Modeling Gaps and Overlaps of Sustainability Standards

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Abstract

Organizational and production dispersions in manufacturing enterprises can create situations where manufacturers are asked to conform to multiple sustainability standards to participate in targeted markets. These standards may vary in scope, application domain, and implementation strategies, thus creating a challenge for stakeholders to identify, select and implement applicable standards. As standard conformity can be evaluated through information requirements, earlier research explored and conclusively advocated the development of information models through an approach based on the Zachman Framework. In further work we were able to demonstrate how results from the Zachman-based approach can be leveraged to identify gaps and overlaps between standards. This paper expands upon our previous research by proposing the use of ontologies as a formal means for representing and comparing the information requirements of sustainability standards, thus enabling a better understanding of gaps and overlaps between standards. To prototype our work, we analyze three selected standards and subsequently model their information elements in the form of three separate taxonomies. These taxonomies are then analyzed and synthesized into a single ontology. Reasoning mechanisms demonstrate how gaps and overlaps can be semi-automatically determined when a new standard is introduced into the ontology. We discuss the implementation of these reasoning mechanisms and the results. Finally, when discussing development and implementation, we allude to how this approach may serve as a basis for a methodology that can assist companies in streamlining the implementation process of sustainability standards.

Keywords:

Sustainability standards, Zachman Framework, information modeling, ontologies, sustainable manufacturing

1 INTRODUCTION

Sustainability operates on a simple principle; that all resources required for survival depend indirectly or directly on the environment [1]. Sustainable development is defined as, "development *that meets the needs of the present without compromising the ability of future generations to meet their own needs [2]."* Sustainability, according to the US National Research Council, is *"the level of human consumption and activity, which can continue into the foreseeable future, so that the systems that provide goods and services to the humans persists indefinitely [3]"*. Regardless of many varying definitions, the "practice of sustainability" has become an inclusive, necessary routine in today's society. Subsequently, many standards have been and continue to be developed to facilitate sustainable practices.

Standards are defined as a "*common and repeated use of rules, conditions, guidelines or characteristics for products or related processes and production methods, and related management systems practices[4]*". Standardization is often very complex; it "*encompasses a broad range of activities and ideas – from the actual development of a standard to its promulgation, acceptance and implementation. It also includes the methods of evaluating whether products, processes, systems, services and personnel comply with a standard* [5]." Sustainability standards are designed to reduce the social, environmental, and economic impact of products, processes and services. As best practices, these standards support the use of fewer resources and faster manufacturing. These practices can lead to lower prices and ultimately an overall reduction in the impact on society, the environment, and the economy [5].

Sustainability standards are uniquely complex in that they often consider all aspects of production. The cradle-to-grave and cradle-to-cradle life cycle approaches address not only the manufacturing of a product, but also resources required and waste created. Therefore, sustainability standards and regulations may apply to any number life cycle phases related to product development. Additionally, when implementing a standard, there is potential for multiple parties to have a vested interest in the results. These complexities make it difficult for interested parties, or stakeholders, to identify with and conform to sustainability standards.

Sustainability standards often present themselves as a type of "mandatory standard," creating immediate challenges for a product manufacturer. All matters conducted within a company often must satisfy these mandatory standards, *"generally published as part of a code, rule or regulation by a regulatory government body and imposes an obligation on specified parties to conform to it,[4]"* in order for their products to reach the shelves. Voluntary standards, *"which by themselves impose no obligations regarding use,[4]"* can provide benefits to companies when followed. Selling certified products often improves a company's marketplace competitiveness, either through marketing or customer perception and satisfaction. Regardless of whether a standard is mandatory or voluntary, as the creator of a product the manufacturer faces conformance challenges not shared by all stakeholders.

To support stakeholders, particularly manufactures, with sustainability standard conformance, the National Institute of Standards and Technology (NIST) created a Sustainability Standards Portal [6]. The goal of NIST's Sustainability Standards Portal (SSP) is to assist companies in determining and meeting the appropriate standards for their industry or products. These standards may pertain to the sustainable impact and resource efficiency of the design, manufacturing, use and post use of products. Since sustainability standards can differ in their implementation and their qualifications, the portal focuses on sustainability standard analyses and analysis techniques.

