Design and Development of a Biocultural Ontology for Personalized Diabetes Self-Management of American Indians

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***Abstract*— In this paper we present the design and development of an ontology model to assist personalized self-management for American Indian diabetes users. The most important part of this ontology is a biocultural user profile modeling that presents various characteristics of American Indian users. We describe the overall ontology development life cycle including six well defined development stages that were employed by ontology engineers and developers to plan for, design, implement, evaluate, and deliver ontology. The ontology development process is iterative, as each phase can be cyclically and incrementally repeated. The proposed ontology has been evaluated with different approaches, standards, and use case scenarios. The ontology is ready to be used as a knowledge base for semantically intelligent personalized diabetes self-management for American Indians.**

Keywords-ontology; personization; self-management; profile; diabetes

I. INTRODUCTION

American Indians/Alaska Natives (AI/ANs) are disproportionally influenced by diabetes and its complications compared to other racial groups in the U.S [1]. Based on CDC 2010, the probability of AI/ANs being diagnosed as diabetes doubles compared with their white peers. The likelihood of an AI/AN youth aged between ten to nineteen years old and being diagnosed as type 2 diabetes is nine times higher than that of white youth in the same age (Search for Diabetes in Youth Study Group, 2006). The epidemic of diabetes and its complications in American Indian and Alaska Natives have caused a great deal of pain and hardship: they are the major contributors to morbidity and mortality in this populations.

As a chronic disease, diabetes requires patients and their families to make various healthcare decisions and perform various healthcare activities every day. If the patients follow a good self-management routine, they can control diabetes through consuming appropriate diets, maintaining healthy body weight, doing suitable physical activities, and regularly checking with their healthcare team. Therefore, self-management is critical for successful diabetes care. A patient's lifestyle choice is the key to successful diabetes control. Although there are many self-management tools for diabetes (e.g.[2][3][4]), none of them are targeted at AI/ANs. AI/ANs normally live in rural areas, experience property and lower health literacy; they have different cultural and social experiences. Most of existing tools fail to consider the special issues of AI/ANs, they cannot effectively manage diabetes for this population. For example, an appropriate diet recommendation is important for diabetic patients. There are many existing diet recommendation tools available for this purpose. However, meals recommended by these tools may not work well on AI patients who have unique diet preferences and traditions. In addition, as many AI tribes are located in the so called "food desert", where lots of food items are not available. If recommended with unavailable or unaffordable food, AI patients cannot get the benefits at all. Therefore, personalization is especially important for them.

To address the aforementioned problem, it becomes important to propose a personalized system to provide AI/AN users with relevant and adapted information for their special need and preferences. This system must consider the different social-economic and cultural characteristics of the patients and all contextual situations that influence patients' lifestyle choices. The foundation of the personalized system is based on the principle of profile management. We propose a biocultural user profile modeling that offers valuable biological, cultural, socio-economic, and environmental factors affecting users' wellbeing. The merit of the biocultural approach is that it presents humans in a comprehensive view from biological, social, and cultural aspects [5]. Through the understanding of both the biological and cultural implications of AI diabetes, self-management can be customized according to the particular biocultural context.

In this paper, we present our design of an AI/AN biocultural profile ontology. The proposed AI/AN biocultural profile ontology defines and organizes the concepts and relationships used to describe AI diabetes patients. It is able to represent user's information including health conditions, personal preference, and geographical, cultural, and socioeconomic characteristics. Based on this ontology, personalization can be realized through providing services tailored to fit specific patients' need.

By modeling an AI user's biocultural properties, the self-management tool can choose appropriate forms of self-management options and thus providing personalized services. We use ontologies to capture patient profile and biomedical knowledge in a simple by effective way. The ontology can work as a knowledgebase for the personalization of AI patients' conditions and self-management plans. It aims to provide context-aware and personalized services adapted to

