Knowledge Representations

- How else can we represent knowledge in addition to formal logic?

Common Knowledge Representations

- Formal Logic √
- Production Rules
- Semantic Nets
- Schemata and Frames

Production Rules

- Frequently used to formulate the knowledge in expert systems.
- BNF is commonly used in Computer Science.
    - for a subset of the German language

```
<sentence>          -> <subject phrase> <verb>
                           <object phrase>
<subject phrase>    -> <determiner> <adjective> <noun>
<object phrase>     -> <determiner> <adjective> <noun>
<determiner>        -> der | die | das | den
<noun>              -> Mann | Frau | Kind | Hund | Katze
<verb>              -> mag | schimpft | vergisst|
                           verehrt | verzehrt
<adjective>         -> schoene | starke | laute | duenne
```

Prolog

- Prolog was developed for AI applications.
- It specifies rules as Horn clauses, a subset of predicate logic.

- Example

```
male( albert ) .
male( edward ) .

female( alice ) .
female( victoria ) .

parents( edward ,  victoria ,  albert ) .
parents( alice ,  victoria ,  albert ) .

sisterof( X , Y )   : -    female( X ) ,
                           parents( X ,  M ,  F ) ,
                           parents( Y ,  M ,  F ) .
```

Prolog Expert System

```
% Automotive Diagnostic Expert System

defect_may_be(drained_battery) :-
    user_says(starter_was_ok, yes),
    user_says(starter_is_ok, no).

defect_may_be(wrong_gear) :-
    user_says(starter_was_ok, no).

defect_may_be(fuel_system) :-
    user_says(starter_was_ok, yes),
    user_says(fuel_is_ok, no).
```

Picture Pattern from my 1974 Thesis

PATTERN = CIRCLE \$ C1 ¢ CIRCLE \$ C2 ¢

GT(VALU(C2,'RADIUS'), VALU(C1,'RADIUS')) ¢

AT(POINT(C2,'TOP'), POINT(C1,'BOT') ¢

CIRCLE \$ C3 ¢

GT(VALU(C3,'RADIUS'), VALU(C2,'RADIUS')) ¢

AT(POINT(C3,'TOP'), POINT(C2,'BOT'))

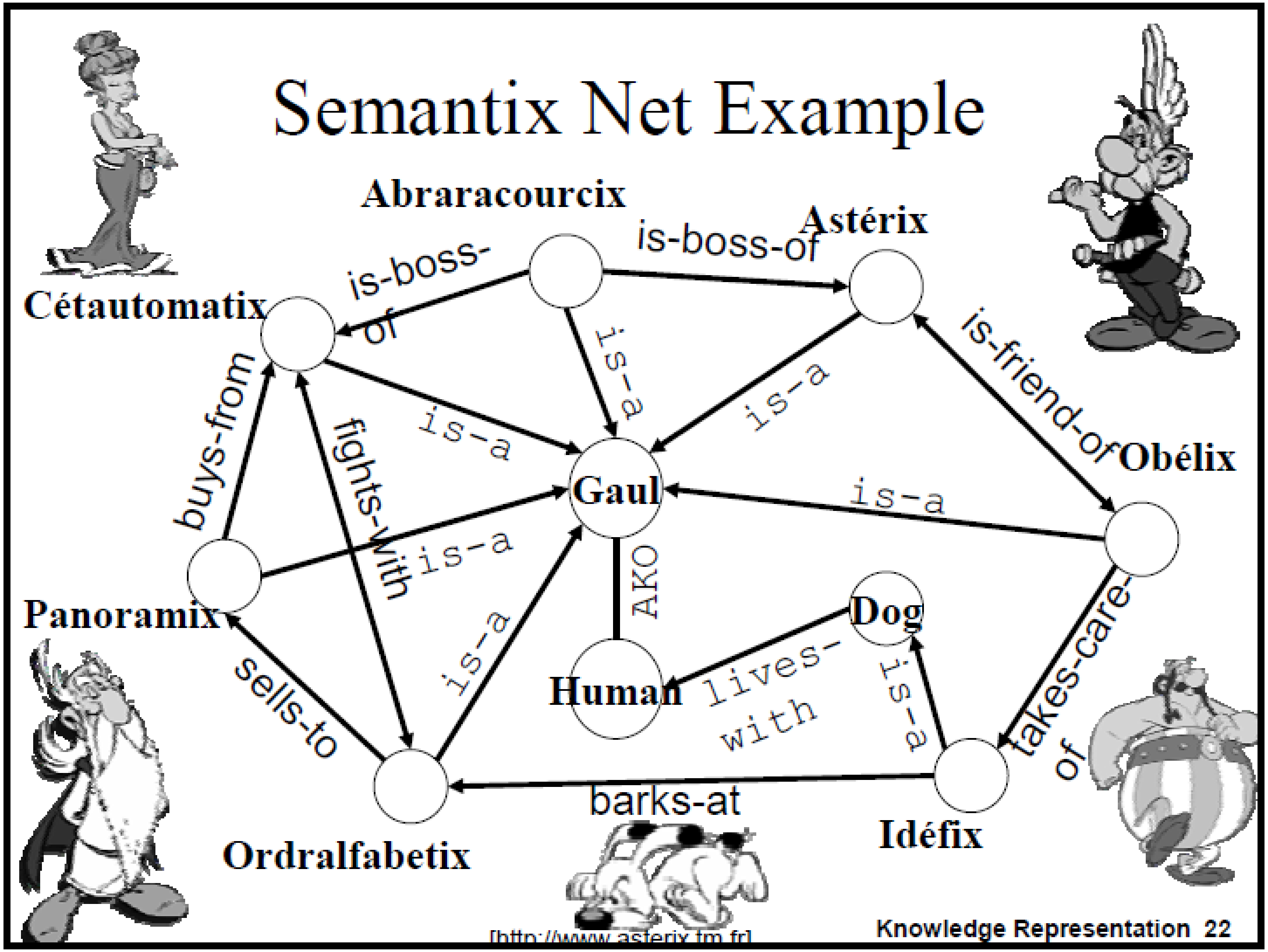
What is it?

Advantages of Production Rules

- Simpler than full predicate logic
- Still pretty expressive
- Simple backtracking search algorithms
- Easy for programmers to construct the rules
- Humans tend to understand the rules

Semantic Nets

- Graphical representation for propositional information
- Originally developed by Quillian as a model for human memory
- Nodes represent objects, concepts, situations
- Edges represent relationships


Semantix Net Example
Abraracourcix
Astérix
Cétautomatix
Obélix
Gaul
Panoramix
Dog
Human
Ordralfabetix
Idéfix
is-boss-of
is-boss-of
is-a
is-a
is-a
is-a
is-a
is-a
is-a
is-friend-of
buys-from
fights-with
AKO
sells-to
lives-with
takes-care-of
barks-at
[http://www.asterix.tm.fr]
Knowledge Representation 22

Semantic Nets

- Relationships
  - Frequently used: IS-A, A-KIND-OF, PART-OF
  - Can be specified by the designer
- Attributes
  - Can be added to the nodes
- Advantages
  - Easy to encode and understand
- Disadvantages
  - May become large and lead to enormous searches

Related Web Developments

- The Semantic Web: an effort to create a web that uses the concepts from semantic nets.
- It would allow people (and programs) to better understand web content.
- Two main representations at present:
  – RDF (Resource Description Framework) low level, triples (node1, relationship, node2)
  – OWL (web ontology language) adds semantics to RDF

Semantic Web Languages

- **RDF (Resource Description Framework)**

– Triples: <subject> <property> <object>

– RDF is a datamodel for objects ("resources") and relations between them. These datamodels can be represented in an XML syntax.

- **RDFS (RDF Schema)**

– A vocabulary for describing properties (subclass, subproperty, domain, range) and classes of RDF resources, with a semantics for generalization-hierarchies of such properties and classes.

- **OWL (Web Ontology Language)**

- OWL adds more vocabulary for describing properties and classes: among others, relations between classes (e.g. disjointness), cardinality (e.g. "exactly one"), equality, richer typing of properties, characteristics of properties (e.g. symmetry), and enumerated classes.

- There are constraints on classes and the types of relationships permitted between them. These provide semantics by allowing systems (reasoners) to infer additional information and provide classification based on the data explicitly provided.

Three “flavors” of OWL:

OWL Full

- OWL Full includes all OWL language constructs without restrictions on how they can be used.
- Not decidable

OWL DL (Description logic)

