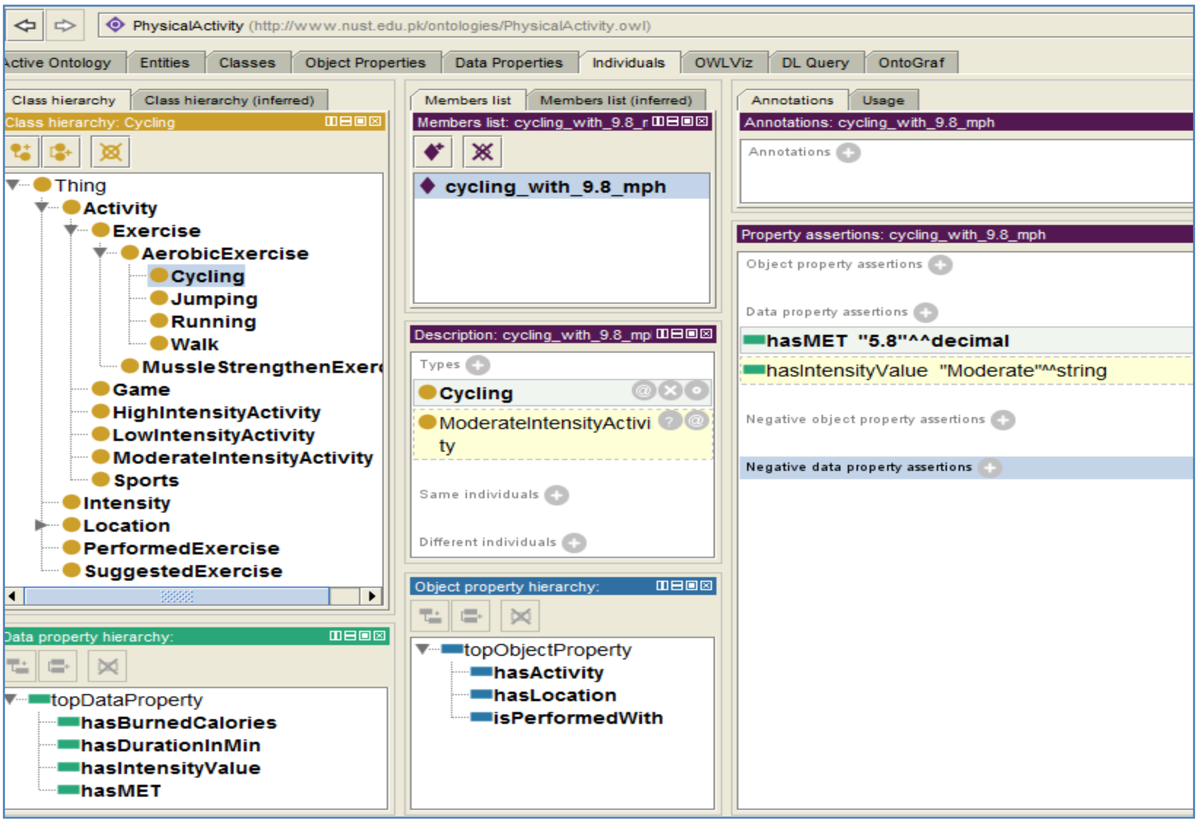


Figure 5.5: Protégé implementation of exercise ontology

On the basis of rules, reasoning engine infers intensity wise classification of the activity. Some context variables also introduced to make it context-aware such that location of exercise, time of exercise etc.

5.1.5 The integrated ontology

Protégé allows reusability of knowledge base by importing existing ontologies and facilitates to extend knowledge. Importing multiple ontologies and defining relationships among their concepts provides easiness in integration and sharing of knowledge. Individual ontologies works independently without effecting change in one ontology into another. Further, due to distribution of each domain knowledge separately, ontology size remains manageable and controllable. In our implementation, personal profile, food, disease and physical activity domain ontologies are imported into an integrated ontology and defines properties and SWRL rules over their concepts to generate diet and exercise suggestions as an inference. The integrated domain ontology is shown in Fig. 5.6. Each of the above domains has its own complexities and business rules; and they are extremely interrelated for diet and exercise recommendations for diabetes patients.

