

## Fixing reasoning (EL) in the FMA

### Introduction:

The following document is a record of issues found in and changes made to FMA version 5.0.0, to make the model coherent (have no unsatisfiable classes). Note that this effort did not include model extension. For example, if an existential axiom referred to a class not in the property range, and there was no obvious replacement class, I did not create one. Instead, the violating restriction was removed.

I attempted to remove as little deliberate modeling as possible. In many cases I was able to make an obvious substitution, in a problematic restriction, rather than delete it. My background is in computer science, not medicine. I attempted to avoid making any decisions that would require in-depth anatomical knowledge.

### Initial state (version 5.0.0):

Query (class expression)
owl:Nothing
<input type="button" value="Execute"/> <input type="button" value="Add to ontology"/>
Query results
Equivalent classes (69152 of 69152)
<ul style="list-style-type: none"><li>● 2-cell conceptus</li><li>● 4-cell conceptus</li><li>● 8-cell conceptus</li></ul>

69152 unsatisfiable classes (equivalent to owl:Nothing).

### Issue #1: range of 'derives from' object property.

Explanation for: '2-cell conceptus' EquivalentTo owl:Nothing

- '2-cell conceptus' SubClassOf 'transforms into' some '4-cell conceptus'
- '4-cell conceptus' SubClassOf 'has developmental stage' some 'Carnegie stage 2'
- 'Carnegie stage 2' SubClassOf 'developmental stage of' some Morula
- Morula SubClassOf 'transforms from' some '8-cell conceptus'
- '8-cell conceptus' SubClassOf 'has developmental stage' some 'Carnegie stage 3'
- 'Carnegie stage 3' SubClassOf 'developmental stage of' some 'Early blastocyst'
- 'Early blastocyst' SubClassOf 'attributed development' some (('development type' some 'Gestational transformation') and ('related developmental entity' some 'Late blastocyst'))
- 'Late blastocyst' SubClassOf Blastocyst
- Blastocyst SubClassOf 'constitutional part' some 'Amniotic cavity'
- 'Amniotic cavity' SubClassOf 'constitutional part of' some 'Amniotic sac'
- 'Amniotic sac' SubClassOf 'constitutional part' some Amnion
- Amnion SubClassOf 'derives from' some Epiblast
- 'derives from' Range 'Developmental structure'
- 'Developmental structure' SubClassOf 'Anatomical structure'
- 'derives from' Range 'Set of developmental entities'
- 'Set of developmental entities' SubClassOf 'Anatomical set'

DisjointClasses: 'Anatomical structure', 'Anatomical set', 'Portion of body substance'

Although the above is an explanation for why '2-cell conceptus' is unsatisfiable, it actually stems from the fact that it is existentially connected (indirectly) to 'Amnion'. An Amnion, as constructed must be connected to something (some object) via the "derives from" relationship. That object must be both an "Anatomical structure" and an "Anatomical set", by the range restrictions on "derives from". Since those two classes are, by definition,

disjoint, there can be no such object.

The first fix, then, is to change the range of derives from to be 'Developmental structure' \*OR\* 'Set of developmental entities'.

That alone did not seem to resolve any unsatisfiable classes:

Query (class expression)

owl:Nothing

Execute Add to ontology

Query results

Equivalent classes (69152 of 69152)

- 2-cell conceptus
- 4-cell conceptus
- 8-cell conceptus

## Issue #2: Deprecated terms

Explanation for: 'Surface of brain' EquivalentTo owl:Nothing

'Surface of brain' SubClassOf bounds some 'Lobule of cerebral hemisphere'

'Lobule of cerebral hemisphere' SubClassOf 'bounded by' some 'Surface of brain'

'bounded by' Domain 'Physical anatomical entity'

'Physical anatomical entity' SubClassOf 'Anatomical entity'

'Lobule of cerebral hemisphere' SubClassOf 'Deprecated term'

DisjointClasses: 'Deprecated term', 'Temporal entity', 'Spatial association value', 'Anatomical entity', 'FMA attribute entity', 'Anatomical transformation entity'

The issue here is that there was an attempt to deprecate classes by dragging them into the "Deprecated term" hierarchy, and removing existential restrictions to the class being deprecate from non-deprecated classes. However, to keep their original definitions, their relationships (including existential restrictions) were kept intact.