In this paper we further our SSP work to expand our previously presented methodologies for analyzing [7] [8] and modeling [9] sustainability standards. We explain how to leverage information modeling techniques, specifically ontologies, to represent sustainability standards. We then discuss the use of reasoning mechanisms to associate products and product data with applicable standards and determine compliance. This work addresses the needs of the manufacturer by providing a repeatable method for creating explicit, adaptable representations of sustainability standards that also serve as frameworks for mapping product data to applicable standards.

We will begin by briefly reviewing previous work with the Zachman Framework, and its contributions in simplifying the comprehension of the standard conformance process for stakeholders.

2 STANDARD ANALYSIS BASED ON THE ZACHMAN FRAMEWORK

The methodology described in the SSP leverages an initial stakeholder's analysis of a sustainability standard to conduct a detailed technical analysis, based on the Zachman framework. After using the stakeholder analysis to carefully consider the needs of all stakeholders involved with a standard, a technical analysis was able to provide a methodical structure to the results. Our two-step approach provides a method for decomposing often complex, usually unstructured sustainability standards.

Developed by John Zachman, the Zachman Framework was originally designed for enterprise architecture modeling [10]. The enterprise architecture framework (shown in Table 1) is a two dimensional, 6 x 6, matrix. Cognitive primitives (who, what, where, when, why, how) form the columns, while the rows represent different levels of abstraction for representing information. Each cell of the matrix models discrete portions of the enterprise. These models can then be integrated to realize an enterprise as a whole. While the cells of the Zachman framework provide a clear decomposition of the enterprise, there are no restrictions on the specific models or notations allowed in each of the cells. Therefore, the Zachman approach can be applied to any "idea." We applied the approach to provide a basis for the technical analysis of sustainability standards.

2.1 Technical Analysis

The Zachman Framework contains multiple categories breaking down any complex idea into smaller parts that are easier to understand. The categories allow stakeholders to view a single entity from multiple perspectives [11]. While previous works (and the SSP) utilize each level of abstraction, this work focuses on results from the first row. The first row of the Zachman Framework is the contextual row, which identifies the scope (of the idea and in our case standard). From the scope, key words and terms that define a standard can be extracted. The six questions, who, what, where, when, why, and how, are answered to determine the scope of a single standard Here, we will use the term "concept" to mean any single term derived from the contextual-technical analysis of a standard.

2.2 Finding Gaps and Overlaps

The Zachman-based analysis results provide an explicit basis for a gaps and overlaps analysis. In particular, the concepts that define the scope of a particular standard can be used to find gaps and overlaps between other standards. Overlaps occur when multiple standards share the same, or sometimes similar, concepts. Gaps occur when a concept exists in one standard and not in another standard that it is being compared with. When employed at the contextual level, gaps and overlaps can help stakeholders decide whether a sustainability standard applies to a product or not, and how to approach conforming to multiple standards. Depending on the product, conformance could be decided by a simple "yes" or "no," or a much more complex answer that requires detailed information about the product and the manufacturing process.

To take advantage of a gaps and overlaps analysis, the results of the technical analyses first had to be properly modeled. While lists of key words can offer insight, the comparison of lists can quickly become cumbersome. The challenges presented by analyzing lists are compounded when trying to relate comparisons back to instances of product information. Without a disambiguation of key terms, and a clear understanding of how they interact, proper associations between products and standards may be difficult to achieve. As an alternative to lists, and for more explicitly defined standards, we have adopted information modeling as a means for representing and structuring the technical analysis results.

3 INFORMATION MODELS OF STANDARDS

Information models can be derived by structuring concepts and their relationships. They allow the explicit representation and visualization of information, and are useful for associating concepts through a specific type of relationship. In this section we discuss the development of information models from the contextual level analysis results of sustainability standards.