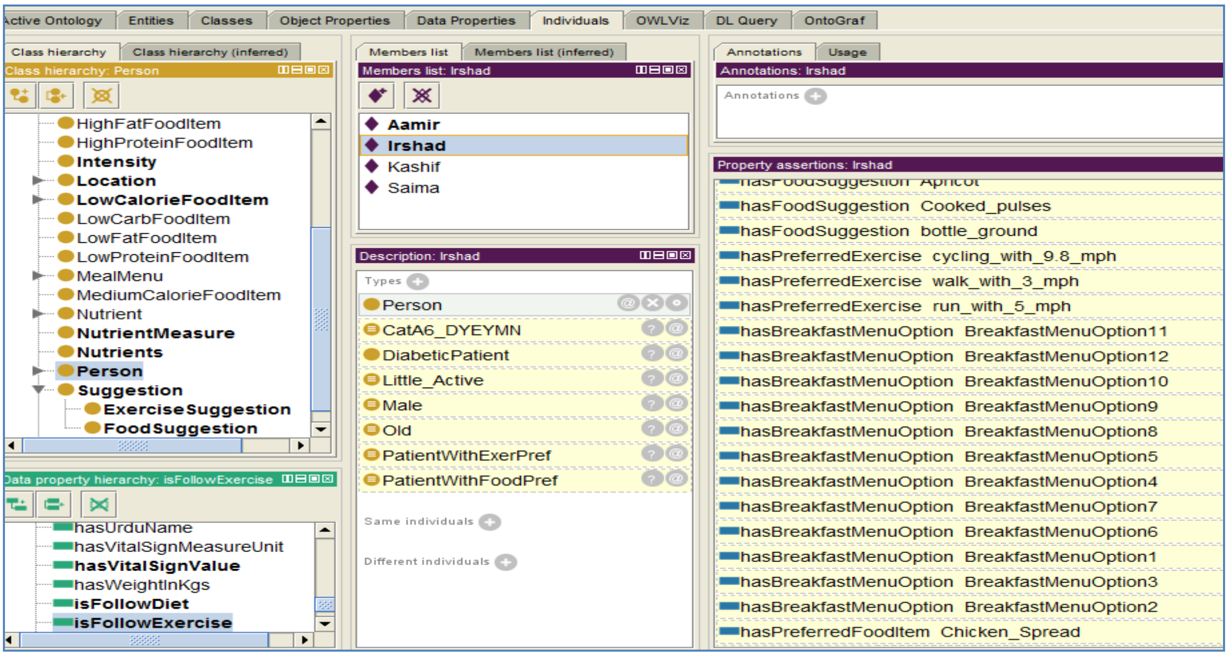


Figure 5.6: Protégé implementation of integrated ontology

The integrated ontology is developed that imports the above domain ontologies and defines relationships among them. For example, concepts between disease ontology and food ontology are defined as there are restrictedly used, allowed and prohibited food items in case of a particular disease. Furthermore, user's preferred food items and exercises are defined. The integrated ontology, as shown in Fig. 18, shows recommended food items and exercises as inferences.

The integrated knowledgebase can be represented in the form of rules so machine get trained in understanding the semantics of data and to infer further knowledge. Some of the examples are described 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 user's preferred low calorie food items to diabetic.

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 old person is low intensity exercise

Old_Age(?p), hasPreferredExercise(?p, ?a), hasDisease(?p, ?d), recommendedActivity(?p, ?b), owl:sameAs(?a, ?b), LowIntensityActivity(?a), → hasExerciseSuggestion(?p, ?a)

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

Similarly, a number of domain rules have been defined for each of the ontology.

5.2 Application Implementation

In order to work as a prototype application, the same ontology modeling and integration work can be done programmatically using Jena and Pellet API, written in Java. Jena allows to dynamically generating ontology or loading an existing ontology. Jena APIs also facilitates in importing existing ontologies, combining them into one integrated model and query over them. Application code is written to load the existing domain ontologies into one combined model, query over them to present the data on graphical user interface and to extend the model dynamically and programmatically by adding further tuples.

