

Taking shortcuts with OWL using safe macros

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Abstract. Accurate representation of complex domains such as biology demands powerful and expressive ontology languages such as OWL. However, the complex nested class expressions required for modeling can be a hindrance to ontology authoring and adoption. These class expressions can appear opaque to domain experts, and even users proficient in OWL can benefit from some kind of syntactic sugar or “short-cut” strategy, especially when authoring large ontologies.

One solution is to have domain experts fill in simple templates (for example, in Excel) and translate the results into more complex axioms, but this has the disadvantage of being disconnected from full ontology authoring and reasoning environment.

We present here a method of specifying shortcut properties directly in OWL. These shortcut properties can be used in similar ways as object properties within the OWL environment, with the resulting simple axioms translated automatically to more complex axioms via macro expansion. We describe some example scenarios where this is of use in authoring existing bio-ontologies.

One of the main implications of this work is a way to simplify the translation between OBO format and OWL, and the use of RDF triple-stores with complex OWL ontologies.

1 Introduction

Accurate representation of complex domains such as biology demand powerful and expressive ontology languages such as OWL. However, the very expressive power of OWL can be a hindrance to widespread adoption and effective use - domain experts may not be comfortable with complex axioms and deeply nested class expressions. Even those proficient in OWL may prefer to work in terms of high-level templates that abstract away from the logical “machine code” of OWL. This is particularly true for the development of large ontologies, which often requires the repeated application of the same template pattern for multiple classes. In addition to being tedious and error-prone, the high-level pattern is not immediately apparent on viewing the ontology. Table 1 shows some example repeated patterns extracted from core bio-ontologies from the OBO Foundry registry[13].

Source	Pattern	Example
DC-CL	hasPart some ('plasma membrane' and hasPart ?Y)	Class: 'alpha-beta T cell' EquivalentTo: 'T cell' and hasPart some ('plasma membrane' and hasPart 'alpha-beta TCR complex')
CL	bearerOf some (realizedBy only ?Y)	Class: 'immune cell' EquivalentTo: 'cell' and bearerOf some (realizedBy only 'immune system process')
GO	(partOf some ?X) disjointFrom (partOf some ?Y)	(partOf some nucleus) disjointFrom (partOf some cytoplasm)
Fly	Class: ?X SubClassOf: partOf some ?Y Class: ?Y SubClassOf: hasPart some ?X	Class: retina SubClassOf: partOf some eye Class: eye SubClassOf: hasPart some retina
Fly	hasPart some ('presynaptic membrane' and partOf some (synpase and hasPart some ('postsynaptic membrane' and partOf some ?Y)))	Class: 'giant fiber neuron' SubClassOf: hasPart some ('presynaptic membrane' and partOf some (synpase and hasPart some ('postsynaptic membrane' and partOf some 'tergotrochanteral muscle motor neuron')))
CL	hasPart exactly 0 ?Y	Class: 'enucleate cell' EquivalentTo: cell and hasPart exactly 0 nucleus
TAO	hasPart some (partOf some ?Y)	Class: 'vertebra 5' SubClassOf: hasPart some (partOf some 'V4-5 joint')
OBI	realizes some ('analyte role' and roleOf some ('scattered molecular aggregate' and hasGrain only ?Y))	Class: 'human antithrombin-III (AT-III) in blood assay' SubClassOf: realizes some ('analyte role' and (roleOf some ('scattered molecular aggregate' and (hasGrain some 'human antithrombin-III protein'))))

Table 1. Example generic patterns taken from various ontologies in the OBO library (<http://obofoundry.org>). CL = cell ontology, DC-CL = dendritic cell ontology, Fly = *Drosophila* anatomy, GO = Gene Ontology, OBI = Ontology for Biomedical Investigations, TAO = Teleost anatomy ontology. Note that for GO and CL these axioms are available as optional extensions[11][3]

There are a number of approaches to this problem. Quick Term Templates (QTTs)[12] are a way of generating complex OWL axioms from simple tables. The domain expert can use a familiar tool such as Excel, structured according to a predetermined template, rather than working directly in an ontology development environment such as Protege. A similar approach is to define a domain-specific intermediate representation language, and translate this to OWL.

