Ontology Languages and Engineering

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What is an Ontology?

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An explicit specification of a conceptualization

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A model of (some aspect of) the world

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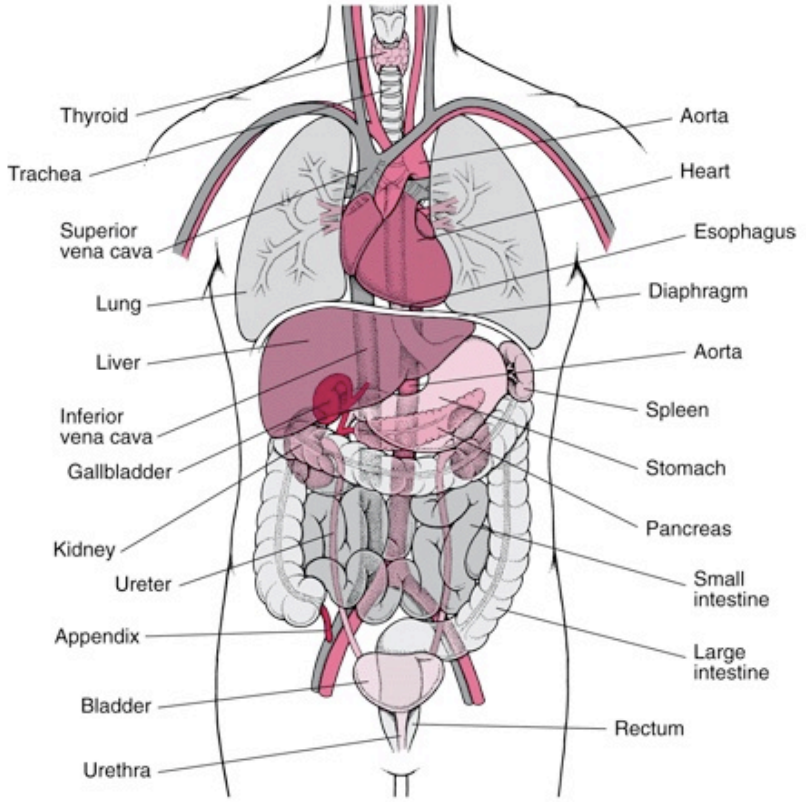
- Introduces **vocabulary** relevant to domain, e.g.:
  - Anatomy



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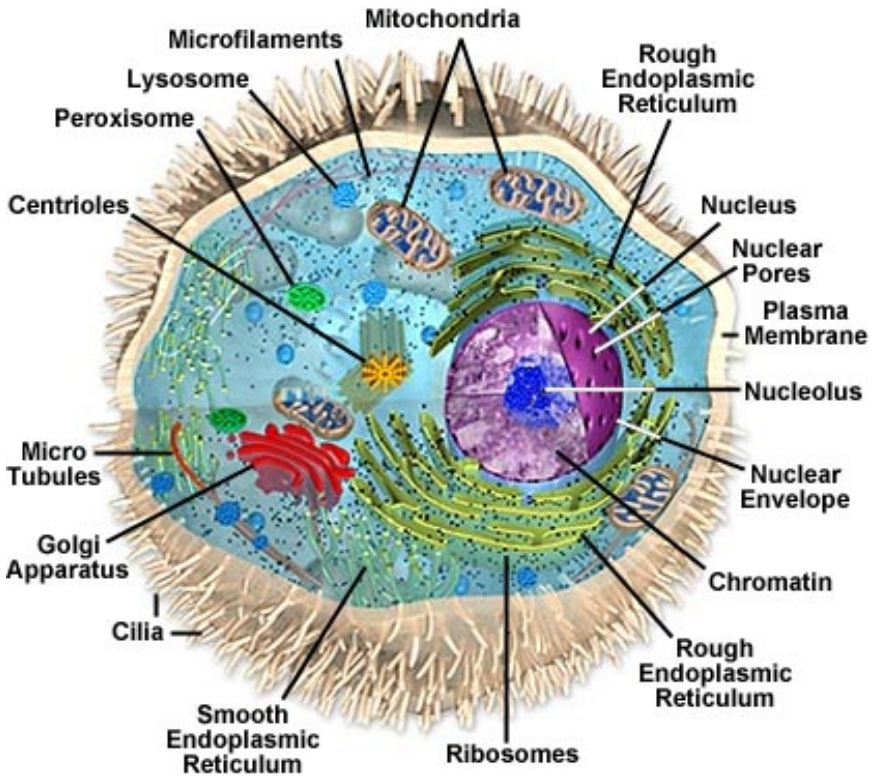

