

Zhang S, Bodenreider O, Golbreich C.
Experience in reasoning with the Foundational Model of Anatomy in OWL DL.
In: Pacific Symposium on Biocomputing 2006; 2006. p. (submitted).
<http://mor.nlm.nih.gov/pubs/pdf/2006-psb-sz.pdf>

Supplementary material

Examples of FMA classes in OWL DL

Available online at:
mor.nlm.nih.gov/pubs/supp/2006-psb-sz/.

Converting slots of the FMA in Protégé into properties in OWL DL

The single-slot *HAS_MASS* is specified as type SYMBOL with allowed-values TRUE and FALSE. Moreover, this slot is introduced in two classes, *Material_physical_anatomical_entity* and *Non-material_physical_anatomical_entity*. The conversion is shown in Supp 1.

has_mass in CLIPS	has_mass in OWL DL
<pre>(defclass CLIPS_TOP_LEVEL_SLOT_CLASS (single-slot has_mass (type SYMBOL) (allowed-values FALSE TRUE) (cardinality 0 1)) ...) (defclass Material_Physical_anatomical_entity (single-slot has_mass...)) (defclass Non-material_Physical_anatomical_entity (single-slot has_mass ...))</pre>	<pre><owl:DatatypeProperty rdf:ID="has_mass"> <rdfs:domain> <owl:Class> <owl:unionOf rdf:parseType="Collection"> <owl:Class rdf:about="#Material_physical_anatomical_entity" /> <owl:Class rdf:about="#Non-material_physical_anatomical_entity" /> </owl:unionOf> </owl:Class> </rdfs:domain> <rdfs:range rdf:resource="http://www.w3.org/2001/XMLSchema#boolean" /> <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#FunctionalProperty" /> </owl:DatatypeProperty></pre>

Supp 1 – Converting slot *HAS_MASS* of the FMA into property in OWL D

The single-slot *DIMENSION* is specified as type SYMBOL with allowed-values 0-dimension, 1-dimension, 2-dimension and 3-dimension. The conversion is shown in Supp 2.

Dimension in CLIPS	dimension in OWL DL
<pre>(defclass CLIPS_TOP_LEVEL_SLOT_CLASS (single-slot dimension (type SYMBOL) (allowed-values 3-dimension 2-dimension 1-dimension 0-dimension) (cardinality 0 1)) ...) (defclass Physical_anatomical_entity (single-slot dimension...))</pre>	<pre><owl:ObjectProperty rdf:ID="dimension"> <rdfs:domain rdf:resource="#Physical_anatomical_entity" /> <rdfs:range> <owl:Class> <owl:oneOf rdf:parseType="Collection"> <owl:Thing rdf:about="#individual_1-dimension" /> <owl:Thing rdf:about="#individual_0-dimension" /> <owl:Thing rdf:about="#individual_2-dimension" /> <owl:Thing rdf:about="#individual_3-dimension" /> </owl:oneOf> </owl:Class> </rdfs:range> <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#FunctionalProperty" /> </owl:ObjectProperty></pre>

Supp 2 – Converting slot *DIMENSION* of the FMA into property in OWL DL

The multi-slot *CONSTITUTIONAL_PART_OF* is specified as type *SYMBOL* with allowed-parents *Physical_anatomical_entity*. Moreover, this slot has inverse-slot *CONSTITUTIONAL_PART*, and is introduced in classes *Anatomical_space*, *Body_substance* and *Anatomical_structure*. The conversion is shown in Supp 3.

constitutional_part_of in CLIPS	constitutional_part_of in OWL DL
<pre>(defclass CLIPS_TOP_LEVEL_SLOT_CLASS (multislot constitutional_part_of (type SYMBOL) (allowed-parents Physical_anatomical_entity) (inverse-slot constitutional_part)) ...)</pre> <pre>(defclass Anatomical_space (multi-slot constitutional_part_of...))</pre> <pre>(defclass Body_substance (multi-slot constitutional_part_of...))</pre> <pre>(defclass Anatomical_structure (multi-slot constitutional_part_of...))</pre>	<pre><owl:ObjectProperty rdf:ID="constitutional_part_of"> <owl:inverseOf rdf:resource="#constitutional_part" /> <rdfs:domain> <owl:Class> <owl:unionOf rdf:parseType="Collection"> <owl:Class rdf:about="#Anatomical_space" /> <owl:Class rdf:about="#Body_substance" /> <owl:Class rdf:about="#Anatomical_structure" /> </owl:unionOf> </owl:Class> </rdfs:domain> <rdfs:range rdf:resource="#Physical_anatomical_entity" /> </owl:ObjectProperty></pre>

Supp 3 – Converting slot *CONSTITUTIONAL_PART_OF* of the FMA into property in OWL DL

Slots typed *INSTANCE* are the attributed slots linking classes to instances in Protégé. As shown in Supp 4, *ATTRIBUTED_PART* is an attributed slot whose allowed values are instances of class *Part_of_relationship_value*.