3.1 Development of Information Models from Technical Analysis

The Zachman Framework is *"a theory of the existence of a structured set of essential components of an object for which explicit expressions are necessary and perhaps even mandatory for creating, operating, and changing the object [12]."* When

Table 1: Zachman framework

	What (Data)	**How (Function)**	**When (Time)**	**Who (People)**	**Where (Location)**	**Why (Motivation)**
Scope (Contextual)	List of things	List of processes	List of events	List of organizations	List of locations	List of goals
Enterprise Model (Conceptual)	Semantic model	Business process model	Master schedule	Work flow model	Logistics network	Business plan
System Model (Logical)	Logical data model	Application architecture	Processing structure	Human interface architecture	Distributed system architecture	Business rule model
Technology Model (Physical)	Physical data model	System design	Control structure	Presentation architecture	Technology architecture	Rule design
Implementation (Detail)	Data definition	Programs	Timing definition	Security architecture	Network architecture	Rule specification
Functioning Enterprise	Usable data	Working function	Usable network	Functioning organization	Implemented schedule	Working strategy

performing a Zachman analysis, each cell essentially provides a meta-model for representing information. A meta-model can be considered an analysis of all of the information which is useful in representing the class, therefore providing a useful generalization of the information, and is the first step in analyzing relationships between concepts [13].

As noted earlier, the meta-model for each cell of the Zachman Framework at the contextual level is a simple list of terms. The lack of relationships between these terms is a direct result of the independence required by each Zachman cell, represented by the who, what, where, when, why, and how columns. While these lists of terms can be useful for a basic understanding of standards, information modeling requires us to identify the relations between the concepts as well.

While maintaining cell independence, the Zachman Framework can be leveraged by providing the necessary constructs for identifying relationships. By using cognitive primitives for column definitions, "sentences" can be created and used to identify inherent relationships. For instance an "electronic product" "marketed" in "Europe" must "comply" with "WEEE." Sentence construction allows for the conceptualization of interactions between entities through relationships. This is an integral part in creating an explicit definition of a standard. The next section will discuss how to use ontologies to model the different concepts of a standard.

3.2 Defining Standards with Ontologies

The constructs and mechanisms available through the syntax and semantics associated with ontologies are very pragmatic for defining and representing the gaps and overlaps that may exist between multiple standards. As a modeling tool, ontologies can provide, *"conceptual models to support the understanding of and communication about application domains in information systems development [14]."*

Using ontologies for defining concepts and relationships provides machine-processable information while maintaining its human understanding. Ontologies provide a means for formal, explicit communication, whether that communication is between humans, between machines, or between machines and humans. This section will discuss how, when modeling a standard using ontologies, standard concepts can be modeled as unique classes within the ontology.

Ontologies can be separated into two separate components, a terminological box (TBox) and an assertion box (ABox). The TBox provides the meta-model for the standard, or a re-usable, concept-based, information model for populating specific instances. The ABox consists of specific instances of the TBox, forming a knowledge base.

Terminological Box

When modeling a standard, the TBox is used to model the standard's concepts, the same ones identified during the contextual level analysis of the standard. Each concept within the standard is subsequently represented as a class within an ontology. For example, the TBox can specify the standard concept of "Product Category."

When creating an ontology, modeling requirements extend beyond creating classes out of concepts. To serve as a useful modeling environment, structure must also be added to these classes. A taxonomic structure is implemented when creating an ontology. Subclasses, which represent sub-concepts of higher-level, generic concepts in information modeling, are added using "is-a" relationships [13]. Subclasses allow for the organization information in a clearer and more specific way. For instance, "is-a" relationships are important for grouping similar standards through a single concept.

While "is-a" relationships are very important for modeling how concepts within a standard relate, "part_of" relationships are also important. These relationships are modeled with properties. In this context, "part_of" describes the relationship that exists when a value from one entity (instance or string) is used to satisfy the information requirements of another. For example, "WEEE" (instance) "has_product_category" (property) of "Electronics" (instance). In this example, the value (Electronics) associated with the concept of "Product Category" contributes to the definition of the instance of "Standard" (WEEE).