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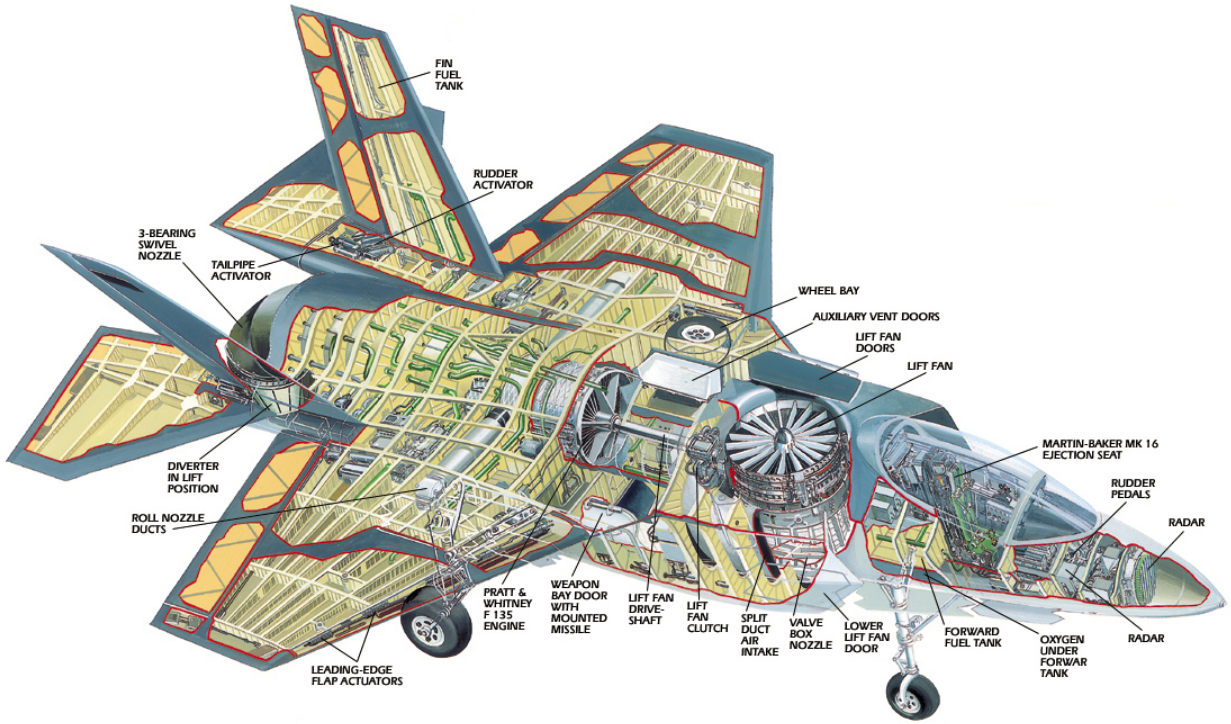

