

Owlifier: Creating OWL-DL ontologies from simple spreadsheet-based knowledge descriptions[☆]

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ARTICLE INFO

Article history:

Received 3 December 2008

Received in revised form 31 August 2009

Accepted 31 August 2009

Keywords:

Ontologies

Ontology development

Ecological metadata

Data discovery and integration

ABSTRACT

Discovery and integration of data is important in many ecological studies, especially those that concern broad-scale ecological questions. Data discovery and integration are often difficult and time consuming tasks for researchers, which is due in part to the use of informal, ambiguous, and sometimes inconsistent terms for describing data content. Ontologies offer a solution to this problem by providing consistent definitions of ecological concepts that in turn can be used to annotate, relate, and search for data sets. However, unlike in molecular biology or biomedicine, few ontology development efforts exist within ecology. Ontology development often requires considerable expertise in ontology languages and development tools, which is often a barrier for ontology creation in ecology. In this paper we describe an approach for ontology creation that allows ecologists to use common spreadsheet tools to describe different aspects of an ontology. We present conventions for creating, relating, and constraining concepts through spreadsheets, and provide software tools for converting these ontologies into equivalent OWL-DL representations. We also consider inverse translations, i.e., to convert ontologies represented using OWL-DL into our spreadsheet format. Our approach allows large lists of terms to be easily related and organized into concept hierarchies, and generally provides a more intuitive and natural interface for ontology development by ecologists.

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1. Introduction

Within the fields of molecular biology and biomedicine considerable effort has gone into developing ontologies for improving data discovery and integration (Ashburner et al., 2000; Bard and Rhee, 2004). While similar benefits can be obtained for ecological data, far fewer efforts exist to develop broad and consistent terminologies within ecology (Madin et al., 2008; Parr and Cummings, 2004). The use of formal ontologies can significantly enhance metadata descriptions of ecological data. For instance, annotating data with ontology terms can both help users interpret data as well as enable advanced capabilities for data discovery and integration, e.g., by exploiting subsumption and part-of hierarchies as well as more formal constraints such as cardinality restrictions on properties and term equivalence (Madin et al., 2008).

Efforts to engage scientists in the development of ontologies typically leverage the W3C Web Ontology Language (OWL) (Smith et al., 2004) as a standard XML syntax for representing and sharing

ontologies. A key advantage of OWL is that it is supported by a wide range of generic tools, including editors (Knublauch et al., 2004; Kalyanpur et al., 2005), reasoning systems (Sirin et al., 2007; Tsarkov and Horrocks, 2006), query languages (Prudhommeaux and Seaborne, 2008; Motik et al., 2005), and storage technologies (Carroll et al., 2004; Broekstra et al., 2002). However, most of these tools are primarily targeted at experts in knowledge engineering and software development familiar with the underlying description logic semantics of OWL-DL (Grau et al., 2008). This is especially true with ontology editors (such as Protege, SWOOP, etc.), which allow for very detailed ontology specifications, but at the same time require considerable understanding of the underlying ontology formalisms and syntax.

The development of the Gene Ontology (GO) has been underway for over a decade within the molecular biology community, and has led to significant improvements in data interoperability by enriching genomic and biomedical data resources with annotations to community-based ontologies. A major lesson learned from these efforts was the importance of keeping the ontology focused, and indeed GO has a highly delimited scope (Bada et al., 2004). Ecology, on the other hand, encompasses an extremely broad range of scales and disciplines, such that a coordinated ontology development effort would need to involve a large number of experts to cover the diverse types of information relevant to ecological investigations. We believe that ecological

[☆] This work supported in part by NSF grants DBI-0743429 and DBI-0753144.

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researchers must also begin constructing ontologies for their own specialized subdisciplines. However, due to the substantial expertise in formal knowledge representation that is required to use most existing ontology editing tools, new tools and approaches are needed to enable the wide-scale creation and adoption of ontologies in ecology.

This paper presents a novel approach for ontology creation that aims at being more intuitive for ecologists and that can be used to rapidly construct large ontologies of ecological terms (classes and properties). These terms can then be used in subsequent steps to annotate ecological data (instances), e.g., as described in our previous work (Bowers et al., 2008; Berkley et al., 2009). Our approach is to allow scientists to use common and familiar spreadsheet-based tools (e.g., Microsoft Excel, Apple Numbers, Open Office Spreadsheet) to describe, in an intuitive way, different aspects of an ontology, and then to take these descriptions (represented as spreadsheets) and convert them into full-fledged OWL ontologies using a software application called owlifier.

