Smart Bin for Incompatible Waste Items

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***Abstract*—In this paper, we present a generalized ontology based system to identify the necessary properties of products and objects and then make inferences of possible incompatibilities between them. This is designed in the context of waste management, where considerable volume of waste is present collectively and there may be chances of hazard or reduces the value of the recyclable waste. These inferences for the group of objects are performed based on the knowledge available locally without looking up from any external sources. Since, the global identification of objects is avoided, preservation of privacy is ensured, which is a concern in the field of pervasive computing. Our model can have applications in various domains. We have demonstrated it's application in the domain of waste management and discussed about other possible domains.**

Keywords-Radio-frequency identification (RFID); incompatible; ontology; OWL; waste

I. Introduction

Today, efficient management and handling of waste are of great importance. The European Union (EU) reports handling around 3 billion tonnes of waste (and still counting) each year among which, around 90 million tonnes are hazardous [1]. So managing the waste i.e. treating and disposing them efficiently causing least possible harm to the environment is becoming difficult. Waste prevention, recycling/reuse and disposal are the three principles laid down by the European Union's approach to waste management. For example, products like packaging waste, batteries, electrical and electronic wastes require special attention for recycling and reuse. Some of these items can be hazardous to be put into a waste bin containing other items.

Sorting is performed for efficient recycling and reuse of the waste materials. Different waste items contain recyclable and reusable materials having economic value. Hence, sorting them at the earliest has advantages. Moreover, it also ensures the quality of the collected waste with no contamination. It also avoids potential hazards. Transporting them to the sorting facilities could be another overhead to cost if not performed early. Lastly they might end up as landfills, if left undetected.

Despite that the early sorting could be beneficial, we need to reason out for the sorting process. Also, care should taken about any possibilities of hazards during this process. The model described in this paper can be used to perform such reasoning.

The rest of the paper is organized as follows: Section 2 presents the background. Section 3 describes the principle for inferring hazardous incompatibilities and how the system is designed to use the principle in Section 4. A demonstration of our Smart Bin and other possible applications are presented in Section 5. Finally, we discuss the complexity of our system before concluding in Section 6 and 7, respectively.

II. Background

Lately, there has been considerable efforts to increase the cost effectiveness and efficiency of waste management system with the advancement of technology. As described above, the sorting process can be handled efficiently and smartly by using information technologies.

Radio-frequency identification (RFID) is currently an upcoming and rapidly growing mobile technology for the purpose of uniquely identifying and tracking an object attached with a RFID tag. Some RFID tags can be read from several meters away and could be beyond the line of sight. They can also be bulk read and costs from a few cents to a few dollars [3], [4]. These tags are now widely used in various fields like asset tracking, manufacturing, supply chain management, retailing, payment systems, security and access control etc [5].

RFID's have also been considered to be used for better waste management. In RFID and sensor based real-time Automatic Waste Identity, Weight and Stolen Bins Identification System (WIWSBIS), the authors have proposed the use of RFID tags in an environmental context [3]. They have used RFID tags to identify the waste bins, uniquely and remotely. RFID supported waste management and load cell sensor technology are used to automate the billing for customers on pay-per-use basis. While this is a paper where all the information processing has been done at the bin level, we have not come across any work that makes inferences at the item level i.e. based on the contents.

The trend of pervasive computing is transforming more and more everyday used objects smarter with embedded technology and connectivity. *Cooperative Artefacts* is a smart container system where the authors have proposed that the chemical containers are able to assess their situation in the world, without requiring any supporting infrastructure in the environment [10], [11]. The movable artifacts can make rule-based inference based on its embedded domain knowledge and perceptual intelligence. The knowledge is stored in a distributed way across the artefacts. So, communication with the artefacts in proximity might be required frequently to obtain the necessary information before making inferences.

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The goal of pervasive computing, which combines current network technologies with wireless computing, voice recognition, Internet capability and artificial intelligence, is to create an environment where the connectivity of devices is embedded in such a way that the connectivity is unobtrusive and always available.

Internet of things (IoT) is a concept where smart devices interact and communicate with other devices, objects, environment and infrastructures. The authors proposes an application for pharmaceutical system for detection of interaction and improper administration of drugs to patients [17]. The drugs are NFC tagged or bar coded for identification and matching with the remote information system. to detect the suitability with patient's health condition. It works within the IoT paradigm.