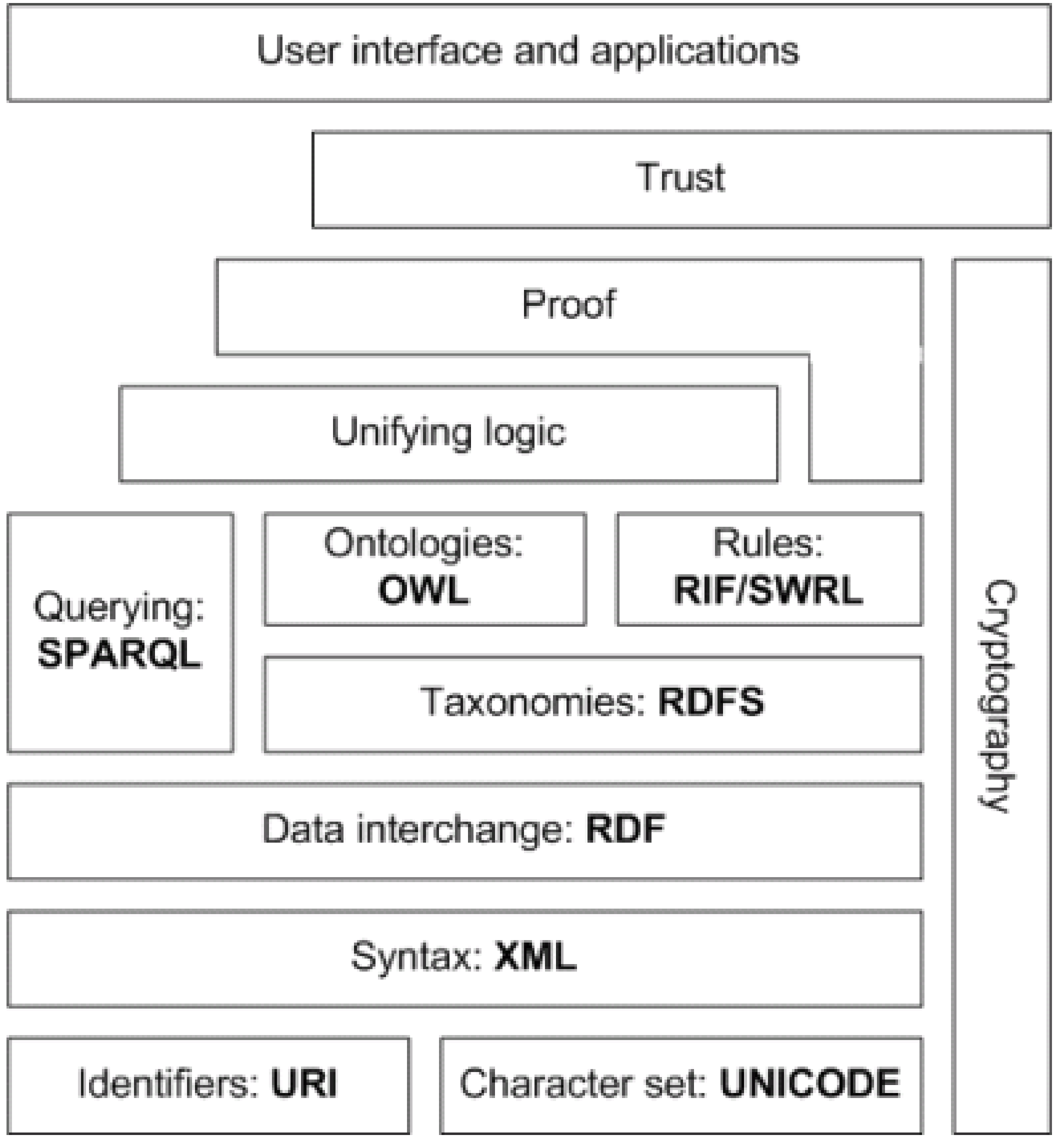
- OWL DL includes all OWL language constructs, but they can be used only under certain restrictions.
- Decidable
- Most ontologies use OWL DL

OWL Lite (even more restricted)

Excerpt of an OWL Ontology (the OPB):

```
<?xml version="1.0"?>
<rdf:RDF
xmlns:temporal="http://swrl.stanford.edu/ontologies/built-ins/3.3/temporal.owl#"
xmlns:rdfs="http://www.w3.org/2000/01/rdf-schema#"
                                        (…many more namespaces…)
xml:base="http://www.owl-ontologies.com/unnamed.owl">
<owl:Ontology rdf:about="">
<owl:imports rdf:resource="http://swrl.stanford.edu/ontologies/built-ins/3.3/query.owl"/>
<owl:imports rdf:resource="http://www.w3.org/2003/11/swrl"/>
                                        (…many more imports…)
</owl:Ontology>
<owl:Class rdf:ID="Rotational_displacement">
<rdfs:label rdf:datatype="http://www.w3.org/2001/XMLSchema#string"
>Rotational displacement</rdfs:label>
<rdfs:subClassOf>
<owl:Class rdf:ID="Solid_displacement"/>
</rdfs:subClassOf>
<protege:subclassesDisjoint rdf:datatype="http://www.w3.org/2001/XMLSchema#boole
>true</protege:subclassesDisjoint>
<owl:disjointWith>
<owl:Class rdf:ID="Bending_displacement"/>
```

Semantic Web Stack



Frames

- A frame represents related knowledge about a subject
- Frames contain multiple named slots
- Slots contain values of many different kinds
  - rules, facts, images, links to other frames
- Slots can have related procedures that get executed when the value is added, modified or deleted
- Frames can be arranged in a hierarchy or graph

Simple Frame Example

Slot Name	***Filler***
name	Astérix
height	small
weight	low
profession	warrior
armor	helmet
intelligence	very high
marital status	presumed single

Frames

- Advantages
  - Intuitive for many applications
  - Easier to understand than logic
  - Very flexible
- Problems
  - There are inheritance problems, particularly multiple inheritance in graphs

Ontologies

- An ontology is a formal representation of a set of concepts within a domain and the relationships among those concepts.

  Does that sound familiar?

- It allows deep understanding of and reasoning about a domain.
- UW Medical School has one enormous and now famous ontology: the Foundational Model of Anatomy (FMA)

Ontology Tools

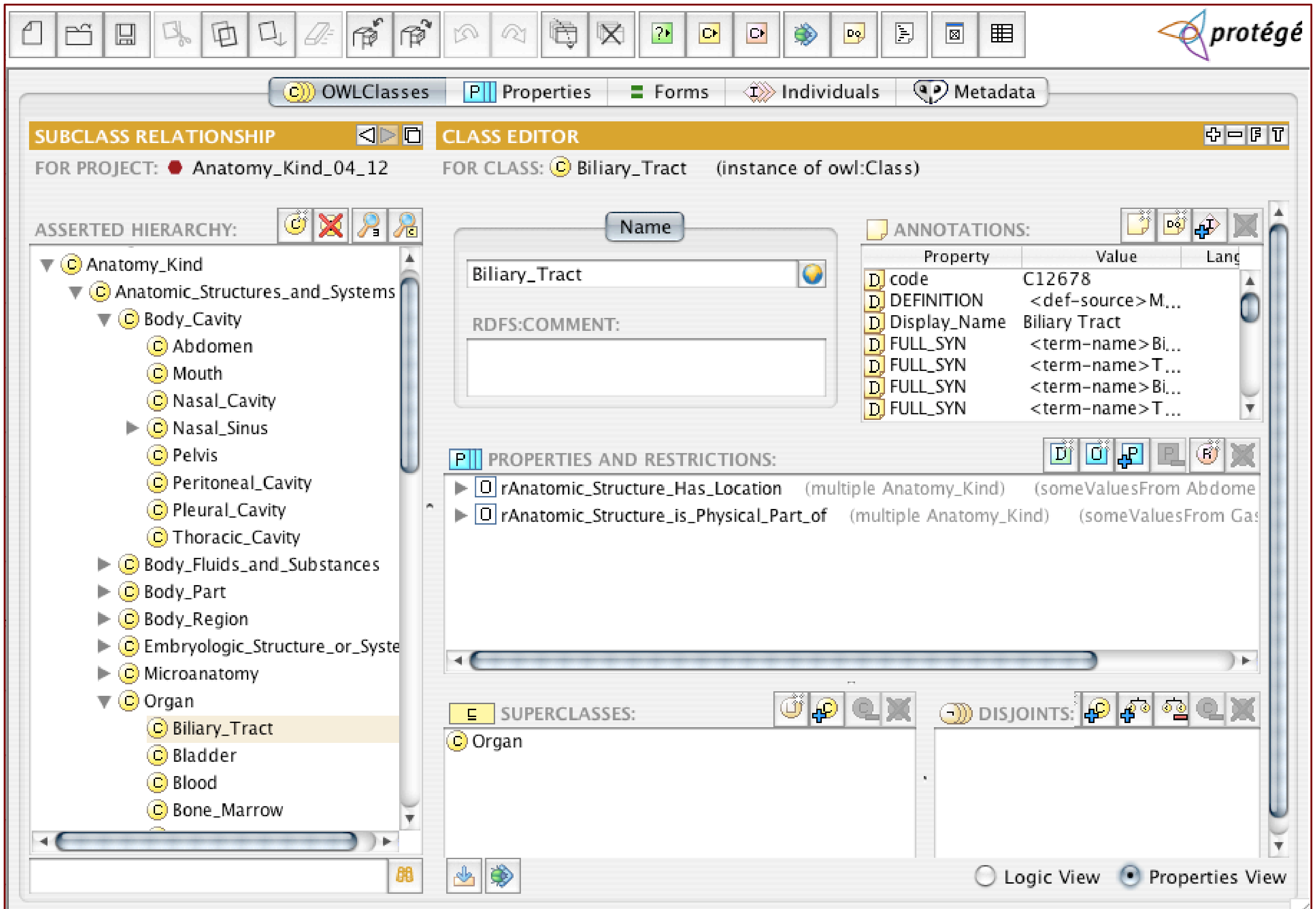
- Ontology-development becomes more accessible
- Protégé
  - Developed at Stanford Medical Informatics
  - Is an extensible and customizable toolset for
    - constructing knowledge bases
    - developing applications that use these knowledge bases

http://protege.stanford.edu

What is Protégé?

