Heuristic Transformation of Well-Constructed Conceptual Maps into OWL Preliminary Domain Ontologies

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Abstract. Ontologies are a form of knowledge representation that is meant for software systems, or agents, as well as for human users. Building an ontology consists of, in short, formally specifying concepts and their relations concerning a certain knowledge domain. Such specification should convey an interpretation of the domain as agreed by experts and requires specific ontology engineering skills. In relation to ontologies, conceptual maps are a more informal, simple and, thus, accessible form of knowledge representation. However, the freedom enjoyed in defining concepts and their links makes it difficult to directly draw formal representations from conceptual maps. This work presents heuristics that are able to transform conceptual maps into ontologies specified in OWL (Web Ontology Language). In this way, the ease of construction of conceptual maps can be taken advantage of to alleviate the knowledge acquisition bottleneck that is inherent in ontology engineering.
Keywords: Conceptual maps; OWL ontologies; translation; heuristics.

1 Introduction

Drawing a conceptual map (or, Cmap) and specifying a formal ontology are tasks that differ in the degree of engineering complexity but share in their core the elicitation of concepts and their relationships that characterise a knowledge domain. There has been other work where this fact is acknowledged. In [6], a two layered approach to knowledge representation is proposed whereby cases are represented in CBR (Case-Based Reasoning) Systems as ontologies, whose understanding by users is facilitated through the use of Cmaps. The work reported in [15], in the field of meaningful learning assessment, uses genetic algorithms to generate a search space through which the semantic distance between Cmaps is measured having an ontology as a reference specification of the domain. We show in this work that it is possible to use conceptual maps, informal as they are, as a basis for a more formal OWL specification of the domain at hand. This is accomplished by way of heuristics that establish correspondences between certain features of conceptual maps and OWL elements.

The next two subsections provide some background on conceptual maps and ontologies. Section 2 presents the heuristics for transformation of the maps into

OWL ontologies. A software system developed in connection with the transformation heuristics is addressed in Sect. 3. Section 4 discusses the work presented and draws conclusions within the wider context of a process where a consensus ontology is derived from a set of individual conceptual maps. Finally, considerations on future work are drawn up in Sect. 5.

1.1 Conceptual Maps

Drawing upon Ausubel's meaningful learning theory [2], Novak developed conceptual maps and applied them in teaching-and-learning research as a tool for constructing, representing and communicating knowledge [12]. Novak advocates that conceptual maps make possible to graphically express the concepts and their relationships that make up the cognitive structure of an individual (or group of people, if the map is built cooperatively) concerning a certain domain, where concepts are seen as regularities perceived in events or objects in the world. A conceptual map represents such structure as a set of interconnected propositions of the form *concept–relation–concept* that can be read as statements about the concepts involved. Concepts are usually represented as boxes or circles, and relations as lines that link the concepts together. Both boxes and lines are labeled with concept names and linking phrases, respectively.

It is worth noting the inherent idiosyncrasy of conceptual maps. Even within the same domain, different individuals (or groups) will most certainly produce different maps. Each conceptual map is just one possible representation of a hierarchical structure of interrelated concepts. Figure 1 depicts examples of conceptual maps where propositions and concepts hierarchically structured can be observed.