In our work, we have proposed an ontology based knowledgebase, which is used to describe the properties and make inferences about the incompatibilities among objects. This knowledgebase is local and powerful enough enabling autonomous decisions. Our objects are passive in nature due to the type of RFIDs used. By contrast, [10], [11] proposes active objects by use of sensors.

III. Hazard Detection Principle

Pervasive computing is the growing trend of progressing beyond the idea of personal computing. Objects used everyday have embedded technologies attached, to perform smarter activities collectively. We have proposed to self describe waste items with their properties using RFID tags. Based on these properties, incompatibilities could be detected among a collection of items present locally. In this section, we discuss its underlying principle. For the purpose we begin with organizing the waste domain in a specific manner for making such inferences.

A. Describing waste items

The waste domain can be categorized based on their various hazardous properties. There are standards that specifies the properties of waste materials and categorizes them [2]. Although, discussion on such standards is outside the scope of this paper, however we utilize its idea for categorization and use few examples of hazards related to some of these categories.

Some examples of hazardous properties for this domain are spark, explosion, toxic fumes etc and can categorize based on them. As discussed in the previous section, we are interested to infer incompatibilities. So, it is essential to pick the properties only that are relevant for interactions with other items.

Figure 1 is the pictorial representation of the three conditions under which these properties can act in hazardous ways. They are summarized as below:

- under effect of: the condition(s) which holds the properties that can affect the category
- can cause: this condition enlists the properties that can be caused by the category
- in presence of: this holds the external conditions under which the **can cause** properties occur

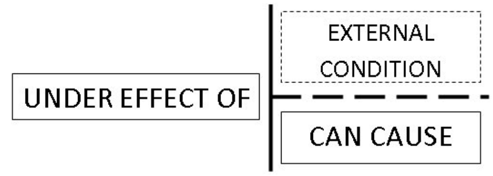

Fig. 1. Conditions to describe a category

In the subsequent sections, we will use the same pictorial representation to describe the waste categories or items in our examples.

Let us take some scenarios of interactions between categories. First, let's take an example of simple incompatibility between a pair of them. Suppose a category *A* can cause an incidence (for instance say hazardous property X) that affects a second category *B*. Hence, an incompatibility exists between the categories *A* and *B*. Our second example is a slightly more complex and realistic than the previous example. If the category *A* causes the incidence (i.e. X) only in presence of an external condition (let's name as C), makes it an important augmentation to the scenario. Hence, the categories does not pose to be incompatible if the condition C is unfavorable. Both of these scenarios consider the incompatibility between different categories where the hazardous property affects each other. However, there are properties like explosion for example, which have hazardous effect by itself. The situation can be represented as a category that causes a hazardous property that affects itself that may depend on the external condition.

B. Inferring incompatibilities

As described above, we can self describe waste items accordingly. When a collection of these items is present locally we can infer incompatibilities based on the discussed scenarios. Sometimes objects are located remotely and communicate within themselves and other knowledgebase using network infrastructure like the Internet to make decisions. Such an idea is called Internet of things (IoT) in the field of pervasive computing. Our approach in this paper proposes making the required information that describes waste domain available locally for inferences. Such collective inferences could be made without using network for communication. We prefer to use the name for such a situation as Intranet of Things (InoT) as it does not involve any devices located remotely and differentiate to avoid confusion.

In III-A, we discussed the interaction scenarios between pairs of categories based on hazardous properties. Multiple such categories can constitute an InoT. The graph in Figure 2 represents an example of InoT formed. The shaded nodes represent some categories. They are connected by an edge if they interact. The dotted edges represent interactions which are unfavorable due to external conditions. One of the external conditions were high temperature at the instance this snapshot was drawn. Hence, the dotted edge encircled in the figure representing an interaction under low temperature becomes unfavorable. The firm edges represents favorable interactions, which could be either the first or second scenario described in III-A. The shaded node with a self-loop represents the last scenario of III-A, is favorable in this case as the external condition is satisfied.