The issue arises from the properties used in those definitions. Many have domain and range constraints. So, if the newly deprecated class has existential property restrictions in its definition, then it must fit the domain of these properties. Many are still "Physical anatomical entity", etc. which are also stated to be disjoint from "Deprecated term". The latter is said to be disjoint from these other branches of the hierarchy:

Disjoint With +

- 'Temporal entity', 'FMA attribute entity', 'Anatomical transformation entity', 'Spatial association value', 'Anatomical entity'

The easiest "fix" in this case, it to remove the assertion that "deprecated term" should be disjoint from these other parts of the hierarchy. Now, perhaps some of those disjointness assertion could have remained, but as a quick way to "relax" the model, I removed them all (but left their disjointness axioms to each other).

This fix brought the number of satisfiable classes down by about 14:

Query (class expression)

owl:Nothing

Execute

Add to ontology

Query results

Equivalent classes (69138 of 69138)

- 2-cell conceptus
- 4-cell conceptus
- 8-cell conceptus

While these early fixes may seem minor, based on the unsatisfiable class count metric, when there are multiple contributing issues, it is always the last fix that seem the most significant (based on sudden drops in the count). However, they all need to be fixed and that impression of significance is often simply a factor of the order that the problems are addressed. Also, when one class is unsatisfiable, any class that is connected to it by existential restrictions (often indirectly) is also unsatisfiable. Fixing any one class often depends on fixing many others.

### Issue #3: Range of "receives input from"

Explanation for: 'Ventral tegmental area' EquivalentTo owl:Nothing

'Ventral tegmental area' SubClassOf 'sends output to' some 'Reuniens nucleus'

'Reuniens nucleus' SubClassOf 'receives input from' some 'Septal nuclear complex'

'receives input from' Range 'Postnatal anatomical structure'

'Postnatal anatomical structure' SubClassOf 'Anatomical structure'

'Septal nuclear complex' SubClassOf 'Set of nuclei of neuraxis'

'Set of nuclei of neuraxis' SubClassOf 'Set of neuraxis structures'

'Set of neuraxis structures' SubClassOf 'Set of cell parts'

'Set of cell parts' SubClassOf 'Anatomical set'

DisjointClasses: 'Anatomical structure', 'Anatomical set', 'Portion of body substance'

The issue stems from the fact that, for "Reuniens nucleus", values for "receives input from" must come from "Septal nuclear complex". "Septal nuclear complex" is an "Anatomical set". But the range of "receives input from" is "Postnatal anatomical structure" (which is\_a "Anatomical structure"). Since Anatomical structure and Anatomical set are disjoint (e.g. nothing can belong to both classes), no value is possible.

Fixing this issue might have benefitted from the input of an anatomist. The fix I made was to adjust the range of 'receives input from' to allow the value 'Septal nuclear complex'. But an anatomist might have said that the issue was not the range but the existential restriction involving 'Septal nuclear context'. The change that I made was to include "Anatomical set" in the range (via a logical OR):

Ranges (intersection) +

● 'Anatomical set' or 'Postnatal anatomical structure'

This fix did not change the unsatisfiable class count.

## Issue #4: Non-spaces where only spaces are allowed

Explanation for: 'Left kidney' EquivalentTo owl:Nothing

```
'Left kidney' SubClassOf 'lymphatic drainage' some 'Left lateral aortic lymphatic chain'
'Left lateral aortic lymphatic chain' SubClassOf 'lymphatic drainage of' some 'Left testis'
'Left testis' SubClassOf 'contained in' some 'Left scrotal sac'
'contained in' Range 'Anatomical space'
'Anatomical space' SubClassOf 'Immaterial anatomical entity'
'Left scrotal sac' SubClassOf 'Scrotal sac'
'Scrotal sac' SubClassOf 'Anatomical compartment'
'Anatomical compartment' SubClassOf 'Anatomical cluster'
'Anatomical cluster' SubClassOf 'Postnatal anatomical structure'
'Postnatal anatomical structure' SubClassOf 'Anatomical structure'
'Anatomical structure' SubClassOf 'Material anatomical entity'
'Immaterial anatomical entity' DisjointWith 'Material anatomical entity'
```

In the FMA there is a rule that "contains" only holds between spaces and their content (and vice versa for "contained in"). The assertion

'Left testis' subClassOf 'contained in' some 'Left scrotal sac'

is incorrect (per FMA rules). The 'Left scrotal sac' is modeled as an 'Anatomical compartment', which includes non-spatial parts (parts with mass). The correct fix would be to create a class like 'Cavity of left scrotal sac' that is a part of the sac, and then change the above assertion to:

'Left testis' subClassOf 'contained in' some 'Space of left scrotal sac'

But that would require creating new entities and modeling the rest of the properties around these new entities. It was not my intent to create any new classes or otherwise extend the property network, in this effort. I sought only to remove/alter axioms as needed to make the ontology consistent under EL reasoning.