Attributed_part in CLIPS	attributed_part in OWL DL
<pre>(defclass CLIPS_TOP_LEVEL_SLOT_CLASS (multislot attributed_part (type INSTANCE) (allowed-classes Part_of_relationship_value)) ...)</pre> <pre>(defclass Anatomical_structure (multi-slot attributed_part...))</pre>	<pre><owl:ObjectProperty rdf:ID="attributed_part"> <rdfs:domain rdf:resource="#Anatomical_structure" /> <rdfs:range rdf:resource="#Part_of_relationship_value" /> </owl:ObjectProperty></pre>

Supp 4 – Converting slot *ATTRIBUTED_PART* of the FMA into property in OWL DL

Generating individuals in OWL DL

Based on the slot *DIMENSION* presented earlier, individuals¹ are generated under `owl:Thing` as shown in Supp 5.

```
<owl:Thing rdf:ID="individual_0-dimension" />  
<owl:Thing rdf:ID="individual_1-dimension" />  
<owl:Thing rdf:ID="individual_2-dimension" />  
<owl:Thing rdf:ID="individual_3-dimension" />
```

Supp 5 – Generating individuals in OWL DL

¹ Individuals are prefixed by “individual_”, because some allowed-values of slots share names with classes in the FMA in Protégé, such as *Inferior* and *Liquid*.

Converting classes of the FMA in Protégé into classes in OWL DL

As shown in Supp 6, the metaclass and instance definitions of class *Integument_of_abdomen*, are merged into OWL DL.

Integument_of_abdomen in CLIPS	Integument_of_abdomen in OWL DL
<p>Metaclass definition:</p> <pre>(defclass Integument_of_abdomen (is-a integument_of_body_part_subdivision))</pre> <p>Instance definition:</p> <pre>(([Integument_of_abdomen] of Anatomical_structure (dimension 3-dimension) (constitutional_part_of Abdominal_wall)) ...)</pre>	<pre><owl:Class rdf:ID="Integument_of_abdomen"> <rdfs:subClassOf rdf:resource="#Integument_of_body_part_subdivision" /> <rdfs:subClassOf rdf:resource="#Anatomical_structure" /> <rdfs:subClassOf> <owl:Restriction> <owl:onProperty rdf:resource="#dimension" /> <owl:hasValue rdf:resource="#individual_d3-dimension" /> </owl:Restriction> </rdfs:subClassOf> <rdfs:subClassOf> <owl:Restriction> <owl:onProperty rdf:resource="#constitutional_part_of" /> <owl:someValuesFrom rdf:resource="#Abdominal_wall" /> </owl:Restriction> </rdfs:subClassOf> </owl:Class></pre>

Supp 6 – Converting class *Integument_of_abdomen* of the FMA into class in OWL DL

Few classes have two direct superclasses. Such classes (e.g., *Physical_anatomical_entity* is-a *Anatomical_entity_template* and *Physical_anatomical_entity* is-a *Anatomical_entity*) in CLIPS are converted into two `subClassOf` axioms as shown in Supp 7.

<pre><owl:Class rdf:ID="Physical_anatomical_entity"> <rdfs:subClassOf rdf:resource="#Anatomical_entity_template" /> <rdfs:subClassOf rdf:resource="#Anatomical_entity" /> </owl:Class></pre>

Supp 7 – Converting classes with two direct superclasses into OWL DL

The class *Body_substance* has slots *CONTAINED_IN* (with allowed-parents) and *HAS_INHERENT_3-D_SHAPE* (with allowed-values and a concrete value specification) introduced in its metaclass definition, the conversion shown in Supp 8.

Body_substance in CLIPS	Body_substance in OWL DL
<pre> Metaclass definition: (defclass Body_substance ... (multi-slot contained_in (type SYMBOL) (allowed-parents Anatomical_space)) (single-slot has_inherent_3-D_shape (type SYMBOL) (allowed-values FALSE TRUE) (value FALSE)) ...) </pre>	<pre> <owl:Class rdf:ID="Body_substance"> <rdfs:subClassOf> <owl:Restriction> <owl:onProperty rdf:resource="#contained_in" /> <owl:allValuesFrom rdf:resource="#Anatomical_space" /> </owl:Restriction> </rdfs:subClassOf> <rdfs:subClassOf> <owl:Restriction> <owl:onProperty rdf:resource="#has_inherent_3-D_shape" /> <owl:hasValue rdf:datatype="http://www.w3.org/2001/XMLSchema#boolean">false</owl:hasValue> </owl:Restriction> </rdfs:subClassOf> ... </owl:Class> </pre>

Supp 8 – Converting class *Body_substance* of the FMA into class in OWL DL

The class *Esophagus* has attributed slot *ATTRIBUTED_PART* and one of the values for this slot is the instance *fm-live_10718*², for which a nested class is generated in OWL, as shown in Supp 9. We constructed such nested classes following the same conversion rules for classes.

