Consiglio Nazionale delle Ricerche
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Abstract

This paper presents the construction of an ontology and rules that can help us to label brain anatomical entities, identified in MRI images. Starting from ontology and rules achieved by O.Dameron at IDM, we have modified them in order to use OWL and SWRL languages for ontology and rules representation.

1 Introduction

At present automatic identification of brain anatomical entities from MRI images is not possible. Achieving this goal could give a great support in the research about neurological pathology such as epilepsy, dementia, sclerosis, etc. Nowadays brain cortex can be automatically segmented, but the problem remains to identify its various parts, such as Lobes and Gyri.

An ontology, which can be defined as *explicit and formal specification of a shared conceptualization*[1], can be a possible way for labelling different brain structure and allows us to describe all entities of our domain and the relationship between them: all concepts and all constraints are represented, so the ontology becomes *machine-readable* and it succeeds in catching all consensual knowledge. So we can built an ontology with classes, properties and instances as basic elements, and with possible restrictions and axioms, in order to define a canonical and shared knowledge of anatomical elements.

The ontology for the description of human brain needs to be combined with a set of rules for representing the relationships between brain anatomical entities. A rule has an antecedent (body) and a consequent (head) :

antecedent → *consequent*

Whenever the conditions specified in the antecedent hold, the conditions specified in the consequent must also hold.

So ontology and rules can help to label anatomical brain structures from MRI images.

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[1] Definition by Thomas R.Gruber (1993)

2 Bases for the ontology construction

Anatomically human encephalon is composed of three main elements: brain stem, cerebellum and brain. The developed ontology describes the brain, which is 80% of encephalon’s volume. Brain has two hemispheres (*left hemisphere* and *right hemisphere*) , they are separated by a deep sulcus: *Falx Cerebri*. The external surface of the hemispheres has many sulci and relieves that make it very irregular and increase its extension. Particularly we identify *primari* (*sulci*) *scissures*, that separate external surface of the hemispheres into *lobes*, and *secondary scissures* , that divide every lobe in *gyri*. There are different kind of connection between two gyri, in the ontology they are called *conventional separation*, *pli de passage* and *operculus*. Gyri can be also composed by other anatomical entities (in the ontology they are called *pars*), that are bounded by sulcus segments.

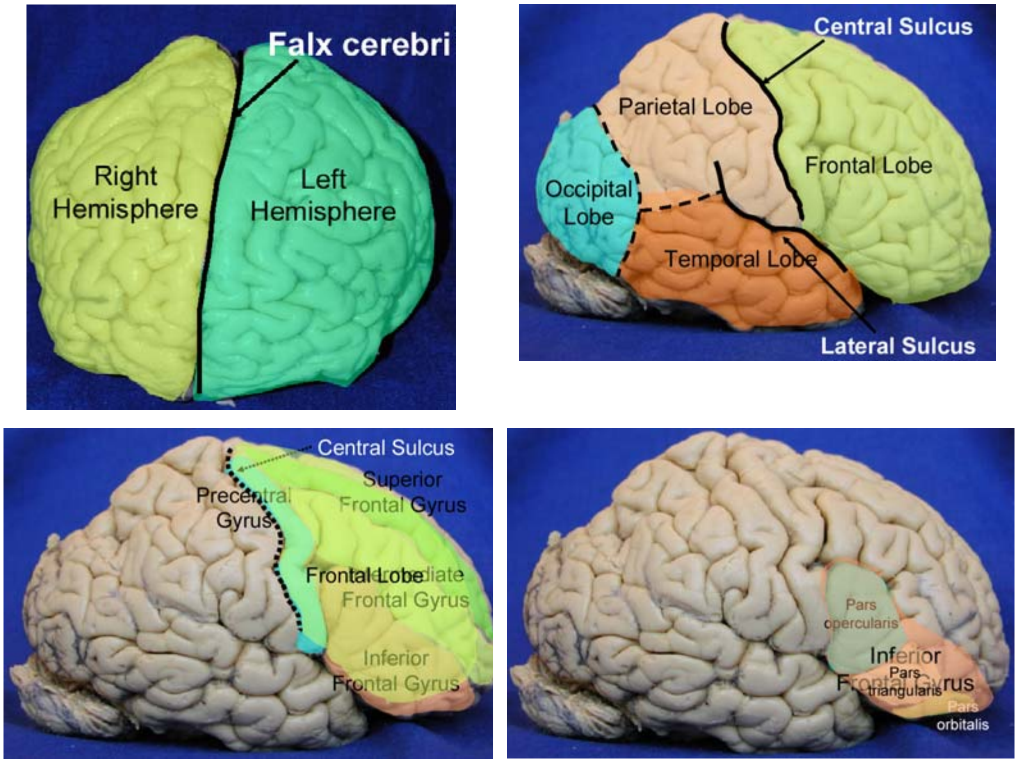


Figure 1 – Brain anatomical entity

The starting point for the development of the ontology has been ontology and rules for the description of brain anatomy achieved by O. Dameron at IDM [2].

But these ontology and rules cannot be developed in OWL DL and SWRL, that usually are used for ontologies and rules, because of the limits of these languages: OWL DL doesn't allow to express n-ary predicates; SWRL doesn't support n-ary predicates, negations and disjunctions in rule body. In this work these limits are overcome through a new formulation of properties and rules, that are described in the following paragraphs.
In order to simplify ontology development we have used Protégé tool, an open-source platform, realized at Stanford University, that offers a graphic and interactive editor for ontology design and for knowledge acquisition, for developing ontology in OWL language and rules in SWRL.

3 Ontology enhancement

Ontology created by O. Dameron is composed of classes, properties and rules (see Appendix):

- classes define names of the relevant domain concepts and their logical characteristics, the concepts are obtained from anatomical studies about brain (for each class necessary conditions and necessary and sufficient conditions to belong to a class have been specified);
- properties are used to describe features and attributes of the classes, they define the relationships between classes and allow to assign primitive values to instances;
- relations represent relationships between different structures.

Three group of ***properties*** are defined : mereological properties , topological properties and ternary properties. The first are used to express that a specific anatomical entity (hemisphere, lobe, gyrus or pars) has another one as anatomical part, or to express that a sulcus has another sulcus as segment. Topological properties are used for the following binary relations :

- *isMAEBoundedBy* : to express that a MAE is bounded by a sulcus or by a gyri connection (ConventionalSeparation, Operculus, PliDePassage);
- *isSFBoundedBy* : when a sulcus is bounded by a Sulci Connection;
- *isInterruptedBy* : there is a sulcus interrupted by an Operculus or a PliDePassage;
- *isMAEConnectedTo*: an MAE is connected to another MAE by a ConventionalSeparation, an Operculus or a PliDePassage;
- *isSFConnectedTo* : for a connection between two sulci;
- *isMAEContiguousTo* : when an MAE is contiguous to another one;
- *isSFContiguousTo* : if a sulcus is contiguous to another one.

At least there are properties to express ternary relations:

- *separatesMAE* is used when a sulcus separates two MAE;
- *separatesSF* expresses that an Operculus or a PliDePassage separates two sulci;
- *connectsMAE* says that an entity (ConventionalSeparation, Operculus o PliDePassage) connects two MAE;
- connectsSF is used when an element connects two sulci.

But OWL DL, the language used to develop the ontology, and SWRL , the language for the construction of the rules, don't allow to express ternary predicates and they cannot be into the rules.

So ternary relations have been translated as an *and* between binary relations, in this way they can be introduced into the rules.

A concept that an entity A separates two elements B and C can be expressed saying that each of them is bounded by A and $B \neq C$, the same thing can be said about connection. So ternary properties are translated in the following way:

- ➢ $separatesMAE(SF, MAE1, MAE2)$

  has been rewritten as:

  $MAEBounds(SF, MAE1) \wedge MAEBounds(SF, MAE2) \wedge MAE1 \neq MAE2$

- ➢ $separatesSF(OP, SF1, SF2)$ e $separatesSF(Pli, SF1, SF2)$

  become respectively:

  $interrupts(OP, SF1) \wedge interrupts(OP,SF2) \wedge SF1 \neq SF2$

  $interrupts(Pli, SF1) \wedge interrupts(Pli,SF2) \wedge SF1 \neq SF2$

- ➢ *connectsMAE(CS, MAE1, MAE2)* , *connects(OP, MAE1, MAE2)* , *connects(Pli, MAE1, MAE2)*

  have been translated as :

  $MAEBounds(CS, MAE1) \wedge MAEBounds(CS, MAE2) \wedge MAE1 \neq MAE2$

  $MAEBounds(OP, MAE1) \wedge MAEBounds(OP, MAE2) \wedge MAE1 \neq MAE2$

$MAEBounds(Pli, MAE1) \wedge MAEBounds(Pli, MAE2) \wedge MAE1 \neq MAE2$

- *connectsSF(SC, SF1, SF2)*

  becomes

  $SFBounds(SC, SF1) \wedge SFBounds(SC, SF2) \wedge SF1 \neq SF2$

In the ontology have been introduced the following properties too:

"Negative properties"	**Domain**
hasNotAnatomicalPart	MAE*MAE
NoMAEBounds	(SF|GyriConnection)*MAE
NoInterrupts	(PliDePassage|Operculus)*SF
hasNotSegment	SF*SF

The introduction of these properties, that are equivalent to negation of other defined properties, is useful to overcome the problem that SWRL doesn't accept negation in rule body. For example there isn't a way to express that the class *PreCentralGyrus* has not *OrbitalParsOfInferiorFrontalGyrus* as anatomical part, using the only property *hasAnatomicalPart* without using these negative properties, in fact it's necessary indicate this thing with a specific property .