In an ontology, "part_of" relationships can be modeled as two different types of properties, the data-type and the object-type. The data-type property allows information to be captured in a lexical space, such as a string or float. Data-type properties are useful for entering information into an ontology when drawing from a text-based source, such as a standard. The power of representing a standard's concepts in an ontology comes when values of these data-type properties are represented as values of object-type properties. The value of an object-type property is an instance of a class. Because the value is the member of a class, it already has inherited some structure and meaning. For instance, consider the property "has_product_category." When implemented as a data-type property, the value of "has_product_category" will be some combination of characters forming a string, for instance "e-l-e-c-t-r-o-n-i-c." However, when implemented as an object-type property, the value of "has_product_category" can be an instance of a class "Electronic." This is an important distinction, because, when an instance of a class, a value already has some inherent meaning far beyond a combination of characters. This meaning is essential for identifying and representing gaps and overlaps between standards (Section 3.3).

Capturing information as an object-type property is equivalent to creating a relationship between two or more classes. The class being defined is called the "domain" and the class defining where an instance of the property may come from is called the "range." When using an object-type property to describe a class, assumed values become additional objects, which themselves can have additional meaning and relationships. The implications of the resulting relationships are discussed further in Section 4.2.

Other constructs offered by ontologies include the relationship types "equivalent to," and "different from," as well as logical axioms offered by the description logic attributes of ontologies [14]. These constructs can expand upon already explicit definitions of individual standards through classes and class relationships.

Assertion Box

The ABox consist of class assertions, or instances, where each value represents a specific instantiation of a concept. For example, an instance of the class "Product Category" may be "electronics." Section 4.1 will discuss the development of the TBox. Section 4.2 will discuss how to use the resulting structure \ to infer standard applicability by drawing conclusions on product information represented within the ABox.

3.3 Defining Gaps and Overlaps with Ontologies

Data-type properties are used to capture the basic context of a text-based standard. However, modeling each concept as a class gives this text-based context additional meaning. As noted in Section 3.2, this meaning is necessary for creating useful models of the gaps and overlaps between standards.

Here we define two types of overlaps (and resulting gaps): those that are equivalent, and those that are similar but not equivalent.

The use of data-type properties allows for the identification of those that are equivalent (assuming they share the same label), however they cannot address the second type of overlap, when concepts are similar, but not the same.

Overlaps

Standard overlaps in ontologies can also be categorized into two types:

Type I Overlap: When concepts of two standards are equivalent. Here logical axioms can be used to define the equivalence. Strings can be compared or classes mapped so a member of one class is automatically considered a member of another. For example, the concepts of "computers" and "pc's" can be made equivalent.

Type II Overlap: When there is clear content overlap between standards, but the explicit information elements or artifacts are different. In this scenario, the class structure of the ontology can be used to group similar items. A class can be created to group two similar, but not equivalent, concepts. The overlaps are then represented by the shared properties between the classes. For example, "computers" and "electronics" are similar, as a computer is a type of electronic, but not equivalent.

Gaps

Gaps between standards can be categorized into two types:

Type I Gap: This gap occurs when the standards simply differ in coverage, and there is no overlap. These gaps can be explicitly modeled as disjoint concepts, which means that a single instance of information cannot belong to both concepts. When using data-type properties, all values that cannot be matched as equivalent would fall in this category.

Type II Gap: This is the complement of the Type II Overlap, when there is overlap between two standards but the overlap is not equivalent. For instance, this may occur when one standard is more detailed than another is. Ontologies can be used to address this by grouping similar information using the "is-a" structure of the ontology. Here the gaps are represented by the properties that are associated with one standard but not another.

With this basic understanding of how ontologies can represent gaps and overlaps between standards, the next section will present a more detailed methodology on how to model these gaps and overlaps.

