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What reasoning support for Ontology and Rules? the brain anatomy case study

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Abstract. This paper presents a medical case study, which requires reasoning with an OWL ontology extended by rules. The application aims at assisting the labeling of the brain cortex structures identified in MRI images. An example is provided to illustrate the needs of reasoning with ontology and rules. Then, we analyze the requirements of the application and discuss the available techniques and tools that might be considered for implementing it.

1. Introduction

As Protégé-OWL has been added with a SWRL editor, it permits editing both SWRL rules [12] and OWL ontologies. Hence an important question now arises: what reasoning support should be provided for SWRL+OWL? In some applications, rules are devoted to a specific task, which can be achieved independently of the ontology. In such cases it is possible to use two distinct languages with specific inference engines, one for the structural part (e.g. OWL DL for the ontology) and another one for the rule component (e.g. SWRL or other rule or logic programming language). But other applications, where rules are used to extend the expressiveness of OWL, require reasoning with rules in *conjunction* with the ontology for problem solving. This case of "hybrid" systems or languages is more complex because of decidability and complexity issues. As mentioned in [12][14], the combination of OWL DL and rules is undecidable. Thus, support for SWRL+OWL is an important issue, however it is also a difficult problem that should be carefully addressed.

This paper presents a medical case study, which precisely requires reasoning with an OWL ontology added with rules. The application aims at assisting the labeling of the brain cortex structures in MRI images. The system being developed relies on two components: an ontology for dealing with the structured knowledge i.e. the main brain entities and properties, and a rule base for representing the interdependencies between the properties. After introducing the application (§2), a simple example is provided to illustrate the needs of combining the ontology and rules inferences for the resolution (§3). §4 presents language requirements issued from this case study. A quick overview of existing techniques and tools that might be considered is given (§5). We conclude by some possible perspectives for fulfilling the needs of the application.

2. The application

The general framework is sharing anatomical knowledge (ontology and rules) and tools (services) needed 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 application aims at developing new methods for assisting the labeling of the brain cortex structures - sulci and gyri - in MRI images. Indeed, the brain cortex can nowadays 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 separating them, 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. However, since generated by numerical tools, such items are unlabelled. The approach proposed to assist their labeling relies on a brain ontology (§ 2.1) storing the a priori "canonical" knowledge [20] about the most important sulci and gyri, and on a rule base (§ 2.2) describing the dependencies between the properties of the brain cortex structures. Documentation about the ontology and the rules was prepared for the W3C Workshop on Rule Languages for Interoperability [9] and is available at http://idm.univ-rennes1.fr/~obierlai/anatomy/annexes/index.html.

2.1. Ontology of brain cortex anatomy

The main entities in brain anatomy are "material entity" and "sulcal folds", and the main relations are "part of" and "bounded by". Material entities are composed of several parts, separated by sulcal folds or other lines. For example, the brain is composed of two "hemispheres", separated by a deep fissure called "longitudinal fissure". Each hemisphere is divided into several "lobes" separated either by fissures named "sulci" or conventional lines. For instance, the Central Sulcus separates the Frontal Lobe and the Parietal Lobe. Each lobe is composed of gyri bounded by sulci. A gyrus may be composed of parts, called "pars", also separated by sulci. For instance, the Inferior Frontal Gyrus is composed of Pars Opercularis, Pars Triangularis and Pars Orbitalis. There are different types of connections between gyri: conventional separation, pli de passage, and operculus. An informal ontology of the brain cortex anatomy has been achieved by O. Dameron at IDM [3] to capture this structured knowledge about the entities and their properties. An HTML document providing its description is publicly available[1]. The classes and properties of the ontology are defined as follows .

Classes: the root is the primitive class `AnatomicalEntity` (AE) from which stem 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: `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. In addition to these general domain entities, a specific class named "Patch" is defined for the application so as to represent the parts of gyri isolated in the images.

Properties: in addition to the subsumption relation, mereological and topological properties are defined in the ontology. Mereological properties concern part-whole relations between anatomical entities. Topological properties concern neighborhood relations. For each property, e.g. `hasAnatomicalPart`, its domain range, inverse or equivalent relation if given, its logical characteristics: transitive and symmetric, its global cardinality: functional and inversefunctional are specified.