An owlifier spreadsheet consists of a set of *blocks* that have a predefined template structure for users to fill in. Each non-empty row in an owlifier spreadsheet constitutes a block. Each block defines different aspects of an ontology including classes, subclasses, synonyms, and properties. We also provide blocks for plain-text descriptions of classes and properties, and for referencing one or more existing ontologies (e.g., to extend an existing ontology or to define ontology articulations). Blocks can be sparse (inheriting from previous blocks), which further simplifies the creation of large ontologies by minimizing the amount of redundant information that must be provided in the owlifier tabular representation. Several of the more advanced OWL features are omitted in owlifier, primarily associated with properties (e.g., role inclusion axioms, domain and range property restrictions, and data-type properties among others), as these can be confusing for non-experts and are more suitable for experienced knowledge modelers.

While not as expressive as OWL-DL, owlifier can be used to produce ontology structures that are essential for improved data discovery and integration (Madin et al., 2007). Just as important, because spreadsheet tools are already frequently used by ecologists to store and analyze data, owlifier can provide ecologists with a familiar and accessible user interface for ontology creation. This approach also leverages the easy-to-use interfaces provided by many spreadsheet tools for organizing and manipulating tabular data, e.g., via cut/copy/paste, search/replace, sort, split-window, track-changes, freeze panes, and so on. In this way, an ecologist can easily construct (or load) a set of terms, and then incrementally organize these into class hierarchies, properties, and constraints. The use of an editing environment that is familiar to scientists can significantly help improve the speed and understanding of ontology construction and avoid the often time-consuming task of locating, downloading, installing, and learning fundamentally new software applications and interfaces (e.g., CMAP-COE (Hayes et al., 2005), Protege (Knublauch et al., 2004)). In initial experiments with ecologists and evolutionary biologists studying trait data, we found that owlifier enabled them to quickly and easily comprehend and construct relatively complex and meaningful ontologies.

The rest of this paper is organized as follows. In Section 2 we describe the basic syntax and semantics of owlifier. The semantics of owlifier blocks is given by mapping owlifier expressions to description-logic statements. Readers unfamiliar with description-logic notation may safely ignore these mappings, focusing instead on the descriptions and examples of blocks given in Section 2. We define blocks that support a large subset of OWL-DL and that also generally follow the ontology creation guidelines defined in (Rector et al., 2004). We also simplify certain aspects of ontology creation using OWL, e.g., by assuming classes are disjoint by default (unless specified otherwise) (Rector et al., 2004). In Section 5 we describe additional characteristics of owlifier and discuss issues with respect to classification and reasoning. In Section 3 we briefly describe the owlifier

implementation, and conclude in Section 4 with related and future work. In general, the goal of owlifier is not to support all constructs in OWL-DL, but instead to provide a higher-level ontology syntax (via spreadsheet blocks) that is easy for ecologists to use and understand while also providing the necessary constructs for developing typical ecological ontologies. By compiling owlifier to OWL-DL, we also allow for experts to refine and extend the ontology using more advanced ontology editing tools if necessary (cf. Fig. 1).

2. The syntax and semantics of owlifier

As described above, an owlifier table defines an OWL-DL (Smith et al., 2004) ontology through a set of *blocks* representing one or more ontology definitions. Each non-empty row in an owlifier table corresponds to a block. The type of the block is given in the first column of the row. We assume that if any properties or classes used in a block are not imported from another ontology, then they are to be added to the ontology being specified by the owlifier table (i.e., the “current” ontology). In general, we name blocks according to the terms used in (Bowers et al., 2008; Madin et al., 2007) as opposed to the names used for corresponding constructs in OWL-DL. This choice of block names helps to simplify terminology (e.g., we use “relationship” below instead of “object property”), allows owlifier to easily generate ontologies that extend the observational model of (Bowers et al., 2008; Madin et al., 2007), and avoids confusion with established terms commonly used within ecology (e.g., “class”).

2.1. Import blocks

Import blocks assign namespace labels to external ontologies. Each external ontology is imported into the current ontology. We refer to the ontologies of import blocks as *imported ontologies*. Using import blocks, classes and properties of imported ontologies can be used within other blocks of an owlifier table. Rows containing import blocks take the form

import	<i>n</i>	<i>u</i>
--------	----------	----------

where *n* is a namespace label and *u* is an OWL ontology URI. Classes and properties from imported ontologies are referenced by prefixing the namespace label *n* to the corresponding class or property name in the normal way. As an example, the following block imports the SWEET “Earth Realm” ontology (Raskin and Pan, 2005).

import sweet <http://sweet.jpl.nasa.gov/ontology/earthrealm.owl>

With this import block the class denoting Marine Ecosystems (a class defined in the SWEET ontology) can be referred to from within an owlifier table using the expression sweet:MarineEcosystem. Because this class refers to a class in another ontology, we refer to it as an *imported class*.