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. Following are the modules of the proposed System:

- User registration module
- User profile update module

- Food item entry module
- Physical activity entry module
- Diet Suggestion Module
- Exercise Suggestion Module
- Preference elicitation module
- Glucose Alert/reminder module
- Activity Life style monitoring and analysis module
- Glucose level monitoring and analysis module
- Entry module for Diet, Exercise and Glucose level
- Diet monitoring and analysis module

Following are the screen shots of the developed application:

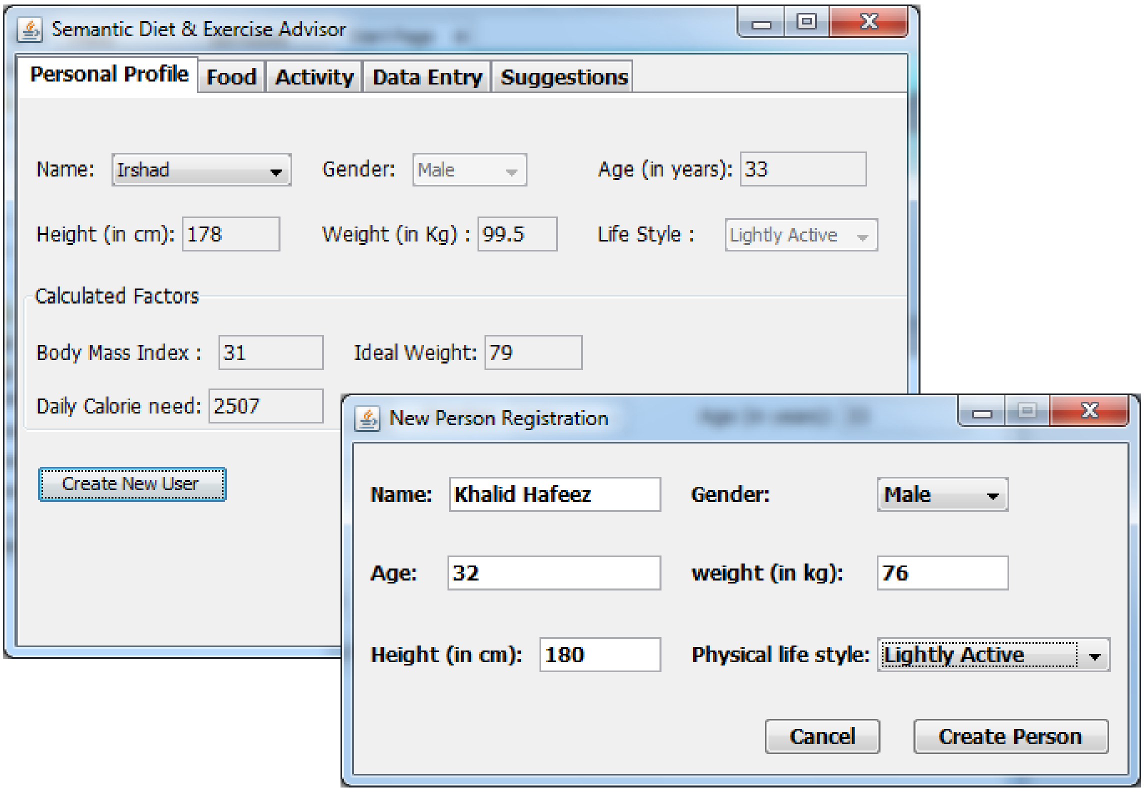


Figure 5.7: User registration and update module