A least two complex properties are introduced, because they are used into the rules:

"Complex Properties"	**Domain**
hasNoCommonPart	MAE*MAE
isNotContainedIn	GyriConnection*MAE

- *hasNoCommonPart* says that two MAE haven't got an anatomical part in common;
- *isNotContainedIn* is used to express that a GyriConnection is not contained in a MAE.

To support the labelling of brain anatomical entities identified in MRI images, an ontology OWL with classes and rules is not enough, a set of ***rules*** is also needed to accompany it. Ontology allows to define a canonical and shared knowledge of anatomical entities, indeed relations between different structures can be represented through rules.

So integration of an ontological approach and of an approach based on rules, is used, with an hybrid system able to integrate standard OWL with SWRL rules in a unique system.

The main problem of SWRL language is that it cannot allow to express n-ary predicates, negations and rules. But these are fundamental requirements to develop rules connected with this ontology, so some “negative properties” have been introduced and ternary properties have been reformulated using binary relations, in order to solve the problem. Disjunctions cannot be expressed in the rules with SWRL, so in these cases the rule can be divided in so many rules such as the number of the elements connected through the OR, putting only one of them in each obtained rule.

We have started from the set of rules in Appendix, these rules contain ternary relations, negations and disjunctions, for the description of the domain. This set has been completely rewritten in order to use SWRL language, so a new set of rules has been obtained.

Below all new rules are listed , explaining briefly their meaning and how they have been obtained from the initial set of rules.

I.

$$\begin{aligned}&MAE(m1) \wedge MAE(m2) \wedge MAE(s) \wedge hasAnatomicalPart(m1,s)\\&\wedge hasNotAnatomicalPart(m2,s) \wedge differentFrom(m1,m2)\\&\rightarrow \quad hasNoCommonPart(m1,m2)\end{aligned}$$

II.

$$\begin{aligned}&MAE(m1) \wedge MAE(m2) \wedge MAE(s) \wedge hasNotAnatomicalPart(m1,s)\\&\wedge hasNotAnatomicalPart(m2,s) \wedge differentFrom(m1,m2)\\&\quad\rightarrow \quad hasNoCommonPart(m1,m2)\end{aligned}$$

Rules I and II have been obtained from rule 5 , using negative properties introduced into the ontology, Boolean algebra and the decoupling of the rule derived by the presence of the OR.

III.

$$\begin{aligned}&MAE(m) \wedge SF(s) \wedge \ hasAnatomicalPart(m,sm1) \wedge\\&\ hasAnatomicalPart(m,sm2) \wedge differentFrom(sm1,sm2) \wedge\\&NoMAEBounds(s,sm1) \quad \rightarrow \quad isNotContainedIn(s,m)\end{aligned}$$

IV.

$$\begin{aligned}&MAE(m) \wedge SF(s) \wedge \ hasAnatomicalPart(m,sm1) \wedge\\&\ hasNotAnatomicalPart(m,sm2) \wedge differentFrom(sm1,sm2)\\&\quad\rightarrow \quad isNotContainedIn(s,m)\end{aligned}$$

Rules III and IV descend from rule 6 , by reformulating property *separatesMAE(s,sm1,sm2)* as *MAEBounds(s,sm1)* Λ *MAEBounds(s,sm2)* Λ *differentFrom(sm1,sm2)*, and using Boolean Algebra and negative properties.

V.

$$\begin{gathered} MAE(m)\ \Lambda\ GyriConnection(s)\ \Lambda\ \ hasAnatomicalPart(m,m1)\ \Lambda \\ hasAnatomicalPart(m,m2)\ \Lambda\ differentFrom(m1,m2)\ \Lambda \\ NoMAEBounds(s,m1)\ \ \rightarrow\ \ isNotContainedIn(s,m) \end{gathered}$$

VI.

$$\begin{gathered} MAE(m)\ \Lambda\ GyriConnection(s)\ \Lambda\ \ hasAnatomicalPart(m,m1) \\ \Lambda\ hasNotAnatomicalPart(m,m2)\ \Lambda\ differentFrom(m1,m2) \\ \rightarrow\ \ isNotContainedIn(s,m) \end{gathered}$$

Rules V and VI have been derived from the reformulation of rule 7 such as rules III and IV have been descended by rule 6 with the only difference that there is the property *connectsMAE* instead of *separatesMAE.*

Rules I-VI need for the definition of ordinary predicates that are not ontology properties.

VII.

$$\begin{gathered} MAE(m)\ \Lambda\ MAE(m2)\ \Lambda\ SF(s)\ \Lambda\ MAEBounds(s,m1)\ \Lambda\ MAEBounds(s,m2)\ \Lambda \\ differentFrom(m1,m2)\ \Lambda\ \ \ \rightarrow\ \ isMAEContiguousTo(m1,m2) \end{gathered}$$

Using reformulation of property *separatesMAE* rule 9 has been translated into the rule VII: it allows to derive contiguity from MAE separation.

Propagation of MAE boundary to a second sulcal fold containing the first:

VIII.

$$\begin{gathered} MAE(m)\ \Lambda\ SF(ss)\ \Lambda\ \ SF(s)\ \Lambda\ hasSegment(s,ss)\ \Lambda\ isMAEBoundedBy(m,ss) \\ \rightarrow\ \ isMAEBoundedBy(m,s) \end{gathered}$$

Propagation of contiguity to parts:

IX.

$$\begin{aligned}&MAE(m1) \wedge MAE(m2) \wedge\ MAE(sm2) \wedge SF(s) \wedge \\ &isMAEBoundedBy(m1,s) \wedge isMAEBoundedBy(m2,s) \wedge \\ &isMAEBoundedBy(sm2,s) \wedge isMAEContiguousTo(m1,m2) \wedge \\ &hasAnatomicalPart(m2,sm2) \quad \to \quad isMAEContiguousTo(m1,sm2)\end{aligned}$$

Propagation of contiguity to a second material entity containing the first :

X.

$$\begin{aligned}&MAE(m1) \wedge MAE(m2) \wedge\ MAE(sm2) \wedge\ hasNoCommonParts(m1,m2) \\ &\wedge hasAnatomicalPart(m2,sm2) \wedge isMAEContiguousTo(m1,sm2) \\ &\quad \to \quad isMAEContiguousTo(m1,m2)\end{aligned}$$

Rules VIII, IX, X are equal to the rules 10,12,13.

Propagation of MAE boundary to a second material entity containing the first, only if the boundary is not contained in the second material entity:

XI.

$$\begin{aligned}&MAE(sm) \wedge MAE(m) \wedge SulcalFold(s) \wedge\ isNotContainedIn(s,m) \\ &\wedge isMAEBoundedBy(sm,s) \wedge hasAnatomicalPart(m,sm) \\ &\quad \to \quad isMAEBoundedBy(m,s)\end{aligned}$$

XII.

$$\begin{aligned}&MAE(sm) \wedge MAE(m) \wedge GyriConnection(s) \wedge\ isNotContainedIn(s,m) \\ &\wedge isMAEBoundedBy(sm,s) \wedge hasAnatomicalPart(m,sm) \\ &\quad \to \quad isMAEBoundedBy(m,s)\end{aligned}$$

Inferring contiguity from separation:

XIII.

$$\begin{aligned}&Operculus(s) \wedge SF(n1) \wedge SF(n2) \wedge \mathrm{int}\,errupts(s,n1) \wedge \mathrm{int}\,errupts(s,n2) \\ &\wedge differentFrom(n1,n2) \quad \to \quad isSFContiguousTo(n1,n2)\end{aligned}$$

XIV.

$$\begin{aligned}&PliDePassage(s) \wedge SF(n1) \wedge SF(n2) \wedge \mathrm{int}\,errupts(s,n1) \wedge \mathrm{int}\,errupts(s,n2) \\ &\wedge differentFrom(n1,n2) \quad \to \quad isSFContiguousTo(n1,n2)\end{aligned}$$

Inferring contiguity from interruption by a common operculus or pli de passage:

XV.
$$\begin{aligned}&\mathit{Operculus}(s) \wedge \mathit{SF}(n1) \wedge \mathit{SF}(n2) \wedge \mathit{differentFrom}(n1, n2)\\ &\wedge \mathit{isInterruptedBy}(n1, s) \wedge \mathit{isInterruptedBy}(n2, s) \quad \rightarrow \quad \mathit{isSFContiguousTo}(n1, n2)\end{aligned}$$

XVI.
$$\begin{aligned}&\mathit{PliDePassage}(s) \wedge \mathit{SF}(n1) \wedge \mathit{SF}(n2) \wedge \ \mathit{differentFrom}(n1, n2)\\ &\wedge \mathit{isInterruptedBy}(n1, s) \wedge \mathit{isInterruptedBy}(n2, s) \quad \rightarrow \quad \mathit{isSFContiguousTo}(n1, n2)\end{aligned}$$

Rules XI and XII have been obtained from rule 11, decoupling it to express the OR. The same is for the rules XIII and XIV that have been derived from rule 19, and for the rules XV and XVI derived from rule 20.