2.2. Entity blocks

Entity blocks are the primary blocks used to define ontologies. An entity block introduces new OWL classes and specifies subclass relationships. Imported classes may also be used within entity blocks by prefixing class names with namespace labels (as described above). Rows containing entity blocks take the form

entity	<i>c</i> ₁	<i>c</i> ₂	...	<i>c</i> _{<i>n</i>}	(<i>n</i> ≥ 1)
--------	-----------------------	-----------------------	-----	------------------------------	-----------------

where each class *c*_{*i*} is asserted in the current ontology to subsume *c*_{*i*+1}, for 1 ≤ *i* < *n*. That is, each *c*_{*i*} in an entity block induces the description logic axiom *c*_{*i*+1} ⊆ *c*_{*i*}. If both *c*_{*i*} and *c*_{*i*+1} are imported classes, we say that

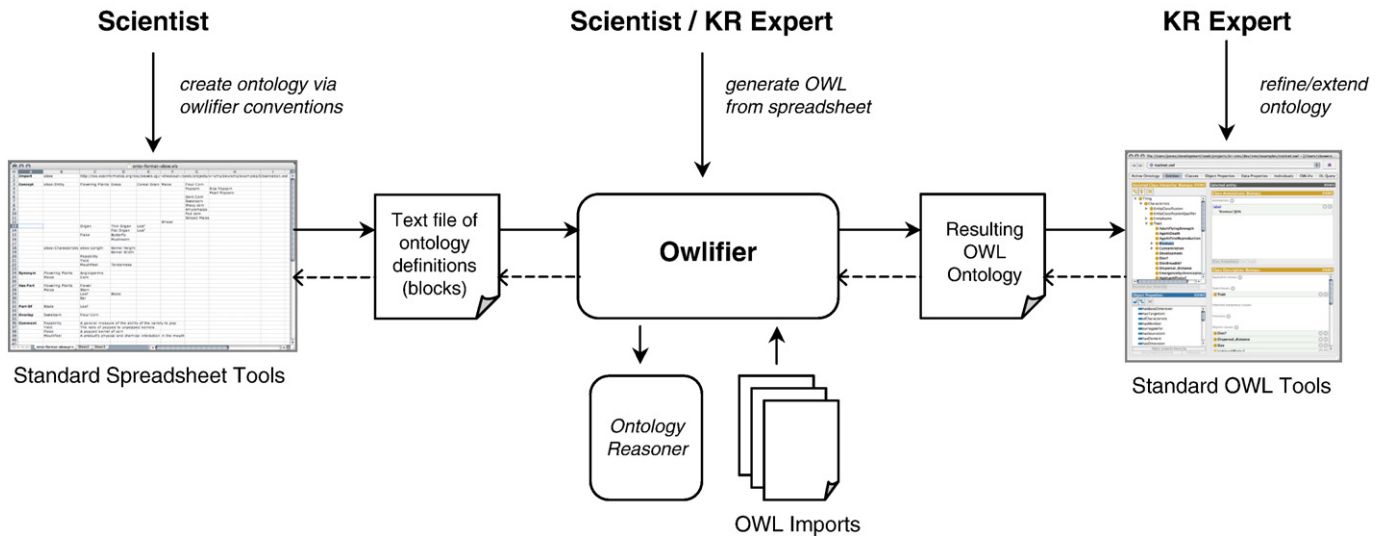


Fig. 1. The basic owlifier application and relation to other technologies.

the block defines an “articulation” (i.e., mapping) between the two classes. The following entity block defines a simple subclass hierarchy.

```
entity PhysicalFeature AquaticPhysicalFeature River
```

This block states that Physical Feature, Aquatic Physical Feature, and River are classes; River is a subclass of Aquatic Physical Feature; and Aquatic Physical Feature is a subclass of Physical Feature. The following entity block introduces a new class via an imported class.

```
entity sweet:MarineEcosystem IntertidalEcosystem
```

This block states that Intertidal Ecosystem is a subclass of the Marine Ecosystem class imported from the SWEET ontology. Similarly, assuming “marine” denotes an existing ontology of marine ecosystem concepts, the following block defines a simple class articulation.

```
entity sweet:MarineEcosystem marine:DeepSeaEcosystem
```

This block states that the Deep Sea Ecosystem class of the marine ontology is a subclass of the Marine Ecosystem class of the SWEET ontology (thus defining a mapping between these two ontologies).

2.3. Synonym blocks

Synonym blocks define equivalence relationships between ontology classes. Rows containing synonym blocks take the form

synonym	c_1	c_2	\dots	c_n
---------	-------	-------	---------	-------

($n \geq 2$)

where each class c_i is equivalent to class c_{i+1} in the current ontology, for $1 \leq i < n$. That is, each c_i in a synonym block induces a description logic axiom of the form $c_i \equiv c_{i+1}$. The following synonym block creates a simple equivalence relationship.

```
synonym Maize Corn
```

This block states that the Maize and Corn classes are synonyms (equivalent classes). Similar to entity blocks, synonym blocks often contain imported classes for extending existing ontologies or defining ontology mappings.