Esophagus in CLIPS	Esophagus in OWL DL
<p>Instance definition:</p> <pre>((Esophagus) (attributed_part [fm-live_10718] [fm-live_10719] ...) ...)</pre> <p>Instance definition of instance fm-live_10718:</p> <pre>([fm-live_10718] of Organ_subdivision_part_of_relationship_value (related_part Wall_of_esophagus) (anatomical_arbitrary Anatomical) (partition Partition_1) (shared_unshared Unshared))</pre>	<pre><owl:Class rdf:ID="Esophagus"> <rdfs:subClassOf> <owl:Restriction> <owl:onProperty rdf:resource="#attributed_part" /> <owl:someValuesFrom> <owl:Class rdf:ID="fm-live_10718"> <!--nested class for instance [fm-live_10718]--> <rdfs:subClassOf rdf:resource="#Organ_subdivision_part_of_relationship_value" /> <rdfs:subClassOf> <owl:Restriction> <owl:onProperty rdf:resource="#related_part" /> <owl:someValuesFrom rdf:resource="#Wall_of_esophagus" /> </owl:Restriction> </rdfs:subClassOf> <rdfs:subClassOf> <owl:Restriction> <owl:onProperty rdf:resource="#anatomical_arbitrary" /> <owl:hasValue rdf:resource="#individual_Anatomical" /> </owl:Restriction> </rdfs:subClassOf> </owl:Class> <!-- end of nested class for instance [fm-live_10718] --> </owl:someValuesFrom> </owl:Restriction> </rdfs:subClassOf> </owl:Class></pre>

Supp 9 – Converting class *Esophagus* of the FMA into class in OWL DL

² Note that instances in Protégé are composed of two groups, one is classes modeled both as instances and metaclasses such as *Esophagus*, and the other is “pure” instances without meaningful names such as *fm-live_10718*.

Defining classes in OWL DL by necessary and sufficient conditions

The class `Cell` is defined as shown in Supp 10, with its taxonomic relation and all constitutional parts in one necessary and sufficient condition. The shadowed part in Supp 10 corresponds to the necessary conditions of `Cell` (global axioms).

Cell in CLIPS	Cell in OWL DL
<p>Metaclass definition:</p> <pre>(defclass Cell (is-a Anatomical_structure) ...)</pre>	<pre><owl:Class rdf:ID="Cell"> <owl:equivalentClass> <owl:Class> <owl:intersectionOf rdf:parseType="Collection"> <owl:Class rdf:about="#Anatomical_structure" /> <owl:Restriction> <owl:onProperty rdf:resource="#constitutional_part" /> <owl:someValuesFrom rdf:resource="#Plasma_membrane" /> </owl:Restriction> <owl:Restriction> <owl:onProperty rdf:resource="#constitutional_part" /> <owl:someValuesFrom rdf:resource="#Cytoplasm" /> </owl:Restriction> <owl:Restriction> <owl:onProperty rdf:resource="#constitutional_part" /> <owl:someValuesFrom rdf:resource="#Cell_nucleus" /> </owl:Restriction> <owl:Restriction> <owl:intersectionOf> <owl:Class> <owl:equivalentClass> <rdfs:subClassOf> <owl:Restriction> <owl:onProperty rdf:resource="#bounded_by" /> <owl:someValuesFrom rdf:resource="#Surface_of_cell" /> </owl:Restriction> </rdfs:subClassOf> </owl:Class> </owl:Class></pre>
<p>Instance definition:</p> <pre>((Cell) of Anatomical_structure (constitutional_part Plasma_membrane Cytoplasm Cell_nucleus) (bounded_by Surface_of_cell) (has_boundary TRUE) (has_physical_state Solid) (part_of Tissue Body_substance) (regional_part Apical_part_of_cell Basal_part_of_cell) ...)</pre>	

Supp 10 – Defining class `Cell` in OWL DL

Designating annotation properties in OWL DL

We manually designate slots of the FMA to become annotation properties in OWL DL, including *UWDAID* (typed STRING in Protégé) and *PREFERRED_NAME* (typed INSTANCE), shown in Supp 11.

```
<owl:AnnotationProperty rdf:ID="UWDAID" />
<owl:AnnotationProperty rdf:ID="Preferred_name" />
```

Supp 11 – Designating annotation properties in OWL DL

For INSTANCE typed slots such as *PREFERRED_NAME* whose value is an instance in Protégé, we wrap all the slot values in the instance into one data literal as annotation value in OWL DL, as shown in Supp 12.

Body_substance in CLIPS	Body_substance in OWL DL
<p>Instance definition: ([Body_substance] of Material_physical_anatomical_entity (UWDAID "9669") (Preferred_name [KB_INSTANCE_08389])...)</p> <p>Instance definition of instance KB_INSTANCE_08389: (([KB_INSTANCE_08389] of Concept_name (author "JOSE MEJINO, MD") (authority "Cornelius Rosse") (modification "Dec 20 1996 1:00:46:193PM") (name "Body substance")))</p>	<pre><owl:Class rdf:ID="Body_substance"> <UWDAID> 9669 </UWDAID> <Preferred_name>author("JOSE_MEJINO_MD") authority("Cornelius_Rosse") modification("Dec_20_1996__10046193PM") name("Body_substance") </Preferred_name> <!-- from [KB_INSTANCE_08389] --> </owl:Class></pre>

Supp 12 – Annotation properties and values in class Body_substance in OWL DL