Propagation of interruption of a first sulcal fold to a second sulcal fold containing the first, only if the second doesn't have any segment separated by the same operculus or pli de passage:

XVII.
$$\begin{aligned}&\mathit{SF}(n) \wedge \mathit{SF}(sn) \wedge \mathit{Operculus}(s) \wedge \ \mathit{isInterruptedBy}(sn, s)\\ &\wedge \mathit{hasSegment}(n, sn) \wedge \mathit{hasSegment}(n, n0) \wedge \mathit{noInterrupts}(s, n0)\\ &\wedge \mathit{differentFrom}(n0, sn) \quad \rightarrow \quad \mathit{isInterruptedBy}(n, s)\end{aligned}$$

XVIII.
$$\begin{aligned}&\mathit{SF}(n) \wedge \mathit{SF}(sn) \wedge \mathit{Operculus}(s) \wedge \ \mathit{isInterruptedBy}(sn, s)\\ &\wedge \mathit{hasSegment}(n, sn) \wedge \mathit{hasNotSegment}(n, n0) \wedge \mathit{differentFrom}(n0, sn)\\ &\quad \rightarrow \quad \mathit{isInterruptedBy}(n, s)\end{aligned}$$

XIX.
$$\begin{aligned}&\mathit{SF}(n) \wedge \mathit{SF}(sn) \wedge \mathit{PliDePassage}(s) \wedge \ \mathit{isInterruptedBy}(sn, s)\\ &\wedge \mathit{hasSegment}(n, sn) \wedge \mathit{hasSegment}(n, n0) \wedge \mathit{noInterrupts}(s, n0) \wedge\\ &\mathit{differentFrom}(n0, sn) \quad \rightarrow \quad \mathit{isInterruptedBy}(n, s)\end{aligned}$$

XX.
$$\begin{aligned}&\mathit{SF}(n) \wedge \mathit{SF}(sn) \wedge \mathit{PliDePassage}(s) \wedge \ \mathit{isInterruptedBy}(sn, s)\\ &\wedge \mathit{hasSegment}(n, sn) \wedge \mathit{hasNotSegment}(n, n0) \wedge \mathit{differentFrom}(n0, sn)\\ &\quad \rightarrow \quad \mathit{isInterruptedBy}(n, s)\end{aligned}$$

Rules XVII, XVIII, XIX and XX have come from the rule 22, by application of Boolean algebra and the separation because of the OR.

Inferring connected entities from connection:

XXI.

$$\begin{aligned}&MAE(m1)\ \Lambda\ MAE(m2)\ \Lambda\ GyriConnection(?s)\ \Lambda\ MAEBounds(s,m1)\\&\Lambda\ MAEBounds(s,m2)\ \Lambda\ differentFrom(m1,m2)\\&\rightarrow\quad isMAEConnectedTo(m1,m2)\end{aligned}$$

Rule XXI has been obtained form the rule 26, reformulating property *connectsMAE* with binary predicates.

Inferring connected entities from a common gyri connection:

XXII.

$$\begin{aligned}&MAE(m1)\ \Lambda\ MAE(m2)\ \Lambda\ GyriConnection(?s)\ \Lambda\ isMAEBoundedBy(m1,s)\\&\Lambda\ isMAEBoundedBy(m2,s)\ \Lambda\ differentFrom(m1,m2)\\&\quad\rightarrow\quad isMAEConnectedTo(m1,m2)\end{aligned}$$

Propagation of connection (to a first material entity) to a second material entity containing the first:

XXIII.

$$\begin{aligned}&MAE(m1)\ \Lambda\ MAE(m2)\ \Lambda\ MAE(sm2)\ \Lambda\ hasNoCommonPart(m1,m2)\\&\Lambda\ hasAnatomicalPart(m2,sm2)\ \Lambda\ isMAEConnectedTo(m1,m2)\\&\Lambda\ differentFrom(m1,sm2)\quad\rightarrow\quad isMAEConnectedTo(m1,sm2)\end{aligned}$$

Propagation of connection (to a first material entity) to a second material entity which is part of the first:

XXIV.

$$\begin{aligned}&MAE(m1)\ \Lambda\ MAE(m2)\ \Lambda\ MAE(sm2)\ \Lambda\ GyriConnection(?s)\\&\Lambda\ isMAEBoundedBy(sm2,s)\ \Lambda\ isMAEBoundedBy(m1,s)\\&\Lambda\ hasAnatomicalPart(m2,sm2)\Lambda\ isMAEConnectedTo(m1,m2)\\&\Lambda\ differentFrom(m1,sm2)\quad\rightarrow\quad isMAEConnectedTo(m1,sm2)\end{aligned}$$

Rule 27, 30, 32 has become respectively rules XXII, XXIII, XXIV, adding the condition that the two MAE must be different.

Inferring connected entities from connection:

XXV.

$$\begin{aligned}&\mathit{SF}(n1)\ \Lambda\ \mathit{SF}(n2)\ \Lambda\ \mathit{SulciConnection}(s)\ \Lambda\ \mathit{SFBounds}(s,n1)\ \Lambda \mathit{SFBounds}(s,n2)\\&\Lambda\ \mathit{differentFrom}(n1,n2)\quad\rightarrow\quad \mathit{isSFConnectedTo}(n1,n2)\end{aligned}$$

Rule XXV has been obtained by rule 34 rewriting property *connectsSF* with binary predicates.

Inferring connected entities from a common sulci connection:

XXVI.

$$\begin{aligned}&\mathit{SF}(n1)\ \Lambda\ \mathit{SF}(n2)\ \Lambda\ \mathit{SulciConnection}(s)\ \Lambda\ \mathit{isSFBoundedBy}(n1,s)\\&\Lambda\ \mathit{isSFBoundedBy}(n2,s)\ \Lambda\ \mathit{differentFrom}(n1,n2)\quad\rightarrow\quad \mathit{isSFConnectedTo}(n1,n2)\end{aligned}$$

Rules XXVI is equal to the rule 35, with the additional condition in the antecedent that the two sulcal fold must be different.

Propagation of boundary of a first sulcal fold to a second sulcal fold containing the first, only if the second sulcal fold doesn't have any other segment which shares the boundary with the first:

XXVII.

$$\begin{aligned}&\mathit{SF}(n1)\ \Lambda\ \mathit{SF}(sn1)\ \Lambda\ \mathit{SF}(n0)\ \Lambda\ \mathit{SulciConnection}(s)\\&\Lambda\ \mathit{isSFBoundedBy}(sn1,s)\ \Lambda\ \mathit{hasSegment}(n1,sn1)\ \Lambda\ \mathit{hasSegment}(n1,n0)\\&\Lambda\ \mathit{noSFBounds}(s,n0) \Lambda\ \mathit{differentFrom}(sn1,n0)\quad\rightarrow\quad \mathit{isSFBoundedBy}(n1,s)\end{aligned}$$

XXVIII.

$$\begin{aligned}&\mathit{SF}(n1)\ \Lambda\ \mathit{SF}(sn1)\ \Lambda\ \mathit{SF}(n0)\ \Lambda\ \mathit{SulciConnection}(s)\\&\Lambda\ \mathit{isSFBoundedBy}(sn1,s)\ \Lambda\ \mathit{hasSegment}(n1,sn1)\ \Lambda\ \mathit{hasNotSegment}(n1,n0)\\&\Lambda\ \mathit{differentFrom}(sn1,n0)\quad\rightarrow\quad \mathit{isSFBoundedBy}(n1,s)\end{aligned}$$

Propagation of connection (involving a first and a second sulcal fold) to a third sulcal fold containing the first, only if the third doesn't contain the second:

XXIX.

$$\begin{aligned}&\mathit{SF}(n1)\ \Lambda\ \mathit{SF}(n2)\ \Lambda\ \mathit{SF}(sn2)\ \Lambda\ \mathit{isSFConnectedTo}(n1,sn2)\ \Lambda\ \mathit{hasSegment}(n2,sn2)\\&\Lambda\ \mathit{hasNotSegment}(n2,n1)\quad\rightarrow\quad \mathit{isSFConnectedTo}(n1,n2)\end{aligned}$$

Rule XXIX is equal to rule 39.

