Using OWL and Description Logics Based Classification for Reasoning in Biomedical Applications

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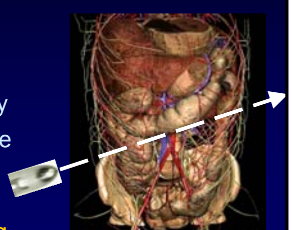
Motivation

- The Virtual Soldier Project
  - Computer-based *in-silico* model of human anatomy/physiology
  - Deliver just-in-time decision support to field medic in caring for battlefield injuries
- Components
  - Geometric representation of human anatomy
  - Computer reasoning services to predict injuries & consequences

Our task

- Use geometric models to predict expected organ damage from penetrating injury
  - Given: 3-D volumetric imaging data
  - Given: injury trajectory
  - Predict: organ damage and extent of injuries

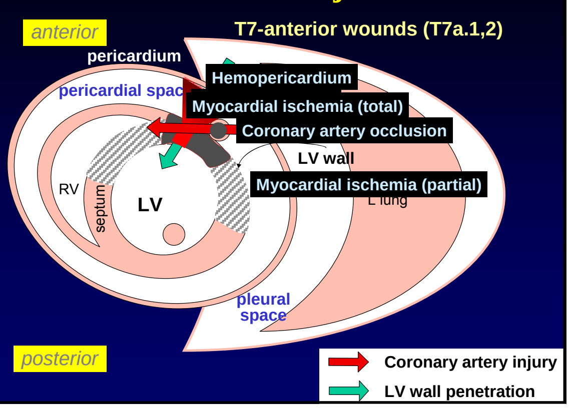
This task requires anatomic reasoning



Anatomic reasoning is complex

- Anatomic structure dependencies
  - Coronary arteries supply regions of myocardium
  - Injury to a coronary artery → myocardial ischemia
- Injury propagation
  - Penetration of LV wall → LV/peric continuity → hemopericardium, possible tamponade
  - Penetration of pericardium → peric/pleural continuity → hemothorax

Two cardiac injuries



Knowledge-based approach

- Knowledge: ontology of anatomy
  - Foundational Model of Anatomy (FMA; Mejino and Rosse)
  - Catalog of organs, organ parts
  - Relationships encode anatomic dependencies
- Reasoning services
  - Use FMA with description of trajectory of trauma to infer injuries

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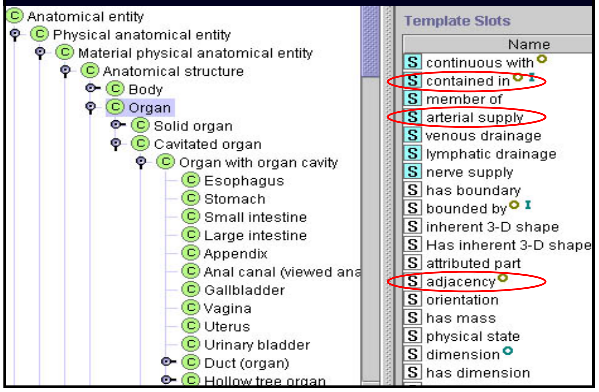
FMA: Frame-based Ontology



What is best approach to anatomic reasoning?

- Embed necessary knowledge for reasoning in application code

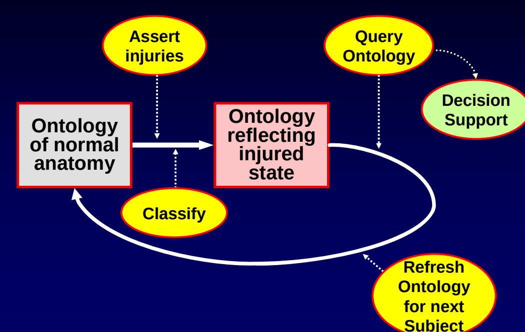
OR

- Represent knowledge in OWL, and use automatic classification for reasoning

Reasoning as classification task

- Inferring injury can be posed as a classification task
- Benefits
  - Declarative representation of all knowledge pertinent to reasoning
  - High-performance domain-independent classifiers
  - Removal of reasoning knowledge from application code

Reasoning pipeline



Method

- Knowledge representation
  - Translate FMA (cardiac anatomy) into OWL
  - Add knowledge describing heart injuries
  - Use automatic classification for reasoning
- Two anatomic reasoning applications
  - Infer consequences of coronary artery injury
  - Infer consequences of heart wall injury with and without clot formation