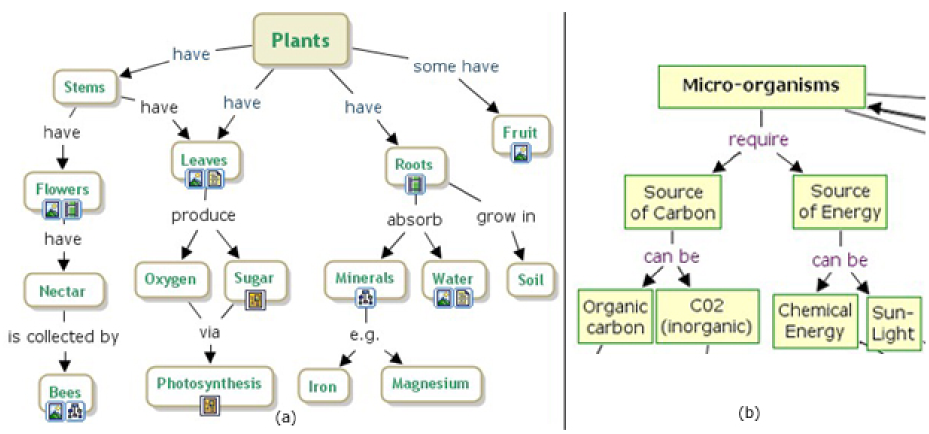

Fig. 1. Conceptual map about plants and microorganisms (extract) (Source: IHMC internal and CMEX-NASA CmapTools servers)

Well-Constructed Conceptual Maps Novak has defined characteristics that conceptual maps should have to be considered well-constructed [12], *viz*: *(a)* the top-level concept defines the map's theme; *(b)* each triple concept–relation–concept makes up a meaningful proposition, even when read independently; *(c)* hierarchical structure, with more general concepts at the top and more specific concepts placed in the lower levels of the map; *(d)* well defined scope, i.e., the concepts refer to a single domain; and *(e)* labels of concepts and links are as short as possible. In this work, it is assumed that the maps to be transformed into ontologies possess these characteristics.

1.2 Ontologies

A formal ontology specification consists of an explicit conceptualisation of a knowledge domain, representing an agreed interpretation of the intended meaning of concerned concepts and their relations, so as to allow semantics-based operations upon the knowledge, such as inference, interpretation and sharing, be they performed by human or software agents [8]. One of the categorizations of ontologies is to do with the degree of specificity (or generality) of the knowledge they represent [7]. Our work is concerned with domain ontologies in particular, since they, like conceptual maps, are restricted to a specific knowledge domain. The process of building a domain ontology involves objectively defining the scope of the domain, describing the essential knowledge that characterizes it and, in doing so, employing a vocabulary that gives no or as little room as possible to ambiguous interpretation.

Web Ontology Language The W3C-recommended Web Ontology Language (OWL) [10] is appealing to the knowledge engineering community, specially OWL-DL with its good compromise between expressiveness and decidability, due to the WWW-oriented features that it can add to ontologies such as accessibility, openness and extensibility. With its Description Logics set theoretical foundation, it has a greater machine-interpretability and inference potential compared to its predecessors, i.e., ontological knowledge not explicitly declared may follow from existing concepts and relations in the ontology.

An OWL ontology comprises classes, individuals and properties, where a class represents a concept, an individual represents an instance of a class, and a property represents a relation between individuals whose classes can be specified as domain and range of the property. OWL provides a number of forms of class description such as named classes, enumerated classes and complex classes which are described in terms of union, intersection and complement operations on other classes. It also allows classes to be described through quantifier (existential and universal), value and cardinality restrictions on properties. Classes as well as properties can be organised into hierarchies. A property can have its inverse property specified (if a property links individual a to individual b, its inverse links b to a). Several property characteristics can be specified, namely, functionality, inverse functionality, transitivity and symmetry.

2 Mapping Heuristics

In this section, we present a set of heuristic rules which, on the grounds of certain, mainly terminological, characteristics of relations between concepts in a conceptual map, establish OWL-DL elements to compose an individual ontology that corresponds to the map. As we will see, the heuristics take advantage of relations being binary and directed in both conceptual maps and OWL. In order to design the heuristics, firstly, we systematically transcribed by hand a set of conceptual maps, sampled from CmapTools servers [4], into OWL ontologies. The Cmaps selected were well-constructed (Sect. 1.1), or easily made so.

The heuristic rules appear in the sections that follow. They are specified as first-order logic formulae assuming a resolution-based proof system. Variables in them are implicitly universally quantified. The CM and OWL acronyms distinguish predicates relative to the conceptual map and OWL language representations, respectively.

2.1 Instances of Concepts

The representation of conceptual maps does not distinguish between concepts and instances of concepts. However, certain linking phrases may indicate an instance-concept relation, such as the *e.g.* label for the relation between concepts *Minerals* and *Iron* in Fig. 1 (a).