Rules of the initial set with ternary properties as consequent have been not considered in the translation (only one property can be represented in the consequent) .
Translation of the rules 8, 18, 25, 33 has not been added to the ontology because it brings to banal rules with a consequent contained in the antecedent, so the implication between the antecedent and the consequent is trivially true.

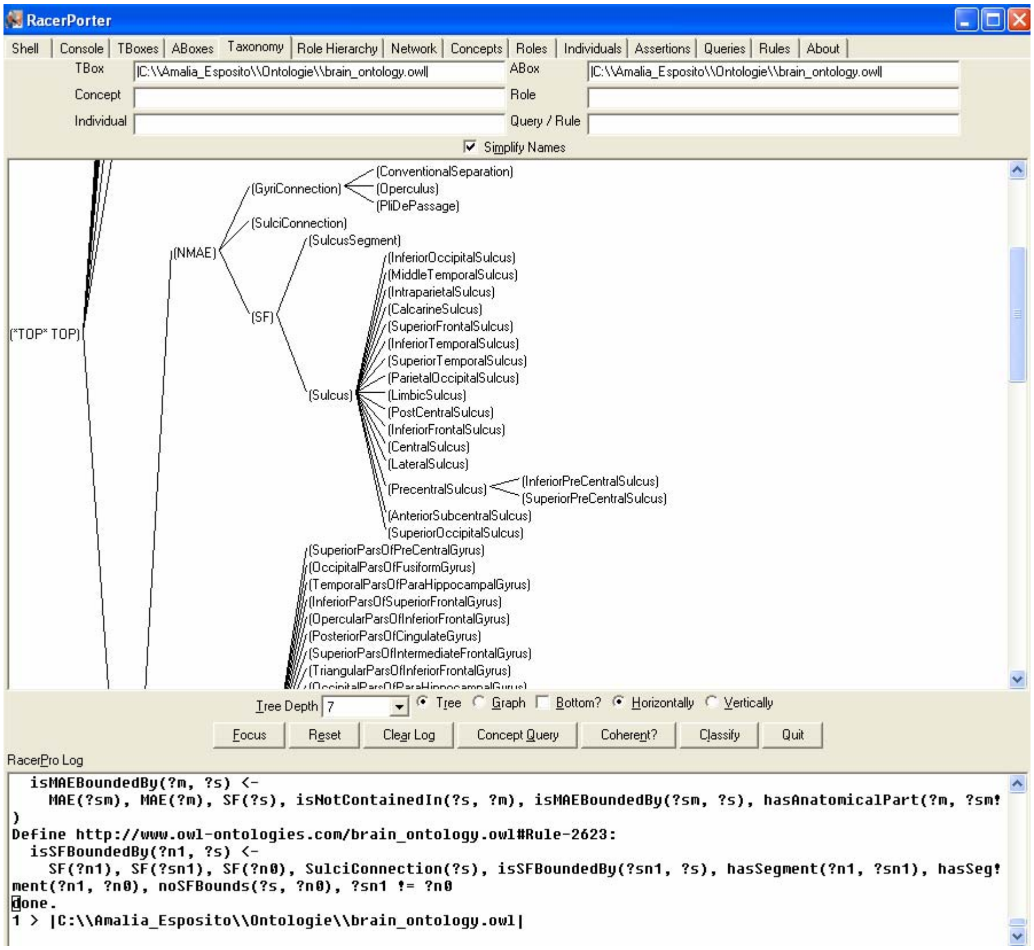
The new set of rules have been added to the ontology using the SWRL Editor of Protégé.

7 Introduction of instances and use of a reasoner: an application

After the development of ontology and rules, some individuals (instances of the classes) have been introduced. After this operation the ontology was submitted to a reasoner: RacerPro.
A reasoner can automatically reason about an ontology and it produces answer to important questions such as:

- *subsuntion :* if a concept is implicitly a case of another concept;
- *instance checking :* if an instance of a concept is consistent with the definition of the concept.

Also rules are submitted to the reasoner: if the conditions specified in the antecedent hold, then all operations specified in the consequent will be executed. We have also used RacerPorted , a graphic interactive interface which is connected to RacerPro to show graphically the instances and their properties.
After having loaded the file of ontology and rules, developed with Protégé, an inspection of the ontology is possible:



TBox |C:\\Amalia_Esposito\\Ontologie\\brain_ontology.owl|
ABox |C:\\Amalia_Esposito\\Ontologie\\brain_ontology.owl|
Concept
Role
Individual
Query / Rule
☑ Simplify Names

Tree Depth 7 ● Tree ○ Graph ☐ Bottom? ● Horizontally ○ Vertically

```
  isMAEBoundedBy(?m, ?s) <-
    MAE(?sm), MAE(?m), SF(?s), isNotContainedIn(?s, ?m), isMAEBoundedBy(?sm, ?s), hasAnatomicalPart(?m, ?sm!
)
Define http://www.owl-ontologies.com/brain_ontology.owl#Rule-2623:
  isSFBoundedBy(?n1, ?s) <-
    SF(?n1), SF(?sn1), SF(?n0), SulciConnection(?s), isSFBoundedBy(?sn1, ?s), hasSegment(?n1, ?sn1), hasSeg!
ment(?n1, ?n0), noSFBounds(?s, ?n0), ?sn1 != ?n0
done.
1 > |C:\\Amalia_Esposito\\Ontologie\\brain_ontology.owl|
```

Figure 2 – RacerPorter for the ontology's inspection

Some instances are introduced to verify the real application of the rules. Below an example is showed.

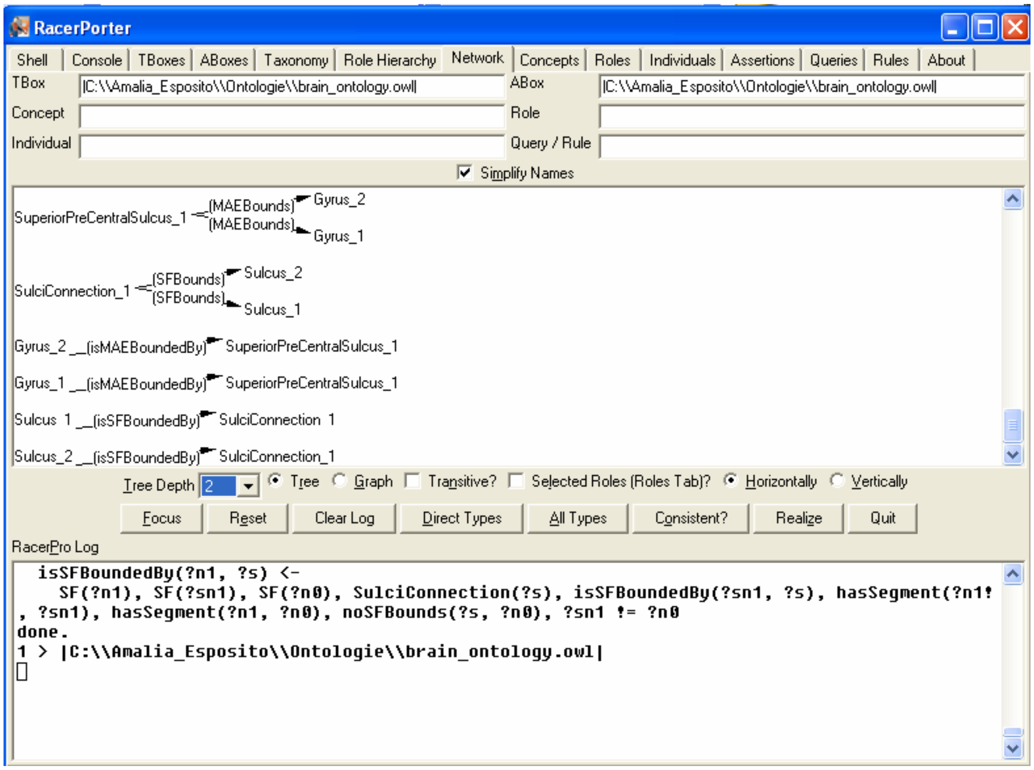
To simplify we have introduced only the following instances:

ISTANCE	CLASS
Gyrus_1	*Gyrus*
Gyrus_2	*Gyrus*
SuperiorPreCentralSulcus_1	*SuperiorPreCentralSulcus*
Sulcus_1	*Sulcus*
Sulcus_2	*Sulcus*
SulciConnection_1	*SulciConnection*

By imponing this facts:

isMAEBoundedBy (Gyrus_1, SuperiorPreCentralSulcus_1)
isMAEBoundedBy (Gyrus_2, SuperiorPreCentralSulcus_1)
differentFrom(Gyrus_1,Gyrus_2)
SFBounds(SulciConnection_1, Sulcus_1)
SFBounds(SulciConnection_1, Sulcus_2)
differentFrom(Sulcus_1, Sulcus_2)

Before the application of rules to the instances , the graph showed by RacerPorter is the following:



TBox |C:\\Amalia_Esposito\\Ontologie\\brain_ontology.owl|
ABox |C:\\Amalia_Esposito\\Ontologie\\brain_ontology.owl|

☑ Simplify Names

Tree Depth 2 ● Tree ○ Graph ☐ Transitive? ☐ Selected Roles (Roles Tab)? ● Horizontally ○ Vertically

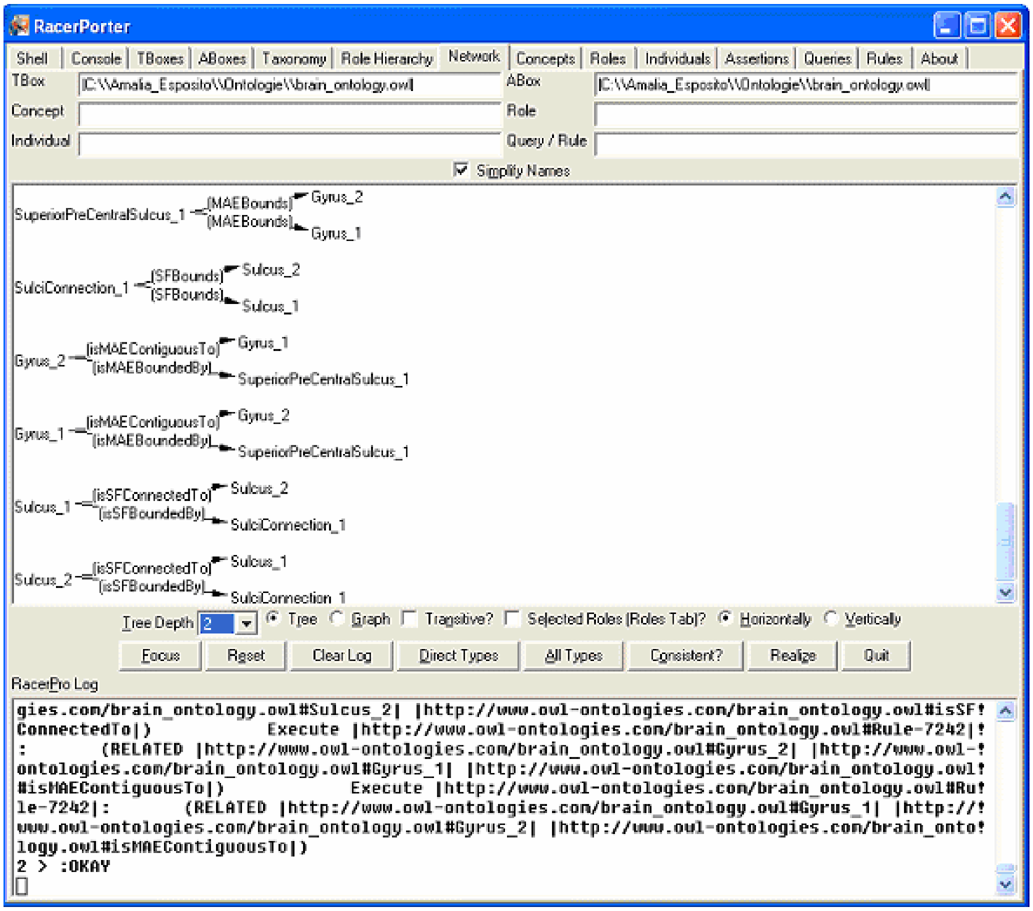
```
  isSFBoundedBy(?n1, ?s) <-
    SF(?n1), SF(?sn1), SF(?n0), SulciConnection(?s), isSFBoundedBy(?sn1, ?s), hasSegment(?n1!
, ?sn1), hasSegment(?n1, ?n0), noSFBounds(?s, ?n0), ?sn1 != ?n0
done.
1 > |C:\\Amalia_Esposito\\Ontologie\\brain_ontology.owl|
```

Figure 3 – Graphical display of the instances and their relations before rules applications

The result of the application of SWRL rules to the instances can be showed as a tree.

The figure 8 shows the new relations isMAEContiguousTo (Gyrus_1, Gyrus_2), isSFConnectedTo(Sulcus_1,Sulcus_2) and their symmetrics obtained by the applications of the rules :

- *SF(?n1) ∧ SF(?n2) ∧ SulciConnection(?s) ∧ SFBounds(?s, ?n1) ∧ SFBounds(?s, ?n2) ∧ differentFrom(?n1, ?n2) → isSFConnectedTo(?n1, ?n2)*
- *MAE(?m1) ∧ MAE(?m2) ∧ SF(?s) ∧ MAEBounds(?s, ?m1) ∧ MAEBounds(?s, ?m2) ∧ differentFrom(?m1, ?m2) → isMAEContiguousTo(?m1, ?m2)*



TBox C:\\Amalia_Esposito\\Ontologie\\brain_ontology.owl

ABox C:\\Amalia_Esposito\\Ontologie\\brain_ontology.owl

☑ Simplify Names

Tree Depth 2 ● Tree ○ Graph ☐ Transitive? ☐ Selected Roles (Roles Tab)? ● Horizontally ○ Vertically

RacerPro Log

```
gies.com/brain_ontology.owl#Sulcus_2| |http://www.owl-ontologies.com/brain_ontology.owl#isSF!
ConnectedTo|)           Execute |http://www.owl-ontologies.com/brain_ontology.owl#Rule-7242|!
:       (RELATED |http://www.owl-ontologies.com/brain_ontology.owl#Gyrus_2| |http://www.owl-!
ontologies.com/brain_ontology.owl#Gyrus_1| |http://www.owl-ontologies.com/brain_ontology.owl!
#isMAEContiguousTo|)            Execute |http://www.owl-ontologies.com/brain_ontology.owl#Ru!
le-7242|:       (RELATED |http://www.owl-ontologies.com/brain_ontology.owl#Gyrus_1| |http://!
www.owl-ontologies.com/brain_ontology.owl#Gyrus_2| |http://www.owl-ontologies.com/brain_onto!
logy.owl#isMAEContiguousTo|)
2 > :OKAY
```

Figure 4 – Graphical display of the instances and their relations after rules applications

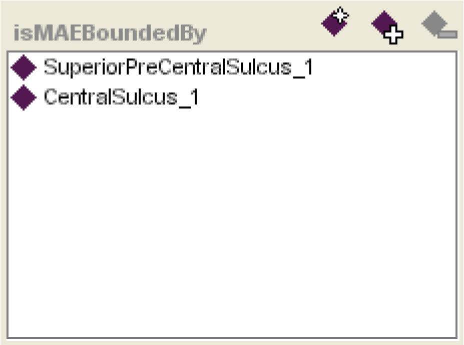
Obviously, introducing other instances, the application of all SWRL rules added to the ontology can be verified.

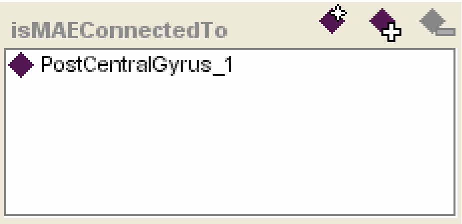
As just said, the aim of the work is labelling brain anatomical entities. Below it's showed how the reasoner can identify an instance of the class *Gyrus* as a *PreCentralGyrus*, using the information contained in ontology and rules.