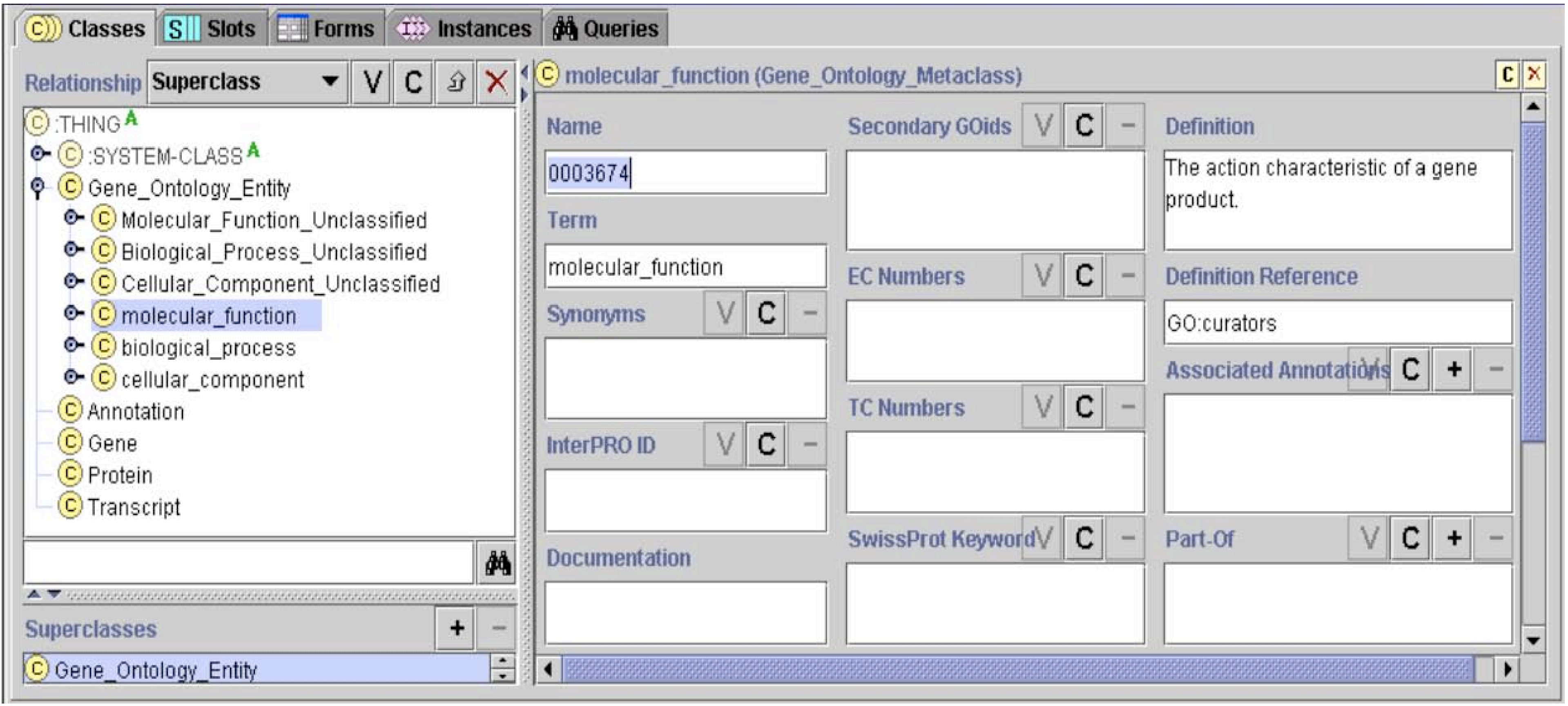
- An ontology editor
- A knowledge-acquisition tool
- A platform for knowledge-based applications

An Ontology Editor



NCI Thesaurus

A Knowledge-Acquisition Tool

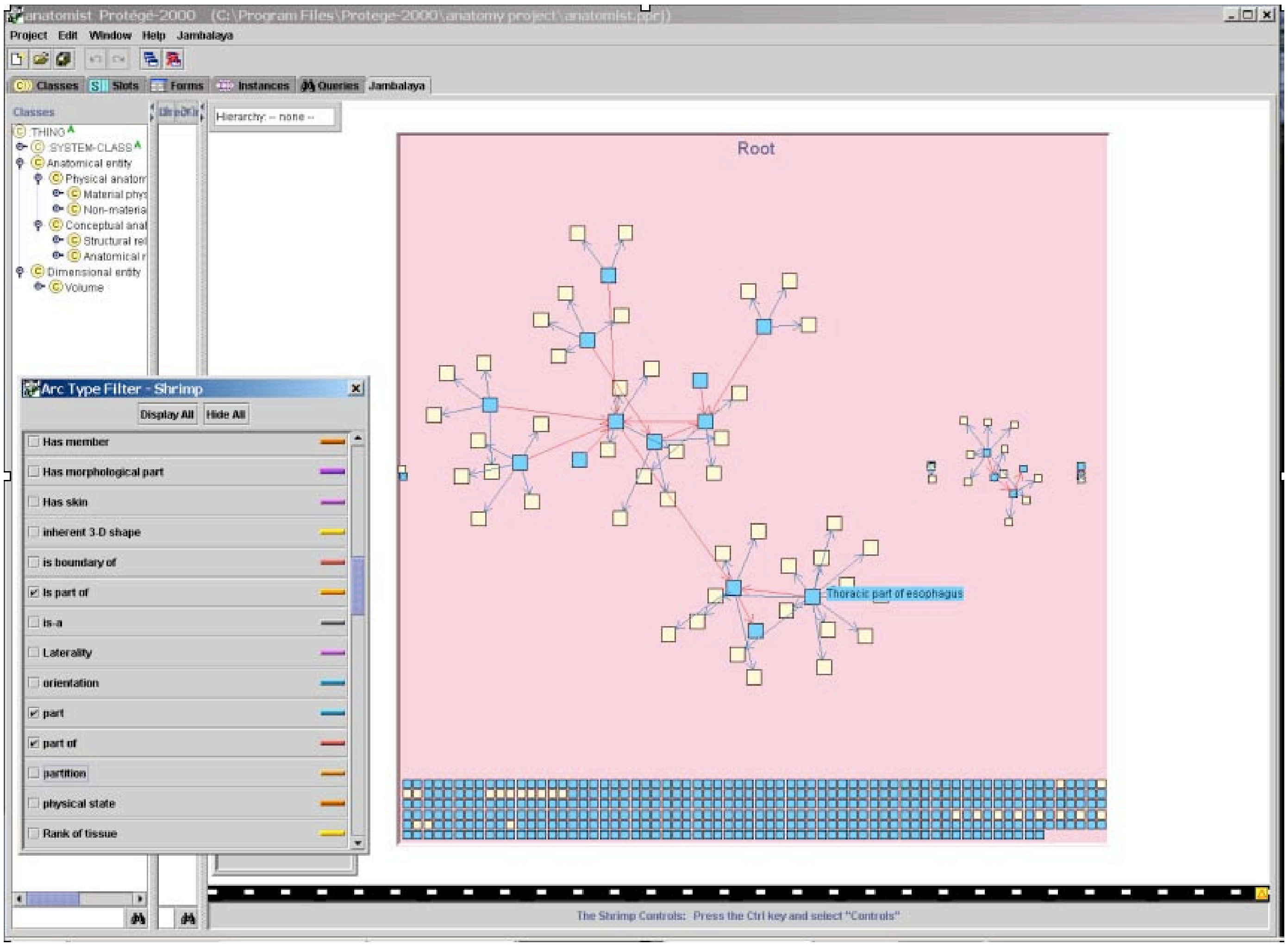


Gene Ontology

A Platform for Other Applications

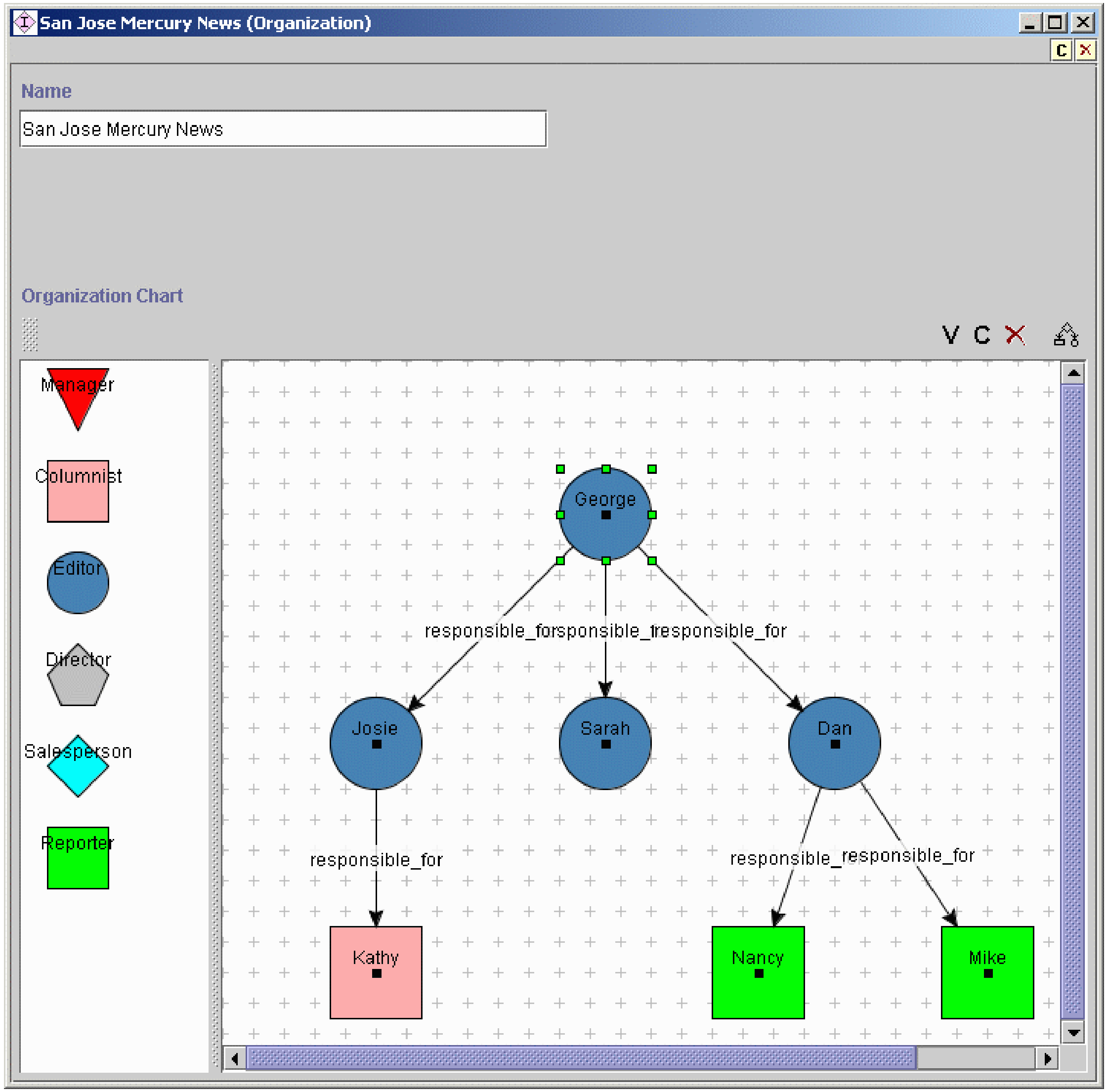
- A Java API that enables developers to write plugins for
  - Visualization systems
  - Inferencing systems
  - Scripting facilities
  - Import and export formats
  - User-interface features
  - Means of accessing external data sources
- About 60 plugins currently in the library (developed at Stanford and elsewhere)