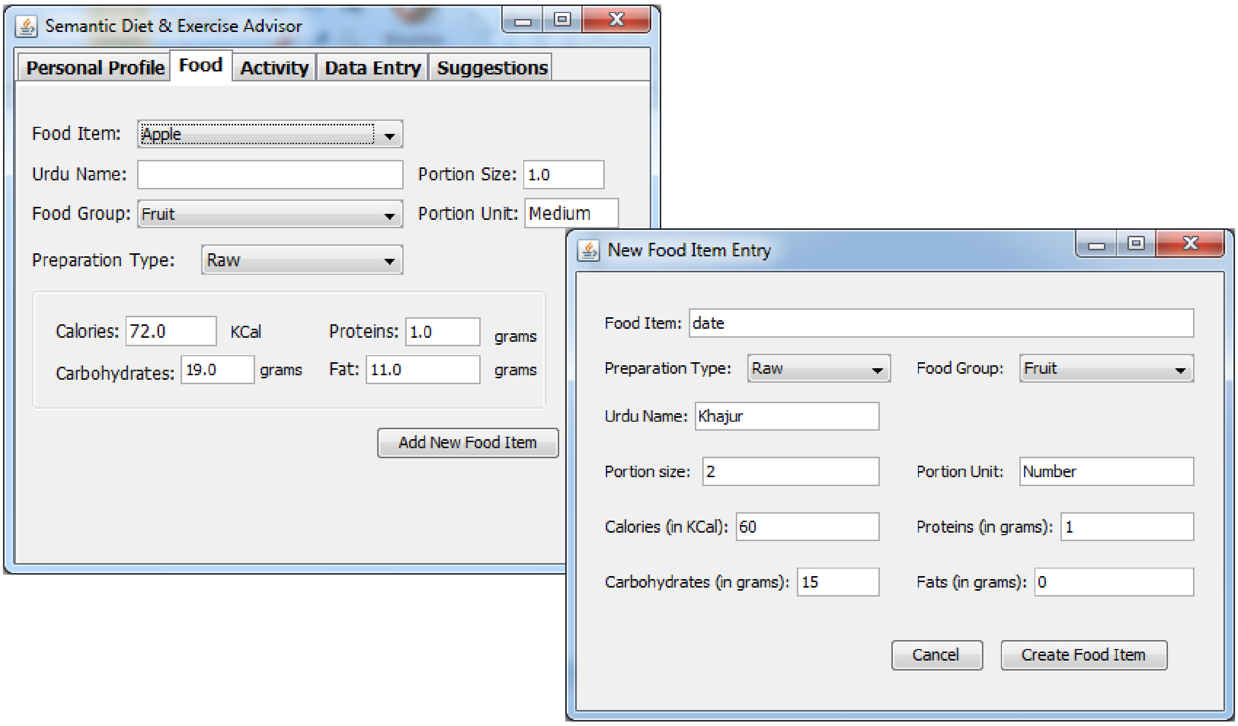


Figure 5.8: Food data update and insert module

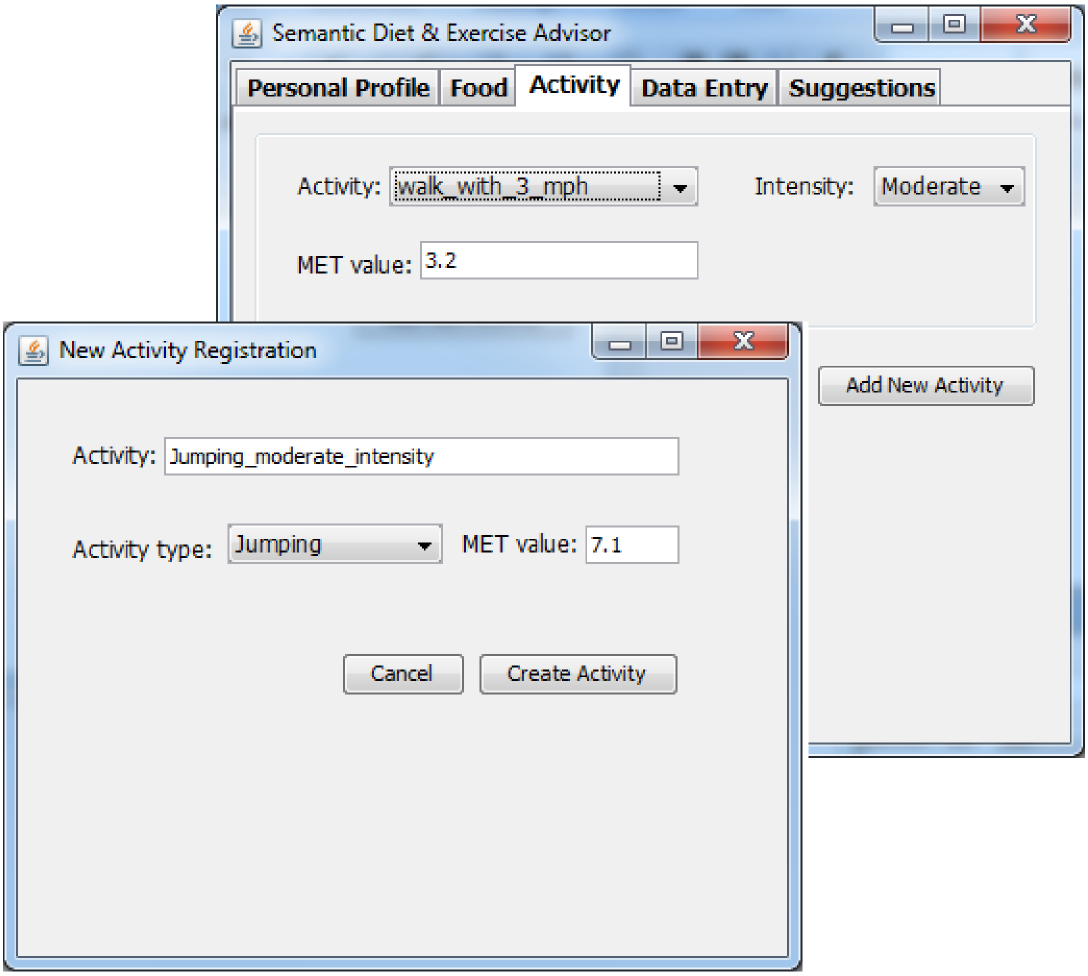


Figure 5.9: Physical activity addition and update module

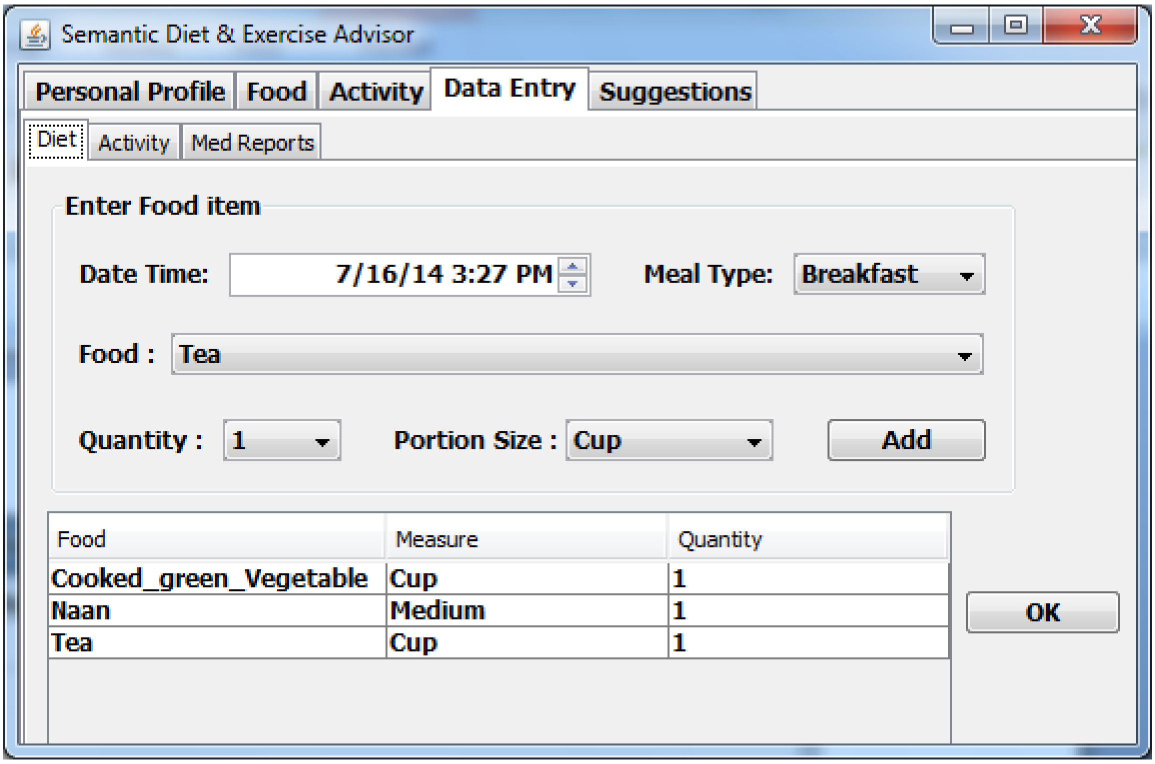


Figure 5.10: Implementation of diet entry module

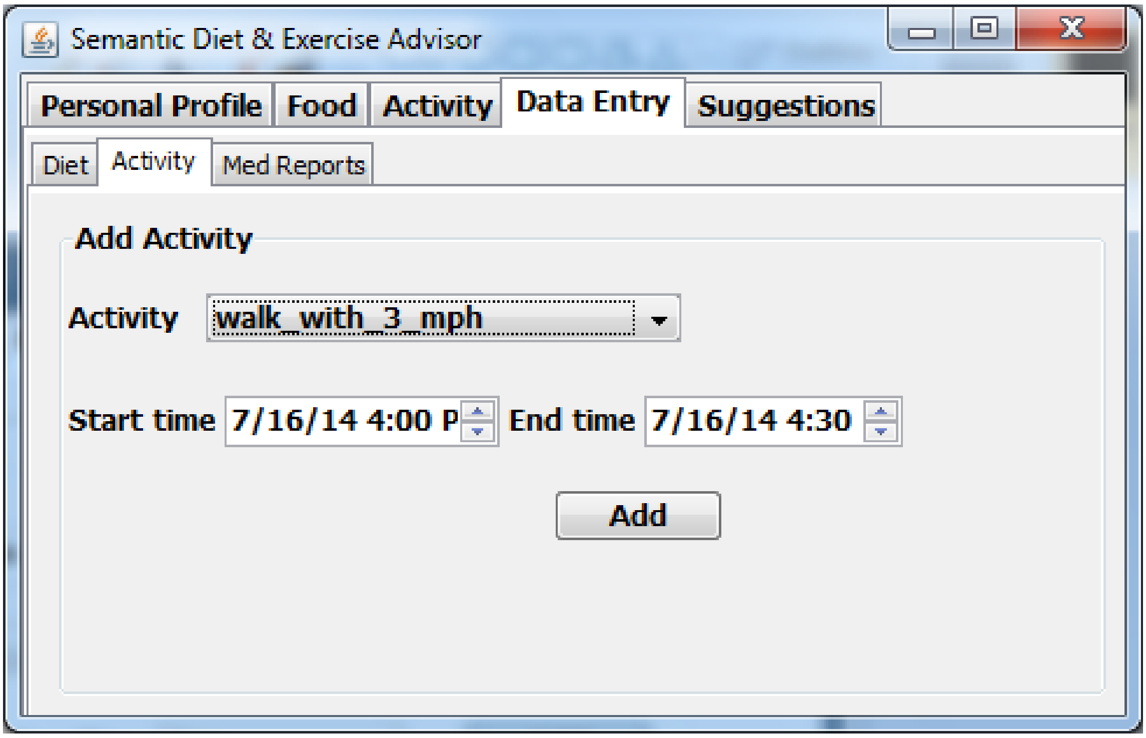


