Use case: Ontology with rules for identifying brain anatomical structures

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Christine Golbreich[1], Olivier Bierlaire[1 2], Olivier Dameron[2 3], Bernard Gibaud[2]

[1] Laboratoire d'Informatique Médicale,
Av du Pr. Léon Bernard, 35043 Rennes France
Christine.Golbreich@univ-rennes1.fr

[2] Laboratoire IDM, UPRES-EA 3192
Av. du Pr. Léon Bernard, 35043 Rennes Cedex France
Bernard.Gibaud @chu-rennes.fr
obierlai@ens.insa-rennes.fr

[3] Stanford Medical Informatics
Stanford University School of Medicine, Stanford CA 94305,USA
dameron@smi.stanford.edu

Abstract. The proposed use case focuses on *interoperating* between a rule base and a brain cortex anatomy ontology, in order to assist the labeling of the brain cortex structures - sulci and gyri - involved in MRI images. The use case documents the ontology and the rules so as to clarify the added value and needs of rules, and the language expressiveness required. The expected result is to get candidate languages extending OWL DL with rules that allow representing all the knowledge required (ontology and rules), joint with the properties of reasoning that are guaranteed.

1. Presentation of the application

Our group is interested in image processing in the context of neuroimaging, applied both to medical practice, i.e. decision support in neurology and neurosurgery, and to research about neurological pathology such as epilepsy, dementia, etc. The considered application aims at developing new methods for assisting the labeling of the brain cortex structures - sulci and gyri - in MRI images. Indeed, nowadays the brain cortex can be automatically segmented but the problem remains to identify its various parts. Numerical tools previously developed at IDM provide a list of items corresponding to the gyrus parts and sulcus segments recognized in the images. Each item is associated with a set of features: (1) attributes depicting intrinsic properties, such as the length and depth of a sulcus segment, or the surface of a gyrus part, (2) binary relationships, such as the neighborhood of two gyrus parts, the connection of two sulcus segments, (3) n-ary relationships such as the separation of two gyrus parts by a sulcus segment. But such items are unlabelled, since generated by numerical techniques without being identified. The approach proposed to assist the labeling of such items relies on a rule base describing the dependencies between the relations of the brain cortex structures, and a brain ontology storing the a priori "canonical" knowledge [9] about the most important sulci and gyri. In order to reuse this labeling functionality in several applications, we propose to implement it as a web service.

The use case focuses on the brain anatomy ontology and on the rules required for identifying the gyri parts and sulci segments included in a particular brain region. The ontology and the rule base are documented by annexes so as to clarify the added value of rules, and the language expressiveness required. The expected result is to gather candidate languages that allow reasoning on the ontology combined with the rules of this application, joint with the guaranteed properties of their inference process.

2. Documentation

The full documentation concerning the ontology, the other domain relations, and the rules is available at http://idm.univ-rennes1.fr/~obierlai/anatomy/annexes/index.html.

2.1. Ontology of brain cortex anatomy

An ontology of the brain cortex anatomy has previously been achieved at IDM [1]. An HTML document providing its informal description is publicly available[1]. For several reasons, mainly needs of its reusability for other applications, this ontology is currently being extended and migrated to OWL-DL.

– **Classes**: the main root of the hierarchy is the primitive class `AnatomicalEntity` (AE). The hierarchy is divided into two subtrees: `MaterialAnatomicalEntity` (MAE) denoting brain entities made of material such as gyri, opposed to `NonMaterialAnatomicalEntity` (NMAE). MAE includes several subclasses representing the main material anatomical entities (Annex1 §1): `Hemisphere`, `Gyrus`, `Lobe`, `Pars`. NMAE includes `SulcalFold` (SF) denoting sulcal folds between material entities such as sulci, `GyriConnection` denoting a connection between two gyri such as `ConventionalSeparation`, and `SulciConnection`. All siblings classes such as `Gyrus`, `Lobe`, `Hemisphere`, etc. are disjoint.