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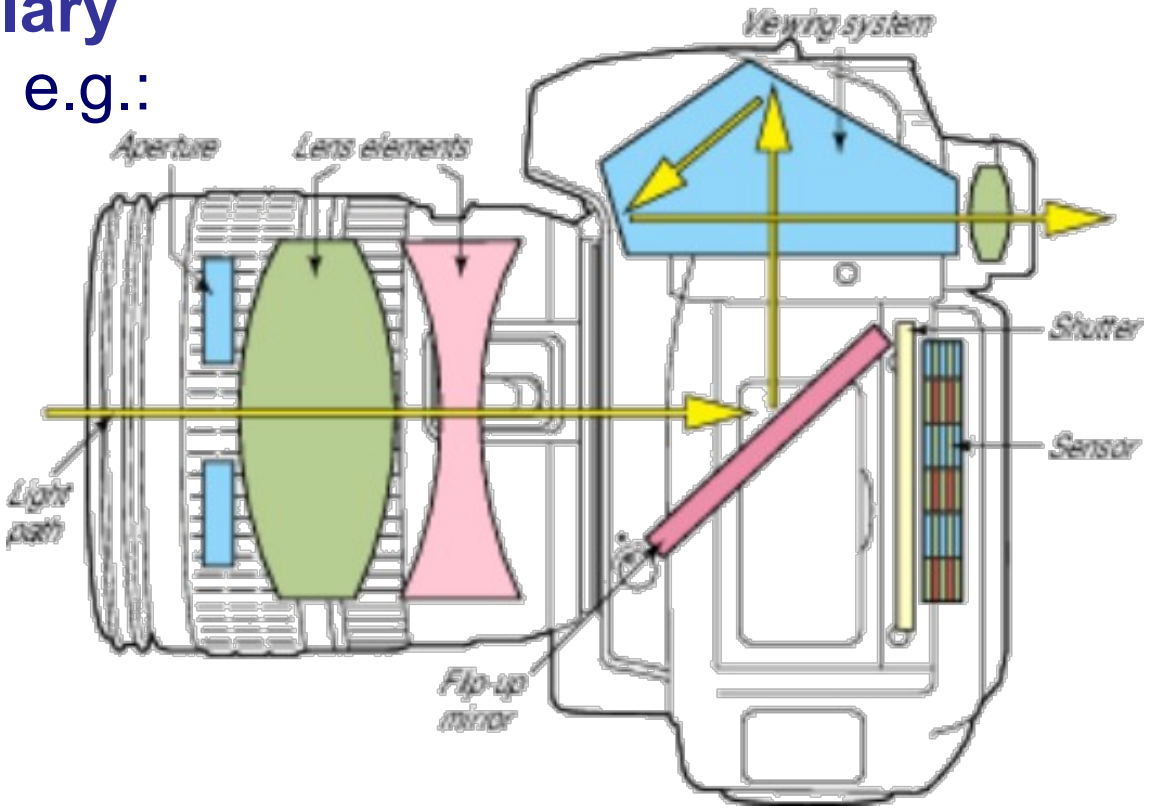

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  - Pizzas
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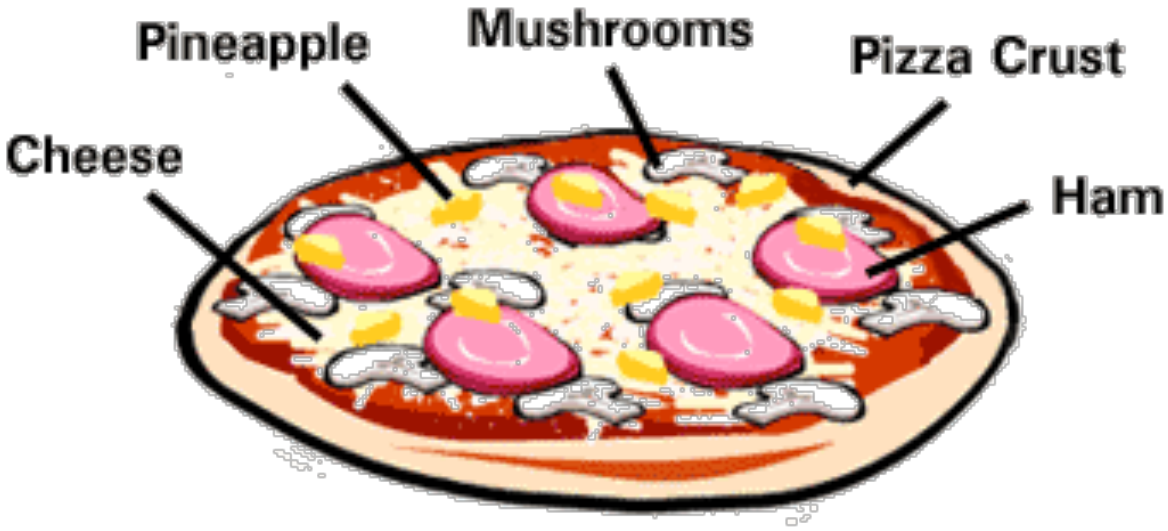