Figure 5.11: Implementation of exercise or physical activity entry module

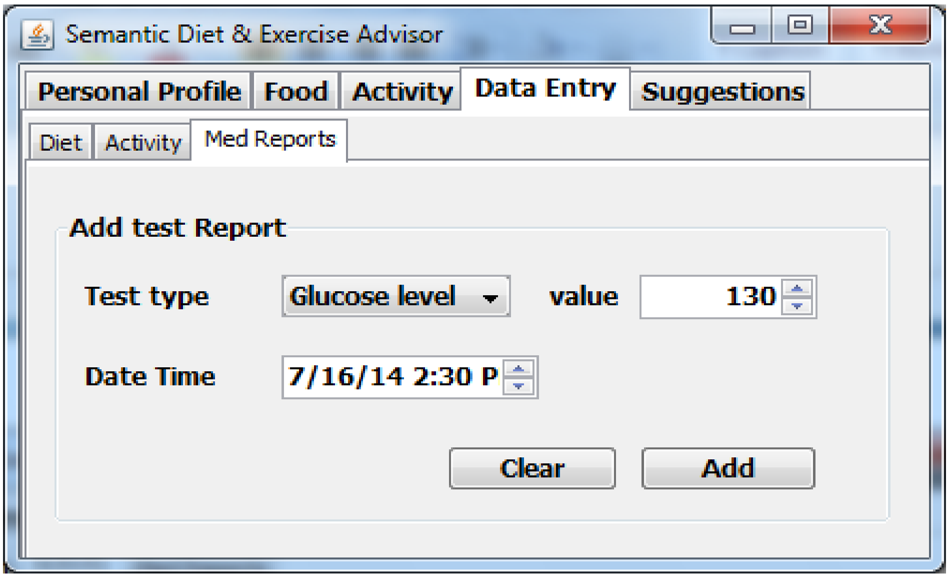


Figure 5.12: Module for blood glucose level entry

5.3 Results

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. 5.13 shows the recommended suggestion for diet. Fig. 5.14 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.