– **Properties**: in addition to subsumption, mereological and topological properties are defined in the ontology. Mereological properties concern part-whole relations between anatomical entities. Topological properties concern neighborhood relations. A documentation (Annex1 §2) provides for each property, e.g. `hasAnatomicalPart`, its domain range, inverse or equivalent relation if given, its logical characteristics: transitive and symmetric, its global cardinality restrictions: functional and inversefunctional such as in the table below:

Property	domain	range	inverse	transitive	symmetric	functional	inversefunctional
hasAnatomicalPart	MAE	MAE	isAnatomicalPartOf	Yes	No	No	No
hasDirectAnatomicalPart	MAE	MAE	isDirect AnatomicalPartOf	No	No	No	Yes

2.2. Other domain properties

In addition to the ontology properties, "ordinary" domain relations, that do not appear in the ontology but occur in the rules, queries, and facts, e.g. the ternary predicate `connects`, `separates`, or the binary predicate `hasNoCommonPart` etc. (cf. Annex 1 « Other domain relations ») are defined. Ordinary predicates are specially useful in ground facts (initial or inferred) e.g. `connectsMAE(op,m,g)` expressing the connection between some instances m, g and op of anatomical entities.

[1] http://idm.univ-rennes1.fr/~odameron/anatomy/abstractModel/index.html

2.3. Rules

Rules are useful to express dependencies between properties in various cases, such as:

- **Dependencies between ontology properties**. Rules are required to capture relationships between ontology properties, for example to express that two entities are connected when they have a common boundary (cf. Examples Rule 1).
- **Dependencies between ontology and other domain properties**. Rules are required to capture relationships not only between ontology properties, but also relationships to other domain properties. For example, a rule is useful to express the continuity (contiguity) of two entities from a connection (sepration) relationship (Rule 2 or Rule 3).
- **Propagation of a property along another**: part-whole relations play a central role in anatomy and are crucial for this application. Different part-whole relations are involved, e.g. `hasAnatomicalPart`, `hasSegment` which have different semantics. Depending on the part-whole relation and on the considered property, some properties are inherited through the part-whole relation, under particular conditions. Rules play the role of axioms providing the semantics of the different part-whole and of the topological properties propagation (Rule 4).

- **Examples**

1. Let be the ontology properties `isMAEConnectedTo` and `isMAEBoundedBy` and the rule expressing their relationship:

   Two MAE entities having a shared boundary are connected.
   Rule 1: `isMAEConnectedTo(?x1,?x2) ← isMAEBoundedBy(?x1,?x3)`
   `Λ isMAEBoundedBy(?x2,?x3)`
   `Λ MAE(?x1) Λ MAE(?x2) Λ GyriConnection(?x3)`

2. Let be the domain property `connectsMAE` and the rule expressing its relationship to the ontology property `isMAEConnectedTo`:

   Two MAE entities having a shared connection are connected
   Rule 2: `isMAEConnectedTo(?x1,?x2) ← connectsMAE(?x3,?x1,?x2)`
   `Λ MAE(?x1) Λ MAE(?x2) Λ GyriConnection(?x3)`

   Let be the domain ternary property `connects` and the rule expressing its symmetry characteristic:

   An entity connecting two entities x1 and x2, connects x2 and x1
   Rule 3: `connects(?x3, ?x2, ?x1) ← connects(?x3, ?x1, ?x2)`
   `Λ AE(?x1)Λ AE(?x2)Λ AE(?x3)`

3. Let be the rule expressing the propagation of a separation relationship along part-whole:

   A sulcus having a segment separating two material entities separates them too
   Rule 4: `separatesMAE(?x1, ?x2, ?x3) ← separatesMAE(?y, ?x2, ?x3)`
   `Λ hasSegment(?x1,?y) Λ Sulcus(?x1)`
   `Λ MAE(?x2) Λ MAE(?x3) Λ SF(?y)`

It can be noticed that extensions such as Role Inference Axioms [5] limited to axioms of the form $P \circ Q \subset P$, where P and Q are roles, i.e. ontology binary relations, can only express special cases of property propagation and are not sufficient to express all the dependencies of domain properties that are required.

Rules are also useful to express queries.

– **Queries.** Queries consist in finding, for given parts m_i of a region under study, all the possible instances of $?x_i$ they are part of (with eventual additional constraints):

$$Q\ (?x_1,\ \ldots,\ ?x_n\ )\ :\ \bigwedge_{i=1\ \text{to}\ n} AE(?x_i)\ \wedge\ hasPart(?x_i,m_i)$$

The language should enable to answer the queries with the knowledge encoded in the rules and the brain ontology.