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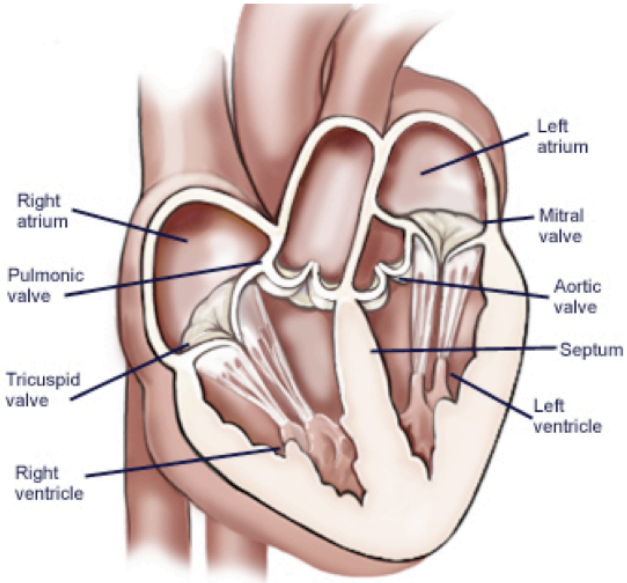
- Specifies *relative* **meaning** (aka semantics) of terms

  Heart is a muscular organ that is part of the circulatory system



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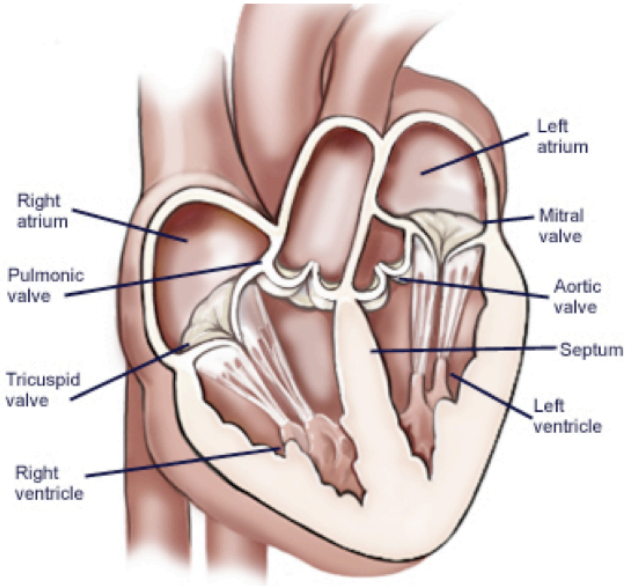
- **Formalised** e.g. using suitable logic

$$\mathsf{Heart} \sqsubseteq \mathsf{MuscularOrgan} \sqcap \exists \mathsf{isPartOf}.\mathsf{CirculatorySystem}$$



What are Ontologies Used For?

- Coherent **shared view** of domain
  - Help identify and resolve disagreements
- Ontology-based **Information Systems**
  - User-centric view of data that is independent of logical/physical schema
  - Answers reflect knowledge & data, e.g.:

Now... *that* should clear up a few things around here

What are Ontologies Used For?

$$Q(x) \leftarrow \text{Patient}(x) \wedge \text{suffersFrom}(x, y) \wedge \text{VascularDisease}(y)$$

i.e., "Patients suffering from Vascular Disease"

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$$+$$

$$\begin{aligned}
\mathsf{Heart} &\sqsubseteq \mathsf{MuscularOrgan} \sqcap \exists \mathsf{isPartOf}.\mathsf{CirculatorySystem} \\
\mathsf{HeartDisease} &\equiv \mathsf{Disease} \sqcap \exists \mathsf{affects}.\mathsf{Heart} \\
\mathsf{VascularDisease} &\equiv \mathsf{Disease} \sqcap \exists \mathsf{affects}.(\exists \mathsf{isPartOf}.\mathsf{CirculatorySystem})
\end{aligned}$$

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  - Query expansion/navigation/refinement
  - Incomplete and semi-structured data
  - ...