4 METHODOLOGY FOR DEVELPING GAPS AND OVERLAPS ONTOLOGY

The previous section discussed the use of ontologies to model standards, their gaps, and their overlaps. This section will detail the steps needed to create and implement an ontology-based meta-model for individual sustainability standards. The methodology discussed in this section can assist industry in explicitly mapping gaps and overlaps between standards. To better explain the methodology, we will create a "Gaps and Overlaps Ontology" (GOO) for three separate standards, WEEE, REACH, and GHG Protocol.

4.1 Modeling and Mapping Sustainability Standards

Modeling Results of Technical Analysis

Before gaps and overlaps can be modeled, the ontologies must be created for the three individual sustainability standards. The contextual level of the analysis results from WEEE, REACH, and GHG make the key concepts straightforward, and each concept is modeled as a class. The modeler, in this case us, must identify any relationships associated with each concept, as described in Section 3. In this case, data-type properties were used in instances to capture strings. As an instance is a member of a class, the string then becomes an object. For example, the class "Product_Category" uses the data-type property "has_product_category" to capture any value.

During the development of a standard ontology, the placement of these classes may change multiple times. However, the organization of the class structure is ultimately guided by the "is-a" relationship.

Mapping Ontologies to Model Sustainability Standard Gaps and Overlaps

Modeling the gaps and overlaps of the sustainability standards is comparable to creating a single ontology from two or more smaller ontologies. To be effective, each ontology within GOO must be mapped to one another. These mappings become the explicit representation of the gaps and overlaps.

To create GOO, we began with WEEE and REACH. Once the initial standards are mapped, additional standard ontologies can continue to be added. During the mapping process, it is important to maintain an understanding of how each of the standard ontologies is conceptually modeled. The mappings will be co-dependent on all ontologies (standards) with the GOO. Where a Type I overlap may exist between two standards with respect to one concept, the same concept may result in a Type II overlap with a third standard.

When mapping ontologies, the modeler first wants to make as many classes and properties as possible equivalent. Equivalencies essentially allow multiple classes or properties to exist as a single, interchangeable entity. During the development of the GOO for WEEE, REACH, and GHG, the Zachman-based analysis allowed the three standards to be defined using the six recurring root classes, who, what, where, when, why, and how. Each standard's concepts were mapped as equivalent at these high-level classes. These equivalencies can be mapped in an ontology with logical axioms, declaring one class "equivalent to" another. Axioms can also make gaps explicit, declaring one class different from, or "disjoint" from another.

After identifying initial equivalencies (Type I overlaps), namely high-level standard concepts such as "Product Category" and "Region," we began the grouping of Type II overlaps. Gaps and overlaps may exist because of differences in comprehensiveness, or slight differences in definition. When similarities exist between two concepts, but they are not equivalent, it is often desired relate both concepts through a single concept. When identifying Type II overlaps, the modeler needs to rely on a working knowledge of the standards and an understanding of the technical analysis results. When determining if concepts are similar, it is important to consider whether one instance of information can populate concepts from multiple standards. If the answer is yes, more likely than not, those concepts should be grouped. In the end, it is at the discretion of the modeler, leveraging key concepts and sentences, to decide which concepts are similar enough to group, and which are distinct enough to leave as separate, distinct classes.

Another way to decide if the classes have similarities is to look for subclass similarities. The closer to the "root" a class is, the more general the class, the greater the number of subclasses, and the less subjective the grouping. However, as the ontology is traversed, the groupings may become less obvious. Classes being compared may have different labels, but it is the "idea" behind them that is important. For instance both WEEE and REACH address materials used in products; however REACH does so in much more detail.

In the development of the GOO for WEEE, REACH, and GHG, it was sometimes difficult to categorize similar information between the three standards because the "is-a" relationship was not always clear. Eventually some classes were moved to classes where the information flowed better and made more sense following the "is-a" rule than the initial results of the technical analysis. In our GOO development, the difference between standards was mainly found to be a result of how broad they were or how complex they were. The final result of the modeling was an instance of a GOO (Figure 1) consisting of 3 separate standards, WEEE, REACH, and GHG, and any classes introduced to group similar concepts between the three standards.