However, this approach can be unsatisfying for a number of reasons. A scripting approach is ad-hoc and difficult to integrate with existing OWL toolchains. In addition, the source intermediate representation is lost on translation into OWL – ideally the intermediate representation would still be visible within environments and tools such as Protege and OntoBee[16].

Here we describe a macro expansion language that allows the representation in a high-level intermediate form directly in OWL, through the use of high-level shortcut relations. A generic simple macro-expansion tool can be used to expand these shortcut relations into more complex axioms and class-expressions. This has the advantage of allowing the intermediate representation to be viewed and manipulated from within standard OWL tools and environments.

2 Macro Expansion Language

We propose a macro expansion language that can be represented directly within OWL-DL. The macro expansions are represented as OWL Manchester Syntax[9] with the addition of template variables. Either annotation properties or object properties are annotated with macros, and these can be used to expand individual axioms at any time during the ontology development or deployment cycle, preferably prior to reasoning. We refer to properties that are annotated in this way as *shortcut relations*. Table 2 shows the two different annotation properties that can be used to define shortcut relations. The first is intended to apply to annotation properties connecting two classes, and the second is intended to apply to object properties used in different contexts. In both cases the value of the annotation property is a template string containing Manchester syntax with variable placeholders denoted by the '?' symbol.

The pattern in the second row of table 1 could be specified as follows:

```
AnnotationProperty: capableOf
Annotations: expand_expression_to "bearerOf some (realizedBy only ?Y)"
```

We now describe these in more detail, first describing expansion of property assertions, followed by expansions of expressions.

2.1 Macro Expansion of Annotation Properties

We propose an annotation property *expand_assertion_to* that specifies how to expand a single OWL AnnotationPropertyAssertion into a more complex axiom by substituting two variables ?X and ?Y with the subject and target of the assertion respectively.

The rule can be specified as:

Annotation Property	Usage	Matches
expand_assertion_to	Expanding annotation assertion axioms connecting two classes	AnnotationPropertyAssertion(?R ?X ?Y)
expand_expression_to	Expanding class expressions	?R some ?Y or ?R value ?Y

Table 2. Annotation properties use to specify a macro expansion. If a property $?R$ is annotated using one of these two annotation properties, then the ontology is scanned for occurrences of the match pattern, which is then expanded according to the specified template.

21 AnnotationPropertyAssertion(*expand_assertion_to* ?R ?T) \Rightarrow
substitute(AnnotationPropertyAssertion(?R ?X ?Y), ?T)

Where *substitute* is a two-argument function that replaces axioms or expressions (argument 1) with a template (argument 2).

For example, given the following shortcut relation specification:

```
AnnotationProperty: spatially_disconnected_from
Annotations: expand_assertion_to
"DisjointClasses: (part_of some ?X) (part_of some ?Y)"
```

The following annotation property assertion axiom:

```
Class: nucleus
Annotations: spatially_disconnected_from cytoplasm
```

would expand to a general class inclusion (GCI) axiom:

```
DisjointClasses: (part_of some nucleus) disjointFrom (part_of some cytoplasm)
```

Note that this pattern is not applicable to all cases in table 1 - for example, we may want to define a class using an equivalence axiom. Here we want a generic way of expanding class expressions using shortcut relations, such that they can be used in different axiom types. This is where the second type of expansion comes in.

2.2 Macro Expansion of Object Properties

As an alternative that works for both SubClass and EquivalentTo axioms, we propose a different expansion rule for a new annotation property *expand_expression_to*. Here, the macro describes how to expand a class expression, not a property assertion, and only uses a single variable.