Table 1 shows other similar violation of the FMA rules around contains and spaces. The "old container" is the non-space that is causing the issue. The "new container" is the space that should be used (if I could determine an obvious suitable value). For each violation, the following changes were required:

1. remove the existing axiom (if found) involving the 'fma:contains' property from the old container to the contained.
2. remove the existing axiom (if found) involving the 'fma:contained\_in' property from the contained to the old container.
3. add a new axiom (if not already present) involving the 'fma:contains' property from the new container to the contained.
4. add a new axiom (if not already present) involving the 'fma:contained\_in' property from the contained to the new container.

Table 1: Contains/Contained\_in relations that violate the FMA space rule.

contained	old container	new container	notes
Left testis	Left scrotal sac		
Right testis	Right scrotal sac		
Geniohyoid	Submental triangle	Space of submental triangle	
Mylohyoid	Submental triangle	Space of submental triangle	
Sternohyoid	Muscular triangle	Space of muscular triangle	
Sternothyroid	Muscular triangle	Space of muscular triangle	
Thyrohyoid	Muscular triangle	Space of muscular triangle	
Thyroid cartilage	Muscular triangle	Space of muscular triangle	
Vastus medialis branch of femoral nerve	Adductor canal	Space of adductor canal	
Saphenous nerve	Adductor canal	Space of adductor canal	
Sternocleidomastoid	Sternocleidomastoid region	Space of sternocleidomastoid region	
T1 segment of esophagus	Superior mediastinum	Superior mediastinal space	
T2 segment of esophagus	Superior mediastinum	Superior mediastinal space	
T3 segment of esophagus	Superior mediastinum	Superior mediastinal space	
T4 segment of esophagus	Superior mediastinum	Superior mediastinal space	
Prostatic fluid	Duct of main gland of prostate	Lumen of main prostatic duct	
Left femoral artery	Left adductor canal	Space of left adductor canal	
Left femoral vein	Left adductor canal	Space of left adductor canal	
Left saphenous nerve	Left adductor canal	Space of left adductor canal	
Vastus medialis branch of left femoral nerve	Left adductor canal	Space of left adductor canal	
Left sternohyoid	Left muscular triangle	Space of left muscular triangle	
Left sternothyroid	Left muscular triangle	Space of left muscular triangle	
Left thyrohyoid	Left muscular triangle	Space of left muscular triangle	
Left adrenal gland	Left side of retroperitoneal compartment	Space of left side of retroperitoneal compartment	
Left kidney	Left side of retroperitoneal compartment	Space of left side of retroperitoneal compartment	
Left hyoglossus	Left submandibular triangle	Space of left submandibular triangle	
Left mylohyoid	Left submandibular triangle	Space of left submandibular triangle	
Left submandibular gland	Left submandibular triangle	Space of left submandibular triangle	
Prostatic fluid	Lobular duct of prostate	Lumen of lobular duct of prostate	
Blood in systemic venous tree(subdivision)	Lumen of systemic venous tree(subdivision)		General anatomical term
Pericardial sac	Middle mediastinum	Middle mediastinal space	
T5 segment of esophagus	Posterior mediastinum	Posterior mediastinal space	
T6 segment of esophagus	Posterior mediastinum	Posterior mediastinal space	
T7 segment of esophagus	Posterior mediastinum	Posterior mediastinal space	
T8 segment of esophagus	Posterior mediastinum	Posterior mediastinal space	
T9 segment of esophagus	Posterior mediastinum	Posterior mediastinal space	
Thoracic part of trunk of left vagus nerve	Posterior mediastinum	Posterior mediastinal space	
Thoracic part of trunk of right vagus nerve	Posterior mediastinum	Posterior mediastinal space	
Right femoral artery	Right adductor canal	Space of right adductor canal	
Right femoral vein	Right adductor canal	Space of right adductor canal	
Right saphenous nerve	Right adductor canal	Space of right adductor canal	
Vastus medialis branch of right femoral nerve	Right adductor canal	Space of right adductor canal	
Right sternohyoid	Right muscular triangle	Space of right muscular triangle	
Right sternothyroid	Right muscular triangle	Space of right muscular triangle	
Right thyrohyoid	Right muscular triangle	Space of right muscular triangle	
Right adrenal gland	Right side of retroperitoneal compartment	Space of right side of retroperitoneal compartment	
Right kidney	Right side of retroperitoneal compartment	Space of right side of retroperitoneal compartment	
Right hyoglossus	Right submandibular triangle	Space of right submandibular triangle	
Right mylohyoid	Right submandibular triangle	Space of right submandibular triangle	
Right submandibular gland	Right submandibular triangle	Space of right submandibular triangle	
Hyoglossus	Submandibular triangle	Space of submandibular triangle	
Mylohyoid	Submandibular triangle	Space of submandibular triangle	Are space of submandibular triangle and space of submental triangle both correct?