2.4. Overlap blocks

Except in certain situations (described further in Section 3), classes are generally assumed to be disjoint in owlifier. Overlap blocks explicitly relax this assumption by stating that a given set of classes may share common instances. Rows containing overlap blocks take the form

overlap	c_1	c_2	\dots	c_n
---------	-------	-------	---------	-------

($n \geq 2$)

where each class c_i is allowed to share instances with each class c_j , for $1 \leq i, j \leq n$. That is, a given c_i and c_j in an overlap block are not defined to be disjoint classes in the current ontology. As an example, consider the following entity blocks that define the classes Estuary, Lagoon, and Marsh as subclasses of Ecological Habitats.

```
entity EcologicalHabitat Estuary
entity EcologicalHabitat Lagoon
entity EcologicalHabitat Marsh
```

Given only these blocks, owlifier treats Estuary, Lagoon, and Marsh as disjoint classes. To relax this assumption and allow, e.g., types of Lagoons to also be types of Estuaries, we explicitly add the following overlap block.

```
overlap Estuary Lagoon
```

In general, overlap blocks are rarely used but provide a mechanism to override the default behavior of owlifier in asserting disjoint classes.

2.5. Relationship blocks

Relationship blocks define *required* class object properties. An object property within OWL is a property defined between two class instances. Rows containing relationship blocks take the form

relationship	p	c_1	c_2	\dots	c_n
--------------	-----	-------	-------	---------	-------

($n \geq 2$)

where p is an object property and each c is a class. For every class c_i , the relationship block induces the description logic axiom $c_i \sqsubseteq \exists p.c_{i+1}$ stating that each instance of c_i is p -related to some instance of c_{i+1} , for

$1 \leq i < n$. For example, the following block states that instances of the class California Voles live in Grassy Areas.

relationship livesIn CaliforniaVole GrassyArea

In some cases, a particular property can apply to a sequence of classes, and for convenience, each such class can be specified in owlifier using a single block. For example, consider the following block.

relationship directlyBelow Hypolimnion Thermocline Epilimnion

This block states that, e.g., within a thermally stratified lake, the Hypolimnion layer is directly below the Thermocline layer, and the Thermocline layer is directly below the Epilimnion layer.

2.6. Transitive blocks

Transitive blocks are special cases of relationship blocks where the object property is asserted to be transitive. That is, if a property p is declared to be transitive, and p relates an individual x to an individual y and y to an individual z , then p is assumed to also relate x to z . Rows containing transitive blocks take the form

transitive	p	c_1	c_2	\dots	c_n
------------	-----	-------	-------	---------	-------

($n \geq 2$)

where p is an object property and each c is a class. The following block is a simple example of a transitive relationship definition.

transitive hasPart Body Head Eye Retina

This block states that every instance of the class Body has a Head as a part, every instance of the class Head has an Eye as a part, and every instance of the class Eye has a Retina as a part. Moreover, because the hasPart property above is defined to be transitive, it is possible to infer that every instance of Body also has an Eye and a Retina as a part through the inherited relationship restrictions $\text{Body} \sqsubseteq \exists \text{has Part. Head}$, $\text{Head} \sqsubseteq \exists \text{has Part. Eye}$, and $\text{Eye} \sqsubseteq \exists \text{has Part. Retina}$.

2.7. Cardinality blocks

Cardinality blocks are also similar to relationship blocks. We consider three types of cardinality blocks for defining minimum, maximum, and exact cardinality restrictions. Rows containing minimum blocks take the form

min	p	m	c_1	c_2	\dots	c_n
-----	-----	-----	-------	-------	---------	-------

($n \geq 2$)

where m is the minimum number of properties p that instances of class c_i must have to instances of concept c_{i+1} , for $1 \leq i < n$. For each class c_i , a minimum cardinality block induces the description logic axiom $c_i \sqsubseteq (\leq m) p.c_{i+1}$ stating that each instance of c_i must be p -related to at least m unique instances of c_{i+1} . The following two blocks demonstrate simple minimum cardinality constraints.

min hasPart 1 Body Head Nose
min hasPart 2 Head Eye

The first block states that instances of the class Body have at least one Head as a part, which in turn have at least one Nose as a part.¹ The

second block states that instances of the class Head have at least two Eyes as parts.

Rows containing maximum blocks take the form

max	p	m	c_1	c_2	\dots	c_n
-----	-----	-----	-------	-------	---------	-------

($n \geq 2$)

where m is the maximum number of properties p that instances of concept c_i may have to instances of concept c_{i+1} , for $1 \leq i < n$. For each class c_i , a maximum cardinality block induces the description logic axiom $c_i \sqsubseteq (\geq m) p.c_{i+1}$ stating that each instance of c_i may be p -related to at most m unique instances of c_{i+1} . The following two blocks demonstrate simple maximum cardinality constraints.

max hasPart 1 Body Head Nose
max hasPart 2 Head Eye

The first block states that instances of the class Body have at most one Head as a part, which in turn has at most one Nose as a part. The second block states that instances of the class Head have at most two Eyes as parts.