Visualization: Jambalaya



Developed at University of Victoria

Graph Widget



Some Applications within SMI Supported by Protégé:

- Surveillance of data sources for evidence of potential bioterrorism
- Concept-based information retrieval
- Modeling of metabolic pathways
- Automation of guideline-based therapy

What Makes Protégé Different

- Easy-to-use graphical interface
- Scalability
  - currently can handle up to 5 million concepts
- Plugin architecture
  - active international community of plugin developers
- It's a platform for other applications
  - Integration with Eclipse (Mayo Clinic)
  - A server and a client for (Semantic) Web Services
- Open source

Foundational Model of Anatomy (FMA) Ontology

Motivating Hypothesis

"A sound ontological framework of biological structure (anatomy) provides a logical, comprehensive and efficient framework for organizing all types of information about biological organisms"

Why Anatomy?

Hypothesis 1: Manifestations of health and disease are attributes of anatomical structures.

Hypothesis 2: Representation of anatomy should facilitate representation of other domains and interoperability between biomedical domains.

Foundational Model of Anatomy (FMA) Ontology

Theory:

The FMA is a *spatio-structural ontology* of the entities and relations which together form the *phenotypic structure* of a biological organism at all salient *levels of granularity*.

High level Objectives of the FMA theory

Foundational Model of Anatomy

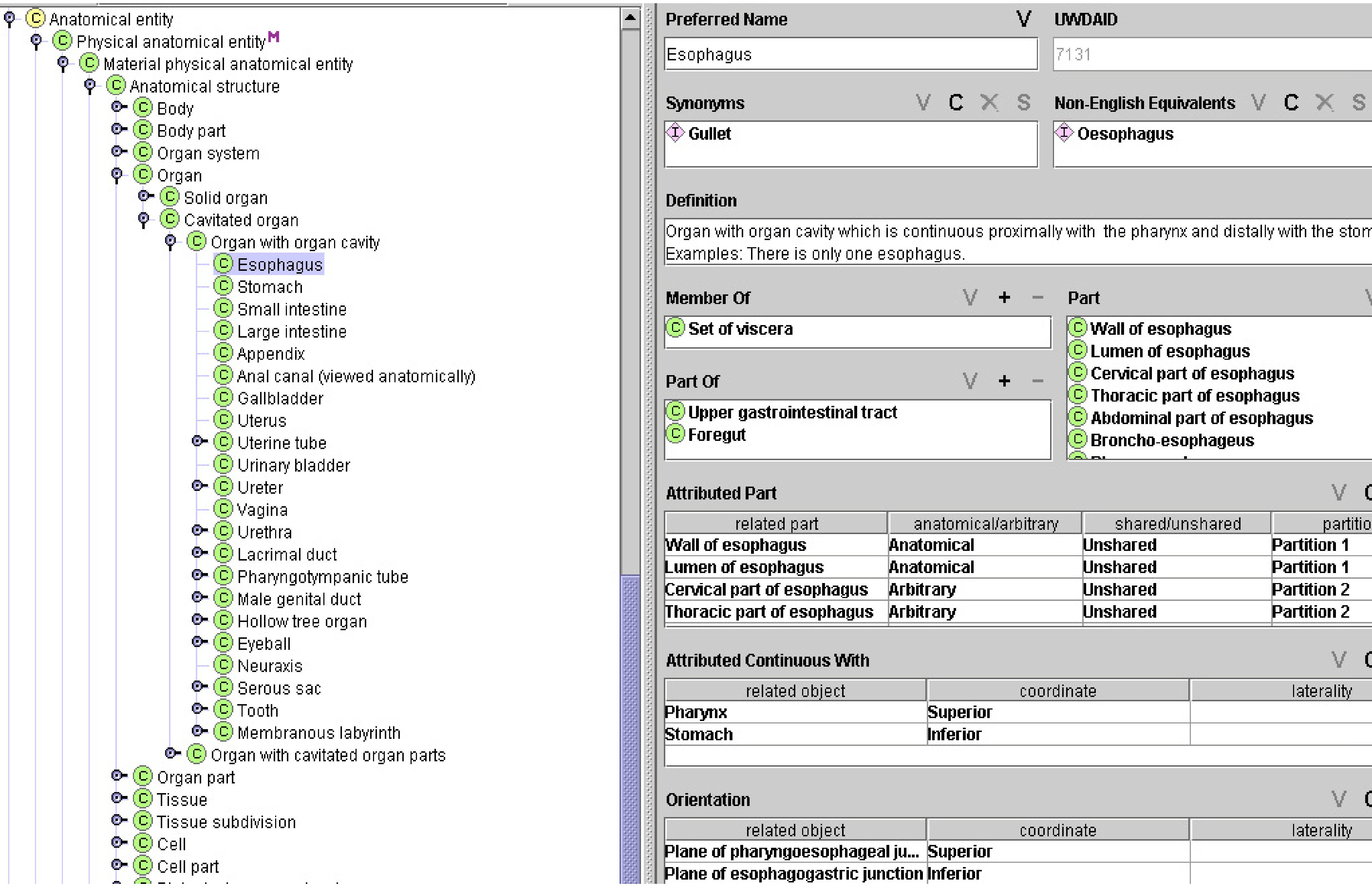
declare the principles

for including entities and relations
that are implicitly assumed
when knowledge of anatomy
is applied in different contexts;

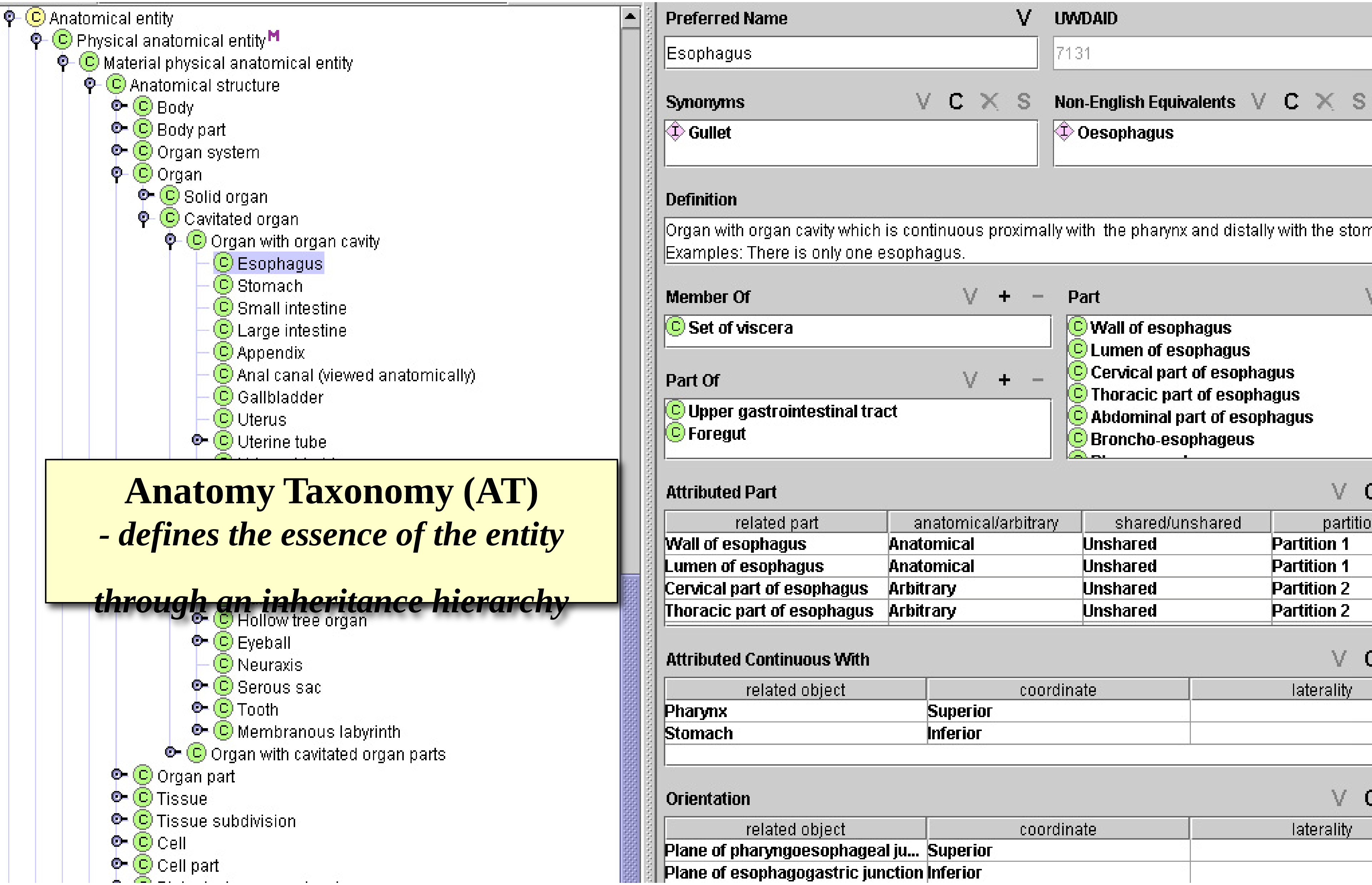
explicitly define

entities and relations
necessary and sufficient for consistently
representing the structure of a
biological organism.