For each row I also recorded which of the 4 changes were actually required (for a removal, was the axiom present, for an add, was it not yet present) via a 1 (yes) or a 0 (no). For most rows that meant a 4 digit value such as "1100". However, for rows where no other class was identified as a valid "new container" (no new classes were created), only removals were attempted and thus only 2-digit status strings were recorded (e.g. "11"). This serves as a record of changes made, but also info for anyone who might attempt a more thorough remodel in the future. Here are those results:

contained,old container,new container,status

"Left testis","Left scrotal sac","",11

"Right testis","Right scrotal sac","",11

"Geniohyoid","Submental triangle","Space of submental triangle",1100

"Mylohyoid","Submental triangle","Space of submental triangle",1100

"Sternohyoid", "Muscular triangle", "Space of muscular triangle", 1100  
 "Sternothyroid", "Muscular triangle", "Space of muscular triangle", 1100  
 "Thyrohyoid", "Muscular triangle", "Space of muscular triangle", 1100  
 "Thyroid cartilage", "Muscular triangle", "Space of muscular triangle", 1111  
 "Vastus medialis branch of femoral nerve", "Adductor canal", "Space of adductor canal", 1111  
 "Saphenous nerve", "Adductor canal", "Space of adductor canal", 1111  
 "Sternocleidomastoid", "Sternocleidomastoid region", "Space of sternocleidomastoid region", 1111  
 "T1 segment of esophagus", "Superior mediastinum", "Superior mediastinal space", 1111  
 "T2 segment of esophagus", "Superior mediastinum", "Superior mediastinal space", 1111  
 "T3 segment of esophagus", "Superior mediastinum", "Superior mediastinal space", 1111  
 "T4 segment of esophagus", "Superior mediastinum", "Superior mediastinal space", 1111  
 "Prostatic fluid", "Duct of main gland of prostate", "Lumen of main prostatic duct", 1100  
 "Left femoral artery", "Left adductor canal", "Space of left adductor canal", 1111  
 "Left femoral vein", "Left adductor canal", "Space of left adductor canal", 1111  
 "Left saphenous nerve", "Left adductor canal", "Space of left adductor canal", 1111  
 "Vastus medialis branch of left femoral nerve", "Left adductor canal", "Space of left adductor canal", 1111  
 "Left sternohyoid", "Left muscular triangle", "Space of left muscular triangle", 1100  
 "Left sternothyroid", "Left muscular triangle", "Space of left muscular triangle", 1100  
 "Left thyrohyoid", "Left muscular triangle", "Space of left muscular triangle", 1100  
 "Left adrenal gland", "Left side of retroperitoneal compartment", "Space of left side of retroperitoneal compartment", 1100  
 "Left kidney", "Left side of retroperitoneal compartment", "Space of left side of retroperitoneal compartment", 1111  
 "Left hyoglossus", "Left submandibular triangle", "Space of left submandibular triangle", 1100  
 "Left mylohyoid", "Left submandibular triangle", "Space of left submandibular triangle", 1100  
 "Left submandibular gland", "Left submandibular triangle", "Space of left submandibular triangle", 1111  
 "Prostatic fluid", "Lobular duct of prostate", "Lumen of lobular duct of prostate", 1100  
 "Blood in systemic venous tree(subdivision)", "Lumen of systemic venous tree(subdivision)", "", 11  
 "Pericardial sac", "Middle mediastinum", "Middle mediastinal space", 1111  
 "T5 segment of esophagus", "Posterior mediastinum", "Posterior mediastinal space", 1111  
 "T6 segment of esophagus", "Posterior mediastinum", "Posterior mediastinal space", 1111  
 "T7 segment of esophagus", "Posterior mediastinum", "Posterior mediastinal space", 1111  
 "T8 segment of esophagus", "Posterior mediastinum", "Posterior mediastinal space", 1111  
 "T9 segment of esophagus", "Posterior mediastinum", "Posterior mediastinal space", 1111  
 "Thoracic part of trunk of left vagus nerve", "Posterior mediastinum", "Posterior mediastinal space", 1111  
 "Thoracic part of trunk of right vagus nerve", "Posterior mediastinum", "Posterior mediastinal space", 1111  
 "Right femoral artery", "Right adductor canal", "Space of right adductor canal", 1111  
 "Right femoral vein", "Right adductor canal", "Space of right adductor canal", 1111  
 "Right saphenous nerve", "Right adductor canal", "Space of right adductor canal", 1111  
 "Vastus medialis branch of right femoral nerve", "Right adductor canal", "Space of right adductor canal", 1111  
 "Right sternohyoid", "Right muscular triangle", "Space of right muscular triangle", 1100  
 "Right sternothyroid", "Right muscular triangle", "Space of right muscular triangle", 1100  
 "Right thyrohyoid", "Right muscular triangle", "Space of right muscular triangle", 1100

