Representing Sustainability Indicator Sets Practising Ontology Design Patterns

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Abstract. Sustainability indicators are increasingly being used to measure the economic, environmental and social properties of complex systems across different temporal and spatial scales. This motivates their inclusion in open distributed knowledge systems such as the Semantic Web. The diversity of such indicator sets provides considerable choice but also poses problems for those who need to measure and report. To address the modelling problems of indicator sets, in this paper, we propose the use of Value Partition patterns to construct two design candidates: *generic* and *specific*. The generic design is more abstract, with fewer classes and properties, than the specific design. Documents describing two indicator systems – the Global Reporting Initiative and the Organisation for Economic Co-operation and Development – are used in the design of both candidate ontologies. We show the use of existing structural ontology design patterns can help solve problems of ontology representations modelling sustainability indicator sets.

1 Introduction

Sustainability indicators estimate the current and future states of complex systems, such as cities, organisations, community groups and natural habitats. In a measurement context, a "system" is referred to as the entity that is the focus of various tasks that include identifying properties, devising scales, testing and measuring, and ultimately, reporting on progress towards defined sustainability goals. In response to the demands of measuring and maintaining sustainability for diverse systems, many indicator sets have been developed and are in use today [3, 13, 16]. The diversity of such indicator sets provides considerable choice but also poses problems for those who need to measure and report. Often, relevant indicators need to be selected from multiple sets, with any gaps in specific measurement goals being filled by the development of new indicators.

We argue *ontology design patterns* offer ways of addressing both problems in a way that is systematic and builds upon the experience of others. Our focus in this paper is on the first of these problems: how to represent indicators from multiple sets in an ontology. This problem includes a further semantic challenge, since multiple sets may overlap at the level of individual concepts or of broader conceptual clusters. We argue this challenge in turn has at least two levels:

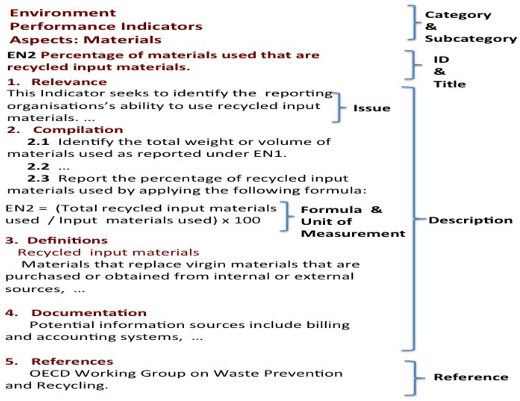

Fig. 1: An extract of a GRI Indicator Set

(i) indicators may be *named differently*, due to different languages, disciplinary jargon, or designer preference; and (ii) indicators may also be *conceptualised organised differently*, due to the knowledge paradigms and priorities motivating indicator selection. In both cases, merging two or more indicator sets into a single, combined ontology can assist in identifying which specific indicators might be most relevant to the measurement task at hand.

Well-known standardised frameworks for sustainability reporting include the Global Reporting Initiative (GRI) indicators and guidelines[1], the Organization for Economic Co-operation and Development (OECD)[2] and the United Nations Statistics Division (UN Social Indicators)[3]. Each of these group sustainability indicators into hierarchical structures that include categories and sub-categories of indicators. An extract of an GRI indicator is shown in Figure 1, which illustrates (i) categories (or aspects) and (ii) sub-categories (themes) and (iii) indicators. This shows, at least at a structural level, that there is some basis for comparison between these two widely used sets of sustainability indicators.

To date, there have been few efforts to represent *multiple* indicator sets in a systematic semantic way. Advantages of representing indicators in a formal *ontology* include developing a consistent definition of what an indicator is, how it can be applied, and how it relates to higher order grouping constructs used in theories and definitions of sustainability. An ontology representation also builds upon the many tools now available for ontology reasoning, alignment and visualisation, allowing organisations to browse and review different kinds of indicators for different measurement applications. Most importantly, by utilising pre-defined matches between non-identical but related indicators, measurements and reports developed by different organisations and contexts could be more easily compared.

