An OWL 2-Based Knowledge Platform Combining the Social and Semantic Webs for an Ambient Childhood Obesity Prevention System

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Abstract

Amid the extremely active Semantic Web community and the Social Web's exceptionally rising popularity, experts believe that an amplified fusion between the two webs will give rise to the next huge advancement in Web intelligence. Such advances can particularly be translated into ambient and ubiquitous systems and applications. In this paper, we delve into the recent advances in knowledge representation, semantic web, natural language processing and online social networking data and concepts, to propose an inclusive platform and framework defining ambient recommender and decision support systems that aim at facilitating cross-sectional analysis of the domain of childhood obesity and generating both generic and customized preventive recommendations.

Keywords: Ambient systems; Web Ontology Language (OWL); Social Web; Semantic Web; Recommender Systems; Biomedical Ontologies; Natural Language Processing; Childhood Obesity Prevention

1. Introduction

An Ambient Intelligent system is a system orientated towards community and cultural enhancement; it assists in building knowledge and skills to improve the quality of work, citizenship and consumer choice, [1]. On top of the largely generic technology requirements for creating Ambient intelligence (AmI), several research clusters have been proposed including “Meta-content services developments to improve information handling, knowledge management and community memory, involving techniques such as smart tagging systems, semantic web technologies, and search technologies” [1].

As a multidisciplinary effort that considers revolutionary advances in different fields related to web technologies, this research paper targets the design and implementation of an ambient system to assist in decision making for prevention of childhood obesity and related chronic diseases through a maximized collaboration between the Semantic Web in all its formal norms on the one hand, and the Social Web, in its ubiquitous aspects, on the other.

Childhood obesity and other diet-related chronic diseases are among the most serious public health problems of the 21st century; particularly in the modern industrialized societies with omnipresence of high-caloric foods [2]. A recent study [3] shows that in 2007 the prevalence rates of obesity and overweight among US children were 16.4% and 31.6% respectively, which indicates a 10% increase from 2003 and a more than threefold increase over the past thirty years. Moreover obesity is known as a leading cause for several diseases including metabolic syndrome (MetS), type 2 diabetes (D2T), cardiovascular diseases (CVD), and certain cancers. These diseases result from a misalignment between a biology evolved in response to food being scarce and uncertain, and a modern environment where abundant food of high motivational quality (those high in sugar, fat and calorie) have become more affordable and accessible than its more nutritional counterparts. It is thus essential to develop novel ways to organize knowledge to help individuals, health professionals, business strategists, and policy makers to envision communities' awareness of the multiple and interacting ways by which biological (i.e., gene, brain and physiology), and societal systems (e.g. education, health, agriculture, agri-business, media, and finance) collectively operate on a diversity of spatial and temporal scales to influence food and diet choice. Such a brain-to-society approach to obesity prevention [2, 4] calls for transformation through the whole of society, starting with individuals and families but encompassing healthcare and all sectors in society that shape lifestyle and environment. Efforts aiming to such whole-of-society (WoS) transformation are hampered, however, by the current state of population health, economic, and other societal data which are generally fragmented, out-of-date, unrepresentative, and unavailable at the point and time of decision. The aim of our decision support systems is to defy simplistic solutions for the complicated multilayered condition of childhood obesity through an integrated framework composed of several diverse knowledge domains along with multiple inter-related, yet distinct, models and simulation approaches. Recent development in ontology and knowledge modelling now make such an integrated knowledge architecture possible.

This paper proceeds as follows: Section 2 introduces some of the related work, and Section 3 provides an overview of our knowledge architecture and modeling platform where we lay a particular emphasis on our enriched backbone metadata repository that supports a multi-language and multi-profile model, relying on its underlined "meta-semantics" structures. To deal with the implicated large amounts of social data, an ontology-aware NLP (Natural Language Processing) layered strategy is also introduced, with an innovative "rule tagging assignment" method to minimize performance and accuracy concerns. In Section 4 we portray some particular system specifications along with a general introduction of the motives behind our proposed COPE (Childhood Obesity Prevention [Knowledge] Enterprise) [5] ontology and its major OWL 2 [6] expressive elements, with a few provisional conjunctive queries that influence our decision support tool. We finally wrap up with a conclusions section that includes a closing discussion along with possible future work.