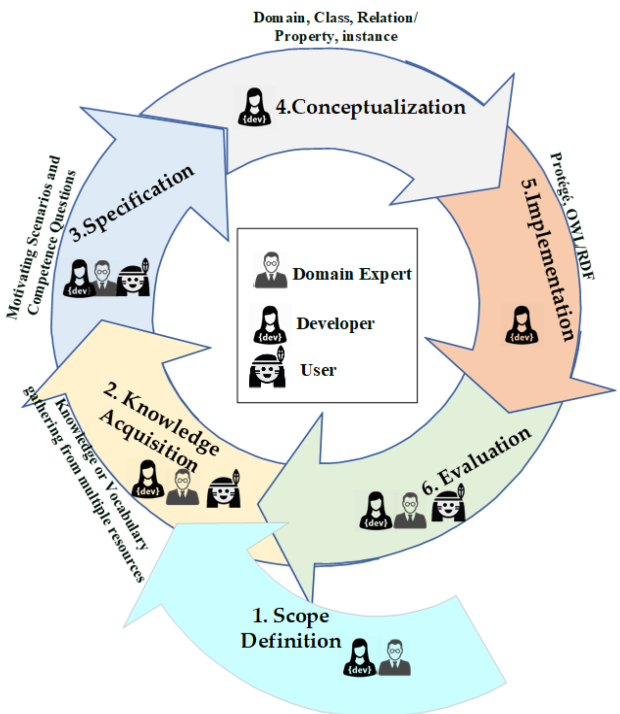

Fig. 1. Ontology design and development life cycle

AI patients based on their physical, socioeconomical, and cultural conditions. The ontology enables the representation, conceptualization, and reasoning functionalities.

The rest of the paper is organized as follows. Section II surveys related work on designing and developing ontologies. Section III describes our proposed methodology in details. Section IV presents use case studies using the proposed ontology. Finally, in Section V, we provide conclusions and future work directions.

II. Related Work

In this section, we review some general methods, tools and languages used for ontology development.

The process of design and development of ontology is similar to develop standards. Therefore, we adopted many methodologies of conception, development, deployment and testing from standard development process [6] to ontology development.

As pointed out by Noy and McGuinness in their best-known ontology development guide – Ontology Development 101 [7], there does not exit one absolute correct way or standard procedure to design an ontology. They proposed an iterative approach: at first, a rough initial version of the ontology was designed, and then revision/refinement would be performed on the evolving ontology. In their guide, they suggested seven steps/procedures to design ontology models based on their experience using Protégé [8]. At the start, the domain and scope of the ontology determine, which is followed by considering of reusing (part of) existing ontologies. Then important concepts/terms in the domain should be enumerated. After classes and class hierarchy are defined, various properties of the classes can be defined. At last, the instances/individuals can be created. Similar guidelines and methodologies are also presented in other researches such as works proposed by Uschold and King [9], Corcho et al.[10], Öhgren et al. [11] and Wang et al. [12].

Software engineering-based approaches have been proposed for ontology design and development. For example, Saripalle et al. proposed the HOD^{2}MLC [13] design model that follows the software engineering lifecycle-based design. The authors propose an agile software process for ontology design, which have nine design phases including requirement analysis, data integration and acquisition, concepts specification, ontology design, ontology analysis, ontology implementation, testing, and maintenance. There are also other engineering-based approaches for ontology design. For example, the ontology development method proposed by Ahmed, Kim, and Wallace [14] is a six-phase methodology using engineering design strategies, a very similar approach is proposed by Gašević et al.[15]. In another example, De Nicola et al. [16] proposed a method based on a popular iterative and incremental software development process – the Unified Software Development Process or Unified Process (UP). In particular, they propose an ontology design method called UPON (representing UP for Ontology) building, which is derived from the UP. They use the eBusiness domain as an example to present UPON.

A variety of ontology languages and tools have been developed. For example, KIF [17], Flogic [18], CyCL [19]are all first-order logic based languages. LOOM [20] is a description logic based language. OIL[21], DAML+OIL[22], and SHOE [23] are web-based language. Telos [24] on the other hand is object-oriented ontology presentation language. Furthermore, various tools are developed to support the ontology language. Examples include Ontolingua [25], WebOnto [26], WebODE[27], and Protégé [8].