The macro object property should be used in existential restrictions, and the translation rule is:

22 AnnotationPropertyAssertion(*expand_expression_to* ?R ?T) \Rightarrow
substitute(?R some ?Y,?T)

For example, the cell ontology defines a shortcut relation used for defining cell types based on the proteins expressed on the plasma membrane (i.e. the boundary of the cell)[8].

```
ObjectProperty: has_plasma_membrane_part
Annotations: expand_expression_to
  "has_part some ('plasma membrane' and has_part some ?Y)"
```

This allows us to specify axioms using existential restrictions as follows:

```
Class: 'alpha-beta T cell'
EquivalentTo: 'T cell' and has_plasma_membrane_part some ('alpha-beta TCR complex')
```

This intermediate level representation would expand to:

```
Class: 'alpha-beta T cell'
EquivalentTo: 'T cell' and
  has_part some ('plasma membrane' and
    has_part some 'alpha-beta TCR complex')
```

Note that the intermediate level representation can still be used by a reasoner. Whilst it may fail to make all the correct inferences, in this particular case it will not produce any incorrect inferences. We regard this semantically correct intermediate representation as a desirable trait, even if the intention is to ultimately reason over the expanded form.

However, if existential restrictions are used in the intermediate level representation, then it is possible to have an intermediate representation that is semantically incompatible with the expanded form.

Consider the following shortcut relation:

```
ObjectProperty: lacksPart
Annotations: expand_expression_to "hasPart exactly 0 ?Y"
```

The author would write in the intermediate form:

```
Class: 'enucleate cell'
EquivalentTo: cell and lacks_part some nucleus
```

Which would expand to:

```
Class: 'enucleate cell'
EquivalentTo: cell and has_part exactly 0 nucleus
```

Note that the intermediate form would produce *different* inferences from the expanded form. For example, if nucleus is a subclass of organelle, then the intermediate form entails that a enucleate cell lacks part some organelle. When expanded, this becomes too strong.

Notice that table 2 has an additional rule for hasValue restrictions:

23 AnnotationPropertyAssertion(*expand_expression_to*, ?R, ?T) ⇒
substitute(?R value ?Y, ?T)

Here we are treating the intermediate property as a relation between an individual and a class.

Now we can write an intermediate representation:

```
Class: 'enucleate cell'  
EquivalentTo: cell and lacks_part value nucleus
```

This expands to the correct form. Whilst the intermediate form does not produce all the same inferences as the intermediate form, the intermediate form does not produce any incorrect inferences.

The meaning of the intermediate form may appear curious. Here we are treating the class *nucleus* as part of the domain of discourse, which is allowed in OWL2. The lacksPart shortcut relation holds between instances and classes.

We can also safely introduce an expansion rule for individuals:

24 *expand_expression_to*(?R, ?T) ⇒
substitute(PropertyValue(?R, ?X, ?Y), ?X Types: *substitute*(?R, ?Y))

We can write property assertions:

```
Individual: imaged-cell00001234  
Properties: lacks_part nucleus
```

Which expand to:

```
Individual: imaged-cell00001234  
Types: has_part exactly 0 nucleus
```

3 Implementation

We have implemented a shortcut relation translator on top of the java OWLAPI (this was based on a prototype prolog implementation, available as part of the Thea2[15] - the new implementation is entirely java-based).

The implementation is distributed as part of the org.oboformat codebase (<http://code.google.com/p/oboformat>), although it is entirely independent of OBO-Format. It is also available as part of the OBO Ontology Release Tool (Oort)[4].

The implementation uses the information artefact ontology (IAO) as the annotation property vocabulary. The *expand_expression_to* annotation property has the IRI http://purl.obolibrary.org/obo/IAO_0000424, and the *expand_assertion_to* annotation property has the IRI http://purl.obolibrary.org/obo/IAO_0000425.

