W3C Workshop Rule Interoperability

Use Case

Interoperating between ontology and rules for identifying brain anatomical structures

Christine Golbreich\textsuperscript{1}, Olivier Bierlaire\textsuperscript{1,2}, Olivier Dameron\textsuperscript{3,2}, Bernard Gibaud\textsuperscript{2}

(1) Laboratoire d’Informatique Médicale University Rennes 1, France

(2) Laboratoire IDM, UPRES-EA 3192 Rennes, France

(3) SMI, Stanford University School of Medicine Stanford CA 94305, USA
Sharing and reuse

• Sharing anatomical knowledge
• Anatomy plays a central role in medicine
  – applications
    • Computer assisted interpretation of 3D MRI images
    • Decision support in (neuro)surgery
    • Intelligent data retrieval in the Semantic Web etc.
Hemispheres

- bounded by "Falx Cerebri"
Lobes

- bounded by sulci or lines
Gyri

- bounded by sulci
Pars

• bounded by sulcus segments
Connections

Conventional Separation

Pli de Passage

Operculus
Brain Anatomy Ontology

Labeling the gyri and sulci in MRI images
INTEROPERATING BETWEEN ONTOLOGY and RULES
Rule Base

• Dependencies between properties
  – Ontology properties
    • Mereological
    • Spatial
    • Mereological and spatial
  – Ontology and other domain properties
• Queries
Topological dependency

- If two entities have a common boundary, they are connected

\[
isConnectedTo(?x, ?y) \leftarrow
isBoundedBy(?x, ?z)
\land
isBoundedBy(?y, ?z)
\]

![Diagram showing entities x and y connected through a common boundary Z](image-url)
Propagation of connection along part-of

- If a part of a gyrus is connected to another gyrus, the two gyri are connected

\[
\text{isConnectedTo}(\text{x}, \text{y}) \leftarrow \\
\text{hasPart}(\text{x}, \text{z}) \\
\Lambda \text{ isConnectedTo}(\text{z}, \text{y})
\]
Other domain properties

- if there is a connection relation between entities, they are connected

\[
\text{isConnectedTo}(\?x, \?y) \leftarrow \\
\text{connectsMAE}(\?z, \?x, \?y)
\]

\[x\quad y\quad z\]
Query

• For given items $m_i$ of a region under study, find all the possible instances of anatomical entities $x_i$ they are part of?

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

• Answering queries with ontology and rules
Very simple example

- **Current facts**
  - `boundedBy (m1, fc0)`
  - `boundedBy (m1, cs0)`
  - `boundedBy (m1, pcs0)`
  - `connects (op, m2, pcg0)`
  - `falxCerebri (fc0)`
  - `centralSulcus (cs0)`
  - `preCentralSulcus (pcs0)`
  - `AE (op)`

- **Query**
  \[ Q(?x_1) :- AE (?x_1) \land hasPart (?x_1, m_1) \land hasPart (?x_1, m_2) \]
  all the possible instances of AE which \( m_1 \) and \( m_2 \) can be part of ?
(1) Rules

\[ \text{isBoundedBy}(\text{x, y}) \leftarrow \text{hasPart}(\text{x, z}) \land \text{isBoundedBy}(\text{z, y}) \]

\[ \text{isConnectedTo}(\text{x, y}) \leftarrow \text{hasPart}(\text{x, z}) \land \text{isConnectedTo}(\text{z, y}) \]

\[ \text{isConnectedTo}(\text{x, y}) \leftarrow \text{connects}(\text{z, x, y}) \]
Rules reasoning

(1) \(\text{isBoundedBy}(g_0, cs_0) \leftarrow \text{hasPart}(g_0, m1) \land \text{isBoundedBy}(m1, cs_0)\) 

... ... ...

(4) \(\text{isConnectedTo}(m2, pcg_0) \leftarrow \text{connects}(op, m2, pcg_0)\)
(2) Ontology

PreCentralGyrus ≡

- Gyrus
- $=1$ isBoundedBy FalxCerebri
- $=1$ isBoundedBy CentralSulcus
- $=1$ isBoundedBy PreCentralSulcus
- $=1$ isConnectedTo PostCentralGyrus

etc.
Ontology reasoning

(1) isBoundedBy \((g_0, cs_0)\)
(2) isBoundedBy \((g_0, fc_0)\)
(3) isBoundedBy \((g_0, pcs_0)\)
(4) isConnectedTo \((g_0, pcg_0)\)

\[ \Rightarrow g_0 \text{ instance of PreCentralGyrus} \]
Test Case

• Annexes
  – Ontology
  – Other domain relations
  – Rules
"Sharable" rule base

Rule 9: isMAEContiguousTo(m1,m2) ← separatesMAE(s,m1,m2) \( \Lambda \) MAE(m1) \( \Lambda \) MAE(m2) \( \Lambda \) SF(s)

//Propagation of MAE boundary (i.e. a first sulcal fold) to a second sulcal fold containing the first/
Rule 10: isMAEBoundedBy(m,s) ← isMAEBoundedBy(m,ss) \( \Lambda \) hasSegment(s,ss) \( \Lambda \) SF(s) \( \Lambda \) SF(ss) \( \Lambda \) MAE(m)