III. Methodology

To the best of our knowledge, there's no existing AI biocultural ontology defined in the literature. The interdisciplinary social and scientific nature of this research requires the use of an integrated approach. We develop this ontology through a collaborative process that includes domain experts, and ontology engineering experts. This section presents our multi-phased iterative and incremental ontology design and development methodology. As there are many synergies between software engineering and ontology development, we adopt some idea of the systems development life cycle of software engineering to our ontology development life cycle. In our design, we divide the ontology development cycle into six work phases. The ontology engineers, developers and domain expert plan for, develop, implement, evaluate and deliver ontology based on these six phases. As shown in Fig. 1, the ontology development process is recurring in cycles, as each work phase will be cyclically and incrementally repeated. At each new cycle the ontology will be further revise and refined. Different personnel (domain experts, ontology engineers, and final users) may get involved

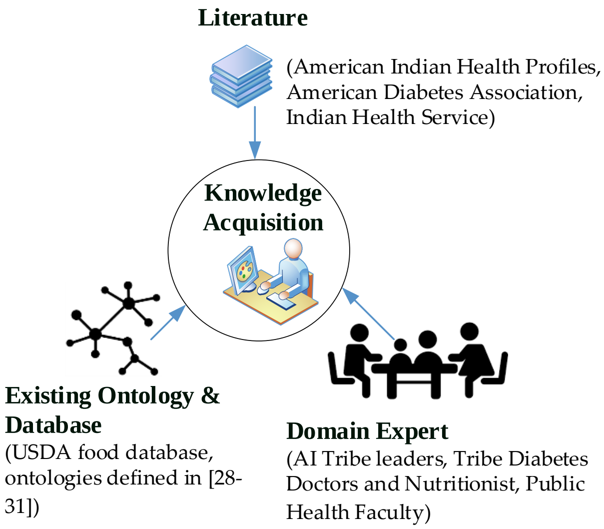

Fig. 2. Knowledge acquisition from multiple sources

in different phases. The details of each work phase in the development life cycle is presented in the rest of this section.

A. Domain Scope Defination

The first phase of our ontology design is the definition of the scope of the onotlogy. The scope of the ontology specifies the domain and the major contents that must be included. We considered the main features and capabilities of our target application – the AI/AN diabetes self-management system, and all related stakeholders, AI/AN patient users, appropriate medical professionals. Since we are not trying to build a generic ontology, but ontologies that serve our personalization healthcare recommendation systems for both human users and automatic semantic agents, our ontology design is use-case driven.

In this phase, we need to answer some basic questions proposed in the ontology development 101 guide [7]: "*what is the domain?*" "*For what we are going to use the ontology?*" "*For what types of questions, the information in the ontology should provide answers?*" "*Who will use and maintain the ontology?*" Our study focuses on the AI/AN diabetes self-management, the domain we consider is mainly about AI/AN diabetes patients, and their life style including food, nutrition, workout, and social life. We do not aim to include the whole clinical information about the patient and disease. The ontology will help us understand physical, social-economic, and cultural features of the AI patients. It will also facilitate us understand how these features affect user's health and wellness. The ontology will be used for providing personalized services, such as personalized diet, workout recommendation, personalized user interface adaptation. The ontology is used by our system developers and eventually given to the AI/AN community for maintenance.

To further narrow down our ontology scope, we sketch a list of competency questions. For example:

Q_1: *Are the traditional foods of the patient's tribe good for his/her diabetes?*

Q_2: *Is the patient's tribe located in a food desert?*

Q_3: *What are the workout facilities locally available?*

Answers to the aforementioned questions contains specific individuals in the domain covered by the ontology. Questions like these can help the designer to understand and formulate the scope of the domain and identify the terms, concepts, and the vocabulary in the domain. For example, the concepts identified for Q1-Q3 may include: *User*, *Tribe*, *Food*, *Diabetes*, *Location*, *Workout*, etc. Eventually we have defined the scope of our ontology including AN/AI patients with their biological, social-economic, and cultural properties, food, nutrition and exercises.

B. Knowledge Acquisition

The goal of this phase is to acquire informal knowledge about the AI biocultural profile and other wellness-related domain. Knowledge acquisition takes place during in the whole life cycle of ontology design and can be performed as often as required.