More "intelligent" applications

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  - Answer reflecting schema & data, e.g.:
    - "Patient suffering from Wasting Disease"
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THE SEMANTIC WEB

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  – **RDF** provides uniform syntactic structure for data

  – **OWL** provides machine readable schemas (**ontologies**)

i.e., a large distributed ontology based information system

A Brief History of OWL

- RDF standard first published 1999; revised 2004
- RDF extended to **RDFS**, a primitive ontology language
  - classes and properties; sub/super-classes (and properties); range and domain (of properties)
- But RDFS **lacks** important **features**, e.g.:
  - existence/cardinality constraints; transitive/inverse properties; localised range and domain constraints, …
- And RDF(S) has “higher order flavour” with no (later **non-standard**) **formal semantics**
  - difficult to understand or to provide reasoning support

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  - Further development carried out by “Joint EU/US Committee”
- DAML+OIL submitted to W3C as basis for standardisation
  - **WebOnt** WG developed OWL (2004)
  - **OWL** WG developed OWL 2 (2009)
- OWL (2) based on $\mathcal{SHOIN}$ ($\mathcal{SROIQ}$) Description Logics!?

What are Description Logics (DLs)?

- Fragments of **first order logic** designed for KR
- Useful computational properties
  - **Decidable** (essential)
  - Low complexity (desirable)
- Succinct and **variable free syntax**

$$\mathsf{Heart} \sqsubseteq \mathsf{MuscularOrgan} \sqcap \exists \mathsf{isPartOf}.\mathsf{CirculatorySystem}$$

$$\forall x.[\mathsf{Heart}(x) \rightarrow \mathsf{MuscularOrgan}(x) \wedge \exists y.[\mathsf{isPartOf}(x,y) \wedge \mathsf{CirculatorySystem}(y)]]$$

Why base OWL on a (Description) Logic?

Can exploit the results of 20+ years of DL research

- Well defined (model theoretic) **semantics**

Constructor	DL Syntax	Example	FOL Syntax
intersectionOf	$C_1 \sqcap \ldots \sqcap C_n$	Human $\sqcap$ Male	$C_1(x) \wedge \ldots \wedge C_n(x)$
unionOf	$C_1 \sqcup \ldots \sqcup C_n$	Doctor $\sqcup$ Lawyer	$C_1(x) \vee \ldots \vee C_n(x)$
complementOf	$\neg C$	$\neg$Male	$\neg C(x)$
oneOf	$\{x_1\} \sqcup \ldots \sqcup \{x_n\}$	{john} $\sqcup$ {mary}	$x = x_1 \vee \ldots \vee x = x_n$
allValuesFrom	$\forall P.C$	$\forall$hasChild.Doctor	$\forall y.P(x,y) \rightarrow C(y)$
someValuesFrom	$\exists P.C$	$\exists$hasChild.Lawyer	$\exists y.P(x,y) \wedge C(y)$
maxCardinality	$\leqslant nP$	$\leqslant$1hasChild	$\exists^{\leqslant n} y.P(x,y)$
minCardinality	$\geqslant nP$	$\geqslant$2hasChild	$\exists^{\geqslant n} y.P(x,y)$

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- **Formal properties** well understood (complexity, decidability)

I can't find an efficient algorithm, but neither can all these famous people.

[Garey & Johnson. Computers and Intractability]

Why base OWL on a (Description) Logic?