The implementation allows two strategies for handling shortcut relations. The first one is to simply expand in place, replacing the expression with the shortcut relation with the expanded expression.

The second strategy leaves the original ontology unmodified, and instead adds a General Class Inclusion (GCI) axiom to a separate auxiliary ontology.

For example, if the source ontology contains:

```
ObjectProperty: has_plasma_membrane_part
Annotations: expand_expression_to
"has_part some ('plasma membrane' and has_part some ?Y)"
```

And has has an axiom:

```
Class: 'alpha-beta T cell'
EquivalentTo: 'T cell' and has_plasma_membrane_part some ('alpha-beta TCR complex')
```

Then the auxiliary ontology will include:

```
has_plasma_membrane_part some ('alpha-beta TCR complex')
EquivalentTo
has_part some ('plasma membrane' and
has_part some 'alpha-beta TCR complex')
```

The auxiliary ontology are source ontology can then be imported in a separate ontology.

4 Discussion

4.1 Comparison with property chains

Property chains are a powerful feature introduced into OWL2. They are even more powerful when combined with self-restrictions, and can be used to recapitulate some of the features of the macro-expansion rules described above. For example, the *has plasma membrane part* relation could be specified as follows:

```
ObjectProperty: has_plasma_membrane_part
SubPropertyChain: has_part o is_plasma_membrane o has_part
```

```
ObjectProperty: is_plasma_membrane
```

```
Class: 'plasma membrane'
SubClassOf: is_plasma_membrane Self
```

A minor disadvantage here is that opaque axioms and properties are inserted into the ontology – but these could in principle be hidden given appropriate annotation properties and tooling.

A more serious disadvantage is that property chains cannot be used to *define* a property. The direction of implication is one-way only.

To see this, consider a standard axiom in mereology defining an overlaps relation in terms of parthood:

$$\text{overlaps}(x, y) \leftrightarrow \exists z : \text{hasPart}(x, z) \wedge \text{partOf}(z, y)$$

The overlaps relation is useful in bio-ontologies[1], so it can be tempting to declare an object property for it, and provide a property chain:

```
ObjectProperty: overlaps
SubPropertyChain: has_part o part_of
```

But this axiom is weaker, and there is a danger if this property is used in assertions thinking it has the same semantics. If an ontology asserts that a overlaps some b, then this is *not* the same as asserting that a hasPart some partOf some b. If a user queries for *hasPart some partOf some b*, then classes asserted to be subclasses of *overlaps some b* will *not* be returned.

The guiding principle here is: if the intention is to *define* a property then a shortcut relation should be specified. If the intention is to infer property assertions then use a property chain.

Note that property chains cannot be used for shortcut relations such as *capableOf*, because in this case the shortcut relation abbreviates a nested class expression involving both an existential and universal restriction.

4.2 Practical usage and implementation: ontology views

The scheme we have proposed is relatively simple and can be implemented easily.

However, to be maximally useful, the translator could be integrated into ontology editing environments such as Protege4[7]. Expanded axioms could be marked using axiom annotations. Users would have the option of viewing the ontology at the intermediate level, the expanded level, or both. Changes at one level would automatically expand/contract to the other level, and feed in to incremental reasoning.

However, even without this tight integration we believe that a translation tool implementing the macro language specified here would be useful.

There is a possible concern about reasoning over the intermediate view, prior to expansion. However, our strategy here insulates us from making incorrect inferences at the intermediate level. Users will still have to be aware of the differences between the two levels to know why they get more inferences in the expanded view.

4.3 Applications for OBO to OWL translation

OBO-Edit is an ontology editing environment popular amongst biologists[2]. The native model for this tool is the OBO file format, which can be translated to a subset of OWL[5][14]. A characteristic feature of the OBO format is that an ontology is treated as a labeled graph (much like RDF). Edges in the graph are by default translated to existential restrictions[10]. Whilst it is possible to write nested class expressions in OBO format by using RDF blank-node style

anonymous classes, this is not well-supported and best avoided. In addition, there is no standard way to write other OWL constructs such as negation and universal restriction, which are becoming increasingly necessary for bio-ontologies.