[1] http://www.globalreporting.org/
[2] http://www.oecd.org/
[3] http://www.un.org/esa

A key concern in ontology engineering is to design and organise groups of related concepts that capture the relevant information of the domain being modelled as an ontology. *Ontology design patterns (ODPs)* have been proposed to encourage compatibility, efficiency and recognisability of ontology designs [11, 14]. In the formal sense provided by those listed[4], patterns make explicit relationships that would otherwise remain implicit, or at best only documented. For example, using the *Role* patten[5] makes clear that two ontology classes are not simply related through user-defined properties, but are related specifically as *task actions* and *role object*.

In this paper we discuss two ontology design candidates, which we term *generic* and *specific*, developed to represent sustainability indicator sets. We have termed the target end ontology OSIS (Ontology for Sustainability Indicator Sets), and the two design candidates GOSIS and SOSIS. The details of ontology engineering steps approach are described in earlier work [10]. This paper instead discusses the varied use of an ODP called *Value Partition* in the construction of the two candidates, and presents conclusions on the relevant merits of each variation.

2 Related Work

To prepare our discussion of the two ontologies, we review briefly literature relating to (i) sustainability indicator sets and (ii) ontology design patterns.

2.1 Ontologies and taxonomies used in Sustainability Indicator Sets

There have been several attempts to develop domain and application ontologies in the context of sustainability and sustainability reporting indicator sets. Brilhante et al. [3] present an ontology for the domain of Indicators and Sustainable Development with the emphasis on the economic dimension. Similarly, Madlberger et al. [15] develop an ontology for the domain of Corporate Sustainability Information Systems. Furthermore, Kumazawa et al. [13] outline an ontological approach to structure the concepts and relations within the field of sustainability science. Han and Stoffel [12] suggest an ontology for the integration of qualitative case studies in the domain of environmental sustainability research. Finally, an ontological approach is presented by Pinheiro et al. [16] to link sustainability indicators. A further recent study on urban indicators is presented by Fox [5], which develops a generic and reusable ontology for the ISO37120 Global City Indicators with the use of existing foundation ontologies and generated trans-foundation axioms.

2.2 Ontology Design Patterns

Ontology design patterns borrow heavily from the related concept of *Software Design Patterns (SDPs)* [6] in software engineering. Using object oriented SDPs

[4] http://ontologydesignpatterns.org
[5] http://ontologydesignpatterns.org/wiki/Submissions:Role_task

provides software class models with well-understood properties and behaviours that solve common engineering challenges in generic or abstract ways, improving software development efficiency [2]. Such patterns can help to generate high-quality and more maintainable software artefacts. An ontology ideally is a composition of different related ODPs, which resemble building blocks constructing the ontology structure. Recognising generic or abstract ontology components is an integral part of specifying appropriate ODPs. This process is of course domain-dependent, and thus requires deep understanding of the key concepts of the domain problem. Similar to SDPs, ODPs are abstract solutions (also referred as small *use cases*) to known problems in the field of ontology engineering [1]. However, given that ontology engineering is a less mature field compared with software engineering, the definition, representation and application of ODPs lack the same level of consensus as software engineering design patterns.

The literature about ODPs can be divided into studies that discuss the notion of ODPs and research that represents concrete ODPs for tackling specific design problems in developing ontologies. Reich [18] begins the discussion about the notion of ODPs in the field of molecular biology. Later, the idea of Semantic Patterns and Knowledge Patterns [20] begins to be presented as reusable components for building knowledge bases. It is followed by Gangemi [7], Gangemi et al. [9] that distinguish between Logical, Conceptual and Content Ontology Design Patterns. Finally, Gangemi and Presutti [8] revisit the patterns and classify them into six major categories including: Structural, Correspondence, Content, Reasoning, Presentation, and Lexico-Syntactic ODPs.