Rows containing exact blocks take the form

exact	p	m	c_1	c_2	\dots	c_n
-------	-----	-----	-------	-------	---------	-------

($n \geq 2$)

where m is the number of properties p that instances of concept c_i must have to instances of concept c_{i+1} , for $1 \leq i < n$. For each class c_i , an exact block induces the description logic axiom $c_i \sqsubseteq (=m) p.c_{i+1}$ stating that each instance of c_i must be p -related to m unique instances of c_{i+1} .

2.8. Inverse blocks

Inverse blocks state that two object properties are inverses of each other. If p_1 and p_2 are defined to be inverse properties, whenever p_1 relates an individual x to an individual y then p_2 (as the inverse of p_1) is assumed to relate y to x . Rows containing inverse blocks take the form

inverse	p_1	p_2
---------	-------	-------

where p_1 and p_2 are object properties. A common example of inverse properties are hasPart and partOf, i.e., if an individual x has an individual y as a part, then y is by definition a part of x .

2.9. Sufficient blocks

Sufficient blocks are similar to synonym blocks in that they state equivalences between classes. We consider two types of sufficient blocks. A sufficient entity block takes the form

sufficient	entity	c_1	c_2	\dots	c_n
------------	--------	-------	-------	---------	-------

($n \geq 2$)

where each c_i is a class. A sufficient entity block induces the description logic axiom $c_1 \sqsubseteq c_2 \sqcap \dots \sqcap c_n$ stating that the class c_1 is equivalent to the intersection of the classes c_2 through c_n . Similarly, a sufficient relationship block takes the form

sufficient	relationship	(not)	p	c_1	c_2
------------	--------------	-------	-----	-------	-------

where p is an object property, c_1 and c_2 are classes, and not is an optional qualifier. A sufficient relationship block (without a not qualifier) induces the description logic axiom $c_1 \sqsubseteq \exists p.c_2$ stating that the class c_1 is equivalent to the set of individuals that are p -related to at least one individual of class c_2 . The not qualifier states that the absence of the property is a defining characteristic of the class. Thus, a sufficient relationship block containing a not qualifier induces the description logic axiom $c_1 \sqsubseteq \neg \exists p.c_2$. The use of multiple sufficient blocks for a particular class results in a

¹ Cardinality restrictions ensuring participation to at least one property are typically not given through minimum cardinality blocks since they are also implied by relationship blocks.

single axiom in which each constraint (i.e., class constructor) is combined via intersection (\sqcap). For example, the following blocks

```
sufficient relationship hasPart Mammal Hair
sufficient entity Eutheria Mammal
sufficient relationship not hasPart Eutheria Epipubic Bone
```

induce the following description logic axioms.

```
Mammal  $\sqsubseteq \exists$ hasPart. Hair
Eutheria  $\sqsubseteq$  Mammal  $\sqcap \neg \exists$ hasPart. Epipubic Bone
```

These axioms state that *any* individual that has Hair as a part is a Mammal and that *any* Mammal that does not have an Epipubic Bone as a part is a Eutheria.

2.10. Comment blocks

There are two types of comment blocks that each provide a mechanism to add plain-text comments to owlifier tables. A description block attaches a plain-text comment to classes and properties. Rows containing description blocks take the form

description	c or p	s
-------------	--------	---

where the string *s* is associated as a comment to the class *c* or property *p*. A note block attaches comments to the current ontology. Rows containing note blocks can occur anywhere within an owlifier table, and take the form

note	s
------	---

where *s* is a comment string.

3. Additional features of owlifier

Here we briefly describe some of the additional features of owlifier, specifically focusing on the use of disjoint classes, owlifier reasoning, and additional block syntax.

3.1. Disjoint class inference

OWL is based on the open world assumption, which can lead to a number of ontology development “pitfalls” for those new to the language (Smith et al., 2004; Rector et al., 2004). One example is in the creation of disjoint classes. In particular, unless explicitly asserted, distinct classes within an OWL-DL ontology are not assumed to be disjoint. However, in many ontologies a large number of classes are typically defined as being disjoint (e.g., sibling classes), and stating these disjoint constraints is often time consuming since each pair of classes must be given an explicit disjoint assertion. Editors such as Protege (Knublauch et al., 2004) provide shortcuts via the user interface to create specific sets of disjoint assertions, e.g., by allowing a user to define all children of a particular class as disjoint. In general, however, many users expect such classes to be disjoint by default (Rector et al., 2004) and this expectation often leads to modeling errors.

Alternatively, the default assumption in owlifier is that distinct classes are disjoint. Specifically, as an owlifier table is converted to an OWL-DL ontology, the system analyzes the class hierarchy structure and identifies pairs of classes that are: (1) not related via subclass relations (either direct or indirect subclasses); (2) not defined as synonyms; and (3) not explicitly defined to overlap via an overlap block. Each such pair of classes is then asserted by owlifier in the resulting ontology as being disjoint. As described in (Rector et al., 2004), undeclared disjoint classes are a common problem in ontology

development using OWL-DL and often limit the utility of reasoning systems (by limiting the inferences that can be obtained). The approach employed in owlifier for handling disjoint classes makes the common expectations of users the default case, which in general should lead to a more intuitive ontology editing environment and an overall fewer number of modeling mistakes.