Both implemented by extending FMA-OWL with a few classes to model injuries

FMA translation into OWL

- Subset of FMA pertaining to cardiac anatomy
  - Manually-compiled translation rules
    - E.g., hasDirectAnatomicalPart slot values → axiom using hasDirectAnatomicPart relation
  - Python scripts implement ontology operations
  - Manual editing of classes in some places
    - E.g., Atrium subclassOf(LA or RA)

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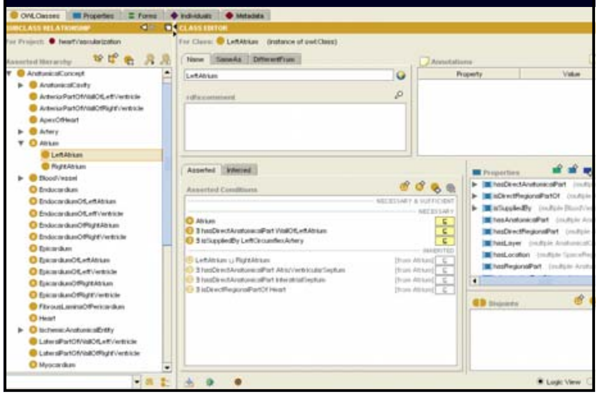
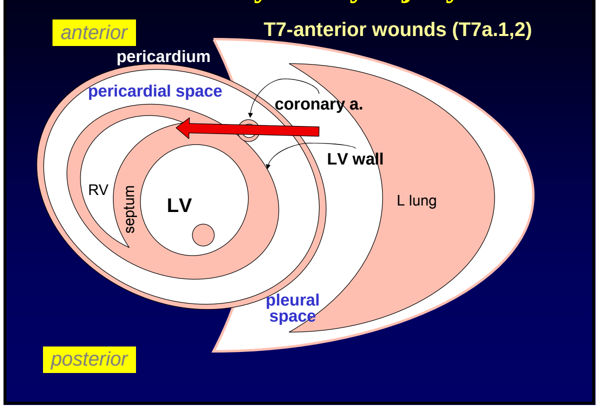
FMA in OWL

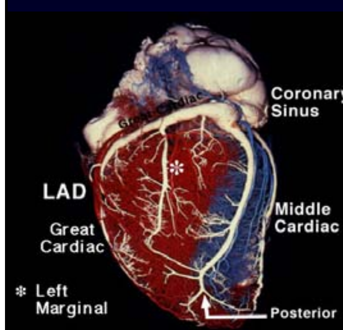


Reasoning about coronary artery injury

Coronary artery injury

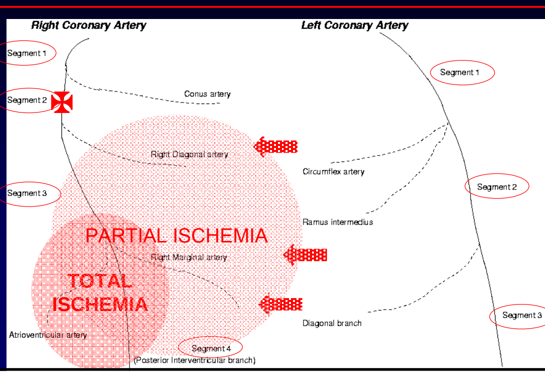


Different parts of heart are supplied by different coronary artery segments



Heart chambers in geometric models are subdivided into perfusion zones using anatomic knowledge in the FMA ontology

Anatomic knowledge: coronary arteries have segments



Reasoning about coronary artery injury in OWL

- Define organ parts in terms of segments of arteries supplying them
- Thus, inferring consequence of coronary artery injury is a classification task
- To *describe injury*, assert segmental arterial injury in the ontology
- To *infer consequences of injury*, apply automatic classification to the ontology

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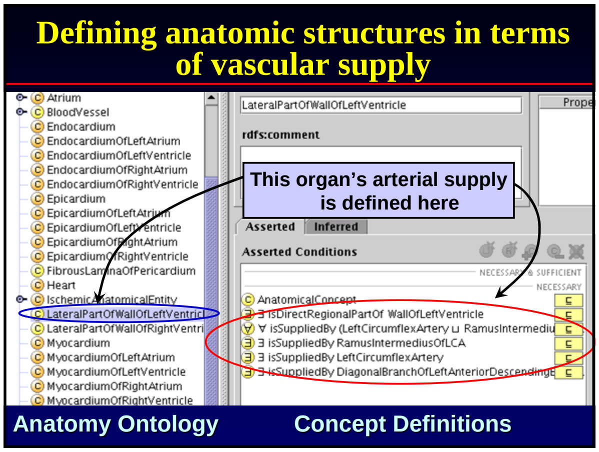