2. Related Work

There are currently a few research projects focusing on automatic surveillance of obesity and its associated diseases. The European project EPODE [7] proposes a framework for analyzing community-based interventions for prevention of childhood obesity, and IBM's Smarter Planet Platform for Analysis and Simulation of Health (SPLASH) [8] in the USA has the goal of creating a platform that takes expert models of constituent real-world systems related to health, synthesizes and integrates those models to lead to an interoperating complex composite system model for policy-makers to try out alternatives in a low-cost responsive way. Most of the existing systems rely heavily on databases and syntactic approaches; our approach enables researchers and public health practitioners to perform semantic integration and querying. On the other hand, a review of the overall Semantic Web realizations for social networking reveals them to be mainly RDF-dependent, with limited reported OWL 1 constructs. These accomplishments contribute to the rise of important Semantic Web and social networking dual concepts, projects and ontologies; no explicit and formalized OWL 2 vocabularies and enhancements are disclosed. Mika in [9, 10] outlines expressivity and encountered issues with Social Network (SN) data representation methods, and reports wrong usages or abuse of constructs. In [11], Gruber highlights the Semantic Web's role in creating value data and points out the trade-off between value and cost (associated with inference depth), without looking into details of vocabularies and constructs. In general, there is a tendency towards low expressivity by avoiding complex constructs in Description Logics (DLs) [12] sophisticated languages, with arguments supporting the fact that low level semantics are amply adequate for the Social Semantic Web needs, and intrinsically linked to its wide adoption, with most algorithms essentially founded on graph pattern detection using very modest formal semantics. Correspondingly, RDF is used to express the vast majority of social semantic web data, and SPARQL to query it; RDF's graph-oriented nature soothes the cooperation process. A set of recommended linked data vocabularies is published in [13], with the RDF data model for structured data publishing and RDF links for data interlinking. An extensive description of the RDF and SPARQL relevant practices can be found in [14].

3. Knowledge Architecture and Modeling Platform

Our approach towards a more Semantic Social Web including dedicated ambient systems covers a variety of phases and layers, as represented in Figure 1. From the domain ontologies' specifications based on different suitable constructs, all the way through network data parsing and possible user interaction with rules and axioms tagging, different reasoning capabilities are underpinned. Here we highlight some of the most impacting aspects of the framework.

3.1. Ontologies and Knowledge Base Repository

A multi-language and multi-profile collaborating knowledge base repository is at the heart of the proposed framework. In this repository, a relational database schema based on W3C's Meta-Object Facility [15] (also one of the OWL 2 supported features) holds the different ontological semantics, with methods and techniques for the tagging and prototyping of axioms related to OWL 2 along with its language fragments (known as OWL 2 profiles [16]), and the Description Logics (DL) [12] constructs. Appropriate classification schemes are mainly obtained based on generic prototypes of the different constructs. Therefore, a certain construct or axiom in a given ontology can be attributed to one or many families or fragments. When needed, a particular language or profile’s axioms can automatically be projected and retrieved for appropriate processing and exploitation. Several factors contribute to attributing an axiom to a certain profile, and consequently extracting all axioms that fall under a given profile. Thus, the nature of the feature, the included DL operation, the location of the constructs forming a certain axiom (at the left hand or the right hand side), and the availability or absence of certain relevantly affecting elements, are all among the most influencing aspects. Accordingly, a set of entities known as the “meta-semantics” entities are used to identify the set of fragments and languages applicable to a given axiom, and point out to any additional pertinent condition, if applicable. These entities are designed in a way to be easily extensible, in order to encompass any future fragment or even language. While the algorithms and methods that allow this categorization procedure are beyond the scope of this paper, the intention behind such an approach remains to provide an optimal set of functionalities while retaining efficient results and satisfactory performance for complex tasks.

This Knowledge Base Repository in its different aspects serves as a backbone for the whole framework. Defined by the domain experts, its ontology or collection of ontologies are composed of wide-ranging sets of constructs and vocabularies. Within the scope of our application domain, the ontology in question is the COPE ontology to be described in Section 4. It comprises the domain definitions, classifications, relations and applicable rules used for an appropriate population process of the SN users, with data compatible with existing relevant SN ontologies (FOAF, SIOC, etc.[1]).