The comparison of standards can be an ongoing process. However, each standard should be compared the same way as to avoid confusion to the user. When reasoning with GOO (Section 4.2), the more details an ontology captures the more "powerful" the ontology's reasoning environment becomes. However, the trade-off is that an increase of detail will likely decrease the robustness of the ontology's reasoning capabilities.

Once a class structure has been finalized, the result is an explicit information model where the concepts of select standards have been formally mapped into a single ontology, GOO. While the explicit representation has much to offer itself as an information model, this new ontology structure also provides an environment where reasoning mechanisms can be used to automatically determine if a standard should be associated with a product.

4.2 Reasoning with GOO

Introducing Reasoning Mechanisms to GOO

In addition to explicitly defining gaps and overlaps, logical axioms allow inferencing mechanisms to associate product data with standards. However, to take advantage of these axioms further modifications must be made to GOO. The first step to achieving these associations is to introduce the concept of "Standard Applicability" into GOO. A new class structure, with a root class of "Standard Applicability," can provide a basis for associating products with standards. Unlike the base GOO ontology, where standard concepts are modeled as classes, "Standard Applicability" classes model different states of standard conformance. Immediate subclasses of the root "Standard Applicability" are different standards, such as WEEE or GHG Protocol.

To model different levels of product conformance, the "Standard Applicability" classes should be defined using the same properties that would define a product. This allows inferred members of the "Standard Applicability" class to be instances of a manufacturer's product. However, while a manufacturer would use concepts associated with a product to define a "Product" class, the "Standard Applicability" class uses the concepts associated with standards.

The properties used to describe the class "Standard Applicability" and its subclasses are used to like standards with their standard concepts, as previously defined in GOO. Object-type properties are used to associate a select standard with each concept that was earlier modeled as classes. Once a subclass's properties have been identified and instantiated, logical axioms can be used to determine product conformance.

Axioms can be added to "Standard Applicability" classes with the ability to make desired inferences. "Necessary and sufficient" axioms are used to determine if an instance of a product is also an instance of a "Standard Applicability" class. These axioms infer membership if and only if an instance satisfies all the axioms associated with a class. This means that if a product instance is determined to be a member of this a particular "Standard Applicability" class, then that standard applies to that product. The level of conformance inferred is determined by the type and number of axioms used.

By placing restrictions on classes, such as what values a property can assume or what cardinality is required, inferencing mechanisms can identify what instances satisfy those requirements. As each class is a variation (in conformity) of the standard it represents, we can reason that any time a product instance is inferred as a member of a "Standard Applicability" class, the product is applicable to, and conforms with at some capacity, to the standard itself. The notion of "standard application" is demonstrated in Section 5.

Reasoning with GOO

Different combinations of axioms can lead to different conclusions to be drawn about how a standard is associated with a product. . What can be learned is dependent on how the classes and axioms are structured. For instance, given a set of product information, can we identify the standards that are a product compliant or applicable with? Given a set of standards, what products should conform to a specific standard? Answers to each of these can be achieved through the calculated modeling of classes and axioms.

When an instance of a product is inferred as a member of multiple "Standard Applicability" subclasses, there are overlaps between the standards and the conformity. The differences between the levels of conformance represent the gaps. It is the responsibility of the user to investigate inference results, using the class definitions to see what property or value differences resulted in gaps. These gaps may be caused by differences in associated properties, or discrepancies in applied axioms. In both cases, mapping and inferencing, followed by the ability to directly compare the results, offers a unique means for evaluating the gaps and overlaps of standards.

In the case where an instance of a product is associated with a standard, but the classification is found inconsistent, then the instance of the product does not satisfy the identified requirements of that particular standard. The notion of inconsistency is useful for checking compliance of a product with a particular standard. The next section discusses a scenario showing how the described methodology can be used to identify gaps, overlaps, and conformity with sustainability standards.

