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Expressing Dependence Relationships in the Integrative Levels Classification Using OWL

Abstract
This article presents the use of Web Ontology Language (OWL) to represent existential dependence relationships between phenomena in the Integrative Levels Classification (ILC). Existential dependence allows expressing that a higher level of reality depends on a level below it for its existence (for example, a forest depends on plants). Since most traditional knowledge organization systems (KOSs) reduce classes to a linear sequence, they are not able to represent this kind of non-linear relations. Computational formats like OWL are based on automatic processing and inference, bringing new capabilities of expressiveness that are explored in this work by some examples extracted from the Integrative Levels Classification schedules.

1 Introduction

In a connected society, the need for knowledge organization systems (KOSs) that emphasize interoperability of concepts instead of mere interoperability of data is an important challenge. Conceptual approaches to achieve this seemed unrealizable for decades, but are now becoming feasible due to the arising of new technologies, including those related to the Web.

This article presents the use of Web Ontology Language (OWL) to represent existential dependence relationships between phenomena in the Integrative Levels Classification (ILC) and discusses its implications and possibilities.

While such traditional KOSs as thesauri or taxonomies are based on the classical hierarchical (class / subclasses) and associative relationships ('see also' or 'related terms'), in a system based on integrative levels, new properties and different kinds of relationships can also be implemented (Gnoli, De Santis & Pusterla, 2015).

Briefly, in the theory of integrative levels, as formulated during the 1950s by philosophers like James Feibleman and Nicolai Hartmann, a higher level depends on the level below it for existence, but, at the same time, has a more complex organization with new emergent properties, which makes each level essentially a different thing. The relationship that allows expressing this kind of connection between levels is existential dependence (Gnoli, Bosch & Mazzocchi, 2007; Lowe, 2015).

The development of a KOS from the theory of integrative levels is an initiative that refers to the work of the British Classification Research Group (CRG). It is registered in the CRG bulletins regularly published between 1952 and 1968 and in individual works of some of its members, notably Douglas J. Foskett and Derek Austin (Foskett, 1978; Austin, 1971). A draft of a bibliographic classification scheme based on the theory of integrative levels developed by the CRG has been published in 1969, but could not be further developed at that time (Classification Research Group, 1969).

The growth of micro-computing since the 1980s began to allow for the development of new approaches to KOSs. Brian Vickery asserted in 1986 that new KOSs should be designed to take into account not only retrieval, but also the possibility of automated reasoning (performed by the computer itself) leading to the redefinition of search strategies: from seeking and browsing to automated techniques (Vickery, 1986).

2 Integrative Levels Classification

The Integrative Levels Classification (ILC) project is an initiative that has been continuously developed since 2004, managed by an international team including researchers, librarians, computer scientists and philosophers, among which are the present authors. ILC is currently implemented in a web system that operates upon a MySQL relational database. This kind of technological construction brings significant progresses in the use of a classification scheme, including management of freely faceted combinations (Integrative Levels Classification, 2004; Slavic, 2008).

The ILC scheme consists in a single schedule listing all classes of phenomena, expressed in notation as lower-case letters. ILC main classes are listed in Table 1.

Table 1. ILC main classes

a	forms	*n*	populations
b	spacetime	*o*	instincts
c	branes	*p*	consciousness
d	energy	*q*	signs
e	atoms	*r*	languages
f	molecules	*s*	civil society
g	continuum bodies	*t*	governments
h	celestial objects	*u*	economies
i	weather	*v*	technologies
j	land	*w*	artifacts
k	genes	*x*	artworks
l	bacteria	*y*	knowledge
m	organisms	*z*	religion

Taking phenomena as main classes is an innovation as compared to most traditional bibliographic classifications, such as Dewey, UDC, Colon or Bliss, which are based on disciplines (Gnoli, 2016).

Each class of phenomena has subclasses expressed by further letters, just as in any other classification scheme, as exemplified in Table 2.

Table 2. Some ILC classes and subclasses

j land *jy* soils	*m* organisms *mp* plants *mq* animals	*n*ulations *ny* ecosystems *nyr* forests *nyu* deserts	*v* technologies *vh* horticulture *vo* husbandry

Additionally, it can be freely combined with different classes by a set of facets. For example*n7mq* ‘animals as parts of populations’, or *x8nyr* ‘artworks representing forests’. General facets are listed in Table 3 (their set has recently been updated as compared to ILC edition 1).