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- Well defined (model theoretic) **semantics**
- **Formal properties** well understood (complexity, decidability)
- Practical **reasoning algorithms**

$\sqcap$-rule	if 1. $(C_1 \sqcap C_2) \in \mathcal{L}(v)$, v is not indirectly blocked, and 2. $\{C_1, C_2\} \not\subseteq \mathcal{L}(v)$ then $\mathcal{L}(v) \rightarrow \mathcal{L}(v) \cup \{C_1, C_2\}$.
$\sqcup$-rule	if 1. $(C_1 \sqcup C_2) \in \mathcal{L}(v)$, v is not indirectly blocked, and 2. $\{C_1, C_2\} \cap \mathcal{L}(v) = \emptyset$ then $\mathcal{L}(v) \rightarrow \mathcal{L}(v) \cup \{E\}$ for some $E \in \{C_1, C_2\}$
$\exists$-rule	if 1. $\exists r.C \in \mathcal{L}(v_1)$, v_1 is not blocked, and 2. v_1 has no safe r-neighbour v_2 with $C \in \mathcal{L}(v_1)$, then create a new node v_2 and an edge $\langle v_1, v_2 \rangle$ with $\mathcal{L}(v_2) = \{C\}$ and $\mathcal{L}(\langle v_1, v_2 \rangle) = \{r\}$.
$\forall$-rule	if 1. $\forall r.C \in \mathcal{L}(v_1)$, v_1 is not indirectly blocked, and 2. there is an r-neighbour v_2 of v_1 with $C \notin \mathcal{L}(v_2)$ then $\mathcal{L}(v_2) \rightarrow \mathcal{L}(v_2) \cup \{C\}$.
$\forall_+$-rule	if 1. $\forall r.C \in \mathcal{L}(v_1)$, v_1 is not indirectly blocked, and 2. there is some role r' with Trans(r') and $r' \sqsubseteq^* r$ 3. there is an r'-neighbour v_2 of v_1 with $\forall r'.C \notin \mathcal{L}(v_2)$ then $\mathcal{L}(v_2) \rightarrow \mathcal{L}(v_2) \cup \{\forall r'.C\}$.
choose-rule	if 1. $\leqslant n\, r.C \in \mathcal{L}(v_1)$, v_1 is not indirectly blocked, and 2. there is an r-neighbour v_2 of v_1 with $\{C, \doteq\neg C\} \cap \mathcal{L}(v_2) = \emptyset$ then $\mathcal{L}(v_2) \rightarrow \mathcal{L}(v_2) \cup \{E\}$ for some $E \in \{C, \doteq\neg C\}$.
$\geqslant$-rule	if 1. $\geqslant n\, r.C \in \mathcal{L}(v)$, v is not blocked, and 2. there are not n safe r-neighbours $v_1, \ldots, v_n$ of v with $C \in \mathcal{L}(v_i)$ and $v_i \neq v_j$ for $1 \leqslant i < j \leqslant n$

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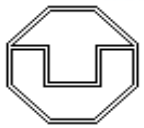
- **Formal properties** well understood (complexity, decidability)
- Practical **reasoning algorithms**
- Effective **implemented systems**

KAON2



CEL

What did OWL ever do for us?

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Ontologies before:

Name	Original Language	de-fined	primi-tive	arti-ficial	$\sum$	de-fined	primi-tive
		concepts				roles	
CKB	SB-ONE	23	57	58	138	2	46
Companies	BACK	70	45	81	196	1	39
FSS	SB-ONE	34	98	75	207	0	47
Espresso	SB-ONE	0	145	79	224	11	41
Wisber	TURQ	50	81	152	283	6	18
Wines	CLASSIC	50	148	237	435	0	10

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Ontologies after:

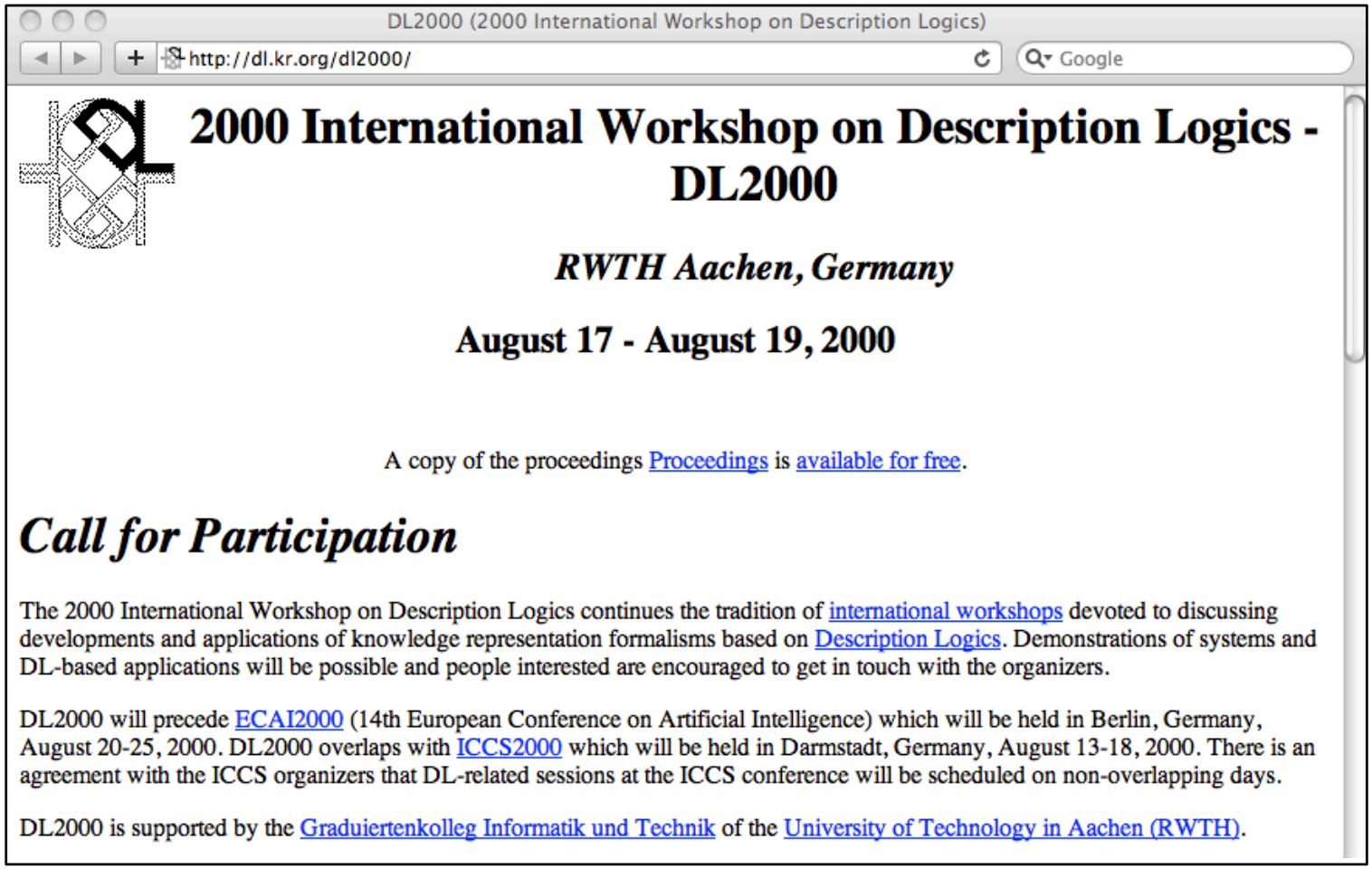
Welcome to the Protege Ontology Library!

OWL ontologies

- AIM@SHAPE Ontologies: Ontologies pertaining to digital shapes. Source: AIM@SHAPE NoE - Advanced and Innovative Models And Tools for the development of Semantic-based systems for Handling, Acquiring, and Processing knowledge Embedded in multidimensional digital objects.
- amino-acid.owl: A small OWL ontology of amino acids and their properties. Source: Amino Acid Ontology Web site.
- Basic Formal Ontology (BFO)
- bhakti.owl: An OWL ontology for the transcendental states of consciousness experienced by practitioners of bhakti-yoga, a form of Vedic consciousness engineering.
- Biochemical Ontologies: Over 30 ontologies for knowledge representation and reasoning across scientific domains. Ontologies are normalized into non-disjoint primitive skeletons and

What did OWL ever do for us?