//Propagation of MAE boundary (with a first material entity) to a second material entity containing the first, only if the boundary is not contained in the second material entity/
Rule 11: isMAEBoundedBy(m,s) ← isMAEBoundedBy(m,ss) \( \Lambda \) hasAnatomicalPart(m,sm) \( \Lambda \) isNotContainedIn(s,m) \( \Lambda \) (SF(s) \( \vee \) gyriConnection(s)) \( \Lambda \) MAE(sm) \( \Lambda \) MAE(m)

//Propagation of contiguity to parts/
Rule 12: isMAEContiguousTo(m1,sm2) ← isMAEContiguousTo(m1,m2) \( \Lambda \) hasAnatomicalPart(m2,sm2) \( \Lambda \) isMAEBoundedBy(m1,s) \( \Lambda \) isMAEBoundedBy(m2,s) \( \Lambda \) isMAEBoundedBy(sm2,s) \( \Lambda \) MAE(m1) \( \Lambda \) MAE(m2) \( \Lambda \) MAE(sm2) \( \Lambda \) SF(s)

//Propagation of contiguity (to a first material entity) to a second material entity containing the first/
Rule 13: isMAEContiguousTo(m1,m2) ← isMAEContiguousTo(m1,sm2) \( \Lambda \) hasNoCommonParts(m1,m2) \( \Lambda \) MAE(m1) \( \Lambda \) MAE(m2) \( \Lambda \) MAE(sm2)

//Propagation of MAE separation to parts/
Rule 14: separatesMAE(s,m1,sm2) ← separatesMAE(s,m1,m2) \( \Lambda \) hasAnatomicalPart(m2,sm2) \( \Lambda \) isMAEBoundedBy(sm2,s) \( \Lambda \) SF(s) \( \Lambda \) MAE(m1) \( \Lambda \) MAE(m2) \( \Lambda \) MAE(sm2)

//Propagation of MAE separation (of a first material entity) to a second material entity containing the first/
Rule 15: separatesMAE(s,m1,m2) ← separatesMAE(s,m1,sm2) \( \Lambda \) hasNoCommonParts(m1,m2) \( \Lambda \) SF(s) \( \Lambda \) MAE(m1) \( \Lambda \) MAE(m2) \( \Lambda \) MAE(sm2)

//Propagation of MAE separation (i.e. a first sulcal fold) to a second sulcal fold containing the first/
Full Brain cortex anatomy ontology


Concepts list

- Hemisphere
  - Frontal Lobe
    - Orbital gyrus
    - Precentral gyrus
      - Superior parts of precentral gyrus
      - Inferior parts of precentral gyrus
    - Superior frontal gyrus
      - Medial parts of superior frontal gyrus
      - Inferior parts of superior frontal gyrus
    - Middle frontal gyrus
      - Superior parts of intermediate frontal gyrus
      - Inferior parts of intermediate frontal gyrus
    - Inferior frontal gyrus
      - Orbital parts of inferior frontal gyrus
      - Triangular parts of inferior frontal gyrus
      - Opercular parts of inferior frontal gyrus
    - Gyrus rectus
    - Medial orbital gyrus
    - Lateral orbital gyrus
    - Anterior orbital gyrus
    - Posterior orbital gyrus
    - Subcentral gyrus
    - Para-central lobule
    - Tranverse frontopolar gyrus
      - Superior parts of transverse rectus gyrus

Anatomical Composition

Direct anatomical parts
- Superior parts of precentral gyrus
- Inferior parts of precentral gyrus

Anatomical continuity
- Subcentral gyrus
- Para-central lobule
- Inferior frontal gyrus
- Superior frontal gyrus
- Opercular parts of inferior frontal gyrus
- Medial parts of superior frontal gyrus

Contiguous sulci
- Central sulcus
- Precentral sulcus
- Lateral sulcus
- Anterior subcentral sulcus
- Inferior precentral sulcus
- Superior precentral sulcus
Potential requirements

- **Ontology Web language**
  1. OWL DL expressiveness (or sublanguage)
  2. Extended by qualified cardinality constraints

- **Rule Web language**
  3. ontology concepts and roles in rule body and head as unary or binary predicates in atoms.
  4. “ordinary” domain relations, not ontology concept nor role, in body and head atoms.
  5. n-ary predicates in body and head atoms
  6. queries expressed by n-ary predicates
  7. “safe” rules, i.e. a variable that occurs in the head also occurs in the body
Candidate technologies

Any language extending OWL DL with rules

1. To represent all the knowledge described in the ontology and rule annexes, as naturally as possible

2. To **interoperate between rules and ontology** for reasoning

3. To indicate properties (decidability, completeness, correctness) that are guaranteed
Workshop Protégé With Rules, July 18th, Madrid

• In conjunction with the 8th International Protégé Conference
• Supported by the RuleML Initiative

www.med.univ-rennes1.fr/~cgolb/Protege2005/ProtegeWithRulesCFP.htm
FMA in OWL DL
• FMA, the Foundational Model of Anatomy
  – 70,000 concepts, over 110,000 terms;
  – over 1.5 million relations from 168 relationships