Table 3. ILC general facets

0 under aspect
1 at time
2 in place
3 by agent
4 suffering from disorder
5 with transformation
6 featuring property
7 with part
8 like form
9 of kind

Facets follow a standard citation order of fundamental categories similar to that recommended by the CRG (Type, Part, Property, Material, Process, Operation, Agent, Space, Time) except from introducing such original categories as Form, Disorder, and Aspect.

A class of phenomena can also have its own special facets, that is, facets that are typical of this particular class of phenomena (in ILC2, the second edition of this KOS currently under development, these are introduced by *9* followed by the appropriate category digits), such as volume as a facet of 3D geometrical shapes. Unlike general facets, these facets only have meaning when applied to their particular class (a language has no volume). Syntactically, special facets work in the same way as facets of disciplinary faceted classifications. General facets, on the other hand, work like phase relationships of disciplinary faceted classification, though being applied more commonly and extensively, or like role operators in such verbal indexing systems as Precis.

In this paper, however, we are particularly concerned with the representation of dependence relationships. This is another type of relationship that is complementary to types and facets and especially relevant in the theory of levels.

3 Existential dependence relationships

Existential dependence is the relationship holding between a level n and a previous level $m < n$. For example, *vh* ‘horticulture’ depends on *mp* ‘plants’ for its existence. In turn, *mp* ‘plants’ depend on *jy* ‘soils’ for existence. The sequence of main classes of phenomena (table 1) should indeed reflect the sequence of existential dependences.

However, several classes may depend on the same class (e.g. both *vh* ‘horticulture’ and *nyr* ‘forests’ depend on *mp* ‘plants’ for existence). Decision on which of them should be listed before others has to be informed by other dependence relationships (e.g. horticulture also depends on civil society, while forests do not). Thus the network of dependences is more complex than a single list of levels.

Reduction of main classes to a linear sequence is needed for the management of classes in a systematic display, which is a basic function of any classification. The ability of managing and displaying the same relationships in different ways is not reachable in a traditional KOS, but can become feasible when considering new emergent technologies as is the case with the Web Ontology Language.

4 Web Ontology Language (OWL)

The Web Ontology Language (OWL) is a knowledge representation language built upon W3C XML standard for objects called the Resource Description Framework (RDF) and is part of the W3C's Semantic Web technology stack (WEB ONTOLOGY LANGUAGE, 2012).

OWL is a computational logic-based language such that knowledge expressed in OWL can be reasoned by computer programs either to verify the consistency of data or to make inferences – which consist in using automatic reasoning rules to make implicit knowledge explicit. OWL documents, usually called *ontologies* [1] are designed to provide interoperability and to be published in the World Wide Web.

An OWL document consists of class axioms, property axioms and facts about individuals [2]. In an OWL document, an axiom is a statement that might be either true or false given a certain state of conditions defined by other axioms and by processing rules.

A class in OWL must have a unique identifier (that forms an URI – Uniform Resource Identifier), usually something like "http://www.url.com/project#class_id". The value of *class_id* is the value that identifies a class. A class may also have one or more labels used for describing it for human reading, using natural language. OWL natively provides features for expressing hierarchy, equivalence, disjoint and union of classes [3].

