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Modeling Gaps and Overlaps of Sustainability Standards

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Abstract

Organizational and production dispersions in manufacturing enterprises create situations where manufacturers are asked to conform to multiple sustainability standards to participate in targeted markets. Variations between standards can create a challenge for stakeholders to identify, select, and implement applicable standards. This paper investigates the use of ontologies as a formal means for representing and comparing sustainability standards based on information requirements. We analyze three selected standards and subsequently model their information elements in the form of three separate taxonomies. We then demonstrate the implementation of reasoning mechanisms to semi-automatically determine gaps and overlaps in standard coverage for a given product.

Keywords:

Sustainability standards; Zachman Framework; information modeling; ontologies

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 important routine in today’s manufacturing. 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 greater efficiency 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 and distribution. 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 of 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 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, the manufacturer faces conformance challenges not shared by all stakeholders.

To support stakeholders, particularly manufacturers, with understanding and achieving 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 requirements, 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 SUSTAINABILITY STANDARD ANALYSIS

The methodology described in [7], and adopted in the SSP, leverages two separate analyses when analyzing a sustainability standard; an initial stakeholder’s analysis, and a detailed technical analysis. The initial stakeholder analysis serves as a means to consider carefully the needs of all stakeholders involved with a standard. The technical analysis should be able to provide a methodical structure to the results. Our two-step approach provides a

method for decomposing often complex, usually unstructured sustainability standards.

In [7], we explored the use of enterprise architectures as a means for technically analyzing and understanding the complexities of sustainability standards and standard implementation. This work led to our eventual adoption and advocacy of a Zachman-based methodology for analyzing sustainability standards in the SSP.

2.1 Technical Analysis Based on Zachman Framework

Developed by John Zachman, the Zachman Framework was originally designed for enterprise architecture modeling [10] [11]. The enterprise architecture framework 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. Because there are no restrictions on the specific models or notations allowed in each of the cells, the Zachman approach can be applied to any "idea." We applied the approach to provide a basis for the technical analysis of sustainability standards.

In [8], we expand upon our work in [7] by focusing on how Zachman-based technical analyses could be used to acquire the necessary information to determine when a standard is applicable to a product. We reached the conclusion that, although the Zachman is a 6x6 matrix, the information gathered from analyses at the first and second rows of abstraction is sufficient for determining when a standard applies to a product. Further levels of abstraction tend to address standards at the level of individual enterprise implementation. Therefore, based on our earlier findings, we will focus on the first row, or scope, when modeling the gaps and overlaps of sustainability standards.

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. The six columns of the first, or scope (contextual), row are defined in Table 1. These columns serve as the guidelines for acquiring the information modeled in this paper.

What (Data)	How (Function)	When (Time)	Who (People)	Where (location)	Why (Motivation)
List of things	List of processes	List of events	List of organizations	List of locations	List of goals

Table 1: Row 1 of Zachman framework.

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 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. 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.

To take advantage of a gaps and overlaps analysis, the results of the technical analyses first had to be purposefully modeled. Analyzing

lists can be challenging. 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. For more explicitly defined standard documentation, we have adopted information modeling as a means for representing and structuring the technical analysis results.

3 INFORMATION MODELS OF STANDARDS

Information models 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 analyses 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 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 domain, 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. While these lists of terms can be useful for a basic understanding of standards, information modeling requires us to identify the relationships between the concepts as well.

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 (Waste Electrical and Electronic Equipment Directive)." Sentence construction allows for the conceptualization of interactions between entities through relationships. The next section will discuss how to use ontologies to model the different concepts of a standard.

3.2 Defining Sustainability 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. 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 "Electronic" (instance). In this example, the value (Electronic) 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. 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).

Implementing object-type properties 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.

It is important that the modeler decides how each key word should be implemented. Using an "is-a" relationship as opposed to a "part-of" relationship may change the meaning and the outcome of comparing the ontologies. Representing properties as either data type or object type will also change the outcome of the relationships between ontologies. Modelers take into account which representations benefit stakeholders. They run the risk of implementing classes and subclasses differently from other modelers which may cause confusion and provide inaccurate results. Though there is no way to "circumvent" the challenge of modeling consistency, our approach is meant to be applied at the enterprise level, and therefore assumes some familiarity with modeling practices used.

Assertion Box

The ABox consists 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 addresses 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

Here we define two types of overlaps (and corresponding gaps) that are created when modeling sustainability standards as ontologies: those that are equivalent, and those that are similar but not equivalent.

Overlaps

Modeled as ontologies, overlaps between sustainability standards can be categorized into two types:

Type I Overlap (Figure 1): When concepts of two standards are equivalent. In an ontology logical axioms can be used to define the equivalence. For example, the concepts of "computers" and "pc's" can be made equivalent. In Figure 1, two standards share equivalent information artifacts and are mapped into a single definition.