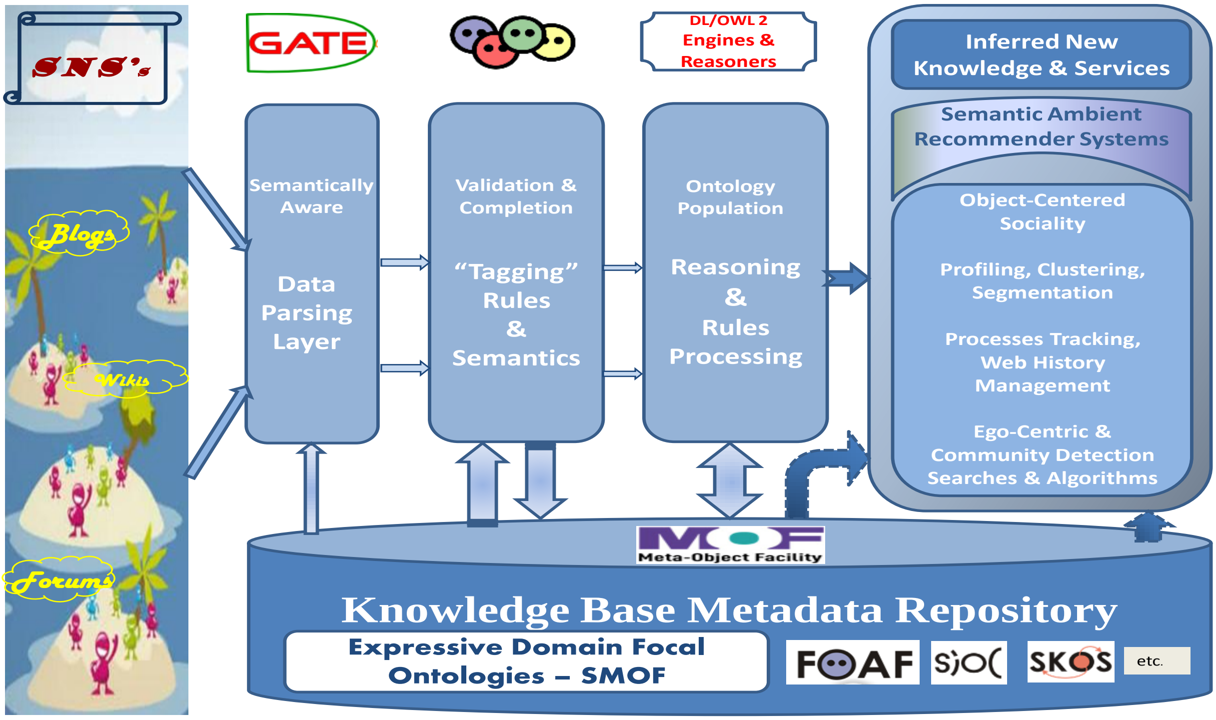

Fig 1. General overview of the proposed real-time knowledge-based architecture and modeling platform.

3.2. The Framework's Approach for Analyzing Online Social Network Data

The different Web 2.0 platforms (such as Twitter, Facebook, LinkedIn, etc.[2]) as well as conventional Web logs (blogs), wikis and forums websites all form adequate sources of online SN data to be exploited by our framework, with different levels of availability. We specifically rely on blog and forum posts due to their accessibility facilities, and predominantly on "mommy blogs" given the nature of their data (describing children problems, activities, behaviors, etc.) presenting particular relevance to our domain.

The data parsing layer targeting semantic information extraction from the available SN data is based on GATE (the General Architecture for Text Engineering) [17], which is considered as one of the most mature NLP platforms. The effectiveness of using GATE for ontology-aware language processing has already been demonstrated within several studies and projects (such as KIM [18]). In the scope of our framework, and as a consequence of this NLP phase, a (semi) automatic creation of the semantic annotations that correspond to the available medical and social ontological knowledge is generated.