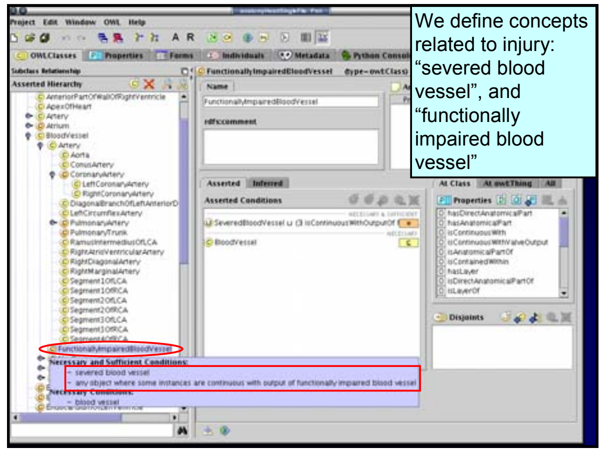

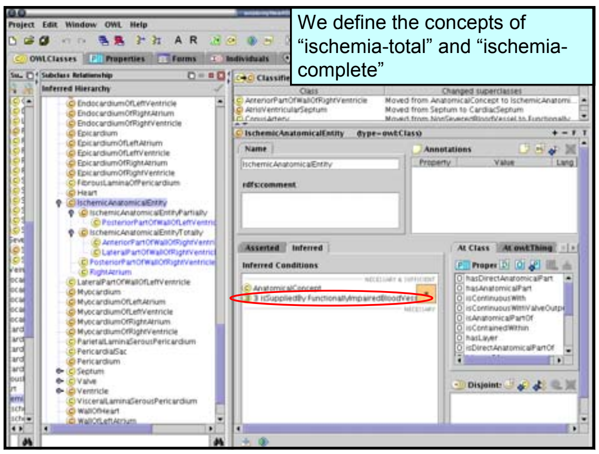

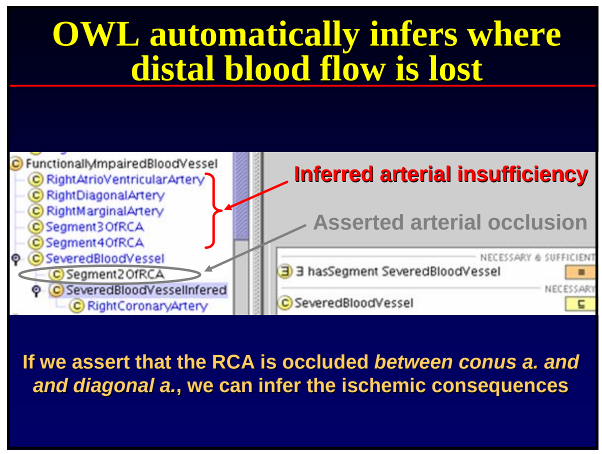

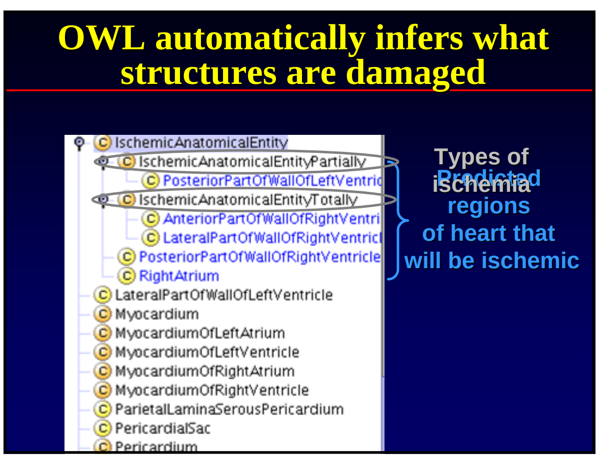

Using inferred knowledge

- After classification, the inferred ontology reflects knowledge about the post-injury state
- Interrogate ontology to find the functionally impaired arteries and ischemic heart regions
- Update the pre-injury geometry to display the post-injury state