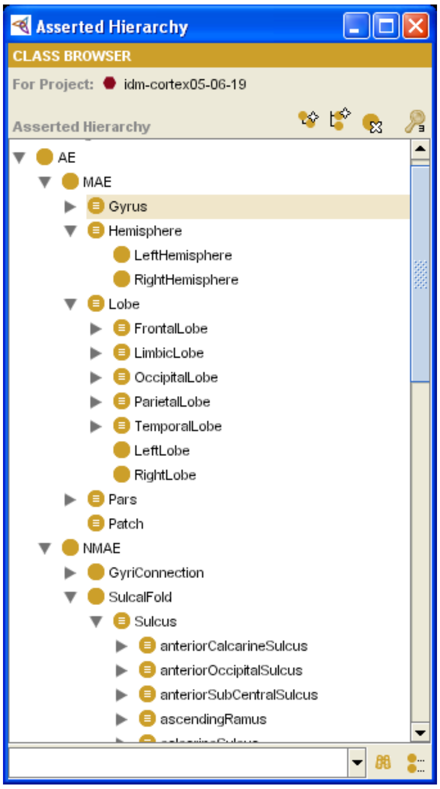

Figure 1: The Brain Ontology

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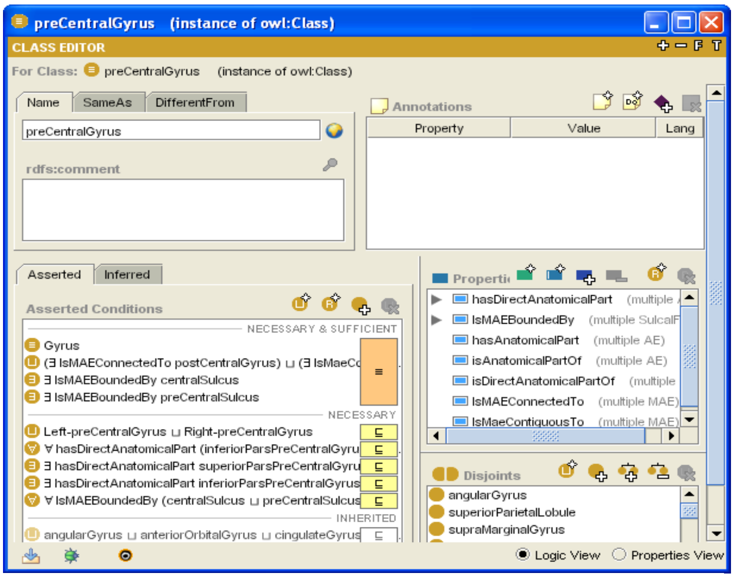
[1] http://idm.univ-rennes1.fr/~odameron/anatomy/abstractModel/index.html

For several reasons, mainly needs of reusability by several applications and of sharing it, this ontology is being extended and migrated from its XML representation to OWL-DL. Taking advantage of the DL powerful inference services is another strong ground. Migrating the Brain ontology to OWL DL will surely provide the same benefits of DL reasoning services as those already obtained in converting the FMA into OWL DL [8], in particular for reclassifying classes, checking consistency or completing the ontology. The recurrent issue is to decide how to enrich the ontology with logical axioms, and in particular with equivalent class definitions. The choice depends on the goal of each application. In this particular one, the facts extracted from the MRI images concern topological rather than mereological relations. Thus it seems relevant to define gyri from their boundaries: each gyrus class definition is based on the restriction of the isBoundedBy property (Figure 2). But other applications may prefer to use another definition, for example a gyrus can be defined from its direct anatomical parts (pars).



For Class: preCentralGyrus (instance of owl:Class)

preCentralGyrus

NECESSARY & SUFFICIENT
Gyrus
(∃ IsMAEConnectedTo postCentralGyrus) ⊔ (∃ IsMaeCo
∃ IsMAEBoundedBy centralSulcus
∃ IsMAEBoundedBy preCentralSulcus

NECESSARY
Left-preCentralGyrus ⊔ Right-preCentralGyrus
∀ hasDirectAnatomicalPart (inferiorParsPreCentralGyru
∃ hasDirectAnatomicalPart superiorParsPreCentralGyru
∃ hasDirectAnatomicalPart inferiorParsPreCentralGyrus
∀ IsMAEBoundedBy (centralSulcus ⊔ preCentralSulcus