3.3. The Social Network User "Rule Tagging" Role

[1] foaf-project.org; sioc-project.org; w3.org/2004/02/skos
[2] twitter.com; facebook.com; linkedin.com; friendster.com;

Ideally, a straightforward fully automatic ontology population with instances assigned based on the ontology-aware NLP grammars allows the populated ontology to be readily exploitable by the different OWL reasoners. Constraints and considerations related to the length of the massive social data in question, as well as to the level of expressivity and complexity of the ontology's semantics stimulate the conceptualization and adoption of a more flexible and beneficial strategy that aims at overcoming or at least limiting the different constraints' significance. It suggests a more progressive role to be held by the SN User who is accordingly encouraged to explicitly authenticate and even communicate meaningful expressive rules based on provided suggestions. We describe such a role with the terminology of "rules tagging" assignment, enthused by the different SN tagging systems - for instance Flickr and Del.icio.us[3] - that make it possible for users to tag their photos, documents and webpages with simple descriptive taxonomies. Accordingly, the provisional output resulting from the described NLP strategy consists of constructed templates of preliminary non-validated sets of semantics including identity relations and rules. These are made available in a user friendly questionnaire form communicated for the Social Networking Sites (SNS) users to optionally confirm, correct or even add more expressive axioms and details.

Although not mandatory, this semi-automatic approach is deemed extremely advantageous, especially for dealing with complex semantics for which the available NLP technology has severe restrictions. A strategic workflow that supports and extends this approach to allow specific treatment of massive social data has recently been described in [19]. The overall flexibility thus provided at both the data and semantics levels limits the accuracy concerns encountered in traditional NLP approaches. Recommender and decision support systems capabilities make use of the populated ontology along with its rules and semantics. By exploiting the typical reasoning services elucidated in [12], such as classification and subsumption, satisfiability and instance checking, inference discovery and query answering, rule validation and processing, our ambient system attains its goals.

4. System Specifications – Emphasis on Semantic Aspects

The ambient systems conform to our proposed framework are generic applications presenting services to the masses of SN users. An important characteristic of the system is that it heavily relies on the semantic aspects presented through our knowledge base. We will now highlight some of them, concretizing the way they were implemented in the system.

4.1. The COPE Ontology

The core ontology represented in our framework is the COPE ontology. It comprises the domain definitions, classifications, relations and applicable rules. Due to the interdisciplinary nature of the domain, the COPE ontology forms an integrated knowledge base consisting of nutrition, obesity and chronic diseases, behaviors, media, and marketing. It has been implemented on the basis of several textual resources, existing controlled vocabularies and thesauruses, blogs and databases [5]. The COPE ontology can be used in various knowledge-based systems at both individual and community levels. It can provide a semantic backbone for a healthy diet recommender system to promote healthy eating habits. The dietary recommendations can be performed not only based on the Canadian Food Guide[4], which mainly focuses on the amount and types of foods[5], but also on other important factors personalized to the individuals' information (e.g. income, dietary restrictions, behaviors) and environmental parameters (e.g., family- and parent-associated interventions). As demonstrated in Figure 2, the COPE ontology can provide the semantic backbone for our intelligent recommender system that employs the c*ollaborative filtering* [23] technique. The users in this figure are moms who actively participate in online SN using mother-focused sites and other related online communities.

By means of collaborative filtering along with intelligent agents and their learning ability in an argumentative framework, we are allowed to automatically predict users' interests by looking into the information that is collected from several users in a domain of interest (network). Semantic bridging between two or more networks combined

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[3] flickr.com; delicious.com;
[4] http://www.hc-sc.gc.ca/fn-an/food-guide-aliment/order-commander/eating_well_bien_manger-eng.php
[5] http://www.hc-sc.gc.ca/fn-an/food-guide-aliment/choose-choix/advice-conseil/child-enfant-eng.php

with the background knowledge provided by ontological axioms and rules enables us to acquire a functional understanding about the implicit relationships between different components within the networks (e.g., the correlation between children's dietary patterns and parental behaviors or parental obesity status).