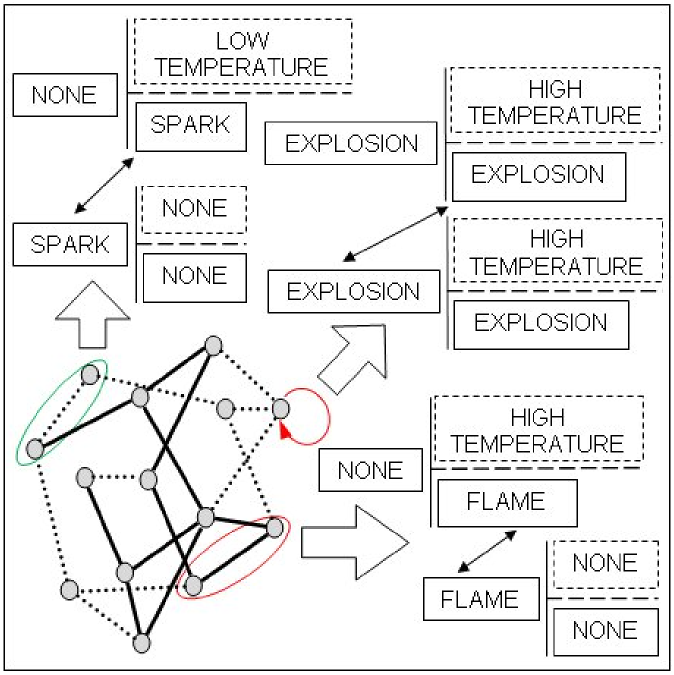

Fig. 2. InoT formed

Finally, if a waste item belongs to one or more categories, it would possess all their conditions. Hence, they could be used for collective inferences also.

IV. System Design

In this section, we describe designing the system for making inferences locally. It essentially means that all the information required are available without referring to remote database or knowledgebase. An alternative could be to distribute the information partially among the waste items and a local knowledgebase. The waste items are identified by the system before inferring on incompatibilities. We have chosen a commonly used architecture for our system, as shown in Figure 3 below.

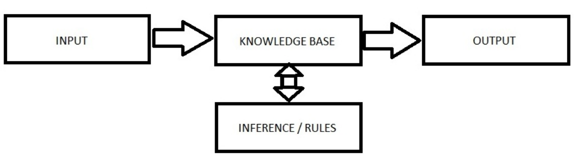

Fig. 3. Commonly used Architecture for Systems

We describe the components briefly.

- Input: It is that point in the system where the waste items are identified and added.
- Knowledge Base (KB): This contains all the required information to identify the items along with their properties. It also updates its knowledge regarding the presence of items that are being added to the system incrementally.
- Inference/Rules: This component of the model uses the KB to reason out about the possible incompatibilities and hazards. The inferences are added back to the KB.
- Output: It sends out notifications to communicate about alerts and warnings to the users of the system.

Next we elaborate on how the system works based on the architecture and uses the principle discussed earlier in Section III.

A. Input

New waste items are added to the system. They are affixed with RFID tags only for the purpose of identification by the system, which contains a RFID reader for scanning. The tags do not contain any such data that has privacy concerns. Mostly they contain the category information.

B. Knowledge Base (KB)

Machines can be made to perform reasoning effectively provided it has the necessary knowledge, which is machine readable. In cases of large domain knowledge with lots of factors influencing the reasoning, using machines should have extra benefits. Using ontologies are a very good way to serve the purpose [7]. An ontology consists of common set of vocabulary as shared information of a domain. It includes machine-interpretable definitions of basic concepts in the domain and relations among them [8]. Lately, the development of ontologies has begun to find many uses outside the Artificial-Intelligence laboratories. They are being commonly used on the World-Wide Web and finds applications for sharing information widely in the field of medicine.

The Web Ontology Language (OWL) is a World Wide Web Consortium (W3C) Recommendation for representing ontologies on the Semantic Web [6]. Presently, there are a lot of ontology editors for OWL. Among them Protégé is a Java based Open Source ontology editor. We used Protégé since we found it to be an efficient and user-friendly tool to prototype our ontology rapidly. During the ontology development phase we visualized the graphical representation of our OWL ontology on the editor. The comprehensive Java API provided by Protégé [12] was also an added advantage while developing our stand-alone application in the later phase.

We have used an ontology based approach for the KB for the reasons stated above. The properties causing incompatibilities must be described in the ontology. Apart from these, other information like conditions in which the categories are incompatible, possible hazards of incompatibility etc are also stored in the ontology.

Due to the advantage for describing a domain easily, we have used ontology based approach for describing the waste domain. The ontology contains description of various categories with the conditions for hazardous properties. This constitutes as the initial knowledgebase of the system, which updates itself as new items are added.

For detailed demonstration, we have used a sample OWL ontology using few hazardous properties, conditions including an external condition to demonstrate the inference of incompatibilities between objects.