"Right adrenal gland", "Right side of retroperitoneal compartment", "Space of right side of retroperitoneal compartment", 1100  
 "Right kidney", "Right side of retroperitoneal compartment", "Space of right side of retroperitoneal compartment", 1111  
 "Right hyoglossus", "Right submandibular triangle", "Space of right submandibular triangle", 1100  
 "Right mylohyoid", "Right submandibular triangle", "Space of right submandibular triangle", 1100  
 "Right submandibular gland", "Right submandibular triangle", "Space of right submandibular triangle", 1111  
 "Hyoglossus", "Submandibular triangle", "Space of submandibular triangle", 1100  
 "Mylohyoid", "Submandibular triangle", "Space of submandibular triangle", 1100

This fix brought the number of unsatisfiable classes to 69128.

### Issue #5: Domain and range of constitutional\_part/constitutional\_part\_of

I note that, in the definition of the constitutional\_part and constitutional\_part\_of properties, the "definition" annotations make reference to their applicability to "Anatomical structures". However, their domain and range axioms are not set based on said definitions. That said, I only update as needed to fix reasoning issues. "Constitutional part of" has the following domain and range assertions:

Domains (intersection) +  
 ● 'Anatomical space' or 'Material anatomical entity'

---

Ranges (intersection) +  
 ● 'Material anatomical entity'

---

That is, the property can be applied to a space or a material entity, but its value can only be material. Another way to say that is, nothing can be a constitutional part of a space. The following whole-part pairs violate this:

Lumen of nasopharynx-Pharyngeal isthmus  
 Lumen of oropharynx-Oropharyngeal isthmus  
 Lumen of right superior pulmonary vein-Lumen of right superior pulmonary vein

The above were corrected in both directions (e.g. if a space can't have constitutional parts, then nothing can be a constitutional part *of* a space).

The "constitutional part" was more problematic. Here are its domain and range:

Domains (intersection) +  
 ● 'Anatomical space' or 'Material anatomical entity'

---

Ranges (intersection) +  
 ● 'Physical anatomical entity'

---

The above suggests that spaces can have the constitutional part property, but the \*values\* can't be spaces. This does not agree with the textual definition, and I believe these were entered backwards. I swapped the domain and range assertions for this property.

### Issue #6: Range of receives drainage from

The range of receives\_drainage\_from was limited to "Material anatomical entity". However, there were quite a few cases where something was asserted to receive drainage from a group of lymph nodes. Therefore, rather than delete all violations, I added "Anatomical set" to the range of receives\_drainage\_from (using logical OR).

Domains (intersection) +

● 'Material anatomical entity'

Ranges (intersection) +

● 'Anatomical structure' or 'Anatomical set'

After this fix the total number of unsatisfiable classes was 69,127.

### Issue #7: Range of has\_insertion

The range of the "has insertion" property was previously set to be 'Postnatal anatomical structure'. However, the inverse property "insertion of" had domain:

Domains (intersection) +

● 'Zone of bone organ' or 'Zone of cartilage organ' or 'Bone process' or 'Tubercle of bone'

To fix issue related to restrictions on "has insertion" with values that were not subclasses of "Postnatal anatomical structure". I set the range of the latter property to be the same as the domain of the former:

Domains (intersection) +

● 'Postnatal anatomical structure'

Ranges (intersection) +

● 'Zone of bone organ' or 'Zone of cartilage organ' or 'Bone process' or 'Tubercle of bone'

After this fix the number of unsatisfiable classes remained unchanged.