In this phase, we try to acquire knowledge from multiple sources, namely existing ontologies, literature, domain experts (including final users) as shown in Fig. 2. To the best of our knowledge, there is no existing ontology to model the biocultural profile of AI/AN population or any other respects related to AI/AN. Therefore, we cannot reuse any ontology in this aspect. There are existing food nutrition ontologies [28], [29], workout ontologies [30], [31], and physical and social activities ontologies. We try to reuse, refine and revise them to fit our application purpose. For example, the USDA food and nutrition database contains comprehensive views about food and nutrition. It includes more than 9000 food items together with their nutrition values. We imported part of the food items from their database. We did not use all of the categories of USDA classification of Foods. Instead, we organize food into 5 different groups based on their function on person's everyday meal according to the dietary guidelines for Americans [32]. Based on the USDA dataset, we have created a food and nutrition ontology including important concepts and relationships between them.

To acquire knowledge from domain experts, meetings have been carried out between the domain experts and ontology engineers. The domain experts of our project include tribe leaders of AI reservation community in the upper Midwest, their local diabetes doctors, diabetes nutritionist, and public health faculty members. First, we held preliminary meetings with the domain experts to get general and coarse-grained knowledge. Then we studied the documentation of the meeting to learn more about the domain.

After getting the basic knowledge, we can start the expert-knowledge acquisition cycle: starting from more general knowledge and gradually moving down to particular details. Nonstructural interviews and structured interviews with the domain experts, and detailed reviews were performed. The domain experts are support for knowledge acquisition during the whole ontology development. To pass the acquired

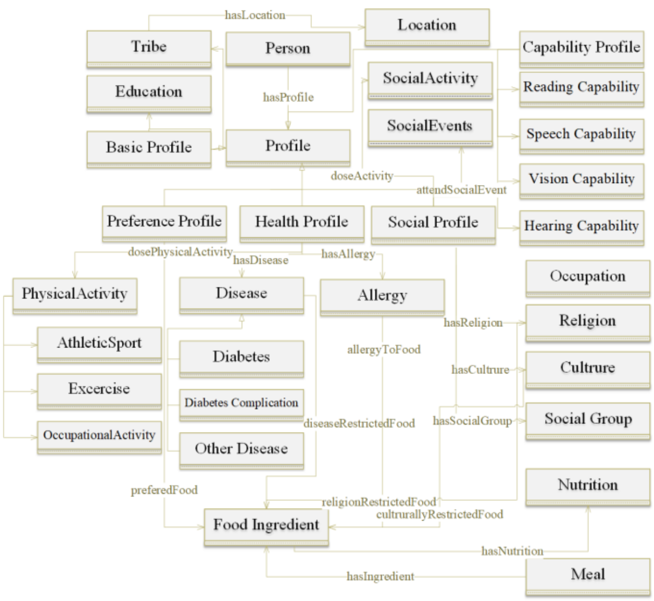

Fig. 3. Part of the UML-base high-level domain knowledge representation

knowledge to domain experts, the ontology engineers would define various intermediate representations in a format that the domain experts can understand. According to the level of conceptualization and granularity, the domain ontology proposed here describes the vocabulary related to the biocultural features of this population.

Domain experts have recommended books, online articles, YouTube videos as references. We have read and analyzed many documents related to AI/AI population. For example, AI health disparity [33], AI community health profile [34], articles in American Diabetes Associations and HIS about diabetes self-management guidelines. We have designed classifiers, text parsers to identify important concepts and relationships.

C. *Specification*

The objective of the specification phase is to further refine the scope of the ontology models based on the domains defined in Phase 1, and knowledge acquired in Phase 2. In this phase, the ontology engineers interacted with the domain experts and potential end users to realize this goal. The refined scope would let the ontology engineer to focus on the narrowed domains without distracted by other details. For example, at Phase 1, we have defined a domain “Disease”. In this phase, we would refine this domain by defining boundaries and specifications on it. For example, our ontology would focus on Diabetes and its complications, such as cardiovascular disease, Kidney damage, eye problems, foot damage, etc. As another example, the “Person” domain identified in Phase 1 would be refined in this domain with a focus on a person’s Health Profile, Preference Profile, Economic Profile, and Cultural Profile. Moreover, the Person concept identified in Phase 1 can be linked with other concepts from various domains such as Food and Nutrition, Physical Workout, and Social Networks.