Foundational Model of Anatomy Ontology



Foundational Model of Anatomy Ontology

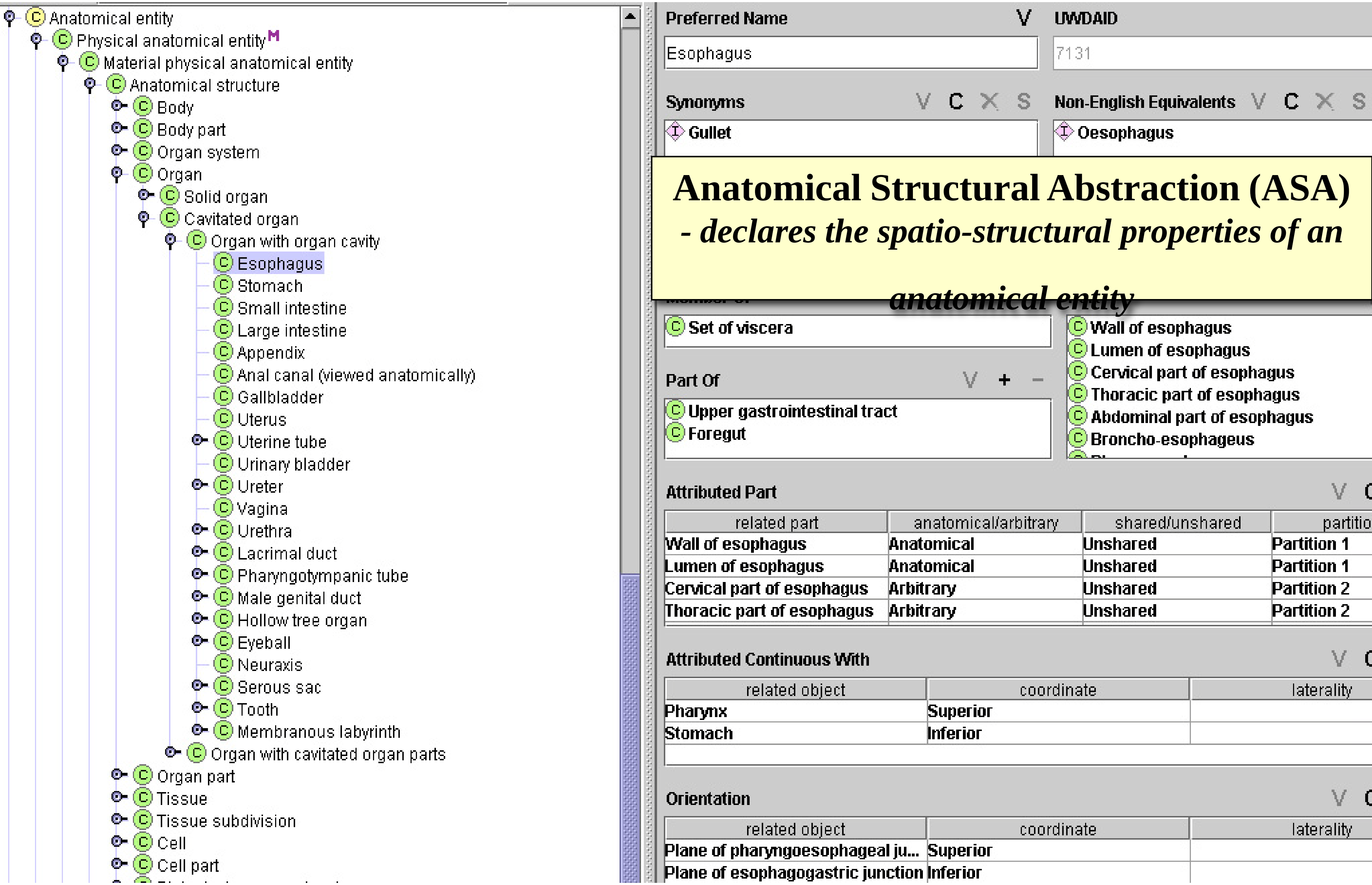


Anatomy Taxonomy (AT)

- defines the essence of the entity

through an inheritance hierarchy

Foundational Model of Anatomy Ontology



Anatomical Structural Abstraction (ASA)

- declares the spatio-structural properties of an anatomical entity

Foundational Model of Anatomy Ontology

Unifying theory of anatomy

High Level Scheme

$FMA = (At, ASA, ATA, Mk)$

where:

At	= Anatomy taxonomy
ASA	= Anatomical Structural Abstraction
ATA	= Anatomical Transformation Abstraction
Mk	= Metaknowledge (principles, rules, axioms)

Exploring the FMA

- The Foundational Model Explorer (FME)

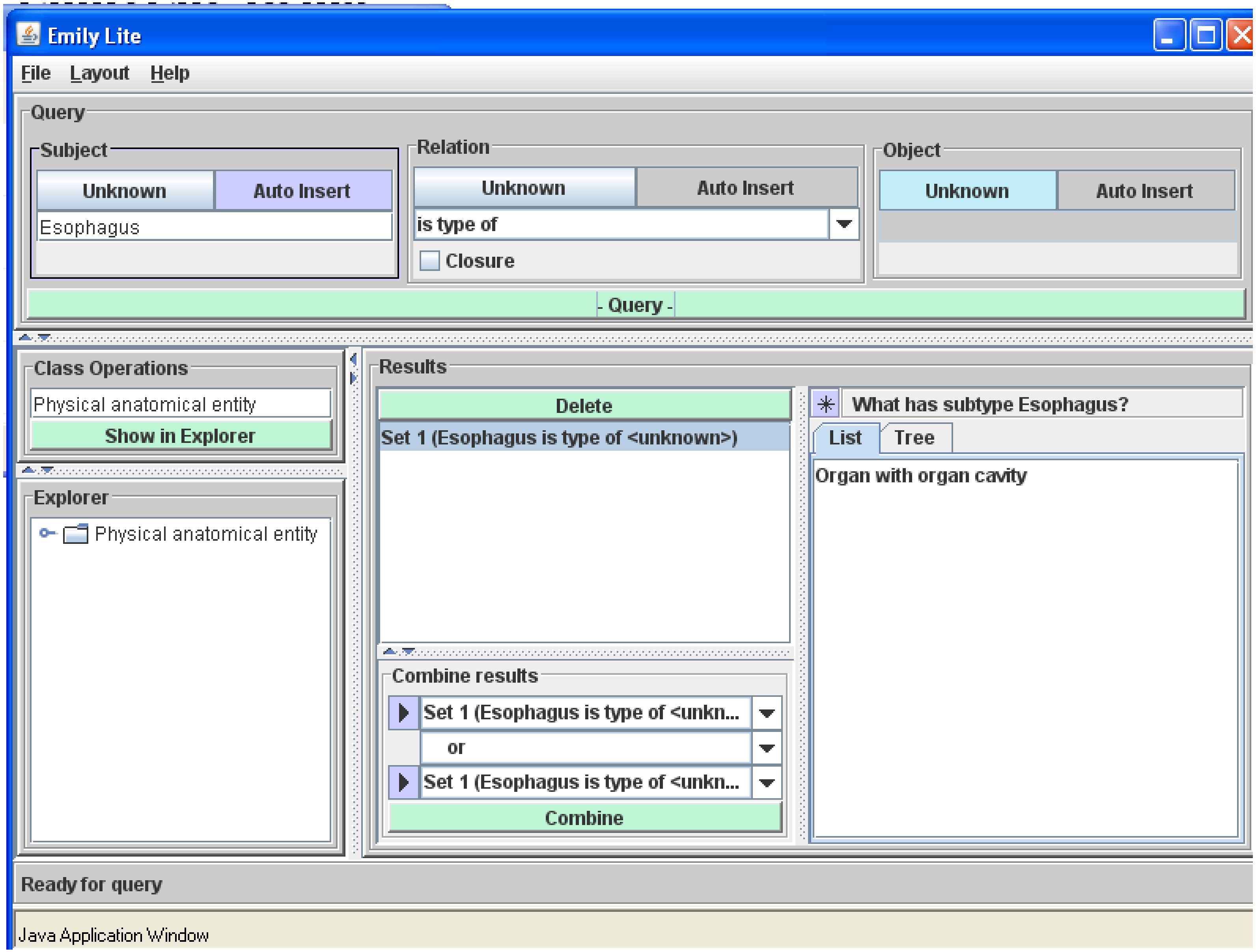
  http://fme.biostr.washington.edu:8089/FME/index.html