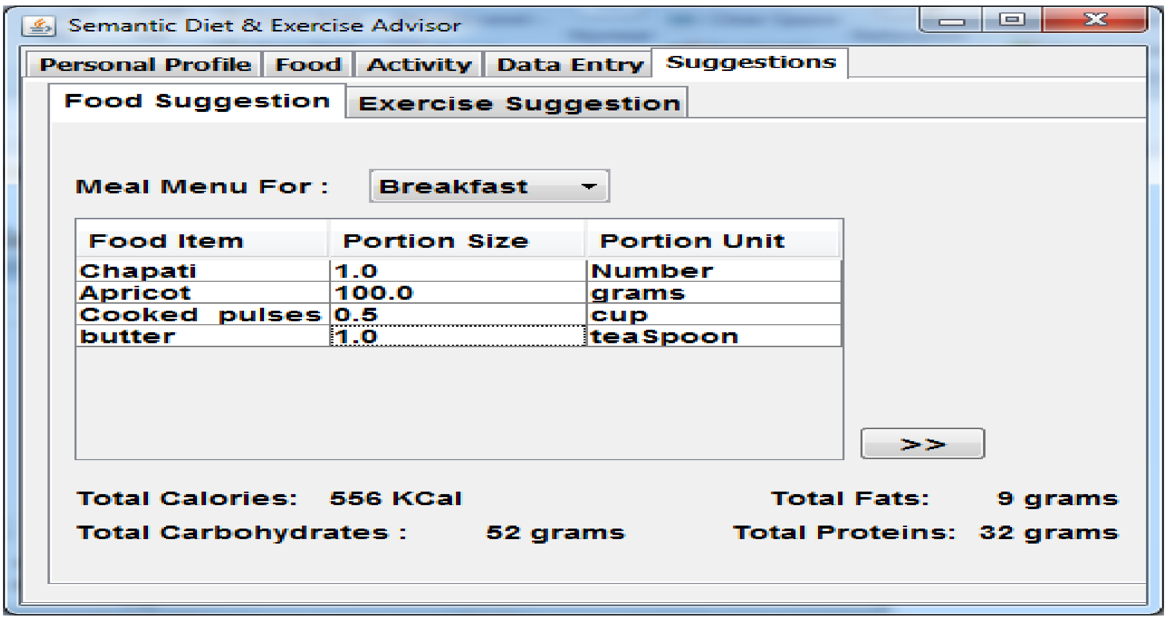


Figure 5.13: Diet menu suggestions

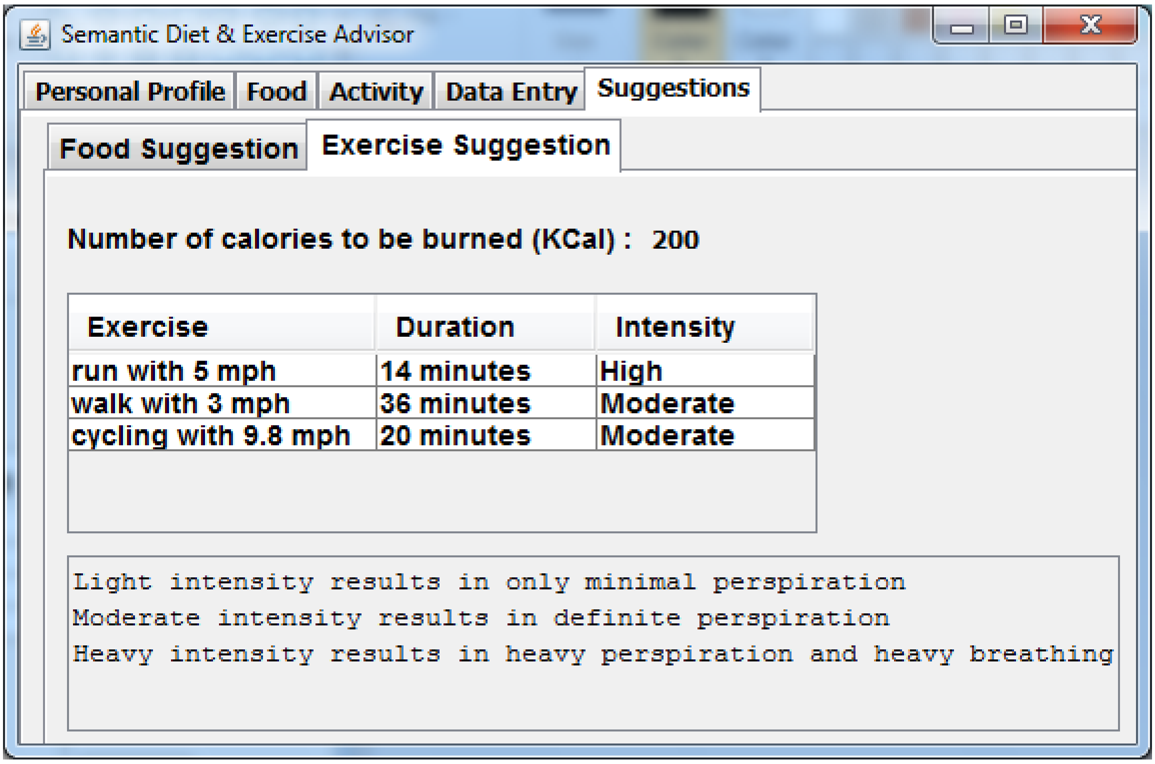


Figure 5.14: Preferred exercise suggestions

Chapter 6 : CONCLUSION AND FUTURE WORK

6.1 Discussion

We have integrated different domains knowledge base using semantic web based technologies to generate personalized and preferred diet and exercise recommendations for diabetes patients. The recommendations consider latest taken diet, performed exercise and blood glucose level in order to balance the intake and burned calories. Finally, diet recommendations are generated in the form of healthy and balanced diet menus.

6.2 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.

Current diet management techniques are food pyramid, diet charts, exchange of food items, carbohydrate counting and glycemic index. None of the single scheme is able to give customized, personalized and balanced diet. We are using a hybrid approach of mixing the above technique to get advantage of each technique and produce a meal plan that is customized, personalized and balanced diet.

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

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.

6.3 Future Work

This work can be extended to add context into the system such as location based diet and exercise services to a user. For example, if a user is near to a restaurant and the restaurant food specialty satisfies all constraints; such food may be recommended to the user.

The social/persuasive perspective may be included in the current work. For example, if a user friend is doing some exercise in a near gym or park, the user may be given recommendation to do exercise with his friend. To do an exercise alone is a difficult task as compare to if a companion is together.

Currently, SWRL rules can be added or enhanced using Protégé editor or can be written in a text file in a particular syntax that can be done only by a computer specialist. An automated procedure or interface may be designed and developed so that dietician or nutritionist can enter or edit the rules.

An android version of the application can be developed to better facilitate the patients for diet, exercise and blood glucose level entries. Customized diabetes control tips can be generated when any discrepancy is found in received data. General diabetes self management recommendation can also be generated.

The developed application may be arranged to be used by the patients. In case, it is evaluated and users enters actual data of taken diet, performed exercise and blood glucose level then such data will open new doors for analysis, mining and new knowledge exploration .

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