The specification process takes an incremental and iterative approach and may evolve over time. The second phase (the Knowledge Acquisition Phase) may be performed simultaneously with this phase to obtain terms and vocabulary at different levels. The competency questions presented in the first phase may also be examined to further determine ontology scope and to verify whether it contains enough information.

D. *Conceptulization*

After most of the knowledge has been acquired and the knowledge scope has been refined, we get a set of unstructured knowledge that needs to be organized. This phase organizes and structures the acquired knowledge. Specifically, the acquired informally perceived domain knowledge was converted to a semiformal specification, which both the domain experts and ontology workers can understand. We adopt a Unified Modelling Language (UML)-based diagram to model the main concepts and relations among the concepts. Fig. 3 shows the high-level ontology representation defined in this project.

The concepts and relationships modeled by the UML diagram is the foundation for creating classes and properties in the ontology. In addition, by generalization and specialization, subclass and superclass can also be defined. We adopt an approach that integrates both of the top-down and bottom-up methods to develop the class hierarchy. For some classes, we use top-down approach and start with the most general class and move down to specialize the class to subclasses. For example, we start with creating the class Profile as a general class. Then we specialize it by creating some of its subclasses, Health Profile, Social Profile, Preference Profile, and Capability Profile. We can further categorize the class Capability Profile into Hearing Capability Profile, Vision Capability Profile, and so on. On the contrary, for some concepts we use the bottom-up approach and start from defining the most specific classes and then group and generalize them to super class. We may also start from a particular class and then generalize and specialize subsequently.

Once we have defined classes, we need to describe their properties. We distinguish two types of properties: object property and data property (also called attribute). The former connects pairs of individuals, while the latter connects individuals with literals. All properties have associated domains and ranges. After the conceptual model the ontology has been crated, we can add relevant instances.

E. *Implementaion*

In this phase, the conceptualized ontology is implemented using a formal knowledge representation language, OWL (Web Ontology Language). OWL is a description logic-based language. Knowledge represented in OWL can be effectively employed by our personalization system, e.g., to infer personalized recommendations, or to verify the consistency of the created knowledge. Besides the its extraordinary ability to represent concepts and relationships, OWL provides interoperability support to applications to enable different applications to exchange information, data and knowledge.