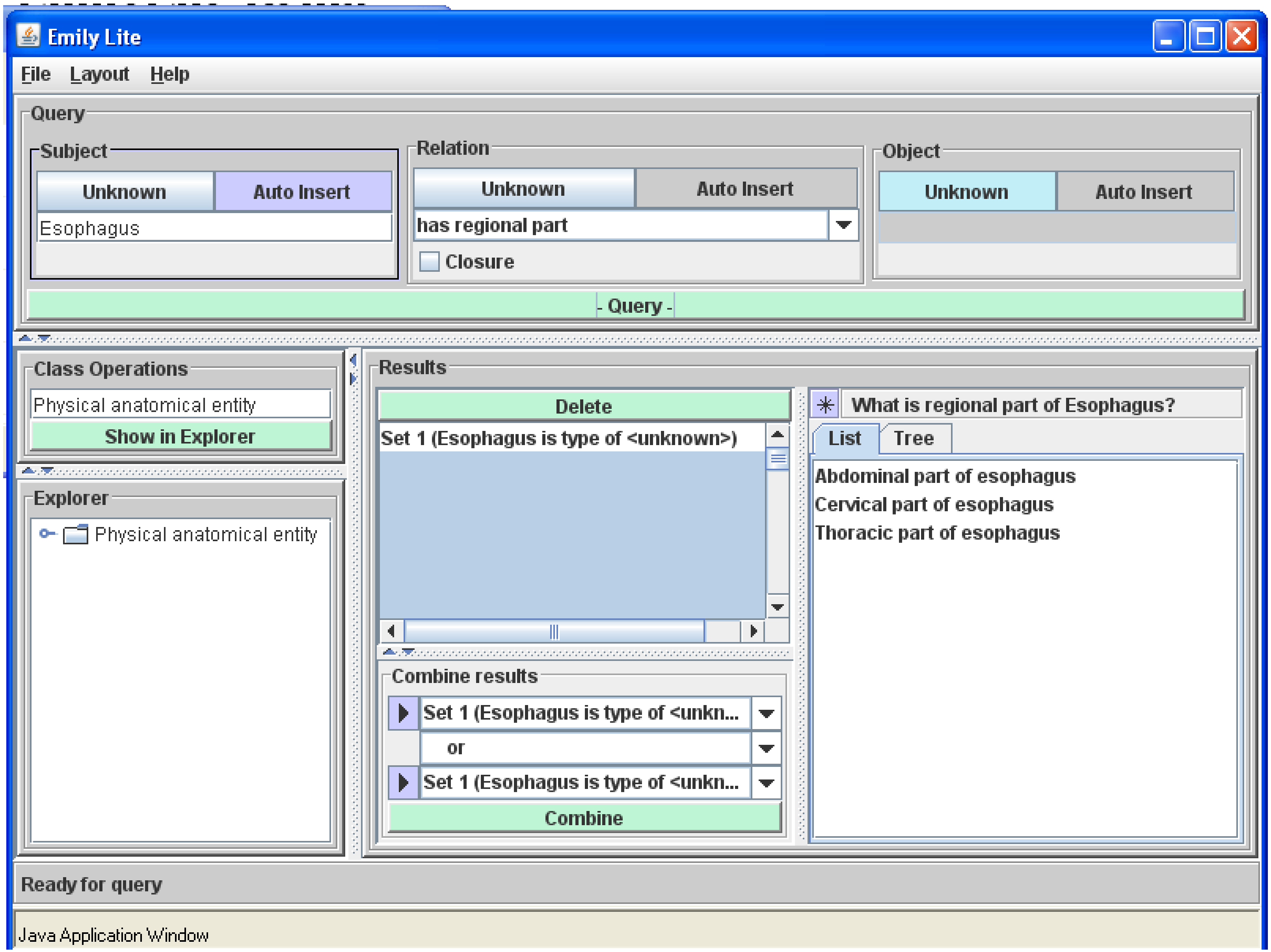
allows browsing through the frames following links.

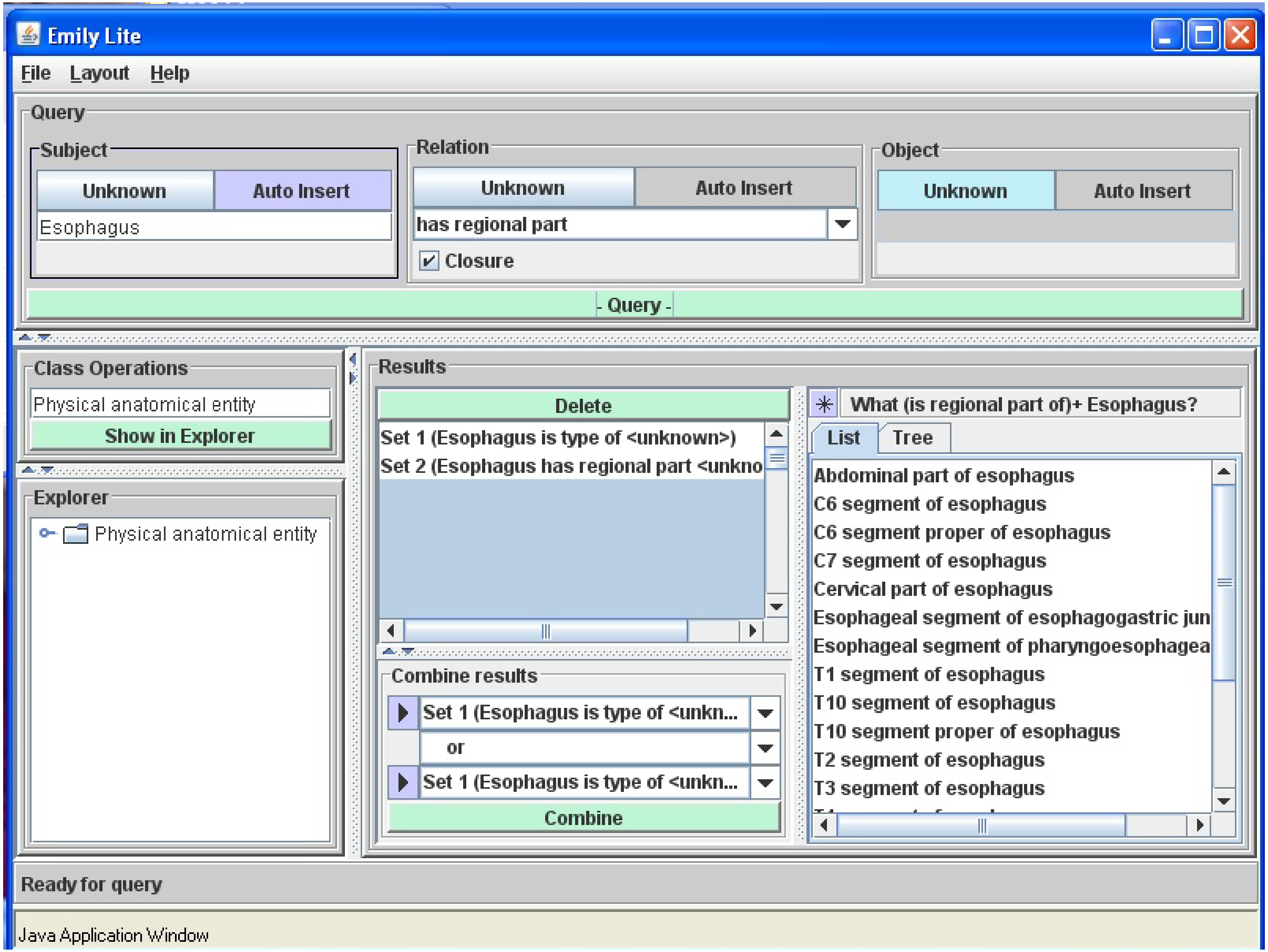
- Emily-Lite

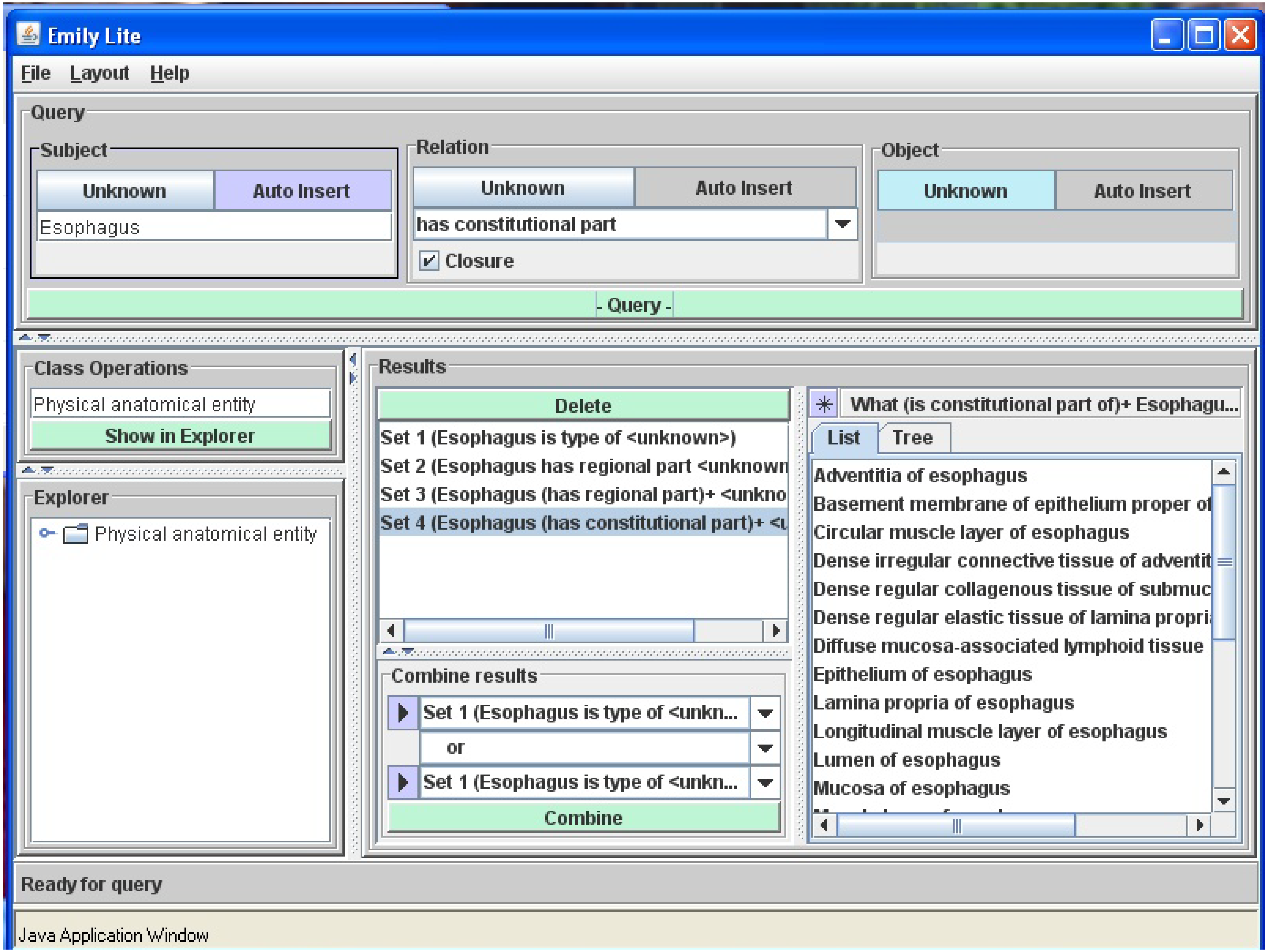
  http://fma.biostr.washington.edu/emilylite/