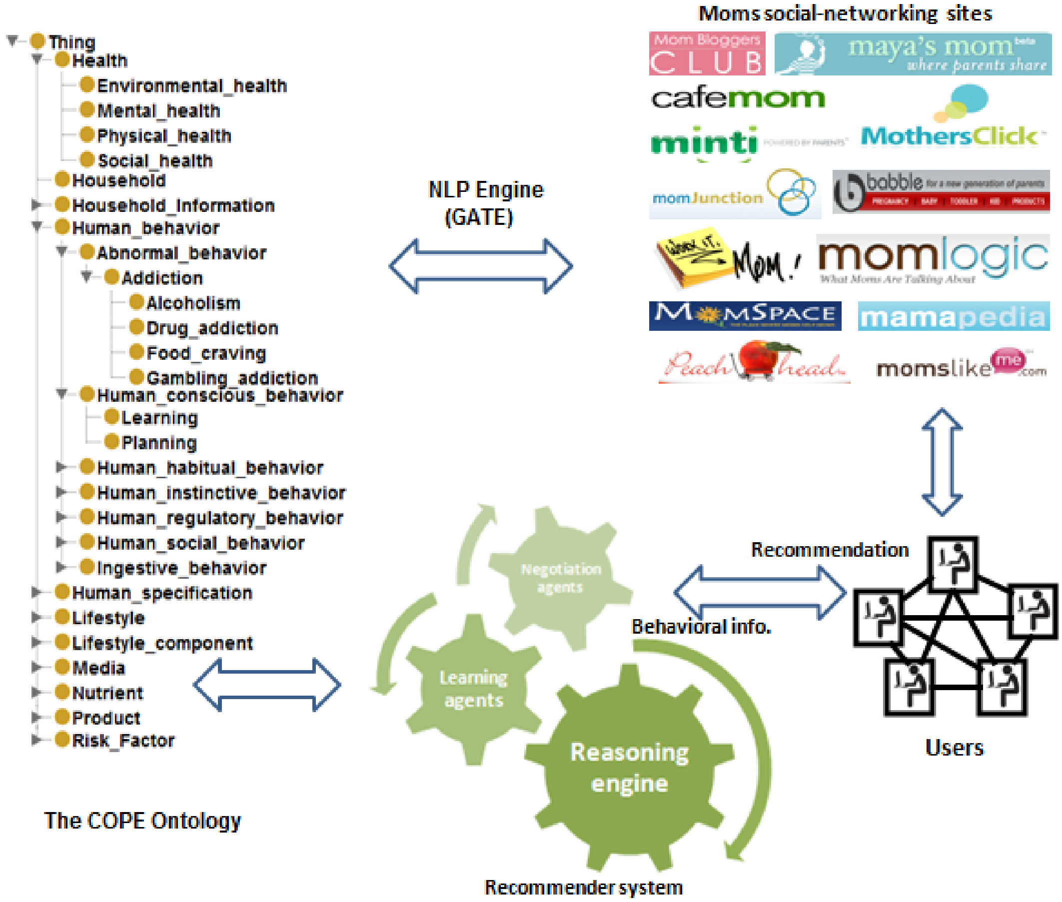

Fig. 2. COPE ontology as basis for appropriate recommendations based on inferred knowledge from users' behaviors and activities.

As an example, if several moms who actively participate in one or more SNS report "hyperactivity" in their children after consuming sugar-sweetened soft drinks, the recommender system may refer them to the ontology-inferred knowledge that says: sugar-sweetened drinks increases the risk of obesity, type 2 diabetes and metabolic syndrome, but there are no sufficient evidence [20] to support their relation with "hyperactivity" in children.

4.2. Main OWL 2 Features

OWL 2 features [6] have been applied to our COPE domain ontology, providing a superior level of semantic significance. Description Logics (DL) being a family of knowledge representation languages [12], the expressivity level of the COPE ontology has been considered to fit into the *SROIQ(D)* [21] DL family. *SROIQ* is a highly expressive, yet decidable language, covering extensive sets of grammars and constructs that form the basis of OWL 2. Table 1 below highlights OWL 2 enhancements that had a direct impact on the modeling of our domain ontology. These features fall into the following categories: syntactic sugars, aiming at a simpler way of conveying information, new properties' constructs for maximized expressivity, extended datatypes support, and metamodeling and various other capabilities. Note that there is no correlation between the different table columns.

Despite the fact that in certain cases, a lack of appropriate querying support was encountered, the OWL 2 additions proved to be beneficial for our application needs. Major developments in properties' constructs helped overcome previous weaknesses in OWL 1 on the one hand, and the witnessed extensions and the "syntactic sugars" proved to be considerably profitable for our domain on the other. This was primarily due to the nature of information available in SN websites, and the writing style adopted in the blogosphere.