3.2. Reasoning in owlifier

Blocks in owlifier are unambiguous, i.e., for every owlifier block (or set of blocks in the case of sufficient blocks) there is a well-defined set of corresponding OWL-DL axioms. This property is important because it implies that reasoning can be performed over ontologies defined in owlifier using standard OWL-DL reasoners. We use this capability in our current owlifier implementation (described further in Section 4) to verify ontologies defined using owlifier and report possible errors to users.

In general, new axioms are inferred from an owlifier ontology primarily from the use of synonym blocks, sufficient blocks, and transitive blocks (whose inferences are described in the previous section). For instance, let *A*, *B*, and *C* be classes and *P* be an object property. From an axiom $A \sqsubseteq B$ generated from a synonym block, and an axiom $A \sqsubseteq \exists P.C$ generated from a relationship block, the axiom $A \sqsubseteq \exists P.B$ would be inferred. Thus, the axioms of a particular class are “inherited” by all of the synonyms of the class. Similarly, from an axiom $A \sqsubseteq \exists P.C$ generated from a sufficient block, and an axiom $B \sqsubseteq A$ would be inferred. For both the case of synonym and sufficient blocks, the use of equivalence permits a number of additional inferences to be made via an OWL-DL reasoner.

As described in (Rector et al., 2004) additional reasoning can occur within OWL-DL ontologies when domain and range axioms are provided (as well as, e.g., property closure axioms). We explicitly do not consider these constraints in the current version of owlifier because they also often result in modeling errors for inexperienced OWL-DL users (Rector et al., 2004). Instead, we adopt the approach of more traditional description logics, which do not have explicit domain and range axioms. Although not currently supported in owlifier, domain and range constraints as well as property closure axioms can be inferred from given relationship blocks.

3.3. Sparse blocks

To help simplify the creation of class hierarchies and property sequences (including transitive, cardinality, and sufficient blocks), we allow for “sparse” blocks that inherit missing information from their closest preceding block. For instance the following entity blocks

```
entity EcologicalHabitat Estuary Bay
entity EcologicalHabitat Estuary Fjord
entity EcologicalHabitat Marsh Tidal Marsh
entity EcologicalHabitat Marsh Salt Marsh
```

can be equivalently represented in owlifier using the following sparse blocks.

```
entity EcologicalHabitat Estuary Bay
                                Fjord
                                Marsh TidalMarsh
                                SaltMarsh
```

In general, the use of sparse blocks simplifies ontology creation by not requiring users to enter every redundant field explicitly, which in turn can simplify the overall layout of the ontology within a spreadsheet. Additionally, owlifier does not place constraints on the order of blocks within a spreadsheet. Classes also do not need to be explicitly defined

within an entity block, e.g., classes without corresponding entity blocks can be introduced simply through synonym and relationship blocks. This typically occurs when a particular class does not participate as a subclass or superclass of another class in the current ontology. Taken together, these approaches allow users to enter minimal information by limiting redundancy and by supporting a range of inferences, while at the same time reducing the causes of many errors commonly made in ontology development by non-experts.

4. The owlifier implementation

Fig. 1 shows the general architecture of the owlifier application. A scientist first creates a spreadsheet containing a set of ontology definitions using owlifier conventions. The spreadsheet is then exported as a plain-text file containing the owlifier table, e.g., using a CSV or tab-delimited format. The owlifier table is then sent to the owlifier application, which performs a number of steps that include: (i) parsing the file; (ii) generating the corresponding OWL-DL representation (e.g., in the current implementation, the OWL-API is used (Horridge et al., 2007), although Jena (Carroll et al., 2004) could be used as well); (iii) validating the ontology and ensuring it is consistent via an OWL-DL reasoner (e.g., the current implementation uses Pellet (Sirin et al., 2007)); and (iv) outputting the corresponding OWL-DL file. The resulting OWL file can then be refined and extended via existing OWL tools (e.g., Protege or SWOOP). It is also possible for the refined ontology to be converted back to a corresponding owlifier representation (shown using dashed lines in Fig. 1). While straightforward to perform, this “back” conversion is not information preserving since not all OWL-DL statements can be represented through owlifier blocks. That is, the conversion from OWL-DL to owlifier will only preserve OWL-DL constructs that are represented by owlifier blocks. In particular, owlifier does not support a number of OWL-DL language constructs, including domain and range constraints, datatype properties, sub properties, property constraints (i.e., functional, symmetric, and inverse functional), value restrictions, individuals, etc., as well as various combinations of OWL-DL constructs.