INHERITED
angularGyrus ⊔ anteriorOrbitalGyrus ⊔ cingulateGyrus

hasDirectAnatomicalPart (multiple
IsMAEBoundedBy (multiple SulcalF
hasAnatomicalPart (multiple AE)
isAnatomicalPartOf (multiple AE)
isDirectAnatomicalPartOf (multiple
IsMAEConnectedTo (multiple MAE)
IsMaeContiguousTo (multiple MAE)

angularGyrus
superiorParietalLobule
supraMarginalGyrus

Figure 2: OWL definition of PreCentralGyrus

2.2. Rules

For assisting the labeling of sulci and gyri identified in the MRI images, an OWL ontology alone is not enough. Indeed, rules are needed to express:

- **dependencies between ontology properties**. Rules are required to capture the relationships between the mereological and topological properties, for example to express that two entities are connected when they have a common boundary (ex. R1).
- **dependencies between ontology and other domain predicate**. 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 or separation relationship (R2-R3). Propagation of a property along another is also often needed: 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 part-whole relations related to the topological propagation (R4).

Examples

1. A rule is needed for expressing the relationship between the two ontology properties `isMAEConnectedTo` and `isMAEBoundedBy`:

   Two MAE entities having a shared boundary are connected.

   R1: `isMAEConnectedTo(?x1,?x2) ← isMAEBoundedBy(?x1,?x3)`
   `∧ isMAEBoundedBy(?x2,?x3) ∧ MAE(?x1) ∧ MAE(?x2)`
   `∧ GyriConnection(?x3)`

2. A rule is needed for representing the relationship between the ternary predicate `connectsMAE` and the ontology property `isMAEConnectedTo`:

Two MAE entities having a shared connection are connected

```
R2: isMAEConnectedTo(?x1,?x2) ← connectsMAE(?x3,?x1,?x2)
                                Λ MAE(?x1) Λ MAE(?x2)
                                Λ GyriConnection(?x3)
```

Expressing the symmetry of the ternary predicate `connects` also requires a rule:

An entity connecting two entities x1 and x2, connects x2 and x1

```
R3: connects(?x3, ?x2, ?x1) ← connects(?x3, ?x1, ?x2)
                              Λ AE(?x1)Λ AE(?x2)Λ AE(?x3)
```

3. A rule is needed for expressing the propagation of a separation along part-whole relationship:

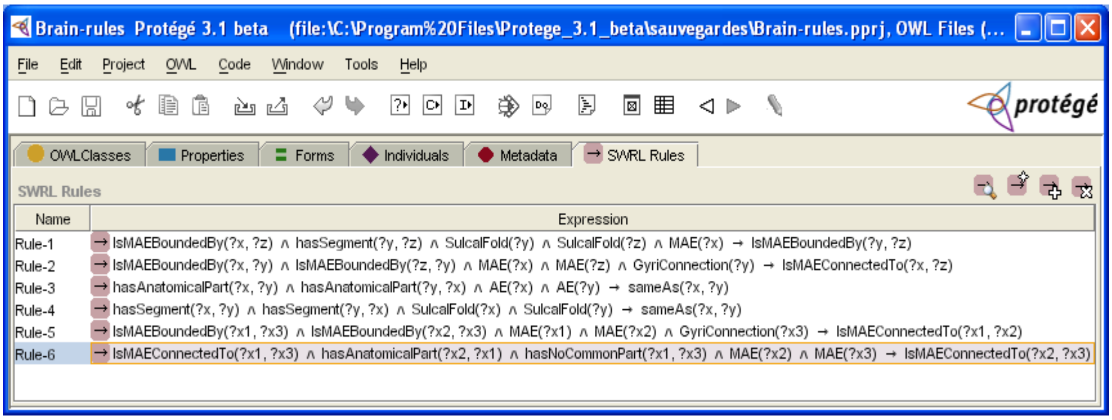
   A sulcus having a segment separating two material entities separates them too

```
R4: separatesMAE(?x1, ?x2, ?x3) ← separatesMAE(?y, ?x2, ?x3)
                                  Λ hasSegment(?x1,?y) Λ Sulcus(?x1)
                                  Λ MAE(?x2) Λ MAE(?x3) Λ SF(?y)
```

- **Queries.** Rules are also useful to express queries. Queries consist in finding, for given parts m_i of gyri of a region under study, all the possible instances of gyri they are part of (with eventual additional constraints):

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

Some of these rules, e.g. R1, can be represented in SWRL and vizualized with the SWRL Editor (Figure 3), but other ones cannot, e.g. R2, R3, R4, since they involve non DL predicates.