In OWL, an instantiated concept, C, becomes a class and one of the ways of representing its instances is as individuals. As we shall see in Sect. 2.3, the instances can also become subclasses of the class corresponding to C. Such mapping, of an instantiated concept in a conceptual map into a class with individuals in the OWL ontology, is formulated as the following heuristic rule.

C_{to} is an individual of C_{from} in the OWL specification of a given conceptual map, if R is a relation in the map from concept C_{from} to concept C_{to} and R is a member of a set of linking phrases that relate concepts with their instances:

$$\text{indivOWL}(C_{\text{to}}, C_{\text{from}}) \leftarrow (\text{relationCM}(R, C_{\text{from}}, C_{\text{to}}) \ \wedge \ R \in \text{InstPhraseSet}) \tag{1}$$

Where, OWL individuals belong to OWL classes:

$$\text{classOWL}(C) \leftarrow \text{indivOWL}(I, C) \tag{2}$$

2.2 Concepts

Concepts in conceptual maps are mapped into OWL classes.

C is an OWL class in the OWL specification of a given conceptual map, if C is a concept in the map:

$$\text{classOWL}(C) \leftarrow \text{conceptCM}(C) \tag{3}$$

Where,

C_{from} and C_{to} are concepts in a conceptual map if they are related in the map:

$$(\text{conceptCM}(C_{\text{from}}) \ \wedge \ \text{conceptCM}(C_{\text{to}})) \leftarrow \text{relationCM}(R, C_{\text{from}}, C_{\text{to}}) \tag{4}$$

2.3 Classification Relations

In [1], a distinction is drawn between associative and classification conceptual maps. The former are those that describe relations in general between concepts. The latter are those where relations between concepts are mainly hierarchical. A hierarchical relation in a conceptual map becomes a relation of the same nature in an OWL ontology, taking place between classes corresponding to the concepts in the map. Heuristic rules (5) and (7) identify hierarchical relations between the names of two linked concepts in a Cmap by way of a set of linking phrases, such as *is a*, *can be*, *type of*, *e.g.*, etc. and the WordNet lexical database [11].

Linking phrases that denote classification relations are separated in two groups: a set of phrases commonly used to denote a descending hierarchical relation, such as *can be* in Fig. 1 (b), and a set of phrases that denote ascending hierarchical relations, such as *is a* in *Tree–is a–Plant*.

Hypernyms and hyponyms are lexical relations that apply to terms whose meanings are subordinated to each other: given two terms T and T', T is a hypernym of T' if it generalises the latter; conversely, T is a hyponym of T' if it specialises the latter. Finding in WordNet a hypernym or hyponym relation between the names of the concepts in the Cmap reinforces the subclass relation between corresponding classes in the ontology.

C_{to} is a subclass of C_{from} in the OWL specification of a given conceptual map, if R is a relation from concept C_{from} to concept C_{to} in the map, and R is a member of a set of linking phrases that indicate that C_{to} is a subconcept of C_{from}, and C_{from} is a hypernym of C_{to}:

$$\begin{aligned}&\text{subclassOWL}(C_{\text{to}}, C_{\text{from}}) \leftarrow \\ &\quad \text{relationCM}(R, C_{\text{from}}, C_{\text{to}}) \ \wedge\ R \in \text{DescHierPhraseSet} \ \wedge\ \text{hypernym}(C_{\text{from}}, C_{\text{to}})\end{aligned} \tag{5}$$

Where,

C and C' are OWL classes if an OWL subclass relation holds between them:

$$(\text{classOWL}(C) \ \wedge\ \text{classOWL}(C')) \leftarrow \text{subclassOWL}(C, C') \tag{6}$$

And,

C_{from} is a subclass of C_{to} in the OWL specification of a given conceptual map, if R is a relation from concept C_{from} to concept C_{to} in the map, and R is a member of a set of linking phrases that indicate that C_{from} is a subconcept of C_{to}, and C_{from} is a hyponym of C_{to} :

$$\begin{aligned}&\text{subclassOWL}(C_{\text{from}}, C_{\text{to}}) \leftarrow \\ &\quad \text{relationCM}(R, C_{\text{from}}, C_{\text{to}}) \ \wedge\ R \in \text{AscHierPhraseSet} \ \wedge\ \text{hyponym}(C_{\text{from}}, C_{\text{to}})\end{aligned} \tag{7}$$