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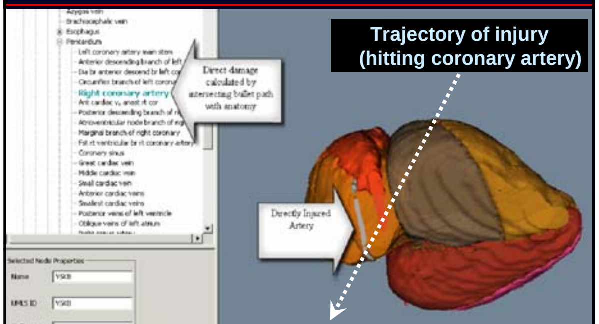
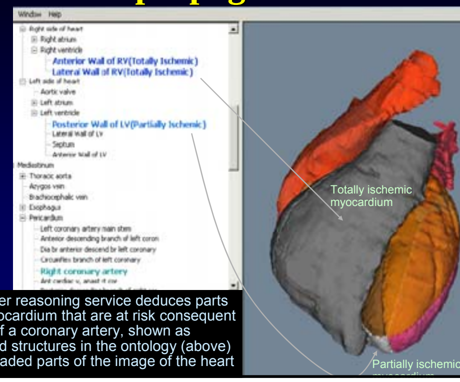
Desiderata: an example injury



A trajectory is described, and predicted initial injuries are displayed

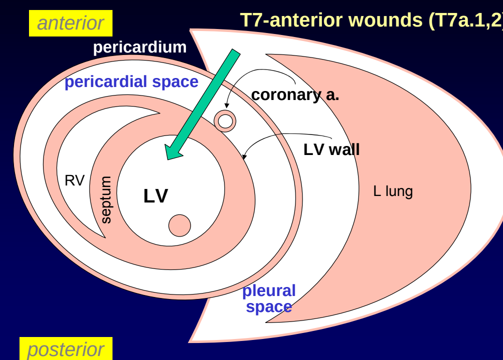
Desiderata: inferring injury propagation



A computer reasoning service deduces parts of the myocardium that are at risk consequent to injury of a coronary artery, shown as highlighted structures in the ontology (above) and as shaded parts of the image of the heart (right)

Reasoning about heart wall injury

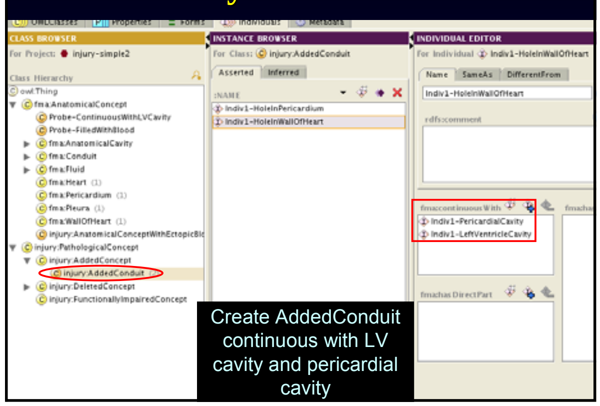
LV wall penetration injury



Representing injury

- Class AddedConduit represents a conduit
- Penetration of the wall of the heart
  - Create instance of AddedConduit and say it is continuous with both the cavity of the left ventricle and the cavity of the pericardium of this individual
  - Add this AddedConduit as a part of the wall of the heart

Continuity of Added Conduit



Create AddedConduit continuous with LV cavity and pericardial cavity

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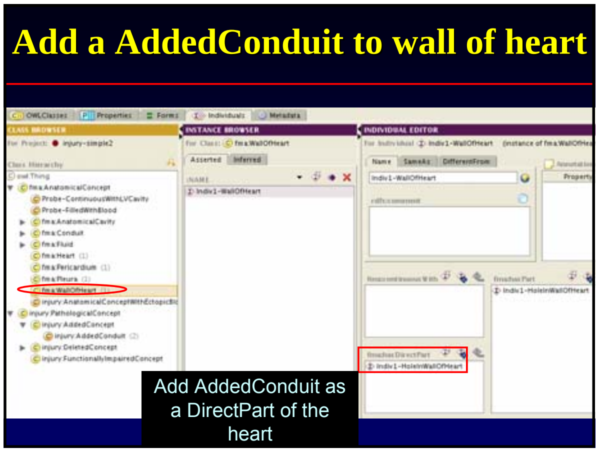