Type II Overlap (Figure 1): When there is clear content overlap between standards, but the explicit information elements or artifacts are different. In this scenario, a class can be created to group two similar concepts. For example, "computers" and "electronics" are similar, as a computer is a type of electronic product, but not equivalent. In Figure 1, information artifacts from two standards are mapped into the same domain, and the hashed blue overlap represents those artifacts that are shared.

Gaps

Gaps between standards can be categorized into two types:

Type I Gap (Figure 1): 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. In Figure 1, two separate standards are mapped into a single domain, but no information artifacts are shared between the standards.

Type II Gap (Figure 1): This is the complement of the Type II Overlap, when there is overlap between two standards but the overlap is not an equivalence. For instance, this may occur when one standard is more detailed than another is. Here the gaps are represented by the properties that are associated with one standard but not another. In Figure 1, two standards are mapped, and the hashed areas represent the information artifacts that differ between two similar, but not same, standards.

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.

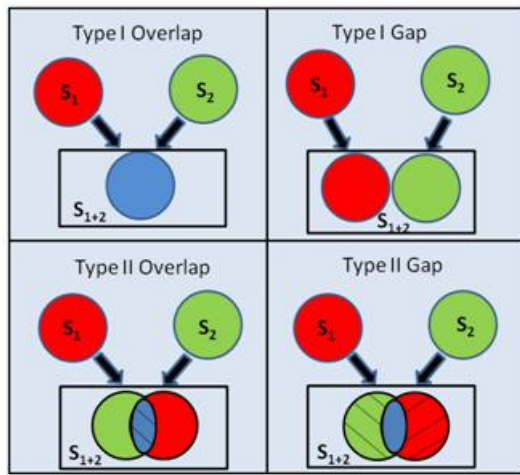


Figure 1: A graphical representation of gaps and overlaps. S_1 and S_2 are circles that represent information from two separate standards. S_{1+2} is the rectangular composite of the information, with blue representing overlap.

4 METHODOLOGY FOR DEVELOPING A GAPS AND OVERLAPS ONTOLOGY

The previous section discussed the use of basic ontology constructs to model standards, their gaps, and their overlaps. This section will detail the steps needed to create and implement a TBox-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 (Registration, Evaluation, Authorization and Restriction of Chemicals), and GHG (Greenhouse Gas) 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 analysis results from WEEE, REACH, and GHG make the key concepts straightforward, and each concept is modeled as a class. The modeler must identify any relationships associated with each concept, as described in Section 3. By relying on object-type properties, the reasoning capabilities of the GOO are emphasized. However, data-type properties must be employed at the most basic levels to capture information. In this scenario, when implementing a GOO, simple instances are employed to capture strings as objects. For example, the class "Product_Category" uses the data-type property "has_product_category" to capture any value. An instance of this class may be "Electronics," and the value of the "has_product_type" property for this instance is "E-l-e-c-t-r-o-n-i-c-s."

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 a GOO must be mapped to one another. These mappings become the explicit representation of the gaps and overlaps.

To create a 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 equivalent classes and properties as possible. 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 Protocol, the Zachman-based analysis allowed the three standards to be defined using six recurring root classes, representing the cognitive primitives, 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 desirable to 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 Protocol, 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 2) consisting of 3 separate standards, WEEE, REACH, and GHG, and any classes introduced to group similar concepts between the three standards. In the figure, each yellow circle represents an artifact of the TBox.

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 a 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 in 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 Employing a GOO as a Tool

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 liken standards with their standard concepts, as previously defined in the GOO. Object-type properties are used to associate a select standard with each concept that was modeled earlier 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 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 a 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 a product is 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 to be 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.

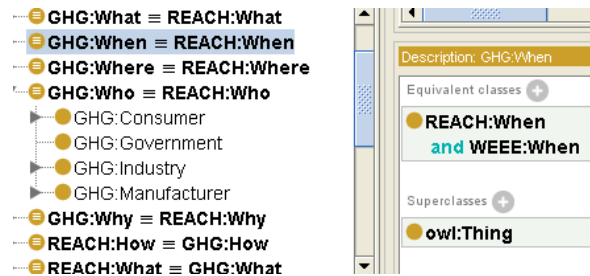


Figure 2: GHG, WEEE, and REACH shown as equivalent classes in the GOO (TBox).

5 CASE STUDY: ASSOCIATING 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 Protocol. A separate class (subclasses of “Standard Applicability”) was created for each ontology, “WEEE,” “REACH,” and “GHG.” Finally, three example products were introduced into the ontology. These products, Product A and Product B, were defined using properties similar to those found in the GOO. If a “Standards Applicability” property was not identical with a “Product” property, but they were deemed equivalent, then they were mapped. For instance, the property of “intended_market” belonging to the product was identified as equivalent to an “applicable region” property associated with the “Standard Applicability” class.