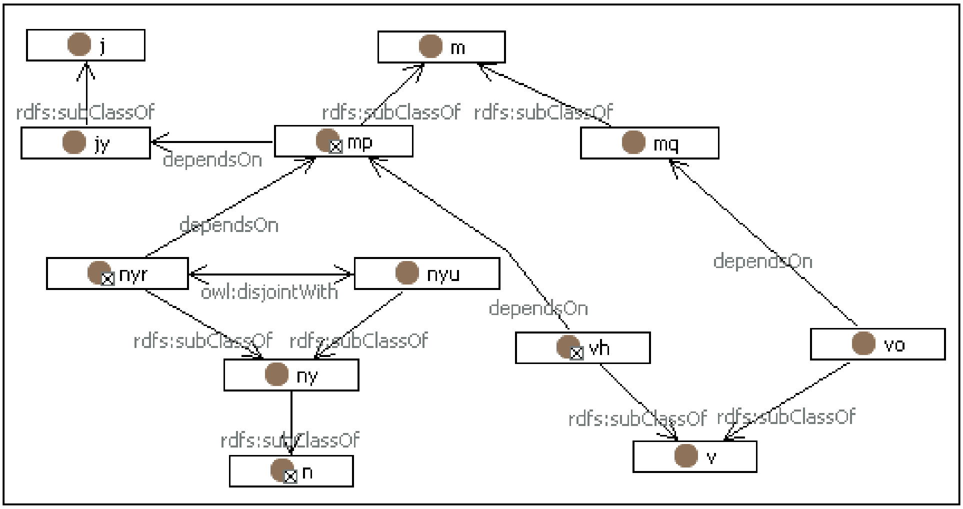
A property (which is, in fact, a special type of class) provides OWL with expressiveness and allows for specification of several kinds of relationships. Besides all native features of a class, a property also has the following predefined axioms: inverse, domain, range, functional, inverse functional, reflexive, irreflexive, symmetric, asymmetric and transitive.

Some examples of classes and properties are provided in the next section. At this point, it is important to emphasize that one of the major differences between OWL and traditional KOS formats is that OWL was conceived to be processed by machine, allowing for the dynamic inclusion of new properties and rules without the need of redefining the whole schema. This makes an OWL-based KOS flexible and extensible, and allows for the creation of user-defined properties, as is the case with existential dependence, which is the focus of this paper.

5 Expressing dependence relationships using OWL

The classes listed in Table 2, as well as some existential dependence relationships among them, have been written in OWL. The result is illustrated in Figure 1, that has been generated by the software TopBraid Composer, version 5.1.3.

Figure 1. Graphical representation of some ILC classes and their dependence relationships



The existential dependences shown here state that *vo* ‘husbandry’ depends on *mq* ‘animals’; *vh* ‘horticulture’ depends on *mp* ‘plants’; *nyr* ‘forests’ depend on *mp* ‘plants’; and *mp* ‘plants’ depend on *jy* ‘soils’.

Table 4 shows an excerpt of OWL code, including declaration of the transitive property *dependsOn* and the class *nyr*.

Table 4. Excerpt of OWL code: property *dependsOn* and class *nyr* ‘forest’

```
<owl:AsymmetricProperty rdf:ID="dependsOn">
<rdfs:range rdf:resource=" http://www.iskoi.org/ilc/owl#Class"/>
<rdfs:domain rdf:resource="http://www.iskoi.org/ilc/owl#Class"/>
<rdfs:label rdf:datatype=" string">dependsOn</rdfs:label>
<rdf:type rdf:resource="http://www.w3.org/2002/07/owl#TransitiveProperty"/>
</owl:AsymmetricProperty>

<rdfs:Class rdf:ID ="nyr">
<owl:disjointWith rdf:resource="#nyu"/>
<dependsOn rdf:resource="#mp"/>
<rdfs:label rdf:datatype="string">forests</rdfs:label>
<rdfs:subClassOf rdf:resource="#ny"/>
</rdfs:Class>
```

The property *dependsOn* is declared as transitive because in integrative levels, when a level depends on a lower level, the following class hierarchy will also depend on it. In the example, as forests depend on the existence of plants, any subclass of forests, like for instance tropical rainforests, will also depend on plants. Transitiveness among levels is also achieved in OWL, but through new dependence relationships, as is the case with *mp* ‘plants’ *dependsOnjy* ‘soil’ that transitively makes *nyr* ‘forests’ *dependsOnjy* ‘soil’.

Intuitively, dependence is an asymmetrical property, as the higher level will depend on the lower while the opposite will not usually be the case. In the previous example, if the property *dependsOn* was declared as symmetric, that would mean that plants also depend on forests for their existence.

The property *dependsOn* has two attributes: domain and range, corresponding respectively to values which may be dependent and values which may cause dependence. In the example, both are set to accept any ILC class.

The class *nyr* ‘forests’ is declared as a subclass of *ny* ‘ecosystems’ and as disjoint with *nyu* ‘deserts’. This means that an ecosystem cannot be simultaneously a forest and a desert. This kind of consistence constraint is ensured by OWL, and is implemented in the major editing tools.