Table 1. Summary of COPE OWL 2 Implemented Features per Category

Syntactic Sugars	Properties Constructs	Datatype &Other Extensions
Disjoint Union	Self Restrictions	Extra Datatypes
Disjoint Classes	Qualified Cardinality Restrictions	Restrictions on Datatypes
Negative Object Property Assertion	Irreflexive Object Properties	Definitions and Ranges
Negative Data Property Assertion	Asymmetric Object Properties	Data range combinations
	Disjointness	Extended Metamodeling (Punning)
	Chain Inclusions	Extended Annotation Capabilities
	Keys	

4.3. Social Network Data Analysis

To illustrate the outcome of our SN data analysis strategy, Figure 3 represents sample extracts from blogs with meaningful ontology annotations.

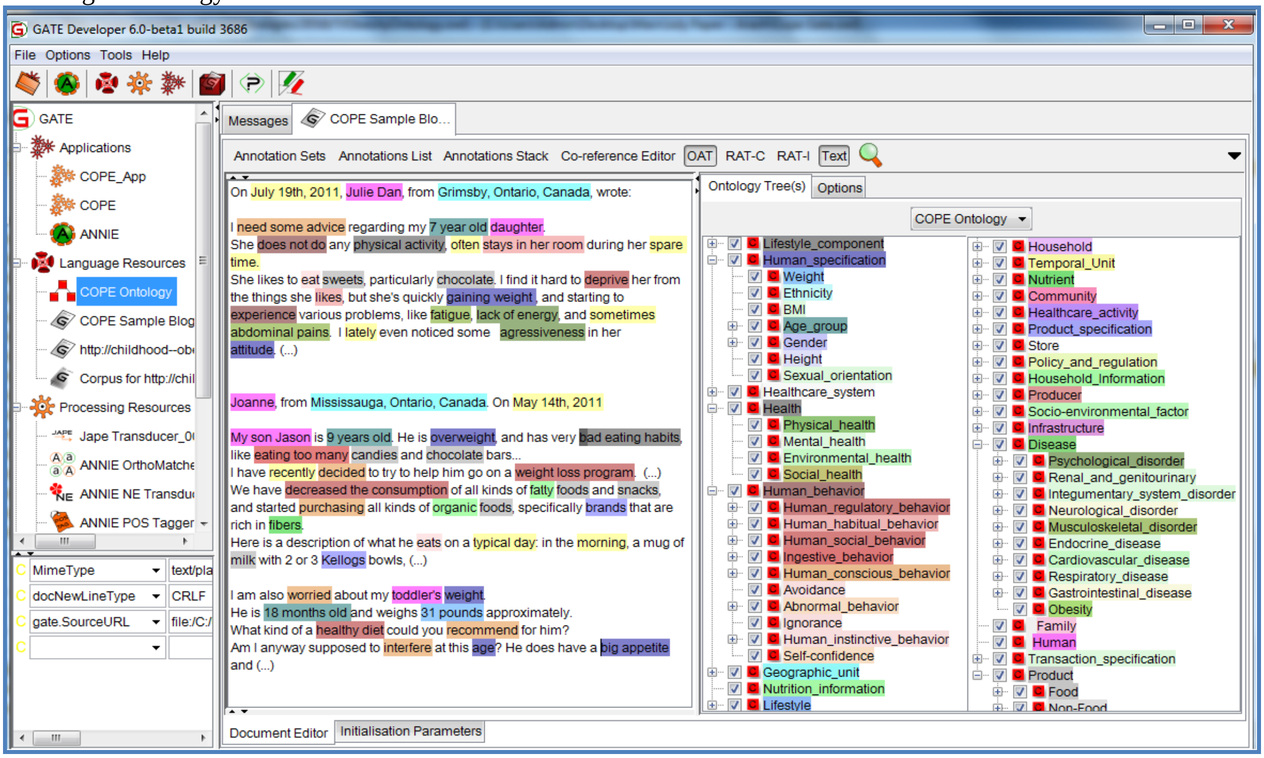

Fig. 3. Sample processed annotations using GATE. (Note that the results have been shown in different color codes)