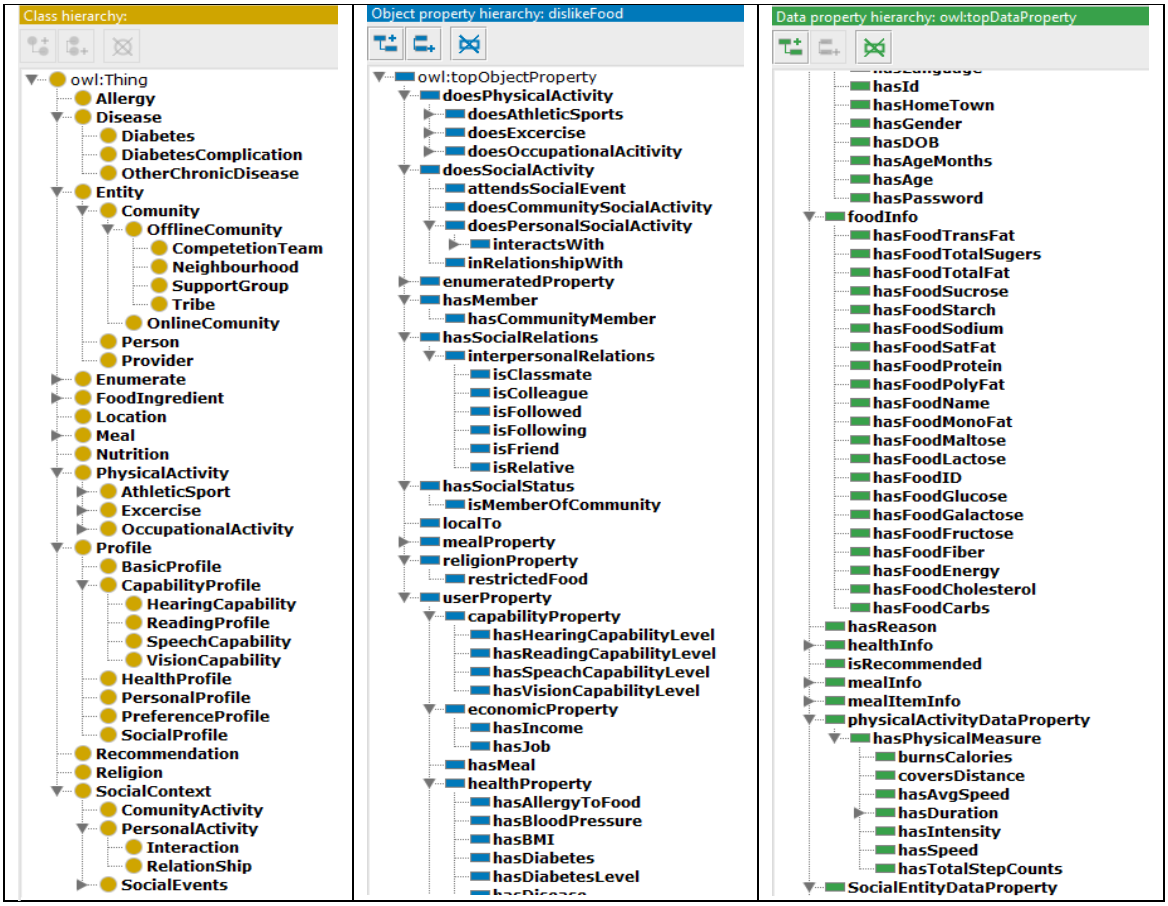

Fig. 4. Screenshot of OWL ontology classes, object properties, and data properties implemented using Protégé 5.2.

Furthermore, its compatibility with web standards and tools extends the usage scope and makes reusing ontology easier.

We choose to use Protégé as our implementation platform to implement the ontology. Protégé is a free, open-source platform developed by Stanford. It provides a set of user-friendly tools to develop and construct ontologies which facilitate to create domain models and knowledge-based applications. Protege provides a plug-and-play service that makes it a good tool for quick prototyping and application development. Fig. 4 shows an overview of part the defined ontology (class, object property, and data property). The ontology has been edited with Protégé 5.2.

F. Evaluation

The developed ontology is evaluated on multiple aspects, such as its coverage, consistency, validity and potential impact on AI diabetes healthcare. As mentioned, our ontology design and develop process was iterative, therefore we created, implemented and evaluated the ontology in various phases of the development cycle. The evaluation result may also guide the development process and may help us refine some development steps. After the refinement, new version of the ontology is further evaluated.

We have considered two categories of evaluations, namely design evaluation and use evaluation. The former is the verification and validation of the ontology, including assessment of the ontology's consistency, correctness, and completeness. The latter evaluates its actual usage in real applications.

We used open source semantic reasoners, in particular, FaCT++ and Pellet with Protégé 5.2 editor to verify the consistency of the ontology model during the ontology creation process. During the whole developing process, our domain experts have been consulted all the time to verify the ontology's correctness and clarity. Moreover, we have designed a list of competency questions related to AI population and diabetes self-management, to evaluate the comprehensiveness and completeness of the ontology. We grouped the competency queries into different categories including foods, exercise, education and AI patient profile. We implement the query with SPARQL and test whether the ontology is able to answer the given queries. To answer the questions, we may also need to populate the ontology with individuals. For example, we pose a query:

"*Find diabetes patients in Lower Sioux tribe in Minnesota who do not have any health insurance and income is lower than 20k per year*."

This query can be represented using our ontology in SPARQL Query format:

```
SELECT ?user
WHERE {
 ?user a Person .
 ?user hasHealthProfile ?userHealthProfile.
 ?user hasSocialProfile ?userSocialProfile .
 ?userHealthProfile hasDisease ?userDisease .
 ?userDisease a Diabetes .
 ?userSocialProfile hasIncome 25kLess .
 ?userHealthProfile hasHealthInsurance False .
 ?userSocialProfile hasTribe LowerSioux .
}
```

In another example, we pose a query:

"*Find people participated in the Creator/Artist Focus Group or the Elders Focus Group or the Youth Focus Group and have Type II diabetes.*"