Name	Expression
Rule-1	IsMAEBoundedBy(?x, ?z) ∧ hasSegment(?y, ?z) ∧ SulcalFold(?y) ∧ SulcalFold(?z) ∧ MAE(?x) → IsMAEBoundedBy(?y, ?z)
Rule-2	IsMAEBoundedBy(?x, ?y) ∧ IsMAEBoundedBy(?z, ?y) ∧ MAE(?x) ∧ MAE(?z) ∧ GyriConnection(?y) → IsMAEConnectedTo(?x, ?z)
Rule-3	hasAnatomicalPart(?x, ?y) ∧ hasAnatomicalPart(?y, ?x) ∧ AE(?x) ∧ AE(?y) → sameAs(?x, ?y)
Rule-4	hasSegment(?x, ?y) ∧ hasSegment(?y, ?x) ∧ SulcalFold(?x) ∧ SulcalFold(?y) → sameAs(?x, ?y)
Rule-5	IsMAEBoundedBy(?x1, ?x3) ∧ IsMAEBoundedBy(?x2, ?x3) ∧ MAE(?x1) ∧ MAE(?x2) ∧ GyriConnection(?x3) → IsMAEConnectedTo(?x1, ?x2)
Rule-6	IsMAEConnectedTo(?x1, ?x3) ∧ hasAnatomicalPart(?x2, ?x1) ∧ hasNoCommonPart(?x1, ?x3) ∧ MAE(?x2) ∧ MAE(?x3) → IsMAEConnectedTo(?x2, ?x3)

Figure 3: SWRL Rules

3. Example of reasoning

The simplified example below is proposed to give a flavor of how problem solving might be obtained in reasoning with the rules and the ontology. Let be m1 and m2 two “patchs” of the region under study, i.e. two gyrus parts to be labeled. Assume that at the current step of resolution we know that m1 is bounded by the Central Sulcus, the PreCentral Sulcus and that there is a connection between three items: `m2`, a gyri connection `op`, and the PostCentral Gyrus. The instances of the structures specific to the brain image under study are denoted by mark 0, for example the particular instance of `CentralSulcus` for the considered image is cs_0,of `PostCentralGyrus` is `pcg0` etc. The current facts are the following:

- Current facts $\mathcal{F}$

```
F1.   hasPart(g1,m1), gyrus(g1)
F2.   hasPart(g1, m2)
F3.   isBoundedBy(m1,cs0)
F4.   isBoundedBy(m1,pcs0)
F5.   connects(op,m2,pcg0)
F6.   centralSulcus(cs0)
F7.   preCentralSulcus(pcs0)
F8.   postCentralGyrus(pcg0)
F9.   GyriConnection(op)
```

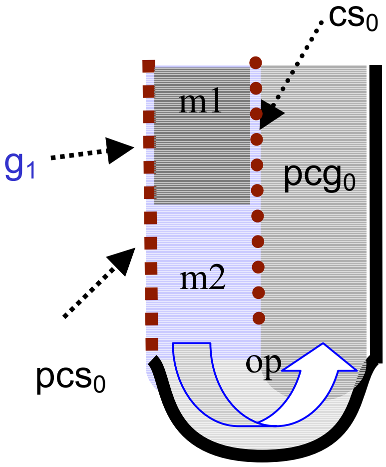


Figure 4 Case under study

- Query

Let be the query "find all the possible instances of gyrus which m_1 and m_2 can be part of" expressed by the rule:
$Q(?x_1) \leftarrow$ Gyrus $(?x_1) \wedge$ hasPart $(?x_1, m_1) \wedge$ hasPart $(?x_1, m2)$