Firstly the following instances of classes are defined :

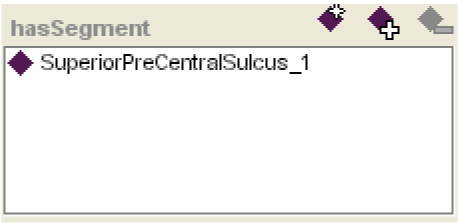
ISTANCE	CLASS
Gyrus_1	*Gyrus*
SuperiorPreCentralSulcus_1	*SuperiorPreCentralSulcus*
PreCentralSulcus_1	*PreCentralSulcus*
CentralSulcus_1	*CentralSulcus*
PostCentralGyrus_1	*PostCentralGyus*

For *Gyrus*_1 these things are imposed:

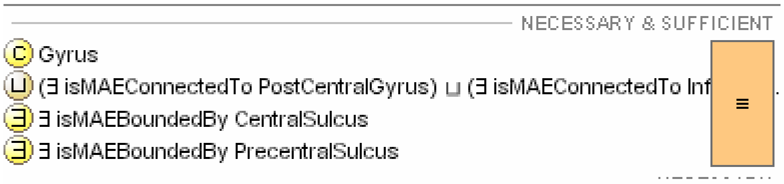

isMAEBoundedBy
- SuperiorPreCentralSulcus_1
- CentralSulcus_1


isMAEConnectedTo
- PostCentralGyrus_1

and for *PreCentralSulcus_1:*


hasSegment
- SuperiorPreCentralSulcus_1

Necessary and sufficient conditions of belonging to the class *PreCentralGyrus* are :


NECESSARY & SUFFICIENT

Gyrus
(∃ isMAEConnectedTo PostCentralGyrus) ⊔ (∃ isMAEConnectedTo Inf
∃ isMAEBoundedBy CentralSulcus
∃ isMAEBoundedBy PrecentralSulcus

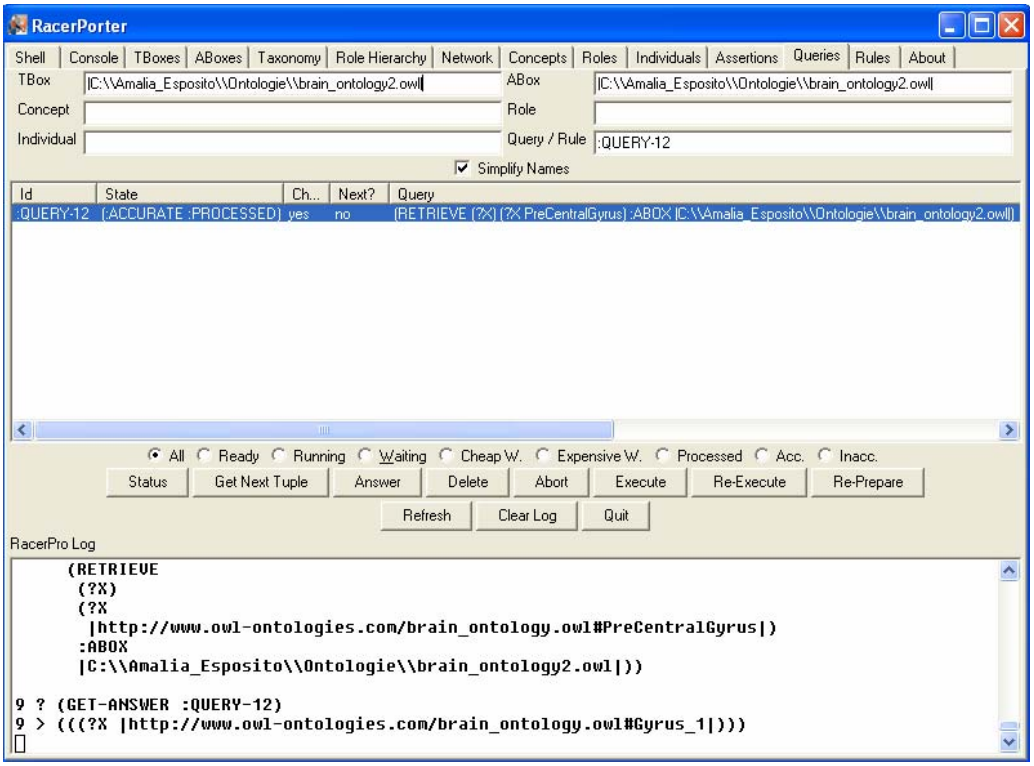
Reasoner cannot classify *Gyrus_1* as a *PreCentralGyrus* from the ontology knowledge alone, because a PrecentralGyrus must be bounded by a PreCentralSulcus too.

But *Gyrus_1* is bounded by *SuperiorPreCentralSulcus*_1, which is segment of *PreCentralSulcus_1,* so, from the application of the following rule :

MAE(?m) ∧ *SF(?ss)* ∧ *SF(?s)* ∧ *hasSegment(?s, ?ss)* ∧ *isMAEBoundedBy(?m, ?ss)* → *isMAEBoundedBy(?m, ?s)*

it's derived the *Gyrus_1* also bounded by *PreCentralSulcus_1*.

We have verified that *Gyrus_1* is really recognized as instance of the class *PreCentralGyrus* through a query, with which it's asked to the reasoner to find all instances of the class *PreCentralGyrus.*



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ABox |C:\\Amalia_Esposito\\Ontologie\\brain_ontology2.owl|
Concept
Role
Individual
Query / Rule :QUERY-12
☑ Simplify Names

Id	State	Ch...	Next?	Query
:QUERY-12	(:ACCURATE :PROCESSED)	yes	no	(RETRIEVE (?X) (?X PreCentralGyrus) :ABOX |C:\\Amalia_Esposito\\Ontologie\\brain_ontology2.owl|)

RacerPro Log

```
     (RETRIEVE
      (?X)
      (?X
       |http://www.owl-ontologies.com/brain_ontology.owl#PreCentralGyrus|)
      :ABOX
      |C:\\Amalia_Esposito\\Ontologie\\brain_ontology2.owl|))

9 ? (GET-ANSWER :QUERY-12)
9 > (((?X |http://www.owl-ontologies.com/brain_ontology.owl#Gyrus_1|)))
```

Figure 5 – Result of the query

Conclusion and perspectives

The overcoming of the present limits of OWL and SWRL languages, through reformulation of properties and rules, can allow to use an hybrid system, which integrates ontology and rules, as good support to the classification of human brain anatomical entities in neuroimaging sphere.

As perspectives, an improvement of the methods of brain anatomical entities classification is possible only after the development of image processing. Nowadays this development isn't still available but there are some studies about it.

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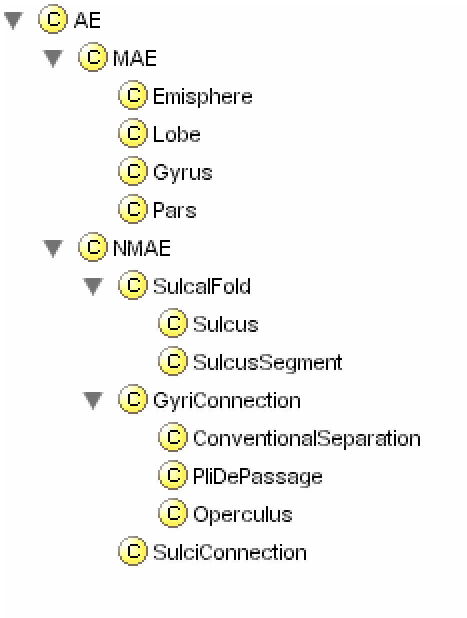
APPENDIX – Ontology and rules

In the following pages brain ontology created by O. DAmeron at IDM is showed.

CLASSES

Classes are brain anatomical entities organized in a hierarchy:



Root class of the tree is the primitive class *Anatomical Entity (AE)*, from which classes *Material Anatomical Entity (MAE -* brain anatomical entities made with matter, such as lobes and gyri), and *NonMaterialAnatomicalEntity (NMAE –* non material entities, such as sulci*)*, descend.
MAE includes subclasses that represent main material anatomical entities : *Hemisphere*, *Lobe*, *Gyrus*, *Pars. NMAE* includes *Sulcal Fold* (sulci that separate material entities) and G*iryConnection* (connections between gyri).
After introduction of the classes , the disjunctions among them are specified, so an object can't be an instance of more than one of the disjoint classes. For example TemporalLobe class is disjointed from *Frontal Lobe, Parietal Lobe, Limbic Lobe* e *Occipital Lobe*.