2.4 Composition Relations

A composition relation, also known as a *part-whole* relation, occurs between two concepts when one is a part, or component, of the other. In the conceptual map shown in Fig. 1 (a), for example, several of such relations are represented: *Plants* are composed of *Stems*, *Leaves*, *Roots* and some, of *Fruit*; *Stems*, in turn, are composed of *Flowers* and *Leaves*. Such relations are mapped into OWL through heuristic rules whose conditions are similar to the classification relations ones (Sect. 2.3), only that now the WordNet lexical relations used are meronym (e.g., *Leaves* is a meronym of *Plants*) and holonym (e.g., *Plants* is a holonym of *Leaves*). The heuristic rules appear in the sequel. Some rule readings are omitted as they follow from the ones given.

R is a subproperty of hasPart, and an existential and a universal restriction on such property R are established as necessary conditions in the description of C_{from} with respect to individuals of C_{to}, if R is a relation in the map from C_{from} to C_{to}, R is a member of a set of linking phrases that indicate that C_{to} is a part of C_{from} and if C_{from} is a holonym of C_{to}:

$$\begin{pmatrix} \text{subPropOfOWL}(R, \text{hasPart}) \ \wedge \\ \text{necesCondOWL}(C_{\text{from}}, \text{rest}(\exists, \forall, R, C_{\text{to}})) \end{pmatrix} \leftarrow \text{relationCM}(R, C_{\text{from}}, C_{\text{to}}) \ \wedge \ R \in \text{DescCompPhraseSet} \ \wedge \ \text{holonym}(C_{\text{from}}, C_{\text{to}}) \quad (8)$$

Where,

C and C′ are OWL classes and R is an OWL property, if a necessary condition of the form rest$(\exists, \forall, R, C')$ is established in the description of C:

$$\begin{pmatrix} \text{classOWL}(C) \ \wedge \ \text{classOWL}(C') \ \wedge \\ \text{propOWL}(R) \end{pmatrix} \leftarrow \text{necesCondOWL}(C, \text{rest}(\exists, \forall, R, C')) \quad (9)$$

Rule (8) states that a relation R in a Cmap from a whole to one of its parts is established as a subproperty of *hasPart*. OWL does not provide built-in primitives for part-whole hierarchies, as it does for subclass (is-a) ones. There are, however, ontology design patterns in use[1] where a property named *isPartOf* and/or its inverse property *hasPart* are standardly employed in the representation of part-whole relations. The rule has the effect of establishing the relation in the ontology as a specialisation of the generic part-whole relation *hasPart*, at the same time preserving its name as expressed in the conceptual map.

What is more, according to (8), a composition relation between two concepts in a Cmap gives rise in the ontology to necessary conditions, formulated as property restrictions, in the description of the class that will correspond to the relation's source concept. For the relation between *Plants* and *Leaves* in the map in Fig. 1 (a), for example, these would result in the following necessary conditions in the description of the *Plants* class: $\exists$ *have Leaves* and $\forall$ *have Leaves*, meaning that the *Plants* class is a subclass of an anonymous class of individuals that relate along the *have* property to at least one individual of the class *Leaves*, and only relate through *have* to individuals of the class *Leaves*. The existential restriction

[1] See, for example, Simple part-whole relations in OWL Ontologies, http://www.w3.org/2001/sw/BestPracticesOEP/SimplePartWhole/simple-part-whole-relations-v1.5.html.

means, in more plain English, that for something to be a plant, it has to have at least one leaf, which, ontologically speaking, is not true. Note, however, that the *Plants* class in the ontology is not intended to describe actual plants but the conceptual notion of plants, expressed in this particular map, as something that has leaves.