## Issue #8: Muscle attachment

Explanation for: 'Flexor carpi ulnaris' EquivalentTo owl:Nothing

```
'Flexor carpi ulnaris' SubClassOf 'muscle attachment' some ((('has origin' some Olecranon) and ('has origin' some 'Common ulnar aponeurosis') and ('related object' some 'Ulnar head of flexor carpi ulnaris'))
'muscle attachment' Range 'Muscle attachment relation'
'Muscle attachment relation' SubClassOf 'Attached_to relation'
'Attached_to relation' SubClassOf 'Connected_to relation'
'Connected_to relation' SubClassOf 'Spatial association relation'
'Spatial association relation' SubClassOf 'Structural anatomical relation'
'Structural anatomical relation' SubClassOf 'Anatomical relation'
'Anatomical relation' SubClassOf 'Non-physical anatomical entity'
'has origin' Domain 'Postnatal anatomical structure'
'Postnatal anatomical structure' SubClassOf 'Anatomical structure'
'Anatomical structure' SubClassOf 'Material anatomical entity'
'Material anatomical entity' SubClassOf 'Physical anatomical entity'
'Physical anatomical entity' DisjointWith 'Non-physical anatomical entity'
```

In the above screenshot note that the 'Flexor carpi ulnaris' is in the domain of a 'muscle attachment' relationship. The range of 'muscle attachment' is 'muscle attachment relation', which is disjoint from physical anatomical entities. The object of that relationship, in this case is a logical intersection. The first component of that intersection is a restriction on 'has origin'. The domain of 'has origin' is 'Postnatal anatomical structure'. So, we have an anatomical structure where we cannot. All other uses of "muscle attachment" are similarly constructed. So, I changed the range from 'muscle attachment' to 'postnatal anatomical structure'.

This did not change the unsatisfiable class count.

## Issue #9: Has origin

The range of 'has origin' is 'Postnatal anatomical structure'. The following where represented as the subject and object of an existential restriction on 'has origin' in the FMA that do not fit that range. I could have considered adding a new class to the range, but it appears as though the intent was (at the least) to restrict the range of has origin to material objects. The table below list violation where the object is not a material object:

sourceLabel	targetLabel
Eighth external intercostal muscle	Inferior margin of eighth rib
External intercostal muscle	Inferior margin of rib
Fifth external intercostal muscle	Inferior margin of fifth rib
Fourth external intercostal muscle	Inferior margin of fourth rib
Iliacus	Iliac fossa
Iliocostalis cervicis	Angle of fifth rib
Iliocostalis cervicis	Angle of fourth rib
Iliocostalis cervicis	Angle of sixth rib
Iliocostalis cervicis	Angle of third rib
Ninth external intercostal muscle	Inferior margin of ninth rib
Seventh external intercostal muscle	Inferior margin of seventh rib

<b>Sixth external intercostal muscle</b>	Inferior margin of sixth rib
<b>Tenth external intercostal muscle</b>	Inferior margin of tenth rib
<b>Third external intercostal muscle</b>	Inferior margin of third rib

Each of the above assertions have been remove (as I did not know how they should be corrected). I have also removed assertions going the other way, via the 'origin of' property). Here are the results:

subject,old\_object,new\_object,status

"Eighth external intercostal muscle","Inferior margin of eighth rib","",11  
 "External intercostal muscle","Inferior margin of rib","",11  
 "Fifth external intercostal muscle","Inferior margin of fifth rib","",11  
 "Fourth external intercostal muscle","Inferior margin of fourth rib","",11  
 "Iliacus","Iliac fossa","",11  
 "Iliocostalis cervicis","Angle of fifth rib","",11  
 "Iliocostalis cervicis","Angle of fourth rib","",11  
 "Iliocostalis cervicis","Angle of sixth rib","",11  
 "Iliocostalis cervicis","Angle of third rib","",11  
 "Ninth external intercostal muscle","Inferior margin of ninth rib","",11  
 "Seventh external intercostal muscle","Inferior margin of seventh rib","",11  
 "Sixth external intercostal muscle","Inferior margin of sixth rib","",11  
 "Tenth external intercostal muscle","Inferior margin of tenth rib","",11  
 "Third external intercostal muscle","Inferior margin of third rib","",11

The new unsatisfiable class count is 69095.