The current implementation of owlifier is written as an open-source Java application² and supports a subset of the blocks defined in Section 2. In particular, we are currently extending owlifier to fully support sufficient blocks (the remaining blocks described in Section 2 are implemented) as well as the potentially lossy, back conversion from OWL-DL files to corresponding owlifier blocks. The current implementation of owlifier is being used within a project focused on integrating vegetation trait data. As noted above, not all the blocks described here are yet supported, however, these priority needs are clearly emerging from our interactions with the vegetation scientists. Nevertheless, these scientists were able to rapidly prototype and revise their trait ontologies using owlifier, with little to no instruction in formal logic or knowledge modeling. In addition, owlifier is being used to construct term hierarchies from large sets of keywords (harvested from existing metadata documents) as well as to define articulations between existing ontologies and the observation ontology defined in (Madin et al., 2007). As we continue to use owlifier within these projects, we intend to extend the application as needed to support additional blocks and services.

5. Conclusion

This paper presents a new approach for developing ontologies to address barriers in ontology development and adoption by ecologists. Our approach allows scientists to use familiar spreadsheet software (e.g., frequently used by ecologists for storing and analyzing data) to create ontologies by filling in a set of templates, or blocks, that generate OWL-DL class hierarchies, properties, and constraints via the

owlifier application. This approach can provide a more intuitive and accessible ontology editing environment for ecologists, especially compared to existing OWL-based tools that require considerable expertise in the underlying logic formalisms. Similar to standard OWL ontologies, owlifier spreadsheets can import and extend existing OWL-DL ontologies (including those generated from owlifier spreadsheets), which further supports the community development and interoperability of ontologies. Blocks in owlifier (or similarly, partially filled in blocks) can also be reused during ontology creation to help ensure that future ontology development adheres to best practices and community standards (e.g., similar to “part-of” properties defined in the Gene Ontology (Bada et al., 2004)).

Protege provides a variety of ontology editing plug-ins, including a simple interface for text-based editing of class hierarchies. In (Kola and Rector, 2007), an approach is described for importing spreadsheet-based ontology descriptions into Protege. However, this approach aims at supporting *ad-hoc* spreadsheet structures by providing an intermediate interface for mapping these structures into ontology axioms. This approach is similar to others (e.g., (Han et al., 2008; Bizer, 2003; An et al., 2006)) for defining mappings from relational data to RDF and OWL ontology class and instance data. In addition to these approaches, a number of visual editing environments have been developed to help novice users create OWL-based ontologies (e.g., (Hayes et al., 2005)). To the best of our knowledge, however, our approach is the first to consider an intuitive spreadsheet-based approach together with a detailed set of templates that can support a large subset of existing OWL constructs. In addition, we define a number of shortcuts for creating owlifier tables, including sparse blocks and default semantics (e.g., disjoint classes) that further simplify ontology creation for end users.

As future work, we plan to extend our current owlifier implementation to support the full set of blocks defined here as well as introduce additional blocks, e.g., for creating OWL datatype properties. We also would like to explore approaches for supporting round-trip conversions between owlifier tables and OWL-DL ontologies that allow scientists and knowledge-representation experts to incrementally develop owlifier-based ontologies. Specifically, we want to extend the owlifier application so that it can store and re-apply changes made by knowledge-representation experts that previously modified an OWL-DL ontology generated by owlifier. For instance, if an OWL-DL ontology generated from an owlifier spreadsheet is refined and extended by a knowledge-representation expert, then converted back into an owlifier ontology that is further edited and extended by a scientist, and then converted again into an OWL-DL ontology, we want to maintain (i.e., re-apply) the original extensions and edits created by the knowledge-representation expert that are still relevant (thus supporting lossless conversions). We also plan to extend the owlifier application to support translation into the observation ontology framework presented in (Bowers et al., 2008) and perform additional testing and evaluation of the owlifier approach with a wide range of ecologists.

References

- An, Y., Borgida, A., Mylopoulos, J., 2006. Discovering the semantics of relational tables through mappings. *J. Data Semantics VII* (4244:0), 1–32.
- Ashburner, M., et al., 2000. Gene ontology: tool for the unification of biology. *Nat. Genet.* 25 (0), 25–29.
- Bada, M., Stevens, R., Goble, C., Gil, A., Ashburner, M., Blake, J.A., Cherry, J.M., Harris, M., Lewis, S., 2004. A short study on the success of the gene ontology. *J. Web Sem.* 1 (0), 235–240.
- Bard, J., Rhee, S., 2004. Ontologies in biology: design, applications, and future challenges. *Nat. Rev. Genet.* 5 (0), 213–221.
- Berkley, C., Bowers, S., Jones, M., Madin, J., Schildhauer, M., 2009. Improving data discovery for metadata repositories through semantic search. *Proc. of the Intl. Workshop on Intelligent Systems for Environmental (Knowledge) Engineering and EcoInformatics (iSEEK)*.
- Bizer, C., 2003. D2R MAP—a database to RDF mapping language. *Proc. of the Intl. World Wide Web Conference (WWW)*, pp. 20–24.
- Bowers, S., Madin, J.S., Schildhauer, M.P., 2008. A conceptual modeling framework for expressing observational data semantics. *Proc. of the Intl. Conference on Conceptual Modeling (ER)*, volume 5231 of Lecture Notes in Computer Science, pp. 41–54.