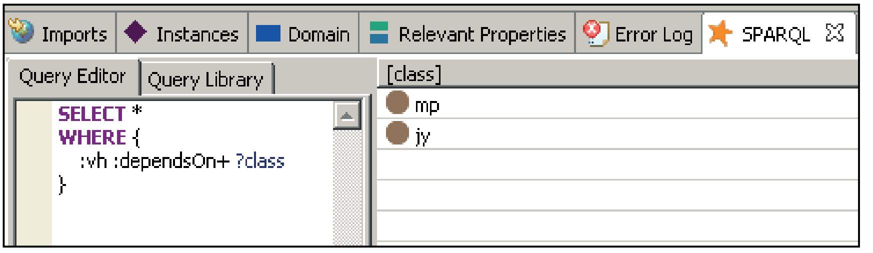
As can be deduced, expressing all kinds of properties axioms for all classes in such a large KOS as ILC may result in an endless task. For this reason, usually only main restrictions are set. In OWL, a restriction is a special kind of property and can be used as a ‘negative relationship’. In the example, stating that *mp* ‘plants’ depend on *jy* ‘soil’would fail when referring to some species of hydroponic or air plants that do not need soil for their existence. A restriction may be expressed for those particular cases through a restriction axiom operating on a relationship, as exemplified in table 5:

Table 5. Syntax of a restriction axiom on relationship *mpdependsOnjv*

```
<owl:Restriction>
<owl:onProperty rdf:ID= "dependsOn"/>
<owl:someValuesFrom rdf:resource="ilc:enumerate_allowed_classes" />
</owl:Restriction>
```

Aforementioned as one of the advantages of OWL, the inference mechanism allows expansion to several steps in the graph of a KOS through the principle of recursion. In the example from ILC, it is explicit that *vh* ‘horticulture’ depends on *mp* ‘plants’, but it is not declared that *vh* ‘horticulture’ depends on *jv* ‘soil’. However, a SPARQL [4] query that searches for all dependences related to *vh* will be able to retrieve both results: *mp* and *jv*, as shown in the screenshot taken from TopBraid Composer software (Figure 2).

Figure 2. Query on ILC database using SPARQL language



The other branches of the given example follow the same principles and serve to illustrate that OWL is structurally extensible. More classes can be added without disturbing the existing schema. This is possible because relationships in OWL are implemented as properties over classes, not on each individual (neither on each subclass, except when this is strictly mandatory). This characteristic also makes possible for a user or a system to browse the KOS either superficially or deeply without needing to know the whole model.

6 Concluding remarks

The use of OWL for implementing a subset of ILC classes has confirmed the capability of this language to represent phenomenon classes and to manage relationships in ways different from the linear approach of traditional KOSs.

The task of expressing dependence relationships among classes has been achieved through activities of indexing and retrieving, and a main result obtained was a demonstration of automated inferences throughout the schema.

The potential relations of this work to Linked Data are also a remark that may lead to future works and possible applications of ILC project. Linked Data is an initiative conducted by W3C and proposed by the creator of the Web, Sir. Tim Berners-Lee. It refers to a set of best practices for publishing and connecting structured data on the Web using RDF to describe things in the world (Bizer, Heath & Berners-Lee, 2009). From this approach it is possible to aim for a general and open KOS, which manipulates shared knowledge, and that can be used in different ways and from several perspectives, such as the Web itself as opposed to local descriptions of closed systems.

Notes

[1] Concerning the discussion about adoption of the term ontology in a different sense from that originally considered in philosophy, in the present work,the authors decided to use “OWL document” when referring to the resulting artifact and consider ontology as defined by Roberto Poli: “ontology is not a catalogue of the world, a taxonomy, or a terminology. If anything, an ontology is the general framework within which catalogues, taxonomies, and terminologies may be given suitable organization” (Poli, 1996, p. 313).

[2] In this work, the emphasis is on classes and properties. Facts about individuals (instances) will not be explored here.

[3] A complete description of OWL syntax is available in thespecification website: [https://www.w3.org/TR/owl2-syntax/]

[4] SPARQL is a semantic query language able to retrieve and manipulate data stored in Resource Description Framework (RDF) format . For details, see: [https://www.w3.org/TR/rdf-sparql-query]

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