3 Ontology Design Patterns Used in OSIS

In this section we discuss the development process of our ontology models. First the key concepts of sustainability indicators are identified after reviewing GRI and OECD indicator sets and interviewing with the sustainability domain experts. These concepts are highlighted in Figure 1 including: *Indicator*, *IndicatorSet*, *Category*, *SubCategory (Group, Theme, Aspect)*, *Issue*, *Description (Relevance, Compilation, Definitions, Documentation)*, *Reference (Sources, Information)*.

3.1 Modelling Problems

Second, given the identified key concepts and relations within OSIS taxonomy, the relation between abstract concepts may have various interpretations. In particular, we have noticed that specific indicator systems, taken from organisations such as GRI and OECD, should be specified in relation to abstract concepts of `IndicatorSet` and `Indicator`. In other words, one of the design problems is the association of `Indicator` with `IndicatorSet`. This also affects the relations of other concepts such as `Category`, `Description` and `Reference`. The question here is how to determine such relations to be represented as classes, subclasses or instances? Addressing these modelling problems ideally should reflect the requirements of the final ontology design, which lead us to choose the appropriate patterns.

3.2 Ontology Design Pattern Solutions

Third, to address the aforementioned modelling problems, we use the Value Partition (VP) patterns. The VP ontology pattern is first introduced by Rector [17] and is further reviewed and developed by Aranguren [1] for the bio-medical domain. The VP pattern has been reviewed in the alignment of two other ontology patterns Class as Property Value and Normalisation by Rodriguez-Castro et al. [19].

As provided in the series of WC3 practices[6], VP pattern represents specified collections of "values" – also known as "feature space" – using hierarchical modelling. Generally speaking, in any domain, such characteristics are used to describe different concepts in the ontology. For example, given the description of "IndicatorSet" concept in the sustainability domain, in the presented ontology model, there are two the VP patterns as follows.

– **Pattern 1:** From the viewpoint of *explicitness*, it is usefulness to specify particular system indicators as subclasses GRI of a superclass (for example `IndicatorSet`). This design supports a specific representation of the domain problem and reflects detailed views of each system indicator. This view is more detailed to include direct references to specific indicator sets, which is called *Specific Ontology for Sustainability Indicator Sets* or SOSIS.
– **Pattern 2:** From the viewpoint of *reusability*, we also see that system indicators can be included as instances of `IndicatorSet` and an `Indicator` class is further linked by a particular relation (for example `belongsToIndicatorSet`). This view is more broader to cover sustainability indicators' key information with no reference to any particular organisations and is called *Generic Ontology for Sustainability Indicator Set* or GOSIS.

4 Discussion

Following the ontology engineering process of METHONTOLOGY [4] described in earlier work [10] and using the Value Partition pattern[7], discussed in Section 3.2, we have then developed two ontology design candidates, which differ largely in terms of abstraction as briefly described below.

1. GOSIS **design**
   In this design, we use pattern 1, that defines broadly a suitable structure and reflects the generic key concepts of sustainability indicators. As a result, GOSIS design applies an object-oriented approach to encapsulate the generic features of all indicator sets.

[6] http://www.w3.org/2001/sw/BestPractices/OEP/SpecifiedValues-20050223/
[7] http://www.w3.org/2001/sw/BestPractices/OEP/SpecifiedValues-20050223/

2. SOSIS **design**
   In this design, the emphasis is on the organisations that specifically develop sustainability indicators. We use pattern 2, that includes the key concepts of these organisations with their own indicator classifications. As a result, SOSIS design uses a range of classes and relations that are specifically added for each sustainability indicator set.