- Knowledge base

(1) Rule base $\mathcal{R}$	(2) Ontology $\mathcal{O}$

`R1:isBoundedBy(?x,?y) ←`
`hasPart(?x,?z) Λ isBoundedBy(?z,?y)`
`R2:isConnectedTo(?x,?y) ←`
`hasPart(?x,?z) Λ isConnectedTo(?z,?y)`
`R3:isConnectedTo(?x,?y) ← connects(?z,?x,?y)`
	`PreCentralGyrus ≡ Gyrus`
	`∧ ∃ isBoundedBy CentralSulcus`
	`∧ ∃ isBoundedBy PreCentralSulcus`
	`∧ ∃ isConnectedTo PostCentralGyrus`
	`etc.`

Figure 5: Rules and ontology

The knowledge base is composed of two parts, rules and ontology (Figure 5). The deduction process relies on rules inferences combined with ontology inferences, as described below. First, from the facts $\mathcal{F}$ the rules $\mathcal{R}$ derive new facts: rule R1 propagates boundaries from part to whole, R2 propagates connection, R3 enables to deduce connected entities. For example, rule R1 entails `isBoundedBy`(g_1, cs_0) from facts F1, F3 (resp. `isBoundedBy`(g_1, pcs_0) from facts F1, F4). Thus, $\mathcal{F} \cup \mathcal{R}$ entails

$$\begin{cases} \texttt{gyrus}(g_1) \\ \texttt{isBoundedBy}(g_1, cs_0) \quad (R1) \\ \texttt{isBoundedBy}\ (g_1, pcs_0)\ (R1) \\ \texttt{isConnectedTo}(g_1,\ pcg_0)\ (R2,\ R3) \end{cases}$$

Then, reasoning with the ontology enables to identify which class g_1 belongs to. As gyrus(g_1) $\wedge$ isBoundedBy(g_1,cs_0) $\wedge$ isBoundedBy (g_1,pcs_0) $\wedge$ isConnectedTo(g_1, pcg_0) is verified, the sufficient condition to be a PreCentralGyrus is satisfied. Hence preCentralGyrus(g_1) is derived. In conclusion, $\mathcal{F} \cup \mathcal{R} \cup \mathcal{O}$ entails `preCentralGyrus`(g_1) and it is possible to answer the query from the rules and the ontology.

This example was voluntarily adapted for illustrating how the solution can be obtained in computing the consequences from the knowledge base. A named individual `g1` was introduced for representing a gyrus having part m1, i.e. the facts `hasPart(g1,m1), gyrus(g1)` have been added so as to permit applying the rules. In fact, the exact information extracted from the image is only the presence of a patch $\texttt{m}_1$, that is a part of some gyrus (to be identified). This should be represented in extending the ontology by a class `Patch` defined by `Patch ≡ ∃ isAnatomicalPartOf. Gyrus` (or adding a rule with an existential in head) with an instance $\texttt{m}_1$ of Patch. Besides, the `PreCentralGyrus` definition is also simplified. Indeed, its third restriction `∃isConnectedTo. PostCentralGyrus` is true only in 75% cases, and should be replaced by a disjunction `∃isConnectedTo PostCentralGyrus ∨ ∃isContiguousTo PostCentralGyrus.` Thus in reality, existential and disjunction occur in the class equivalent definitions of the ontology. Let be $\mathcal{O}'$ the ontology added with the Patch definition and $\mathcal{F}'$ the same facts as $\mathcal{F}$ apart F1 which is replaced by $\texttt{Patch(m}_1\texttt{)}$. Then, although $\mathcal{F}' \cup \mathcal{R} \cup \mathcal{O}'$ also entails the expected result, computing ontology inferences and applying the rules *separately* as before, will not produce it, since the rules could not be fired from the facts explicitly known. This is a well-known problem, clearly identified by [4] [17] and [15] who explains why usual inference mechanisms are inadequate for hybrid languages: “a KB may entail the antecedent of a rule without the antecedent being instantiated in the KB”, which is precisely the case here. Second, “a KB may entail the disjunction of antecedents of two rules without entailing either of them”.