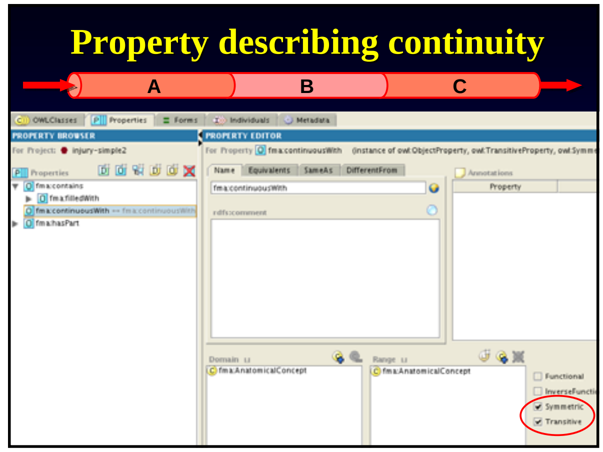

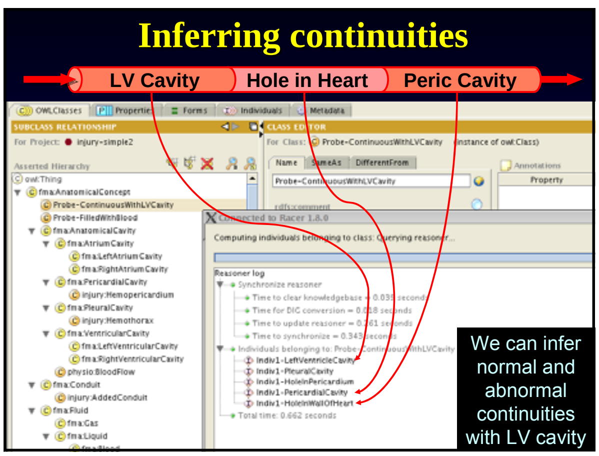

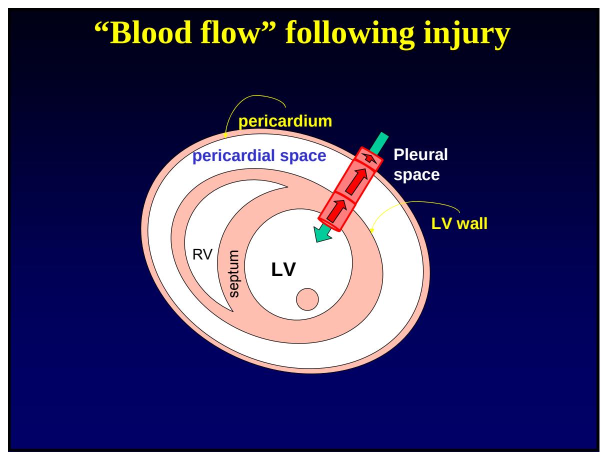

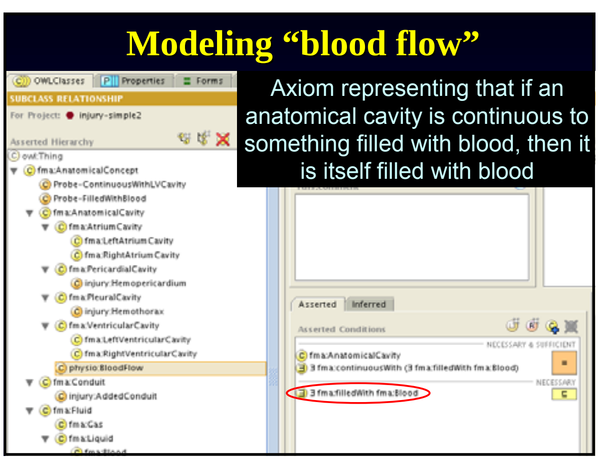

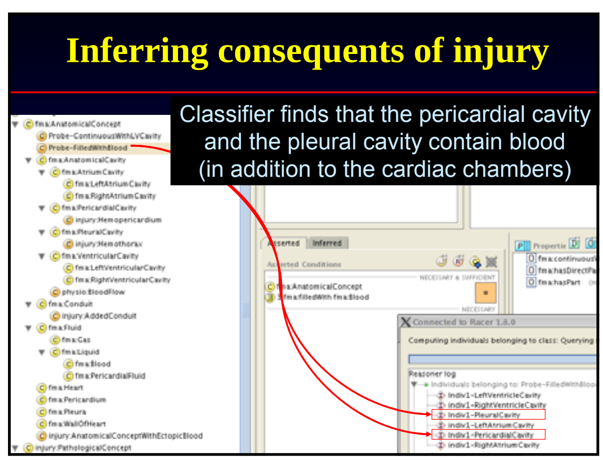

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Discussion

- OWL in biomedical applications has to date focused on "terminological" aspects of knowledge
- Can use OWL for other reasoning applications
  - Advantage: promotes knowledge reuse
  - Disadvantage: difficulty in OWL modeling for inexperienced users; may not be most computationally efficient approach

Conclusions

- Certain biomedical reasoning tasks can be posed as classification problem
- Benefits of OWL & automatic classification for automated reasoning
  - Declarative model of knowledge used for reasoning in ontology
  - OWL is an emerging KR standard
  - Representation of patient state in ontology
  - Exploits reuse of existing ontologies—can create new reasoning applications via straightforward extensions to ontology

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Thank you.

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