– **Example**
Let be the rule expressing the following query:
for each items a_i and b_i of a region under study, find the possible instances of sulci $?x_i$ and gyri $?x_j$ of which they are parts.
Rule 5:
$Q\ (?x_1,\ldots,?x_n) \leftarrow isSegmentOf(a_1,\ ?x_1) \wedge \ldots \wedge isSegmentOf(a_j,\ ?x_j) \wedge isAnatomicalPartOf(b_1,\ ?x_{j+1}) \wedge \ldots \wedge isAnatomicalPartOf(b_{n-j},\ ?x_n) \wedge Sulcus(?x_1) \wedge \ldots \wedge Sulcus(?x_j) \wedge Gyrus(?x_{j+1}) \wedge \ldots \wedge Gyrus(?x_n)$

3. Potential requirements

The presented use case requires rules interoperating with the ontology for answering queries. Thus, requirements for the rule language cannot be considered independently of the ontology language. First results about the ontology language requirements previously presented [2] exhibited that DAML-OIL was a good candidate for the ontology, but was not sufficient and should be extended by rules.

Ontology language requirements

Using OWL for the ontology raises several questions, related to its expressiveness and to its extension with rules. The use case enlightens some ontology language requirements.

[R1] A first requirement is that the ontology language offers at least OWL DL expressiveness, constructs and axioms. However, since a rule extension is assumed to be provided, some OWL DL constructors or axioms, such as those expressing the various characteristics of a property, e.g. inverse, transitive, symmetric, might be represented by rules instead.

[R2] A second requirement is that OWL DL should be extended to support qualified cardinality constraints. Qualified cardinality constraints, that existed in DAML+OIL have been excluded from OWL. However, as already exhibited by brain ontology examples [2] and also more recently by the FMA migration to OWL DL [3], they are particularly useful in anatomy for defining composite structures from their parts For example, a main question is how to represent in OWL-DL that an hemisphere is an anatomical entity whose direct parts are lobes, each part being of a distinct type (i.e. frontal lobe, parietal lobe, occipital lobe, limbic lobe, temporal lobe, or similarly, to express that the boundaries of a precentral gyrus are exactly the falx, the precentral sulcus, the central sulcus, and the operculum Rolando:

```
Hemisphere := Anatomical Entity ∩ (∀ hasDirectAnatomicalPart Lobe)
∩ (= 1 hasDirectAnatomicalPart FrontalLobe) ∩ (= 1 HasDirectAnatomicalPart
ParietalLobe) ∩ (= 1 hasDirectAnatomicalPart OccipitalLobe) ∩ (= 1
hasDirectAnatomicalPart LimbicLobe) ∩ (= 1 hasDirectAnatomicalPart
TemporalLobe)
```

Rule language requirements

The use case enlightens some rule language requirements. A rule language should support:

[R3] ontology concepts and roles to occur in rule bodies or head as unary or binary predicates in atoms.

[R4] n-ary predicates to occur in bodies and head atoms, e. g. the predicate separatesMAE(x,y,z). Languages supporting n-ary predicates in bodies and head atoms are preferred to those limiting their use to the head of queries and allowing only ontology unary binary predicates in the body.

[R5] “ordinary” domain predicates, which are neither ontology concept nor role, to occur both in body and head atoms.

[R6] queries to be expressed by n-ary predicates.

[R7] “safe” rules, i.e. rules where a variable that occurs in the head also occurs in the body.

This effort is a first attempt. Changes may still occur in the ontology or rules description. We are also aware that further refinement will be needed, in particular for reasoning with uncertain class descriptions (to cope with the inter-individual variability) and quantitative properties (e.g. length and depth of sulcal folds).

4. Conclusion

Any language extending OWL DL with rules, whatever the chosen approach, for instance reducing the OWL DL or Rules component like CARIN [7] or the DLP language [4], limiting the interface between them [8], or combining OWL-DL with rules where concept and role predicates are allowed without any restrictions like ORL [6], can be candidate for the use case. It has to meet two conditions 1) to allow representing all the knowledge described in the ontology and rule annexes, as naturally as possible, 2) to clearly indicate the properties (decidability, completeness, correctness) that are guaranteed.

5. References

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