We start with building our KB using *Object properties* of OWL ontology that would represent the conditions. As mentioned earlier, a category is described to have various properties under three different conditions. Mapping and comparing Figures 1 and 4 would make the idea very clear.

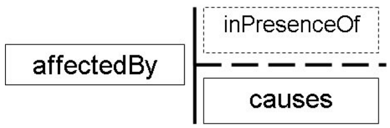

Fig. 4. Object properties as mapped in OWL

Next we define two *Data properties* in the ontology namely *hasStatus* and *hasTemperature*. While the first one can store values of type boolean and acts as a flag, the other is used to hold integer data as in Figure 5. They are used to express the external conditions as explained subsequently.

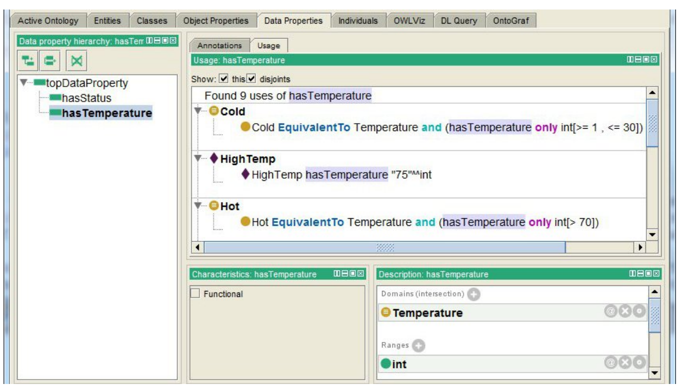

Fig. 5. Data property *hasStatus*

The left side of Figure 6 shows the representation of a domain knowledge using hierarchy of classes in ontology. The class *Waste* is the topmost level in our ontology structure and hence, all its subclasses would represent information of this domain. Following are the description of its subclasses and the information it holds:

- *Properties* list the various instances representing the hazardous properties of the domain. It also includes some external ones like temperature, pressure etc.
- *Categories* represent the classifications of the waste domain. Each of these categories are represented as classes in ontology along with the description of conditions. The RFID tagged waste items added contains reference to these categories. They are added to the system as individuals of the referred subclasses.
- *Hazardous* contain all the incompatible or hazardous items. It's subclass *selfHazardous* holds items that could pose hazardous by itself. They would be subsumed by the upper class. The user can glance through all the incompatible objects added to the ontology.

The right side of Figure 6 displays subclass *Properties* containing the list of seven properties that are possible with this domain. Examples of OWL individuals such as *Explosion*, *Flame* etc. are some possible properties. *None* represents a special kind of property, which indicates no conditions at all.

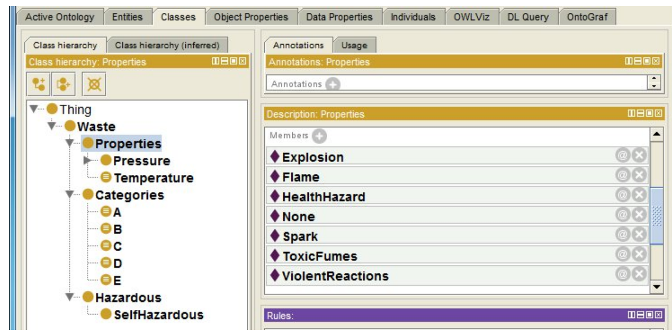

Fig. 6. Sample Ontology with Classes and Conditions

The Figure 7, we have listed examples of five different types of categories named *A, B, C, D, E* subclassed under *Categories* as examples. It should be noted that each of these five classes represent the types of categories possible in the domain described with the conditions of hazardous properties. They are described in form of relationships with individuals of the class *conditions* using the *OWL object properties*.