After all the OWL binary composition relations of a source class are established, a closure axiom on the composition property is specified as a necessary condition in the description of the class. For the *Plants* concept and *have* relation in Fig. 1 (a), for example, this would be the necessary condition $\forall$ *have* (*Stems* $\sqcup$ *Leaves* $\sqcup$ *Roots*) in the description of the *Plants* class, meaning that in the scope set by the conceptual map from which the ontology originates, the only parts of *Plants* captured by the *have* property are *Stems*, *Leaves* and *Roots*. Due to the semantics of the universal restriction ($\forall x, y <x, y>\in \mathit{have} \rightarrow y \in \mathit{Stems} \cup \mathit{Leaves} \cup \mathit{Roots}$), this class specification alone would include individuals that do not relate through *have* with any individual. The existential restrictions on *have* with respect to *Stems*, *Leaves* and *Roots*, that are also part of the description of *Plants*, assure that such interpretation does not apply to the class.

Composition relations are transitive by definition. Still in line with best practices of representing part-whole relations in OWL, having R established as a subproperty of *isPartOf* leads to their characterisation in the ontology as transitive properties and of *hasPart* as the inverse of *isPartOf*.

hasPart and R are transitive properties and hasPart is the inverse of isPartOf, if R is a subproperty of hasPart:

$$\begin{pmatrix} \text{transPropOWL(hasPart)} \ \wedge \\ \text{transPropOWL}(R) \ \wedge \\ \text{inverseOWL(hasPart, isPartOf)} \end{pmatrix} \leftarrow \text{subPropOWL}(R, \text{hasPart}) \tag{10}$$

Rules (11) and (12) below are the counterparts of (8) and (10) for composition relations from parts to wholes.

$$\begin{pmatrix} \text{subPropOfOWL}(R, \text{isPartOf}) \ \wedge \\ \text{necesCondOWL}(C_{\text{from}}, \text{rest}(\exists, \forall, R, C_{\text{to}})) \end{pmatrix} \leftarrow \tag{11}$$
$$\text{relationCM}(R, C_{\text{from}}, C_{\text{to}}) \ \wedge \ R \in \text{AscCompPhraseSet} \ \wedge \ \text{meronym}(C_{\text{from}}, C_{\text{to}})$$

$$\begin{pmatrix} \text{transPropOWL(isPartOf)} \ \wedge \\ \text{transPropOWL}(R) \ \wedge \\ \text{inverseOWL(hasPart, isPartOf)} \end{pmatrix} \leftarrow \text{subPropOWL}(R, \text{isPartOf}) \tag{12}$$

Where, OWL transitive properties are OWL properties:

$$\text{propOWL}(R) \leftarrow \text{transPropOWL}(R) \tag{13}$$

2.5 Bidirectional Relations

Bidirectional relations in conceptual maps are those that occur in both directions between two concepts, as would be, for example, the relation of *marriage* between the concepts of *Husband* and *Wife*. These are mapped into symmetric OWL properties, as formulated in (14).

A symmetric OWL property R is established between individuals of C_{from} *and* C_{to} *in the OWL specification of a given conceptual map, if R is a relation from* C_{from} *to* C_{to} *and also a relation from* C_{to} *to* C_{from} *in the map*:

$$\mathrm{symPropOWL}(R, C_{\mathrm{from}}, C_{\mathrm{to}}) \leftarrow \mathrm{relationCM}(R, C_{\mathrm{from}}, C_{\mathrm{to}}) \wedge \mathrm{relationCM}(R, C_{\mathrm{to}}, C_{\mathrm{from}}) \tag{14}$$

Clearly, OWL symmetric properties are OWL properties:

$$\mathrm{propOWL}(P, C, C') \leftarrow \mathrm{symPropOWL}(P, C, C') \tag{15}$$

2.6 Other Relations

Other than relations between instances and their concepts and classification and composition relations, conceptual maps are filled with regular associative relations [1] such as *Leaves–produce–Sugar* and *Roots–grow in–Soil* in Fig. 1 (a). Such relations are mapped into OWL properties, as formulated in (16).