This query can be represented using our ontology in SPARQL Query format:

```
SELECT ?user
WHERE {
 ?user a Person .
 ?user hasHealthProfile ?userHealthProfile;
 ?user hasSocialProfile ?userSocialProfile .
 ?userHealthProfile hasDisease ?userDisease .
 ?userDisease a Diabetes .
 ?userDisease typeOf Type_II .
 ?userSocialProfile attendsSocialEvent ?userSocialEvent .
 ?userSocialEvent a FocusGroup .
 FILTER (
        ?userSocialEvent = CreatorArtistFocusGroup  | |
        ?userSocialEvent = EldersFocusGroup | |
        ?userSocialEvent = YouthFocusGroup
 )
}
```

Applying these queries to our knowledgebase, we can locate individuals who satisfy the constraints of the queries.

IV. Use Cases

To evaluate its actual use, the proposed the ontology was evaluated with use cases and usage scenarios. Based on this ontology, we have developed a personalized recommendation system for AI diabetes patient. The following is a concrete example showing how the system makes personalized recommendation with the assistance of the ontology.

Assume Mark Hammer is a 35-year-old Native American male living in Lower Sioux Indian Community in the state of Minnesota. His detailed health information is listed in Table 1. After adding his information to the knowledge base, the system will provide general dietary recommendations and supply medical guidelines specific to him.

For example, based on the basic information, some other information (such as CPM (Choices Per Meal), BMI (Body Mass Index), EER (Estimated Energy Requirement), blood pressure level (normal, elevated, hypertension I, hypertension II, hypertension crisis) can be inferred or computed. As an example, the guideline used to infer his CPM for men that are not very active as (3-4), according to the International Diabetes Center Guidelines for people with diabetes. The SWRL rule corresponding to CPM guideline is:

```
Person(?user)                                          ^
hasPhysicalActivity(?user, ?pa)                        ^
differentFrom(?pa, AIOnto:VeryActive)                  ^
BMI(?user, ?bmi)                                       ^
swrlb:greaterThanOrEqual(?bmi, 25)                     ^
Gender(?user, ?gender)                                 ^
swrlb:stringEqualIgnoreCase(?gender, "male")          ->
MaxCPM(?user, 4)                                       ^
MinCPM(?user, 3)
```

From the ontology base we have the following instance related to user Mark:

Mark	Type	Person
Mark	hasPhysicalActivity	Sedentary
Mark	BMI	31.6
Mark	Gender	Male

After applying the rule, Mark will have the CPM range set as (3-4).

In another example, based on the Diabetes Care guidelines, people with diabetes and blood pressure should consume less than 1500mg per day (or less than 600mg per meal). Now assume Mark chooses a meal as lunch. We can apply this rule to check if Mark's meal is good for his health.

```
Person(?user)                                          ^
hasMeal(?user,?meal)                                   ^
hasSodium(?meal,?sodium)                               ^
hasBloodPressure(?user,?bp)                            ^
moreThan(?bp,NormalBloodPressure)                      ^
hasEnergy(?meal,?energy)                               ^
hasEER(?user,?eer)                                     ^
swrlb:divide(?mealPer,?energy,?eer)                    ^
swrlb:multiply(?limit,?mealPer,1500)                   ^
swrlb:greaterThan(?sodium,?limit)                     ->
isRecommended(?meal,false)
```

From the ontology base, we have the following profile related to Mark:

```
Mark Type Person
Mark hasMeal lunchOption
Mark hasBloodPressure HypertensionII
Mark HasEER 2880
HypertensionII moreThan NormalBloodPressure
lunchOption hasSodium 1220
lunchOption hasEnergy 1020
```

Applying the rule on Mark's ontology profile, the reasoner can figure out that the meal is not recommended for Mark. Based on his profile information and dynamic context information, the system can provide various healthy recommendations and medical guidelines specific to him.

V. Conclusions

In this paper, we present our study towards the design and development of an ontology to model AI diabetes patient's profile and different intervention aspects of their life style including food, physical exercise, and education, etc. This ontology covers special genetic, cultural, geographical, and socioeconomic status of AI patients. By integrating the AI users' profile ontology with the diabetes self-management system, the system can make personalized recommendations which are more appropriate to AI users. The proposed ontology is still under development. We are keeping revising and enriching the ontology according to our new discovery and understanding of this domain.

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