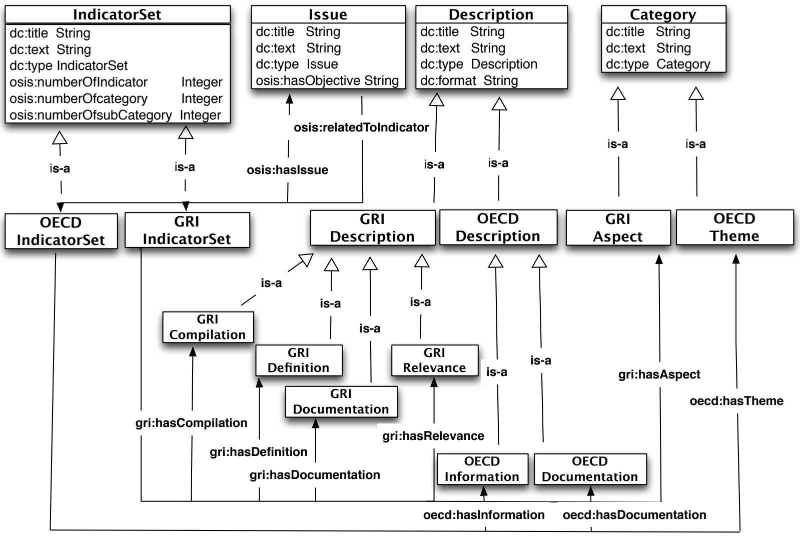

Fig. 2: UML Diagram of SOSIS Design Using Value Partition Pattern 1

The UML diagrams, built upon the aforementioned Patterns of VP, are shown in Figures 3 and 2. The GOSIS design applies an abstract variation, or sub-pattern, of the Value Partition ontology design pattern. Here, for example, the concept `IndicatorSet` is defined as a class, while specific instances of indicators are treated as individuals which instantiate properties and relations of the `IndicatorSet` class. By contrast, the SOSIS design treats each indicator instance as a class as well. Accordingly, they inherit rather than instantiate properties and relations of the `IndicatorSet` class. This produces a much larger ontology that maps directly to the specific frames of reference that it is derived from, and we term this the *concrete* variation, of sub-pattern, of the Value Partition ODP.

5 Conclusion and Future Work

In this work, we discuss how the use of existing ontology design patterns can help resolve modelling issues in developing and constructing an ontology for sustainability indicators.

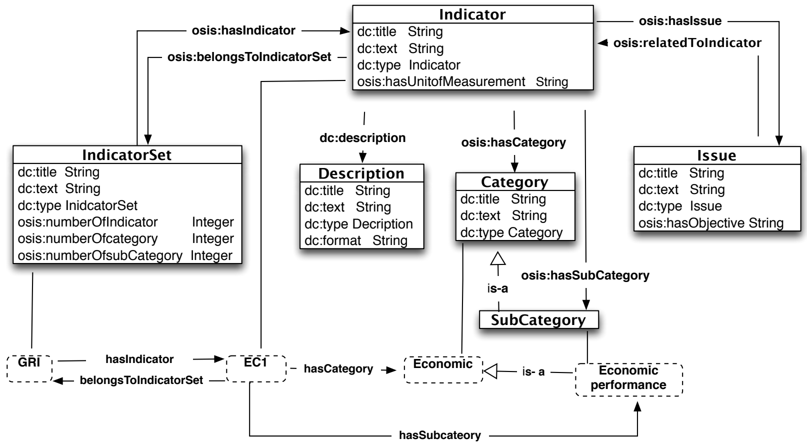

Fig. 3: UML Diagram of GOSIS Design Using Value Partition Pattern 2

Our focus in designing GOSIS and SOSIS was to employ generic and specific models for sustainability indicators that covers broad key concepts of the domain as well as specific indicator sets. The findings from the previous section indicate the novelty of our ontology designs. The two candidates, generic GOSIS and specific design SOSIS, differ largely in terms of abstraction.

We conclude that the specific design sub-pattern is preferable where the domain requirements require a high degree of fidelity to seen frames of reference, while the generic design sub-pattern offers greater reuse in contexts where unseen sets of indicators need to be added to the ontology in an *ad hoc* fashion. We also suggest the use of both ontology design models, where each model captures an aspect of the requirements for supporting indicator systems, which continue to evolve. Such requirements are generally and reusably in GOSIS, and precisely and intuitively in SOSIS.

Further work can be undertaken to incorporate additional sustainability indicators systems, and to further refine the candidate OSIS ontologies presented in this research, and evaluate our ontology models by aligning indicators from multiple providers using Ontology Matching approaches[8].

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[8] http://ontologymatching.org/projects.html

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