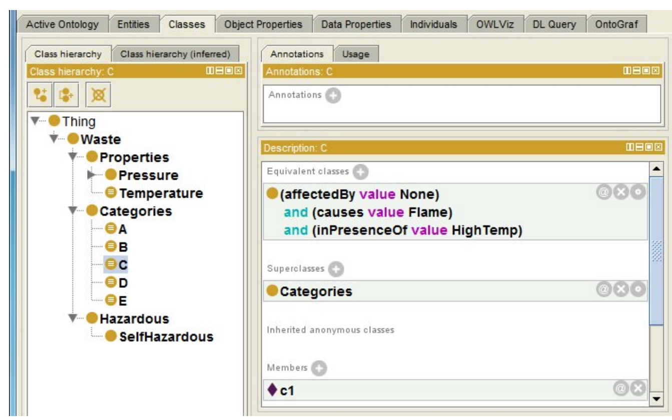

Fig. 7. Describing Categories

In Figure 8, shows an example to represent temperature as an external condition for incompatibility of objects. In this example, we have three individuals of the class *Temperature* as *LowTemp*, *ModerateTemp* and *HighTemp*. They are linked to the two data properties, *hasStatus* and *hasTemperature*. The *hasTemperature* property basically defines the temperature ranges it represents. The *hasStatus* property can be set to *true* for any one of the instances which would indicate that external temperature around the system. Hence, from this way of representation we can indicate discretized levels of some external conditions and the one prevailing around the system.

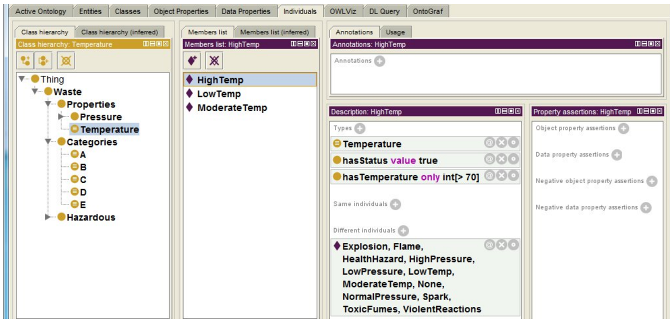

Fig. 8. External Conditions

The class *Hazardous* consists of a subclass *SelfHazardous*. *SelfHazardous* contains all the items that are self hazardous which would be subsumed by the upper class as well. Additionally the class *Hazardous* holds all pairs of incompatible items that are inferred hazardous. In fig 9, we see there are currently one pair of item *c1, d1* that exhibit possible incompatibility under an external condition of *HighTemp*.

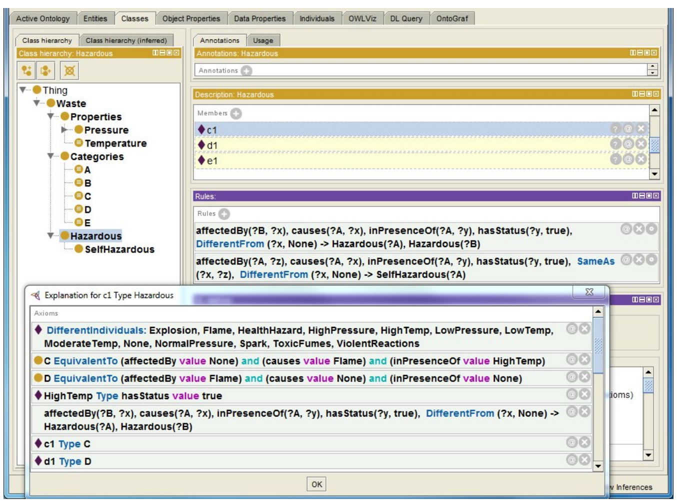

Fig. 9. Dashboard

C. Reasoning/Rules

Given the ontology, which acts as a KB in our architecture, we are all set with having all the necessary information at hand to reason out something useful i.e. the objective of inferring incompatibility or hazards. In the recent years, rule languages have been added on as a layer combined with ontology in order to enhance the reasoning capabilities. Semantic web Rule Language (SWRL) is used to write rules expressed in terms of OWL concepts and for reasoning about OWL individuals. It provides a deductive reasoning specification that can be used for inferring new knowledge from the Knowledge base.

We have used two SWRL rules to make selection of the proper objects and classify them as members of specific class. The first rule is used to classify all the item pairs that may have incompatibility considering if the the external conditions are favorable. In that case they asserted as members of the class

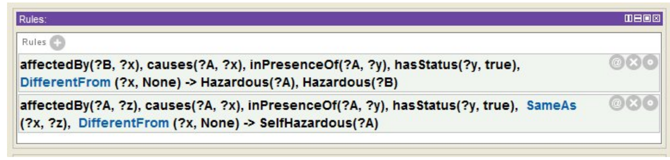

Fig. 10. SWRL Rules

Hazardous. The first rule in fig 10 performs this classification. The second rule verifies if an item is self hazardous with favorable external condition. If it's so, the item is asserted as member of class *SelfHazardous*.