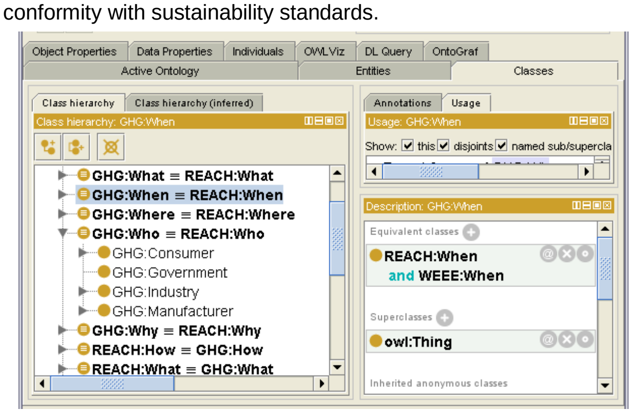

Figure 1. GHG, WEEE, and REACH shown as equivalent classes in GOO.

5 CASE STUDY: ASSOCIATIONG STANDARD WITH PRODUCT USING INFERENCING

An ontology building tool, Protégé [15] was used to create and map the three separate ontologies discussed in Section 4.1, WEEE, REACH, and GHG. A separate class (subclasses of "Standard Applicability") was created for each ontology, "WEEE," "GHG," and "REACH." Finally, an example product was introduced into the ontology. This product, Product A, was defined using properties similar to those found in the GOO. If a “Standards Applicability” property was not identical with a “Product” property, buth they were deemed equivalent, then they were mapped. For instance, the property of “intended_market” belonging to the product was identiffied as equivalent to an “applicable region” property associated with the “Stanard Applicability” class.

To demonstate our methodogy, a simple scenario was introduced. Product A was identified as an electronics product to be marketed in Europe. Product B was identifed as a piece of furniture to be marketed globally. As a manufactuer, the question to be answered was “What standards do I need to consider in order to sell my products in Europe?”

To answer this question, the proper axioms had to be introduced in the the “Standard Applicabilty” subclasses for each of the three standards. Because the objective was to identify only applicable standards, not level of comformity or even compliance, axioms were created to only identify if a standard apllies. For example, for the “WEEE Applicable” class, a necessary and sufficient axiom was created stating that ANY product that has a product category of “Electronics” and an intended market of “Europe” was a member of the class. Alternatively, if a “WEEE compliance” class were introduced class axioms would be created constraining each property of the class that were an information requirement of WEEE, so only those products that satisfied all requirements would be a member.

After running the reasoner, Product A was inferred as also being a member of the WEEE and REACH classes (Figure 2). No further inferences were made on Product B. Therefore, the manufacturer was able to deduce that in order to sell Product A in Europe he has to make sure he considers both WEEE and REACH, while Product B will be unnafected by all three.

In summary, ontologies provide a means to not only explicity represent gaps and overlaps between sustainabitliy standards, but also provide a means for identifying when these standards need to be considered. As new standards are introduced or being considered, they are able to be mapped into the existing GOO environment. In addtion, because all gaps and overlaps mappings were performed in the TBox of the ontology, new products can be continuosly introduced into the gaps and overlaps environement without disrupting it.

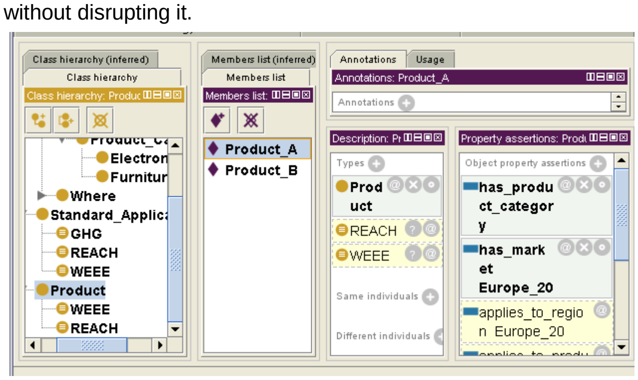

Figure 2. Inferred standards for Product A.

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