An OWL property R is established having individuals of C_{from} *as domain and individuals of* C_{to} *as range in the OWL specification of a given conceptual map, if R is a relation from concept* C_{from} *to concept* C_{to} *in the map, and* C_{to} *is not an individual of* C_{from}*, and an OWL subclass relation does not hold between* C_{from} *and* C_{to}*, and R is not a composition relation*:

$$\begin{aligned} &\mathrm{propOWL}(R, C_{\mathrm{from}}, C_{\mathrm{to}}) \leftarrow \\ &\quad \mathrm{relationCM}(R, C_{\mathrm{from}}, C_{\mathrm{to}}) \ \wedge \neg \ \mathrm{indivOWL}(C_{\mathrm{to}}, C_{\mathrm{from}}) \ \wedge \\ &\quad \neg \ (\mathrm{subclassOWL}(C_{\mathrm{from}}, C_{\mathrm{to}}) \ \vee \ \mathrm{subclassOWL}(C_{\mathrm{to}}, C_{\mathrm{from}})) \ \wedge \ \neg \ \mathrm{compRel}(R) \end{aligned} \tag{16}$$

Where,

R is a composition relation if it is a subproperty of hasPart or of isPartOf:

$$\mathrm{compRel}(R) \leftarrow (\mathrm{subPropOWL}(R, \mathrm{hasPart}) \ \vee \ \mathrm{subPropOWL}(R, \mathrm{isPartOf})) \tag{17}$$

Lastly, OWL properties occur between individuals of OWL classes:

$$(\mathrm{classOWL}(C) \ \wedge \ \mathrm{classOWL}(C')) \leftarrow \mathrm{propOWL}(P, C, C') \tag{18}$$

3 A Cmap-to-OWL Translation System

The heuristics in Sect. 2 are implemented in the logic-based, declarative language Prolog. By way of the Jasper Java-Prolog interface, they compose a working system implemented in Java, which we call Translator Module, whose role, in a process of deriving a consensus ontology from a set of individual maps (Sect. 4), is to translate each individual map into a corresponding individual ontology.

To achieve that, the heuristics in Sect. 2 work in combination. Firstly, OWL classes and object properties are established. Then, for each of such classes, super-classes (based on classification relations), individuals and property restrictions (based on composition relations) are established. Finally, domain and range classes of object properties are set as well as symmetric and transitive characteristics, if applicable. Domain and range specifications are left open for properties that have the heuristics identifying more than one class as domain or range for them. This is done in this way, rather than specifying a union of domain (or range) classes, because it is not guaranteed that a corresponding union of concepts occur in the Cmap.

In order for the Translator to manipulate the conceptual maps, they must be converted to a format that allows propositions extracting. Through an export feature of CmapTools, we can obtain graphically designed maps as text or XML files. With such a specification of a conceptual map at hand, the Translator, which comprises three software components, works as follows:

- A **Parser** component analyses the conceptual map in text or XML format, identifying propositions and their parts (concepts and relations), and transcribes them into a set of Prolog facts of the form $\mathrm{relationCM}(R, C_{\mathrm{from}}, C_{\mathrm{to}})$ as used by the heuristic rules;
- By way of the heuristics, a **Mapper** component establishes mappings between the relation facts delivered by the Parser and OWL constructs;
- A **Generator** component writes out in the language's proper syntax the resulting OWL constructs.

The OWL specification of the conceptual map can then be open by the Protégé editor [14]. Figure 2 shows parts of the Plants map in Fig. 1 (a) transformed into an ontology by the Translator Module. Note that this map in particular does not give rise to OWL subclass relations (Sect. 2.3).

4 Discussion and Conclusions

The work presented insofar is part of a research project on a larger process of deriving a consensus ontology from individual conceptual maps. Given a knowledge domain of interest of which a formal specification is sought for, domain experts create individual conceptual maps, each map representing an expert's cognitive structure in relation to the domain. In order to unify such representations of the domain: *(a)* each map is transformed into an individual preliminary ontology; and *(b)* ontology merging techniques [13] are applied to the set of preliminary ontologies so as to yield a consensus ontology.