² See <https://semtools.ecoinformatics.org/owlifier>.

- Broekstra, J., Kampman, A., van Harmelen, F., 2002. Sesame: a generic architecture for storing and querying RDF and RDF Schema. *Proc. of the Intl. Semantic Web Conference (ISWC)*, volume 2342 of *Lecture Notes in Computer Science*. Springer, pp. 54–68.
- Carroll, J.J., Dickinson, I., Dollin, C., Reynolds, D., Seaborne, A., Wilkinson, K., 2004. Jena: implementing the semantic web recommendations. *Proc. of the Intl. World Wide Web Conference (WWW)*, pp. 74–83.
- Grau, B.C., Horrocks, I., Motik, B., Parsia, B., Patel-Schneider, P., Sattler, U., 2008. OWL 2: the next step for OWL. *J. Web Sem.* 60 (4):0, 309–322.
- Han, L., Finin, T., Parr, C.S., Sachs, J., Joshi, A., 2008. RDF123: from spreadsheets to RDF. *Proc. of the Intl. Semantic Web Conference (ISWC)*, pp. 451–466.
- Hayes, P., Eskridge, T.C., Saavedra, R., Reichherzer, T., Mehrotra, M., Bobrovnikoff, D., 2005. Collaborative knowledge capture in ontologies. *Proc. of the Intl. Conference on Knowledge Capture (K-CAP)*, pp. 99–106.
- Horridge, M., Bechhofer, S., Noppens, O., 2007. Igniting the OWL 1.1 touch paper: the OWL API. *Proc. of the OWL Experiences and Directions Workshop (OWLED)*.
- Kalyanpur, A., Parsia, B., Sirin, E., Cuenca-Grau, B., Hendler, J., 2005. Swoop: a 'web' ontology editing browser. *J. Web Sem.* 40 (2).
- Knublauch, H., Musen, M.A., Rector, A.L., 2004. Editing description logic ontologies with the Protégé OWL Plugin. *Proc. of the Intl. Workshop on Description Logics (DL)*, volume 104 of *CEUR Workshop Proceedings*.
- Kola, J., Rector, A., 2007. Importing spreadsheet data into Protege: spreadsheet plug-in. *Proc. of the Intl. Protege Conference*.
- Madin, J., Bowers, S., Schildhauer, M., Krivov, S., Pennington, D., Villa, F., 2007. An ontology for describing and synthesizing ecological observation data. *Ecol. Inf.* 20 (3:0), 279–296.
- Madin, J., Bowers, S., Schildhauer, M., Jones, M., 2008. Advancing ecological research with ontologies. *Trends Ecol. Evol.* 230 (3:0), 159–168.
- Motik, B., Sattler, U., Studer, R., 2005. Query answering for OWL-DL with rules. *J. Web Sem.* 30 (1:0), 41–60.
- Parr, C., Cummings, M., 2004. Data sharing in ecology and evolution. *Trends Ecol. Evol.* 20 (0), 362–363.
- SPARQL query language for RDF. W3C. In: Prudhommeaux, E., Seaborne, A. (Eds.), *World Wide Web Consortium (W3C)*. January.
- Raskin, R., Pan, M., 2005. Knowledge representation in the semantic web for earth and environmental terminology (SWEET). In: Babaie, H., Ramachandran, R. (Eds.), *Computers & Geosciences, Special Issue on Applications of XML in Geosciences*, vol. 31, pp. 1119–1125.
- Rector, A.L., Drummond, N., Horridge, M., Rogers, J., Knublauch, H., Stevens, R., Wang, H., Wroe, C., 2004. OWL pizzas: practical experience of teaching OWL-DL: common errors and common patterns. *Proc. of the Intl. Conference on Knowledge Engineering and Knowledge Management (EKAW)*, pp. 63–81.
- Sirin, E., Parsia, B., Grau, B.C., Kalyanpur, A., Katz, Y., 2007. Pellet: a practical OWL-DL reasoner. *J. Web Sem.* 50 (2:0), 51–53.
- OWL web ontology language guide. W3C. In: Smith, M.K., Welty, C., McGuinness, D.L. (Eds.), *World Wide Web Consortium (W3C)*. February.
- Tsarkov, D., Horrocks, I., 2006. FaCT++ description logic reasoner: system description. *Proc. of the Intl. Joint Conference on Automated Reasoning (IJCAR)*, volume 4130 of *Lecture Notes in Artificial Intelligence*, pp. 292–297.