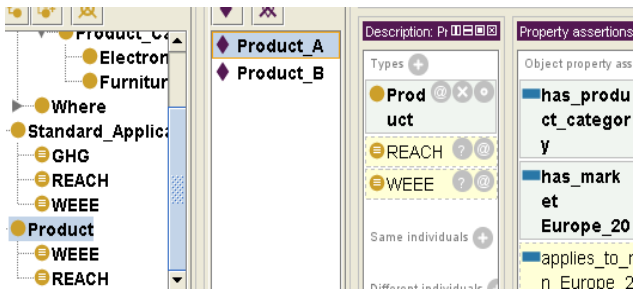


Figure 3: Inferred standards for Product A (ABox).

To demonstrate our methodology, a simple scenario was introduced. Product A was identified as an electronics product to be marketed in Europe. Product B was identified as a piece of furniture to be marketed globally. As a manufacturer, the question to be answered was "What standards do I need to consider to sell my products in Europe?"

To answer this question, the proper axioms had to be introduced in the "Standard Applicability" subclasses for each of the three standards. Because the objective was to identify only applicable standards, not level of conformity or even compliance, axioms were created to only identify if a standard applies. 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 of that class.

After running the reasoner, Product A was inferred as also being a member of the WEEE and REACH classes (Figure 3). No further inferences were made on Product B. In this figure, the Products are members of the ABox, or instances, while the yellow circles again represent the TBox. 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 unaffected by all three.

One of the main advantages of this approach is the reusability offered. Let us now consider a Product C. Because we have already mapped the ontologies in GOO (the TBox), a new product (ABox), can be introduced with little difficulty. Consider the introduction of a sensor-activated lamp. Though a piece of furniture, due to its characteristics it can also be considered an electronic. Implemented axioms in a GOO, identifying it has having properties associated with electronics, allow it to inference that the lamp is not only a piece of furniture, but also an electronic. The lamp therefore must abide by the same standards as Product A. As new products are introduced, a properly configured GOO is able to identify when and what mapped standards apply to the new product.

Another prominent advantage of our approach is the ability to adapt to changing landscapes. As new sustainability standards are introduced, they can be mapped into the existing GOO infrastructure, without starting from the beginning. By mapping into an existing infrastructure, and introducing the proper axioms, a GOO can easily infer which existing products are affected by the introduction of a new standard. If a newly introduced standard references previously uncaptured product information, the product model can also be easily adapted without losing existing knowledge.

6 CONCLUSION

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

7 DISCLAIMER

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9 REFERENCES

- [1] Rosenbaum, M, (1993): "Sustainable Design Strategies,"(March/April), Solar Today.
- [2] World Commission on Environment and Development (WCED), (1987): "Our Common Future (Brundtland Report)," Oxford University Press.
- [3] Board on Sustainable Development and National Research Council, (1999) "Our Common Journey:A Transition Toward Sustainability," National Academy of Sciences.
- [4] What are Standards?, (2011): National Institute of Standards and Technology [URL:www.standards.gov/standards_gov/standards.cfm](http://www.standards.gov/standards_gov/standards.cfm)
- [5] ANSI Course : Why Standards Matter, (2010): American National Standards Institute [URL: www.standardslearn.org/coursedetails.aspx?key=44](http://www.standardslearn.org/coursedetails.aspx?key=44).
- [6] Sustainability Standards Portal, 2011, [URL:www.mel.nist.gov/msid/SSP/](http://www.mel.nist.gov/msid/SSP/)
- [7] Rachuri, S., Sarkar, P., Narayanan, A., Lee, J. H., and Witherell, P., (2010): "Towards a Methodology for Analyzing Sustainability Standards," 18th CIRP International Conference on LCE.
- [8] Witherell,P., Sarkar, P., Narayanan, A., Lee, J., and Rachuri, S., (2011): "An Approach for Identifying Gaps and Overlaps in Standards to Determine Product Applicability," *ASME 2011 IDETC/CIE*.
- [9] Narayanan,A., Lee,J., Witherell, P., Sarkar, P., and Rachuri, S., (2011): "An Information Modeling Methodology for Sustainability Standards," *ASME 2011 IDETC/CIE*.
- [10] Sowa J.F. and Zachman, J. A., (1992): "Extending and Formalizing the Framework for Information Systems Architecture," *IBM Systems Journal*, 31(3).
- [11] Zachman, J, (2011): "The Zachman Framework for Enterprise Architecture," Version 1b.
- [12] Zachman, J.,(2011): "John Zachman's Concise Definition of The Zachman Framework," [URL: www.zachmaninternational.com](http://www.zachmaninternational.com).
- [13] Borgida, A., and Mylopoulos, J., (2008): "A Sophisticated's Guide to Information Modeling," *Metamodeling for Method Engineering*, edited by M.A.Jeusfeld et al MIT Press, pp. 1-41.
- [14] Bera, P., Krasnoperova, A., and Wand,Y., (2010): "Using Ontology Languages for Conceptual Modeling," *Journal of Database Management*, 21(1), pp. 1.
- [15] Welcome to Protege, (2011): [URL:http://protege.stanford.edu/](http://protege.stanford.edu/)