In this illustration, original markups and default GATE PR annotations are merged with ontological elements from the COPE Ontology to detect geographical and temporal units, humans' names, household, health, and lifestyle data, behavioral information, products and food types, etc. Figure 4 concentrates on identified properties along with their values, as assigned to a certain "Human" retrieved individual. Pertinent examples of semantic data processing within the scope of the COPE project can for instance consist of the identification of individuals that have children with diet-related problems, and/or who might be presenting certain abnormal behaviors or health symptoms; the classification of individuals in the ontology according to several factors, including gender, age, BMI, etc.; the retrieval of types of foods frequently consumed by individuals, of bad eating habits, of popular brands per certain date periods; the recognition of certain individuals' geographical location, or more meaningfully the type of area at which they reside (urban, countryside, etc.); the detection of the physical activities practiced by children, of certain individuals with a family history of obesity, and so on. The illustrated result is obtained further to a user collaboration role incorporating rule tagging and validation of preliminary automatically processed results.

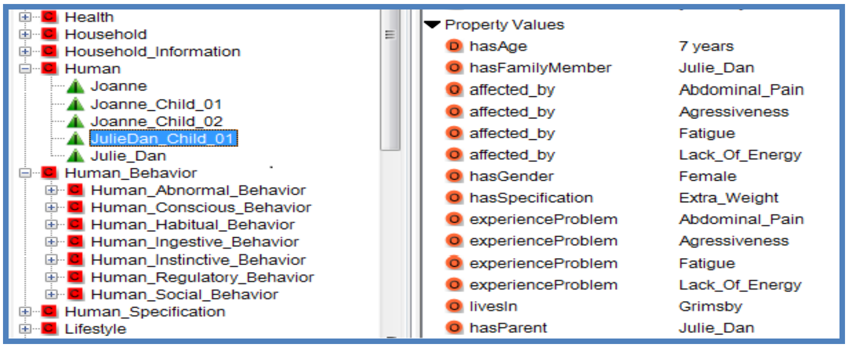

Fig. 4. Sample individual properties and values.

4.4. Semantic Querying

The system functionalities consisting in searches, inquiries and suggested recommendations are deduced based on the adopted COPE OWL 2 ontology, through conjunctive queries and rules, examples of which will follow. These are all based on parts of our knowledge base KB = (*T*, *A*), where *T* is a restricted finite set of inclusion and functionality axioms, called *TBox*, and *A* is a finite set of membership axioms, called *ABox*. A conjunctive query is a conjunction of atoms or query conditions, where every atom is either a simple, logical operator-free description logic formula, or its negation. It is composed of the structure $\exists y\ \varphi(x, y)$, where φ is a conjunction of atoms and x and y are variable or individual names; a query atom can take one of the following forms:

- *C(x)* or ¬ *C(x)*, where *C* is a class name, and x is a variable or an individual's name
- *R(x,y)*, where *R* is a property name, and x and y are individual or variable names

The KB depicted below, followed by Table 2, contain a subset of sample axioms, queries and rules:

(1) has Age(Sara_Miller, 12) → Child (Sara_Miller)
(3) Disease (Obesity)
(4) affectedBy (Sara_Miller, Obesity)
Child(x) → Human(x)
Child(x) ∧ affectedBy(x, Obesity) → currentlyRisk (x, PoorSelfEsteem)
Child(x) ∧ affectedBy(x, Obesity) → currentlyRisk (x, NegativeSelfImage)
Child(x) ∧ affectedBy(x, Obesity) → currentlyRisk (x, SocialIsolation)
Child(x) ∧ affectedBy(x, Obesity) → currentlyRisk (x, PeersTeasing)
Child(x) ∧ affectedBy(x, Obesity) → currentlyRisk (x, SadnessFeelings)
Human(x) ∧ affectedBy(x, Obesity) → hasFutureRisk (x, CVD)
Human(x) ∧ affectedBy(x, Obesity) → hasFutureRisk (x, ElevatedBloodLipidLevel)
Human(x) ∧ affectedBy(x, Obesity) → hasFutureRisk (x, HighBloodPressure)
Human(x) ∧ affectedBy(x, Obesity) → hasFutureRisk (x, TypeIIDiabetes)