## Issue #10: Has projection range.

The next issue detected stemmed from restrictions on "has projection" with anatomical sets in the value position:

Explanation for: 'Superior frontal gyrus' EquivalentTo owl:Nothing	
1)	'Superior frontal gyrus' SubClassOf 'regional part of' some 'Frontal lobe'
2)	'Frontal lobe' SubClassOf 'has projection' some 'Set of corticorubral fibers'
3)	'has projection' Range 'Cell part cluster of neuraxis'
4)	'Cell part cluster of neuraxis' SubClassOf 'Cell part cluster'
5)	'Cell part cluster' SubClassOf 'Anatomical cluster'
6)	'Anatomical cluster' SubClassOf 'Postnatal anatomical structure'
7)	'Postnatal anatomical structure' SubClassOf 'Anatomical structure'
8)	'Set of corticorubral fibers' SubClassOf 'Set of neuraxis fibers'
9)	'Set of neuraxis fibers' SubClassOf 'Set of nerve fibers'
0)	'Set of nerve fibers' SubClassOf 'Set of organ components'
1)	'Set of organ components' SubClassOf 'Set of organ parts'
2)	'Set of organ parts' SubClassOf 'Anatomical set'
3)	DisjointClasses: 'Anatomical structure', 'Anatomical set', 'Portion of body substance'

Here is the range of "has projection":

Ranges (intersection)   
 'Cell part cluster of neuraxis'

And here is the domain of its inverse property 'projects from':

Domains (intersection)

- 'Region of cerebral cortex' or 'Segment of neuraxis' or 'Cell part cluster of neuraxis'

Ranges (intersection)

- 'Cell part cluster of neuraxis'

This domain assertion suggests that sets should be allowed. I changed the range of 'has projection' to match the domain of 'projects from'.

This did not change the number of unsatisfiable classes.

## Issue #11: Has location

Has location had the range of "Physical anatomical entity", but had uses like this:

● Epiblast **SubClassOf** 'has location' **some** Dorsal

Dorsal is an "anatomical location". I changed the range of 'has location' accordingly. Afterwards the number of unsatisfiable classes went up to 69100. The only way it could have gone up is if that change introduced new issues. So I looked at the subproperties. Many of them would not have a location (like Dorsal) as values, but are expecting anatomical entities (relations like 'anterior to', 'distal to', ...). I don't think these properties should be hierarchically related. But the simplest fix was then to go back into 'has location' and remove its range class altogether (leave for a future fix).

With this fix the number of unsatisfiable classes was back to 69095.

## Issue #12: Optic canal (and others) disjointness

The following classes are declared disjoint (plus the 'Adductor canal' which was selected for this screenshot):

Disjoint With

- 'Diaphragmatic aperture', 'Superior pelvic aperture', 'Cellular conduit', 'Frontonasal duct', 'Inferior pelvic aperture', 'Cranial conduit', 'Obturator canal', 'Hypoglossal canal', 'Tympanic isthmus', 'Spiral canal of modiolus of cochlea', 'Canal for vertebral artery', 'Longitudinal canal of modiolus of cochlea', 'Occipito-cervical foramen', 'Conduit of axilla', 'Interventricular sulcus', 'Scleral external collector channel', 'Superior thoracic aperture', 'Canal of Volkmann', 'Inferior thoracic aperture', 'Haversian canal', 'Nutrient canal', 'Respiratory conduit', 'Subdivision of coronary sulcus', 'Tunnel of tendon', 'Coronary sulcus', 'Inguinal canal', 'Endothelial fenestration', 'Optic canal', 'Hyaloid canal', 'Intervertebral foramen'

Of note in the above is that 'optic canal' and 'cranial conduit' are disjoint. However, the former is also modeled as a subclass of the latter. Thus, there can be no 'optic canal' individuals. 'Cranial conduit' was also the superclass of some of the other disjoint classes. Looking further at the disjoint classes list above, it was not simply a set of siblings. Values occurred at different levels of the is\_a hierarchy. As these disjointness assertions were problematic, likely incorrect in several places, and would need a more thoughtful remodel, I simply removed them for now.

The new unsatisfiable class count was 69079 after this modification.