Material Entities

- Hemisphere
  - Frontal Lobe
    - PreCentralGyrus
    - Superior Pars of Precentral Gyrus
      - Inferior Pars of Precentral Gyrus
  - Superior Frontal Gyrus
    - Medial Pars of Superior Frontal Gyrus
    - Superior Pars of Superior Frontal Gyrus
    - Inferior Pars of Superior Frontal Gyrus
  - Intermediate Frontal Gyrus
    - Superior Pars of Intermediate Frontal Gyrus
    - Inferior Pars of Intermediate Frontal Gyrus
  - Inferior Frontal Gyrus
    - Orbital Pars of Inferior Frontal Gyrus
    - Triangular Pars of Inferior Frontal Gyrus
    - Opercular Pars of Inferior Frontal Gyrus
  - Gyrus Rectus
  - Medial Orbital Gyrus
  - Lateral Orbital Gyrus
  - Anterior Orbital Gyrus
  - Posterior Orbital Gyrus
  - Transverse Frontopolar Gyrus
    - Superior Pars of FrontoPolar Gyrus
    - Middle Pars of FrontoPolar Gyrus
    - Inferior Pars of FrontoPolar Gyrus
  - FrontoMarginal Gyrus
  - Parietal Lobe
    - Post Central Gyrus
      - Superior Pars of PostCentral Gyrus
      - Inferior Pars of PostCentral Gyrus
    - Superior Parietal Gyrus
    - Supramarginal Gyrus
    - Inferior Parietal Gyrus
    - Angular Gyrus
    - Precuneus
  - Temporal Lobe
  - Superior Temporal Gyrus
  - Intermediate Temporal Gyrus
  - Inferior Temporal Gyrus
  - Uncus
    - Temporal Pars of ParaHippocampal Gyrus
    - Temporal Pars of Lingual Gyrus
    - Temporal Pars of Fusiform Gyrus
  - Occipital Lobe
  - Superior Occipital Gyrus
    - Intermediate Occipital Gyrus
    - Inferior Occipital Gyrus
    - Cuneus
    - Occipital Pars of ParaHippocampal Gyrus
    - Occipital Pars of Lingual Gyrus
    - Occipital Pars of Fusiform Gyrus
  - Limbic Lobe
    - Limbic Gyrus
    - Cingulate Gyrus
      - Anterior Pars of Cingulate Gyrus
      - Posterior Pars of Cingulate Gyrus
    - Hippocampus
    - Dentate Gyrus

Non Material Entities

- Central Sulcus
- Precentral Sulcus
  - Inferior Precentral Sulcus
  - Superior Precentral Sulcus
- Superior Frontal Sulcus
- Intermediate Frontal Sulcus
- Inferior Frontal Sulcus
- Horizontal Ramus
- Ascendine Ramus
- Diagonal Sulcus
- Lateral Sulcus
- Superior Temporal Sulcus
- Inferior Temporal Sulcus
- Middle Temporal Sulcus
- PostCentral Sulcus
  - Inferior PostCentral Sulcus
  - Superior PostCentral Sulcus
- Olfactory Sulcus
- Orbital Sulcus
  - Transverse Orbital Sulcus
  - Lateral Longitudinal Orbital Ramus
  - Medial Longitudinal Orbital Ramus
- Callosal Sulcus
- Calcarine Sulcus
  - Anterior Calcarine Sulcus
  - Posterior Calcarine Sulcus
- Cingulate Sulcus
- Intraparietal Sulcus
- FrontoOrbital Sulcus
- FrontoMarginal Sulcus
- OccipitoTemporalSulcus
- Medial Frontal Sulcus
- Marginal Frontal Sulcus
- Marginal Precentral Sulcus
- Subparietal Sulcus
- Anterior subcentral Sulcus
- Triangularis Sulcus
- ParaCentral Sulcus
- Anterior Occipital Sulcus
- Occipital Sulcus
- Inferior Occipital Sulcus
- Parietal Occipital Sulcus
- Limbic Sulcus

PROPERTIES

In this ontology there are mereological properties (they express part-whole relations between anatomical entities), topological properties (they concern neighbourhood relations) and properties to express ternary relations.

MEREOLOGICAL PROPERTIES							
ProprERTY	**Dom.**	**Range**	**Inverse**	**Trans.**	**Sym.**	**Functional**	**Fun. inv.**
hasAnatomicalPart	MAE	MAE	isAnatomicalPartOf	yes	no	no	no
hasDirectAnatomicalPart	MAE	MAE	isDirectAnatomicalPartOf	no	no	no	yes
hasSegment	SF	SF	isSegmentOf	yes	no	no	no
hasDirectSegment	SF	SF	isDirectSegmentOf	no	no	no	yes

Table 1 – Mereological Properties

TOPOLOGICAL PROPERTIES							
Binary relations	**Dom.**	**Range**	**Inverse**	**Trans.**	**Sym.**	**Functional**	**Fun. inv.**
isMAEBoundedBy	MAE	(SF|GyriConnection)	MAEBounds	no	No	no	No
isSFBoundedBy	SF	SulciConnection	SFBounds	no	No	no	No
isInterruptedBy	SF	(PliDePassage|Operculus)	interrupts	no	No	no	No
isMAEConnectedTo	MAE	MAE	no	no	Yes	no	No
isSFConnectedTo	SF	SF	no	no	Yes	no	No
isMAEContiguousTo	MAE	MAE	no	no	Yes	no	No
isSFCountiguousTo	SF	SF	no	no	Yes	no	No

Table 2 – Topological Properties

Ternary Relations	Domain
Separates	AE*AE*AE
separatesSF	(Operculus|PliDePassage)*SF*SF
separatesMAE	SF*MAE*MAE
Connects	AE*AE*AE
connectsSF	SulciConnection*SF*SF
connectsMAE	GyriConnection*MAE*MAE

Table 3 – Ternary relations

RULES

Rules represent relationships between brain anatomical entities.

Irreflexiveness:

1) $p(x,x) \rightarrow \bot$

2) $p(x,y,y) \rightarrow \bot$

Symmetry:

3) $AE(x) \land AE(y) \land AE(z) \land \mathit{separates}(x,z,y) \rightarrow \mathit{separates}(x,y,z)$

4) $AE(x) \land AE(y) \land AE(z) \land \mathit{connects}(x,z,y) \rightarrow \mathit{connects}(x,y,z)$

Definition of ordinary predicates that are not ontology properties:

5) $MAE(m1) \land MAE(m2) \land MAE(s) \land \neg(\mathit{hasAnatomicalPart}(m1,s) \land \mathit{hasAnatomicalPart}(m2,s))$
$\land \neq (m1,m2) \rightarrow \mathit{hasNoCommonPart}(m1,m2)$

6) $MAE(m) \land SF(s) \land \neg(\mathit{hasAnatomicalPart}(m,sm1) \land \mathit{hasAnatomicalPart}(m,sm2)$
$\land \mathit{separatesMAE}(s,sm1,sm2)) \rightarrow \mathit{isNotContainedIn}(s,m)$

7) $MAE(m) \land \mathit{GyriConnection}(s) \land \neg(\mathit{hasAnatomicalPart}(m,sm1) \land \mathit{hasAnatomicalPart}(m,sm2)$
$\land \mathit{connectesMAE}(s,sm1,sm2)) \rightarrow \mathit{isNotContainedIn}(s,m)$

Rules about MAE separation:

8) $MAE(m1) \land MAE(m2) \land SF(s) \land \mathit{separatesMAE}(s,m1,m2) \rightarrow \mathit{isMAEBoundedBy}(m1,s)$

9) $MAE(m1) \land MAE(m2) \land SF(s) \land \mathit{separatesMAE}(s,m1,m2) \rightarrow \mathit{isMAEContiguousTo}(m1,m2)$

10) $MAE(m) \land SF(ss) \land SF(s) \land \mathit{hasSegment}(s,ss) \land \mathit{isMAEBoundedBy}(m,ss)$
$\rightarrow \mathit{isMAEBoundedBy}(m,s)$

11) $MAE(m)\ MAE(sm)\ (SF(s) \lor \mathit{gyriConnection}(s)) \land \mathit{isNotContainedIn}(s,m)$
$\land \mathit{hasAnatomicalPart}(m,sm) \land \mathit{isMAEBoundedBy}(sm,s) \rightarrow$
$\mathit{isMAEBoundedBy}(m,s)$

12) $MAE(m1) \land MAE(m2) \land MAE(sm2) \land SF(s) \land \mathit{isMAEBoundedBy}(m1,s)$
$\land \mathit{isMAEBoundedBy}(m2,s) \land \mathit{isMAEBoundedBy}(sm2,s) \land \mathit{isMAEContiguousTo}(m1,m2)$
$\land \mathit{hasAnatomicalPart}(m2,sm2) \rightarrow \mathit{isMAEContiguousTo}(m1,sm2)$

13) $MAE(m1) \land MAE(m2) \land MAE(sm2) \land \mathit{hasNoCommonParts}(m1,m2)$
$\land \mathit{hasAnatomicalPart}(m2,sm2) \land \mathit{isMAEContiguousTo}(m1,sm2)$
$\rightarrow \mathit{isMAEContiguousTo}(m1,m2)$

14) $MAE(m1) \land MAE(m2) \land MAE(sm2) \land SF(s) \land \mathit{hasAnatomicalPart}(m2,sm2)$
$\land \mathit{isMAEBoundedBy}(sm2,s) \land \mathit{separatesMAE}(s,m1,m2) \rightarrow \mathit{separatesMAE}(s,m1,sm2)$