This paper addresses stage *(a)* of the process, having shown the transformation of individual conceptual maps into individual preliminary ontologies by employing heuristic rules designed to establish representational correspondences between conceptual map features and OWL constructs. Concepts and relations

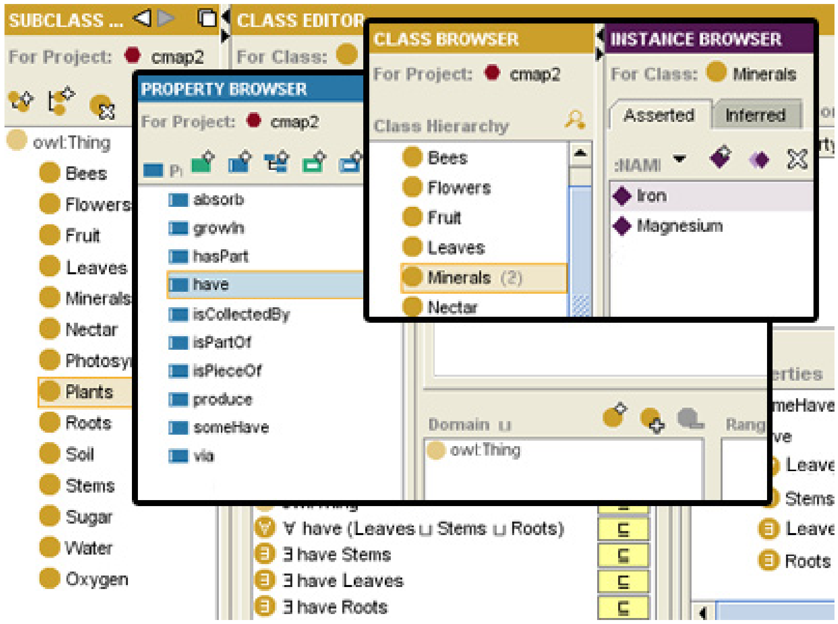

Fig. 2. Screenshots of Protégé showing the conceptual map about plants (Fig. 1 (a)) transformed into an ontology through the Translator Module

in an informal Cmap are reasonably mapped into classes, object properties, property restrictions and individuals, which compose a preliminary ontological specification of domain knowledge. The specification is preliminary in the sense that it is, at this stage, still to be merged with other visions of the domain (expressed in other Cmaps) and, after that, still amenable to refinement by an ontology engineer. Through a software tool such as our Translator Module, one can take advantage of the large amount of domain knowledge already modelled in the form of conceptual maps currently accessible from the CmapTools servers and other sources.

It has been argued [3] that in order to derive formally represented knowledge from conceptual maps, the usual approach has been to restrict concepts and relations to predefined taxonomies or controlled vocabularies, such as the recent work in [9], and that this approach is somewhat oxymoronic since the free style of structuring and labeling is the very point where resides the interestingness of conceptual maps as a knowledge elicitation and representation tool. The heuristics presented here for transformation of a conceptual map into an OWL representation only assume that the map is well-constructed.

5 Future Work

The heuristics can produce more than one possible OWL representation for a conceptual map feature. For example, the same relation in the Cmap may be represented as a concept-instance relation and as a class-subclass relation. A stage of refinement of the ontology is necessary to treat inconsistencies that may be caused by multiple representations. Also, more mapping heuristics may come into being as we have not yet exhausted OWL resources with respect to their suitability for representing conceptual map features.

Work on stage *(b)* of the process will involve identifying, and probably adapting, techniques that are adequate to merge the individual ontologies originated from the conceptual maps, tackling issues such as ambiguity and similarity of concepts, and differences in the ontologies' granularity levels.

While the heuristics presented here have been tested on a number of Cmap examples, they have not yet been systematically evaluated. Evaluation goals include to identify more precisely the situations in which the heuristics can lead to inconsistent or redundant OWL specifications and to verify whether they suffice to generate preliminary ontologies from Cmaps. To validate the process of deriving a consensus ontology from conceptual maps as a whole, we intend to carry out experiments where subjects will create conceptual maps on a certain domain, the translation and merging software modules applied, and the resulting ontologies evaluated with respect to the consistency, completeness and conciseness criteria, described in [7]. Consistency and conciseness checks can be made through the ODEval tool [5]. Merged ontologies will be evaluated on completeness with the aid of domain experts.

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