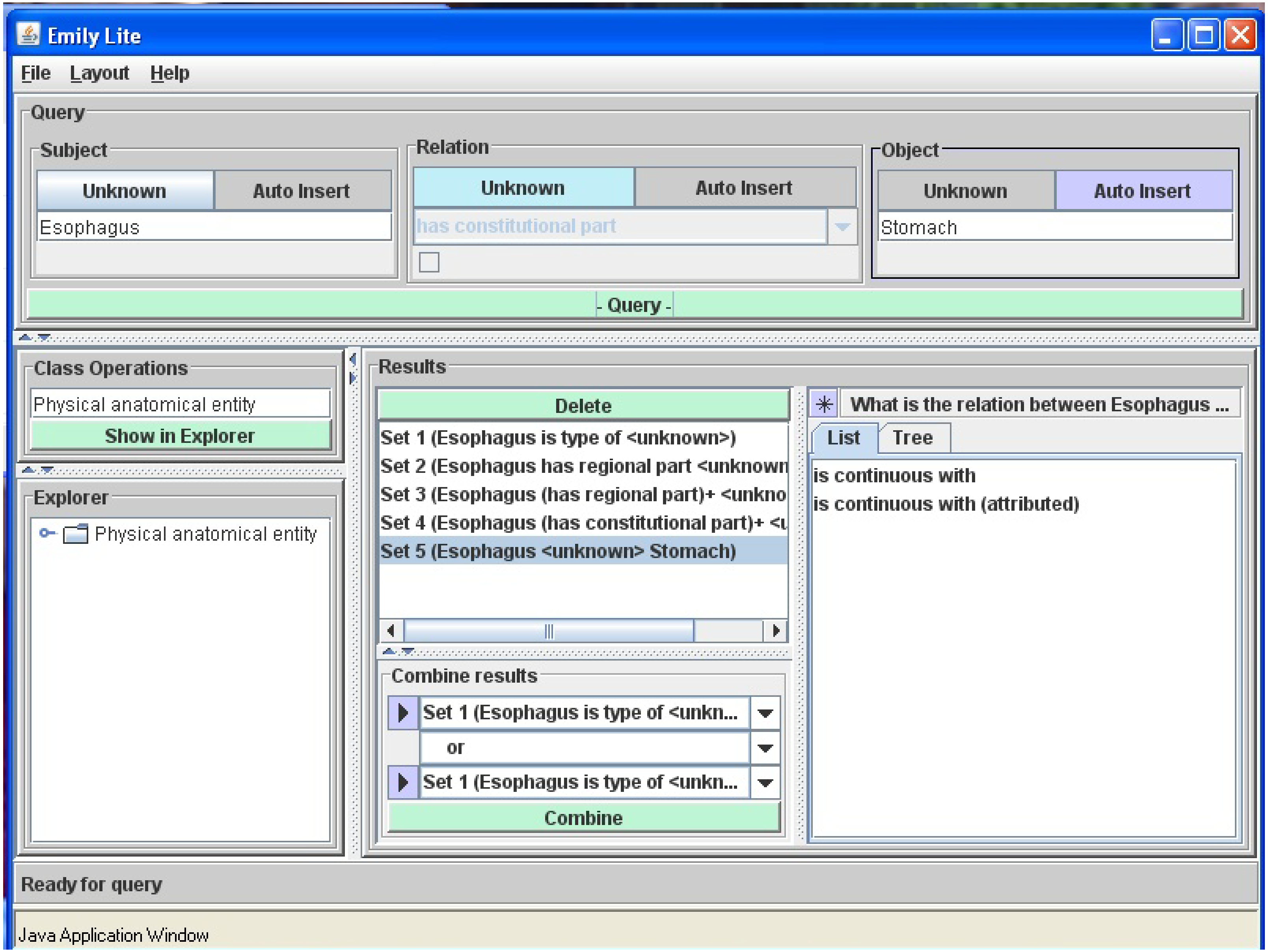
allows queries about entities and their relationships.

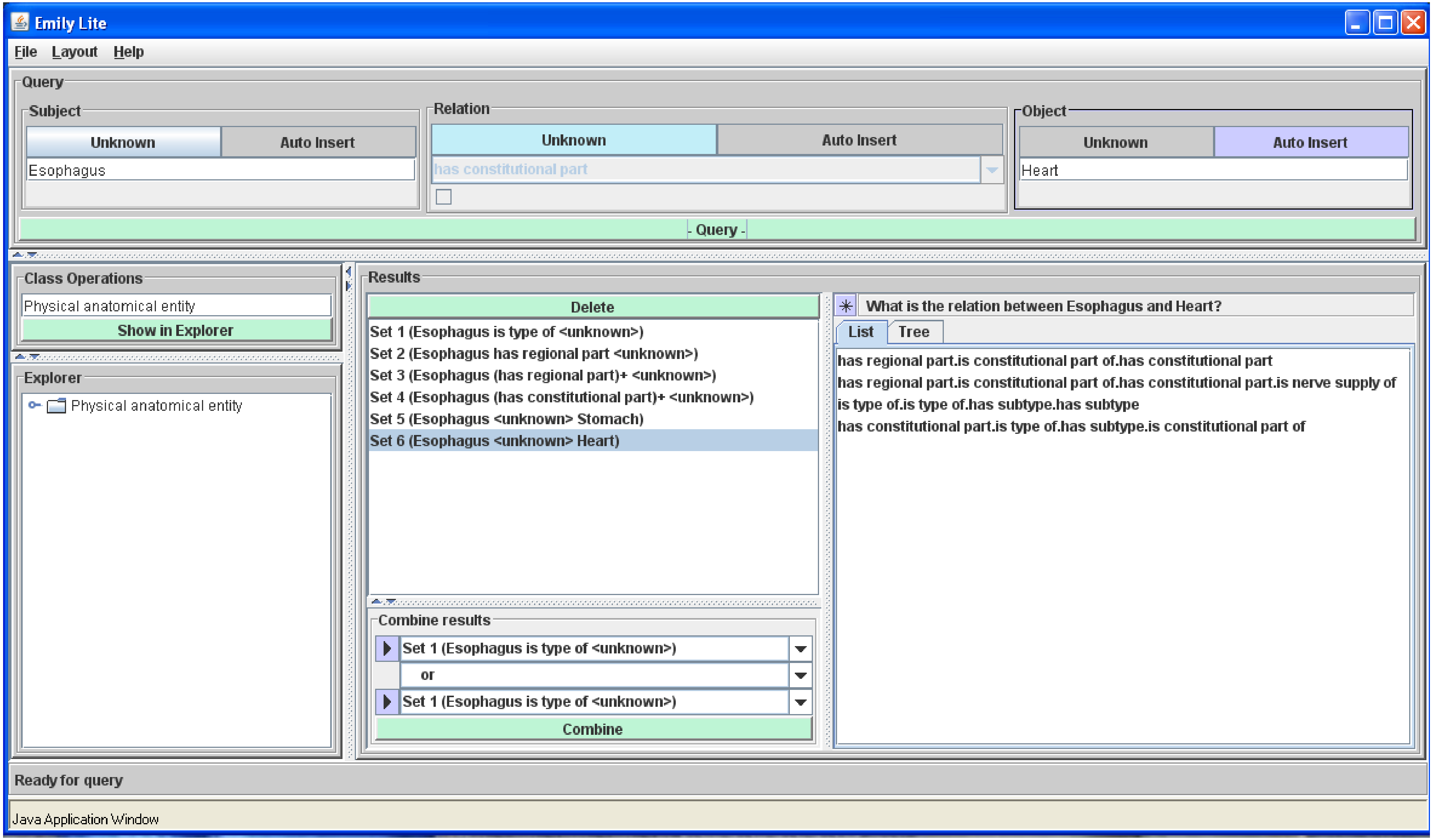

Emily Lite
File Layout Help
Query
Subject
Unknown
Auto Insert
Esophagus
Relation
Unknown
Auto Insert
is type of
Closure
Object
Unknown
Auto Insert
- Query -
Class Operations
Physical anatomical entity
Show in Explorer
Explorer
Physical anatomical entity
Results
Delete
Set 1 (Esophagus is type of <unknown>)
What has subtype Esophagus?
List
Tree
Organ with organ cavity
Combine results
Set 1 (Esophagus is type of <unkn...
or
Set 1 (Esophagus is type of <unkn...
Combine
Ready for query
Java Application Window