15) $MAE(m1) \land MAE(m2) \land MAE(sm2) \land SF(s) \land \mathit{hasAnatomicalPart}(m2,sm2)$
$\land \mathit{hasNoCommonParts}(m1,m2) \land \mathit{separatesMAE}(s,m1,sm2) \rightarrow \mathit{separatesMAE}(s,m1,m2)$

16) $MAE(m1) \land MAE(m2) \land SF(s) \land SF(ss) \land \mathit{hasSegment}(s,ss)$
$\land \mathit{separatesMAE}(ss,m1,m2) \rightarrow \mathit{separatesMAE}(s,m1,m2)$

17) $MAE(m1) \land MAE(m2) \land SF(s) \land SF(ss) \land \mathit{hasSegment}(s,ss) \land \mathit{separatesMAE}(s,m1,m2)$
$\land \mathit{isMAEBoundedBy}(m1,ss) \land \mathit{isMAEBoundedBy}(m2,ss) \rightarrow \mathit{separatesMAE}(ss,m1,m2)$

Rules about SF Separation:

18) $(Operculus(s)\ \ V\ PliDePassage(s))\ \Lambda\ \ SF(n1)\ \Lambda\ SF(n2)\ \Lambda\ separatesSF(s,n1,n2)$
$\rightarrow\ \ isInterruptedBy(n1,s)$

19) $(Operculus(s)\ \ V\ PliDePassage(s))\ \Lambda\ \ SF(n1)\ \Lambda\ SF(n2)\ \Lambda\ separatesSF(s,n1,n2)$
$\rightarrow\ \ isSFContiguousTo(n1,n2)$

20) $(Operculus(s)\ \ V\ PliDePassage(s))\ \Lambda\ \ SF(n1)\ \Lambda\ SF(n2)\ \Lambda\ isInterruptedBy(n1,s)$
$\Lambda\ isInterruptedBy(n2,s)\ \ \rightarrow\ \ isSFContiguousTo(n1,n2)$

21) $(Operculus(s)\ \ V\ PliDePassage(s))\ \Lambda\ \ SF(n1)\ \Lambda\ SF(n2)\ \Lambda\ isInterruptedBy(n1,s)$
$\Lambda\ isInterruptedBy(n2,s)\ \ \rightarrow\ \ separatesSF(s,n1,n2)$

22) $(Operculus(s)\ \ V\ PliDePassage(s))\ \Lambda\ \ SF(n)\ \Lambda\ SF(sn)\ \Lambda\ isInterruptedBy(sn,s)$
$\Lambda\ hasSegment(n,sn)\ \Lambda\ \neg(hasSegment(n,n0)\ \Lambda\ separatesSF(s,sn,n0))$
$\rightarrow\ \ separatesSF(s,n1,n2)$

23) $(Operculus(s)\ \ V\ PliDePassage(s))\ \Lambda\ \ SF(n1)\ \Lambda\ SF(n2)\ \Lambda\ SF(sn1)\ \Lambda\ \ hasSegment(n1,sn1)$
$\Lambda\ \ \neg hasSegment(n1,n2)\ \Lambda\ separatesSF(s,sn1,n2))\ \ \rightarrow\ \ separatesSF(s,n1,n2)$

24) $(Operculus(s)\ \ V\ PliDePassage(s))\ \Lambda\ \ SF(n1)\ \Lambda\ SF(n2)\ \Lambda\ SF(sn1)\ \Lambda\ isInterruptedBy(sn1,s)$
$\Lambda\ hasSegment(n1,sn1)\ \Lambda\ \ separatesSF(s,n1,n2))\ \ \rightarrow\ \ separatesSF(s,sn1,n2)$

Rules about MAE Connection:

25) $MAE(m1)\ \Lambda\ MAE(m2)\ \Lambda\ GyriConnection(s)\ \Lambda\ connectsMAE(s,m1,m2)$
$\rightarrow\ \ isMAEBoundedBy(m1,s)$

26) $MAE(m1)\ \Lambda\ MAE(m2)\ \Lambda\ GyriConnection(s)\ \Lambda\ connectsMAE(s,m1,m2)$
$\rightarrow\ \ isMAEConnectedTo(m1,m2)$

27) $MAE(m1)\ \Lambda\ MAE(m2)\ \Lambda\ GyriConnection(s)\ \Lambda\ isMAEBoundedBy(m1,s)$
$\Lambda\ isMAEBoundedBy(m2,s) \rightarrow\ \ isMAEConnectedTo(m1,m2)$

28) $MAE(m1)\ \Lambda\ MAE(m2)\ \Lambda\ GyriConnection(s)\ \Lambda\ isMAEBoundedBy(m1,s)$
$\Lambda\ isMAEBoundedBy(m2,s) \rightarrow\ \ connectsMAE(s,m1,m2)$

29) $MAE(m1)\ \Lambda\ MAE(m2)\ \Lambda\ MAE(sm2)\ \Lambda\ GyriConnection(s)\ \Lambda\ hasNoCommonPart(m1,m2)$
$\Lambda\ hasAnatomicalPart(m2,sm2)\ \Lambda\ connectsMAE(s,m1,sm2) \rightarrow\ \ connectsMAE(s,m1,m2)$

30) $MAE(m1)\ \Lambda\ MAE(m2)\ \Lambda\ MAE(sm2)\ \Lambda\ hasNoCommonPart(m1,m2)$
$\Lambda\ hasAnatomicalPart(m2,sm2)\ \Lambda\ isMAEConnectedTo(m1,sm2)$
$\rightarrow\ \ isMAEConnectedTo(m1,m2)$

31) $MAE(m1)\ \Lambda\ MAE(m2)\ \Lambda\ MAE(sm2)\ \Lambda\ GyriConnection(s)\ \Lambda\ isMAEBoundedBy(sm2,s)$
$\Lambda\ hasAnatomicalPart(m2,sm2)\ \Lambda\ connectsMAE(s,m1,m2) \rightarrow\ \ connectsMAE(s,m1,sm2)$

32) $MAE(m1)\ \Lambda\ MAE(m2)\ \Lambda\ MAE(sm2)\ \Lambda\ GyriConnection(s)\ \Lambda\ isMAEBoundedBy(m1,s)$
$\Lambda\ isMAEBoundedBy(sm2,s)\ \Lambda\ hasAnatomicalPart(m2,sm2)\ \Lambda\ isMAEConnectedTo(m1,m2)$
$\rightarrow\ \ isMAEConnectedTo(m1,sm2)$

Rules about SF connection:

33) $SF(n1)\ \Lambda\ SF(n2)\ \Lambda\ sulciConnection(s)\ \Lambda\ connectsSF(s,n1,n2)$
$\rightarrow\ \ isSFBoundedBy(n1,s)$

34) $SF(n1)\ \Lambda\ SF(n2)\ \Lambda\ sulciConnection(s)\ \Lambda\ connectsSF(s,n1,n2)$
$\rightarrow\ \ isSFConnectedTo(n1,n2)$

35) $SF(n1)\ \Lambda\ SF(n2)\ \Lambda\ sulciConnection(s)\ \Lambda\ isSFBoundedBy(n1,s)\ \Lambda\ isSFBoundedBy(n2,s)$
$\rightarrow\ \ isSFConnectedTo(n1,n2)$

36) $SF(n1)\ \Lambda\ SF(n2)\ \Lambda\ sulciConnection(s)\ \Lambda\ isSFBoundedBy(n1,s)\ \Lambda\ isSFBoundedBy(n2,s)$
$\rightarrow\ \ connects(s,n1,n2)$

37) $SF(n1)\ \Lambda\ SF(sn1)\ \Lambda\ SF(n0)\ \Lambda\ sulciConnection(s)\ \Lambda\ isSFBoundedBy(sn1,s)\ \Lambda\ hasSegment(n1,sn1)$
$\Lambda\ \neg(hasSegment(n1,n0)\ \Lambda\ connectsSF(s,sn1,n0))\ \ \rightarrow\ \ isSFBoundedBy(n1,s)$

38) $SF(n1)\ \Lambda\ SF(n2)\ \Lambda\ SF(sn2)\ \Lambda\ sulciConnection(s)\ \Lambda\ \neg hasSegment(n2,n1)\ \Lambda\ hasSegment(n2,sn2)$
$\Lambda\ connectsSF(s,n1,sn2))\ \ \rightarrow\ \ connects(s,n1,n2)$

39) $SF(n1)\ \Lambda\ SF(n2)\ \Lambda\ SF(sn2)\ \Lambda\ \neg hasSegment(n2,n1)\ \Lambda\ hasSegment(n2,sn2)$
$\Lambda\ isSFConnectedTo(n1,sn2)\ \ \rightarrow\ \ isSFConnectedTo(n1,n2)$