V. Applications

We have proposed the system using ontology as it's local knowledgebase to infer incompatibilities on the principle of InoT. We think that it can be used to infer incompatibilities among objects in various domains. "Bin That Thinks" is a project, that aims to propose an intelligent waste management solution based on item level identification. The goals are to improve recycling efficiency, reducing waste processing cost and avoiding hazardous situations [16]. Though we have not assessed for the financial benefits figuratively for using our system, our approach hints at the benefits qualitatively. Sorting wastes at the earliest retains the purity of the recyclables. This reduces the cost of sorting at a later stage in processing plants by waste management companies like Veolia, which is usually passed on to the consumers as penalties on the cities.

Fig. 11. Smart Bin

We have developed an application for the domain of waste management using the system described in this paper. It can be used to make inferences for incompatibilities and hazards among the waste items present collectively at a place. They may be situated inside a bin or a waste collecting vehicle or at the processing plant. For very complex domains like waste management, they are sometimes verified at every step in the processing chain. Alternatively, when the processing is performed at a single point, we consider the acceptance of

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error up to some limit. Fig 11 shows the smart bin developed that can identify the RFID tagged wastes and make inferences from its contents. In fig 12 below shows a screenshot of our application. It shows the instance when an incompatibility is detected with two items present locally in the bin and the last item that was scanned. It also displays the inferred reasoning.

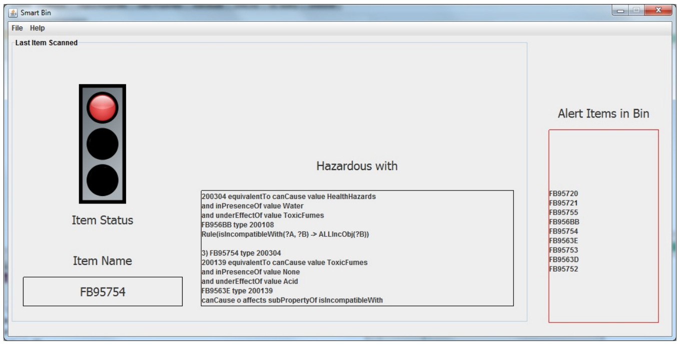

Fig. 12. Hazard Detection Application for Waste

Another domain of application for our model can be in the field of medicine. Storing medicines together can sometimes be potentially dangerous. It might also lead to confusion and take wrong medications. The elderly people and children are more vulnerable to such mistakes. Also some medicines might react with each other ('interact') if taken together and might cause serious problems.

VI. Complexity

The OWL from the W3C has capabilities to describe concept from very simple to quite complex ones. It provides with a variety of features to express some domain of interest. OWL ontology has has three different types of sub-languages namely OWL-Lite, OWL-DL and OWL-Full. These sub-languages differ in the amount of features incorporated in it and hence, have varying degrees of expressiveness. W3C provides a description of the features to be used for OWL-Lite compared to OWL-DL or OWL-Full [6]. The profile for our model gets disqualified from being OWL-Lite as we have used OWL individuals to occur in descriptions or class axioms i.e. by using the value constraint owl:hasValue [6], [13], [15]. The OWl-Lite has computational complexity of polynomial order whereas the rest grows exponentially [14]. So, it essentially means that the computational complexity of our model can be calculated to grow exponentially with increase in the ontology size. This is important in the context of pervasive computing as the setup would be functioning on embedded computers, which have limited memory and computational capabilities.

VII. Conclusion

In this paper, we demonstrated a system to infer the incompatibilities between collective waste items. As discussed earlier, the model can have applications in various domains. Presently, we have designed to make inferences particularly for the domain of waste management. In the context of waste management, the originality of our approach consists in representation and processing of knowledge, and make inferences at the item level, rather than container or bin level. And more importantly, this can be done locally without referring to external knowledge base. Privacy is also maintained in spite of using RFID tags containing category information of the item itself. This is a concern for pervasive computing applications. Our future direction would be to fine-tune the ontology further, so that the complexity remains in the order of polynomial time. Also, we are interested to keep greater amount of distributed information to make our inferences better, precise and more scalable. An approach would be putting more semantic data into the RFID tags to describe the item as we have proposed in [18]. It would make the system more distributed, thus reducing the information in the knowledgebase and also the dependency on it.

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