The KB query allowing the retrieval of inferred risks of psychological and medical diseases based on the fact that Sara Miller is a child who suffers from obesity (Axioms (1), (2), and (3)), is the following:

$$Q_1(x) = (PsychologicalDisease(y) \wedge currentlyRisk(Sara\_Miller, y)) \vee (MedicalRisk(z) \wedge hasFutureRisk(Sara\_Miller, z))$$

Table 2. Sample queries and rules along with their interpretation

Conjunctive Query/Rule	**Interpretation**
$Q_2(x) = \exists x\ (HumanChild(x) \wedge livesIn(x, Downtown\ \_Montreal) \wedge affectedBy(x, ElevatedBloodLipid\ Level))$	Localizing children residing in a certain area type and suffering from a particular health problem
$Q_3(x) = \exists x, y(Child(x) \wedge food(y) \wedge promotedOn(y, TV) \wedge hasEatingBehaviour(x, y) \wedge affectedBy(x, FoodCraving))$	Recognizing a product that promoted on TV & included in the diet habit of a child presenting a "Food Craving" behaviour
$Q_4(x) = \exists x((Product(x) \wedge hasSpecification(x,highCalorific)) \wedge \neg (\exists hasGoodEffect\{typeIIDiabetes\}(x)))$	Retrieving the nutrients children suffering at the same time from diabetes and obesity are to cut down from their diet
$Q_5(x) = \exists x\ (Food(x) \wedge hasGoodEffect(x, Metabolism\ Boosting) \wedge \neg (\exists hasBadEffect\{HighBloodPressure\})\ (x))$	Enumerating foods that boost the metabolism while not leading to an increase in blood pressure
$Human(x) \wedge skipMeal(x,Breakfast) \rightarrow HasBadDiet\ Behaviour(x)$	Simple rule expressing the fact that skipping breakfast is a bad dieting behaviour
$\exists x\ (Human(x) \wedge hasEatingBehaviour(x, SaltyFood) \wedge hasFamilyHistory(x, HighBloodPressure) \wedge \neg (\exists perform\ \{PhysicalActivity\}(x)) \rightarrow hasHighFutureRisk(x,HighBloodPressure)$	Rule defining the factors that highly risk to cause an increase in blood pressure

These KB components all serve the primary goal of our proposed knowledge-based surveillance system by describing and monitoring the prevalence of childhood obesity. They capture the condition's associated diseases and diet-related conditions along with the various risk factors that emanate from the economic and societal sectors that impact health outcomes.

5. Conclusions

In this manuscript, we have introduced the key components of a social semantic ambient system aiming at monitoring the prevalence of childhood obesity along with its associated diseases and diet related health conditions, minimizing the various risk factors that emanate from the economic and societal sectors that impact health outcomes. Our knowledge base, henceforth enriched with semantically engineered social data, is consequently accessible for further extensive reasoning and analysis. The outcome reached surpasses by far the sum of its social and semantic data components, typically leading to significant services and recommender systems.

Analogous features accessible through this semantically engineered social data and possibly serving the purposes of recommender systems include the ability to perform:

- User profiling, clustering and segmentation based on certain traits and criteria, all of which are endeavors considered closely related to opinion mining undertakings.
- Tracking processes to identify a user's Web history from different Web 2.0 platforms, outlining this user's general overall contributions to the Web and reporting their different activities, goals and problems.
- Improved quality of the search process, with ego-centric algorithms and searches to identify a key user's associated or closely related nodes, as well as community detection algorithms to trace two or more key users' surrounding community.

The key contributions of our research can be briefly summarized in providing:

- An inclusive approach and framework, with its comprised layers and methodologies.

- A multi-language and multi-profile knowledge base repository, endorsed by a "meta-semantics" model.
- A layered strategy for applying ontology-aware pattern matching NLP grammars.
- A "rule tagging assignment" Web 2.0 user collaboration role.
- An extension of the COPE ontology enriched by OWL 2 features.

In terms of future work, our aim is to further exploit this proposed framework and accomplish in-depth analysis, comparative studies, performance and functional experiments that involve various Semantic Web technologies. We plan to pursue fostering our efforts that include implementation and verification tools, with an incorporation of maximized sets of rules and Description Logics-based fragments.

Acknowledgements

COPE is a part of the Brain-to-Society (BtS) [2, 22] research agenda within the McGill World Platform for Health and Economic Convergence (MWP) [24] initiative.

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