4. Language requirements

For the ontology language, the choice is OWL DL, for the reasons explained above (§2.1), in particular to benefit of DL services such as those of Racer [11]. OWL DL expressiveness is at least needed (∃ and ∪ occur in class definition), even better, extended by qualified cardinality that previously existed in DAML+OIL. As already exhibited by brain examples [6] and more recently by the FMA migration to OWL DL [8], qualified cardinality is particularly useful in anatomy for defining structures from their parts or from their boundaries. For example, they are needed to represent in OWL-DL an ‘hemisphere’ as 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 a precentral gyrus is bounded by exactly one precentral sulcus, one central sulcus, and is connected or contiguous to a postcentral gyrus. Other OWL DL extensions such as $\mathcal{SHIQ}$ added with Role Inference Axioms [13] limited to the form $P \circ Q \subset P$, are not sufficient for this application. For example, the “triangle” rule R1 (§2.2) `isMAEBoundedBy(?x, ?y) Λ isMAEBoundedBy(?z, ?y) Λ MAE(?x) Λ MAE(?z) Λ GyriConnection(?y) → isMAEConnectedTo(?x, ?z)` cannot be represented in DL. An extension with some form of rules is required for it. Moreover, in addition to the ontology properties, other “ordinary” relations not defined in the ontology, also called “non DL” predicates [17] are needed. They occur in rules e.g. R2, R3, R4, queries, or facts, e.g. the ternary predicate `connects`, or the binary predicate `hasNoCommonPart` etc. (cf. Documentation). Ternary predicates are specially useful for representing the ground facts issued from the information extracted by the numerical tools, e.g. the initial fact `F5 separates(s,m1,m2)` captures the separation relation between a sulcus segment `s` and two gyrus parts `m1 and m2`, or `connectsMAE(op,m,g)` expresses the connection between three anatomical entities. Although it is possible to express a n-ary relationship with unary and binary predicates thanks reification, arbitrary arity is preferred. Hence, this study shows that OWL DL should be extended at least by a rule language like SWRL [12] that supports ontology concepts and roles to occur in rule bodies or head as unary or binary predicates. However, SWRL is not yet enough, and the language should also support non DL predicates, in particular n-ary predicates that occur in body and head atoms, and negation (and disjunction) in rule body.

5. Support for reasoning

Hybrid systems are not a new idea. Rules have been earlier added to DL, e.g. in Classic [1] [2]. DL reasoner have been combined with Datalog reasoner, e.g. AL-log [4] [5], Carin [15]. But a particular recrudescence of interest is now noted in the context of the Semantic Web, related to interoperating between rules and the OWL standard. Alternative approaches and tools are investigated, including SweetRules[2], KAON2[3], OWL2Jess and SWRL2Jess[4] or ROWL[5] translators, SWRL with HOOLET[6].

A first direction privileges decidability. SweetRules[2] proposes hybrid reasoning with ontologies and rules, based on the DLP fragment of FOL [10]. Defined as the intersection of DL and Horn logic programming, DLP is a decidable language. Several translators are proposed to merge the ontology and the rules within the same programming framework, e.g. Jena 2, Jess etc. For example SweetOnto permits to convert DLP OWL ontologies with RDF facts into SWRL, SweetJena translates the set of all the resulting SWRL rules into Jena 2, which is then executed. The main drawback of DLP is the restriction in the form of axioms: DLP does not support existential quantifier, disjunction, negation in the axiom consequent. According to DLP author, “extensions to DLP, including extension that treats existential, have already been worked out in a DLP 2 version, based on skolemization.”[7]

Other recent techniques suggest solutions retaining decidability in extending DL with rules, by imposing a “safe” interaction between the DL and rule components, instead of restricting the languages (see [19] for a survey). [17] presents a decidable extension of OWL-DL with so-called “DL-safe” rules, that is, rules where each rule variable occurs in a non-DL atom of its body. This approach is implemented in KAON2. KAON2 supports the $\mathcal{SHIQ}(\mathcal{D})$ subset of OWL-DL (all features of OWL-DL apart from enumerated classes) and the DL-safe subset of SWRL. Its hybrid reasoner is based on reduction of a $\mathcal{SHIQ}(\mathcal{D})$ knowledge base to a disjunctive datalog program.

A different direction is suggested with SWRL [14], privileging a DL extension with no restriction on the languages nor on their integration, at the price to be no longer decidable. OWL DL is extended by unary/binary datalog rules which atoms are all DL atoms. Reasoning is achieved by a first-order theorem prover. Hoolet supports such an extension and uses Vampire for reasoning.