Many OBO-Edit authored ontologies have started informally adopting shortcut relations with a view to translating these to expanded OWL axioms further down the line. One approach is to do this as part of the obo to owl translation, but we believe there are advantages to doing the expansion as a separate independent step. For one thing, it simplifies the already complicated translation, which has some problems in the existing translation. It also has the advantage of maintaining the shortcut relations in the OWL environment.

Currently a piece of obo-format may look like this:

```
[Typedef]
id: has_part
is_transitive: true
inverse_of: part_of
xref: BFO:0000051

[Typedef]
id: lacks_part
expand_expression_to: "BFO_0000051 exactly 0 ?Y" []
is_class_level: true

[Term]
id: CL:0000595 ! enucleate erythrocyte
intersection_of: CL:0000232 ! erythrocyte
intersection_of: lacks_part GO:0005634 ! nucleus
```

The OBO-Format 1.4 specification (<http://purl.obolibrary.org/obo/oboformat/spec.html#7>) states that this is translated to:

```
ObjectProperty: BFO_0000051
Characteristics: Transitive

ObjectProperty: lacks_part
Annotations:
  expand_expression_to "BFO_0000051 exactly 0 ?Y"

Class: CL_0000595 /* enucleate erythrocyte */
EquivalentTo: CL_0000232 /* erythrocyte */
  and lacks_part value GO_0005634 /* nucleus */
```

Applying the expansions rules we would get an auxiliary ontology with the axiom:

```
(lacks_part value GO_0005634)
EquivalentTo
(BFO_0000051 exactly 0 GO_0005634)
```

Which has the intended semantics.

This has the advantage of allowing the users of OBO format tools to access the more expressive constructs in OWL, yet retain a simple graph-like model. This has positive implications for many downstream consumers of OBO format ontologies, many of which are tools or databases that also have a simple graph-like model of ontologies.

4.4 Applications for RDF and semantic web applications

If an OWL ontology contains complex axioms involving nested class expressions this can result in RDF triples that are difficult to work with at the RDF level. This difficulty is ameliorated by languages such as SPARQL-DL, but there is still problem for many triple stores and RDF libraries that are not OWL-aware.

The shortcut relation strategy provided here could provide a means of providing a “triple-friendly” view over complex OWL ontologies.

4.5 Comparison with other methods

Hoehndorf et al[6] provide a method to translate obo to owl ontologies that expands relations at the time of translation from obo to owl. This method provides similar means of translating relations such as lacksPart to the appropriate OWL class expression.

However, by coupling this translation to the obo to owl translation mechanism, this method is limited to users of obo-format ontologies. Many developers of obo-format ontologies are beginning to move to OWL, but would still like to retain shortcut relations.

Another limitation of the Hoehndorf et al method is that it is not applicable to equivalence axioms (intersection_of tags in obo-format). They state: “Solving this problem is subject to future research, and falls in line with the effort to provide a standard semantics for the OBO Flatfile Format that is compatible with currently available resources and allows expressive relation assertions between categories”.

We believe that the solution we have provided here solves this problem. By expanding expressions rather than binary relationships we allow the use of shortcut relations in a variety of contexts.

5 Conclusions

We have defined two annotation properties that can be used to specify shortcut relations that can be used in intermediate OWL-DL representations that provide a simplified view over a complex ontology. Axioms or expressions that use these relations can be expanded to a more verbose form prior to reasoning. At the same time, the intermediate form is safe for reasoning.

We believe that these shortcut relations will assist with ontology authoring for both novices and experts. We also believe that these relations will assist with

interconversion between OWL and popular but less expressive formalisms and data models, opening up OWL to a wider community of users.

6 References

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