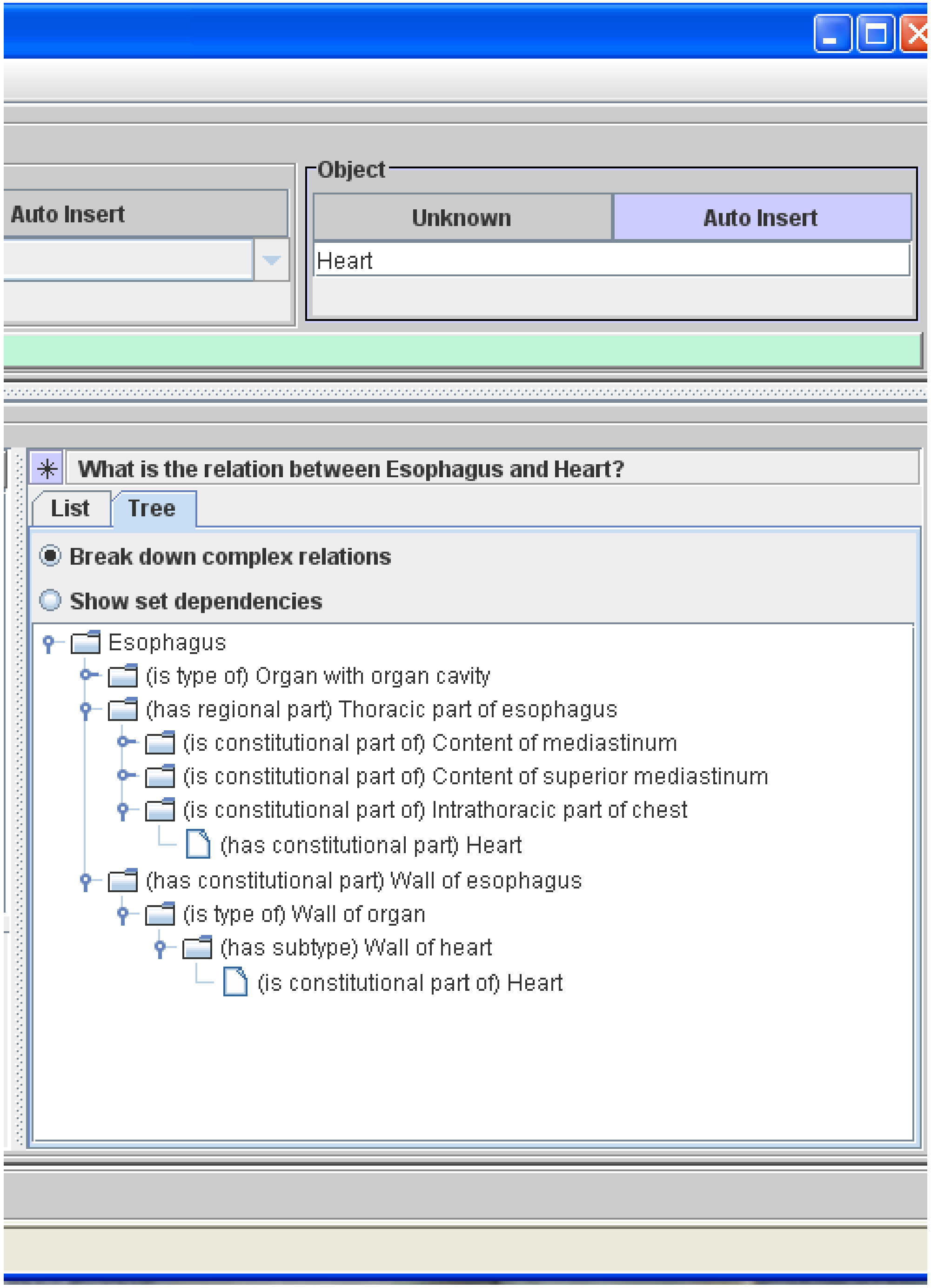

Emily Lite
File
Layout
Help
Query
Subject
Unknown
Auto Insert
Esophagus
Relation
Unknown
Auto Insert
has regional part
Closure
Object
Unknown
Auto Insert
- Query -
Class Operations
Physical anatomical entity
Show in Explorer
Explorer
Physical anatomical entity
Results
Delete
Set 1 (Esophagus is type of <unknown>)
What is regional part of Esophagus?
List
Tree
Abdominal part of esophagus
Cervical part of esophagus
Thoracic part of esophagus
Combine results
Set 1 (Esophagus is type of <unkn...
or
Set 1 (Esophagus is type of <unkn...
Combine
Ready for query
Java Application Window


Emily Lite
File Layout Help
Query
Subject
Unknown
Auto Insert
Esophagus
Relation
Unknown
Auto Insert
has regional part
Closure
Object
Unknown
Auto Insert
- Query -
Class Operations
Physical anatomical entity
Show in Explorer
Explorer
Physical anatomical entity
Results
Delete
Set 1 (Esophagus is type of <unknown>)
Set 2 (Esophagus has regional part <unkno
Combine results
Set 1 (Esophagus is type of <unkn...
or
Set 1 (Esophagus is type of <unkn...
Combine
What (is regional part of)+ Esophagus?
List
Tree
Abdominal part of esophagus
C6 segment of esophagus
C6 segment proper of esophagus
C7 segment of esophagus
Cervical part of esophagus
Esophageal segment of esophagogastric jun
Esophageal segment of pharyngoesophagea
T1 segment of esophagus
T10 segment of esophagus
T10 segment proper of esophagus
T2 segment of esophagus
T3 segment of esophagus
Ready for query
Java Application Window


Emily Lite
File Layout Help
Query
Subject
Unknown
Auto Insert
Esophagus
Relation
Unknown
Auto Insert
has constitutional part
Closure
Object
Unknown
Auto Insert
- Query -
Class Operations
Physical anatomical entity
Show in Explorer
Explorer
Physical anatomical entity
Results
Delete
Set 1 (Esophagus is type of <unknown>)
Set 2 (Esophagus has regional part <unknown
Set 3 (Esophagus (has regional part)+ <unkno
Set 4 (Esophagus (has constitutional part)+ <u
Combine results
Set 1 (Esophagus is type of <unkn...
or
Set 1 (Esophagus is type of <unkn...
Combine
What (is constitutional part of)+ Esophagu...
List
Tree
Adventitia of esophagus
Basement membrane of epithelium proper of
Circular muscle layer of esophagus
Dense irregular connective tissue of adventit
Dense regular collagenous tissue of submuc
Dense regular elastic tissue of lamina propri
Diffuse mucosa-associated lymphoid tissue
Epithelium of esophagus
Lamina propria of esophagus
Longitudinal muscle layer of esophagus
Lumen of esophagus
Mucosa of esophagus
Ready for query
Java Application Window


Emily Lite
File Layout Help
Query
Subject
Unknown
Auto Insert
Esophagus
Relation
Unknown
Auto Insert
has constitutional part
Object
Unknown
Auto Insert
Stomach
- Query -
Class Operations
Physical anatomical entity
Show in Explorer
Explorer
Physical anatomical entity
Results
Delete
Set 1 (Esophagus is type of <unknown>)
Set 2 (Esophagus has regional part <unknown
Set 3 (Esophagus (has regional part)+ <unkno
Set 4 (Esophagus (has constitutional part)+ <u
Set 5 (Esophagus <unknown> Stomach)
Combine results
Set 1 (Esophagus is type of <unkn...
or
Set 1 (Esophagus is type of <unkn...
Combine
What is the relation between Esophagus ...
List
Tree
is continuous with
is continuous with (attributed)
Ready for query
Java Application Window


Emily Lite
File Layout Help
Query
Subject
Unknown
Auto Insert
Esophagus
Relation
Unknown
Auto Insert
has constitutional part
Object
Unknown
Auto Insert
Heart
- Query -
Class Operations
Physical anatomical entity
Show in Explorer
Explorer
Physical anatomical entity
Results
Delete
Set 1 (Esophagus is type of <unknown>)
Set 2 (Esophagus has regional part <unknown>)
Set 3 (Esophagus (has regional part)+ <unknown>)
Set 4 (Esophagus (has constitutional part)+ <unknown>)
Set 5 (Esophagus <unknown> Stomach)
Set 6 (Esophagus <unknown> Heart)
What is the relation between Esophagus and Heart?
List
Tree
has regional part.is constitutional part of.has constitutional part
has regional part.is constitutional part of.has constitutional part.is nerve supply of
is type of.is type of.has subtype.has subtype
has constitutional part.is type of.has subtype.is constitutional part of
Combine results
Set 1 (Esophagus is type of <unknown>)
or
Set 1 (Esophagus is type of <unknown>)
Combine
Ready for query
Java Application Window


Object
Auto Insert
Unknown
Auto Insert
Heart
What is the relation between Esophagus and Heart?
List
Tree
Break down complex relations
Show set dependencies
Esophagus
(is type of) Organ with organ cavity
(has regional part) Thoracic part of esophagus
(is constitutional part of) Content of mediastinum
(is constitutional part of) Content of superior mediastinum
(is constitutional part of) Intrathoracic part of chest
(has constitutional part) Heart
(has constitutional part) Wall of esophagus
(is type of) Wall of organ
(has subtype) Wall of heart
(is constitutional part of) Heart