## Issue #13: More disjointness problems

Explanation for: Skull EquivalentTo owl:Nothing

```

Skull SubClassOf 'constitutional part' some 'Set of all joints of head'
'Set of all joints of head' SubClassOf member some 'Set of cranial syndesmoses'
'Set of cranial syndesmoses' SubClassOf member some 'Right tympanostapedial syndesmosis'
'Right tympanostapedial syndesmosis' SubClassOf 'Tympanostapedial syndesmosis'
'Tympanostapedial syndesmosis' SubClassOf 'Cranial syndesmosis'
DisjointClasses: 'Interchondral syndesmosis', 'Intervertebral syndesmosis', 'Tibiofibular joint', 'Radio-ulnar syndesmosis', 'Tympanostapedial syndesmosis', 'Cranial syndesmosis'

```

In the above screenshot, you will note that we again have a case of a subclass-superclass pair that are declared to be disjoint. I removed 'Tympanostapedial syndesmosis' from the set.

Explanation for: 'Sagittal sinus' EquivalentTo owl:Nothing

```

'Sagittal sinus' SubClassOf 'Unpaired dural venous sinus'
'Unpaired dural venous sinus' SubClassOf 'Dural venous sinus'
'Dural venous sinus' SubClassOf 'venous drainage of' some 'Pituitary gland'
'Pituitary gland' SubClassOf 'arterial supply' some 'Lateral branch of left inferior hypophyseal artery'
'Lateral branch of left inferior hypophyseal artery' SubClassOf 'branch of' some 'Left inferior hypophyseal artery'
'Left inferior hypophyseal artery' SubClassOf 'regional part of' some 'Left internal carotid artery'
'Left internal carotid artery' SubClassOf 'regional part of' some 'Left common carotid artery'
'Left common carotid artery' SubClassOf 'branch of' some 'Systemic arterial tree'
'Systemic arterial tree' SubClassOf 'continuous with' some 'Left side of heart'
'Left side of heart' SubClassOf 'regional part' some 'Left ventricle'
'Left ventricle' SubClassOf 'direct right of' some 'Left atrium'
'Left atrium' SubClassOf 'anterior to' some 'Right atrium'
'Right atrium' SubClassOf 'continuous with' some 'Superior vena cava'
'Superior vena cava' SubClassOf 'regional part of' some 'Superior systemic venous tree'
'Superior systemic venous tree' SubClassOf tributary some 'Right brachiocephalic vein'
'Right brachiocephalic vein' SubClassOf 'regional part' some 'Right vertebral vein'
'Right vertebral vein' SubClassOf tributary some 'Right occipital vein'
'Right occipital vein' SubClassOf 'Occipital vein'
'Occipital vein' SubClassOf 'Superior superficial cerebral vein'
'Superior superficial cerebral vein' SubClassOf 'tributary of' some 'Superior sagittal sinus'
'Superior sagittal sinus' SubClassOf 'Sagittal sinus'
DisjointClasses: 'Circular sinus', 'Sagittal sinus', 'Superior sagittal sinus', 'Inferior sagittal sinus', 'Straight sinus', 'Occipital sinus'

```

Similarly, amongst the disjoint classes for Sagittal sinus I found two of its subclasses. Given that it looked like the attempt was to make the immediate siblings of 'sagittal sinus' disjoint, I removed the two subclasses from the list.

The number of unsatisfiable classes (in EL) after the above modifications is now 0.

## Additional resources:

[SPARQL query for invalid contains/contained\\_in relationships:](#)

```

PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX owl: <http://www.w3.org/2002/07/owl#>
PREFIX fma: <http://purl.org/sig/ont/fma/>

SELECT DISTINCT ?containedLabel ?containerLabel
WHERE {
  {
    # Case 1: [Container] contains [Contained]
    # Restriction is on the container class
    ?container rdfs:subClassOf [
      a owl:Restriction ;
      owl:onProperty fma:contains ;
      owl:someValuesFrom ?contained
    ] .
  }
}

```

```

}
UNION
{
  # Case 2: [Contained] contained_in [Container]
  # Restriction is on the contained class
  ?contained rdfs:subClassOf [
    a owl:Restriction ;
    owl:onProperty fma:contained_in ;
    owl:someValuesFrom ?container
  ] .
}

# 1. Validation Logic: The container is invalid if it is NOT
# a subclass (direct or indirect) of "Anatomical space"
FILTER NOT EXISTS {
  ?container rdfs:subClassOf* ?spaceClass .
  ?spaceClass rdfs:label "Anatomical space"@en .
}

# 2. Filter out blank nodes (ensure we are only dealing with named classes)
FILTER (!isBlank(?container) && !isBlank(?contained))

# 3. Get the labels for the final table
?contained rdfs:label ?containedLabel .
?container rdfs:label ?containerLabel .
}
ORDER BY ?containerLabel ?containedLabel

```