Meanwhile, other works investigate practical tools based on Jess for reasoning with SWRL. The SWRL editor, associated to the Protégé OWL plugin, has recently been integrated with the Jess rule engine [18]. Sharing some features with the previous SWRJessTab plugin [7], this tool adds new very interesting developments: its interactive editor with a visual interface and the use of the SWRL factory Java API, which makes its integration with Java rule engines easier. But, it also exhibits some limitations. The translation from OWL to Jess is limited, and does not handle all the constructors. Managing conflicts and iterating between Racer and Jess is left to the user. [16] suggests a practical way to extend the translation to all the OWL DL and SWRL constructors. The XSLT OWL2Jess.xsl transforms ontologies from OWL to Jess, SWRL2Jess.xsl translates rules from SWRL to Jess. But, since basically all the OWL constructors, e.g. existential in consequent, *cannot* be translated by Jess rules, these cases are handled by Jess rules asserting caution or error messages. Doing so, as the authors say, their inference service is neither complete nor sound. For example, suppose the ontology has a class A= `∃ hasChild. Man` and the relation hasChild is verified for some individuals, but no one is asserted to be a man in the KB, then a Jess rule asserts a new fact, which may be false, since based on the Jess random process. In fact, all these tools share a common drawback due to the basic difference of expressiveness of OWL DL and Jess rules. As they are based on explicit facts and an incomplete representation of the ontology in Jess, they may provide wrong answers, as already pointed out. For example for $\mathcal{R}'$ and $0'$, even after iterations, the output reported by Jess may be failure, although a solution exists (§3).
Several options might be considered for the brain application. A first one would be to transform the ontology, thanks to a representation similar to the simplified example, i.e. defining explicit g_i representing the solution associated to each patch m_i, with facts hasPart(g_i, m_i), gyrus(g_i) instead of each fact patch(m_i) (and also to reify the n-ary predicates). Remaining in DLP, different tools, e.g. a

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[2] http://sweetrules.projects.semwebcentral.org/
[3] http://kaon2.semanticweb.org/
[4] http://www.inf.fu-berlin.de/inst/ag-nbi/research/owltrans/
[5] http://mycampus.sadehlab.cs.cmu.edu/public_pages/ROWL/ROWL.html
[6] http://owl.man.ac.uk/hoolet/
[7] B.Grosof personal communication

rule engine like Jess could be used safely. Another option would be to have an extension of SWRL to function-free first-order logic (with arbitrary arity) and to use a FOL reasoner. The possibility of using DL-safe rules and KAON2 needs further investigation.
At the moment, existing tools support SWRL but not full FOL. So we extended the representation of SWRL in Protégé OWL to function-free FOL, following the recent proposal, SWRL FOL[8], extending SWRL to function-free unary/binary first-order formula, but adding non DL predicates of arity n, interpreted in the usual manner by relations of arity n over the domain of interpretation. A class NonDLRelation has been defined for the non DL predicates, and two disjoint subclasses of Atom: swrl:Atom and NonDLAtom respectively for DL and non DL atoms. The brain non DL relations are imported, from an external BrainRelations ontology similar to the built-ins ontology swrlb.owl. Instances of Non DL predicates are stored in external files (database or XML file).

6. Conclusion

Using rules with OWL ontology requires caution, in particular with an "integrated" language like SWRL. It is impossible to have at the same time, decidability, soundness, completeness, performance and expressivity. Therefore, the features expected from the application should be carefully evaluated, with regards to the properties and limitations of the method to be used. Using Jess in conjunction with Racer, or converting the ontology and rules into the same programming framework (Prolog, production rules, etc.) may be relevant, when the expressiveness of OWL DL is not needed and a restriction such as DLP OWL is enough, or when some guarantees are not necessary. Else, if the ontology really requires existential and disjunctions, another method should be generally preferred, for example based on a SWRL extension to FOL or an OWL DL extension with a "safe" interaction with rules, depending on the wanted properties. A next perspective might be to extend the SWRL Editor and the SWRL Factory to handle FOL formula[9], so as to integrate different reasoning supports with it, first-order provers, Prolog or production rules engines. Like for OWL sublanguages, it might be proposed to determine the language used, DLP-SWRL, SWRL, Datalog, FOL etc., and to select a suited corresponding reasoner.

7. References

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[8] http://www.w3.org/Submission/2005/SUBM-SWRL-FOL-20050411/

[9] or perhaps a superset including FOL and negation as failure

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