"**Profile**" before:



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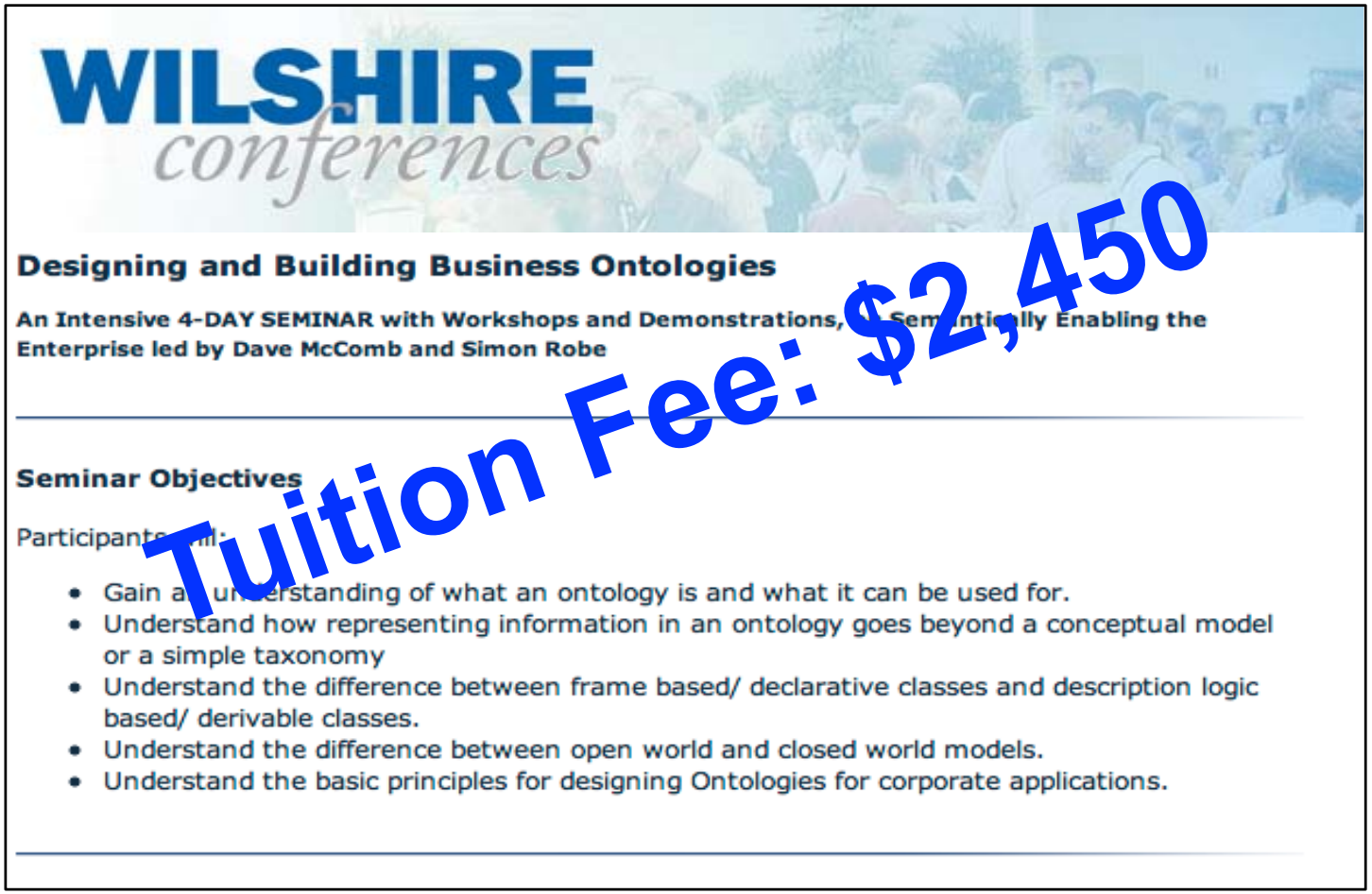

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Applications before:

What did OWL ever do for us?

Applications after:

- eScience, eCommerce, geography, engineering, defence, …
- Major impact in healthcare and life sciences
- Mainstream technology supported by, e.g., ORACLE 11g
- Increasing impact in business applications

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Peter and Ian before:

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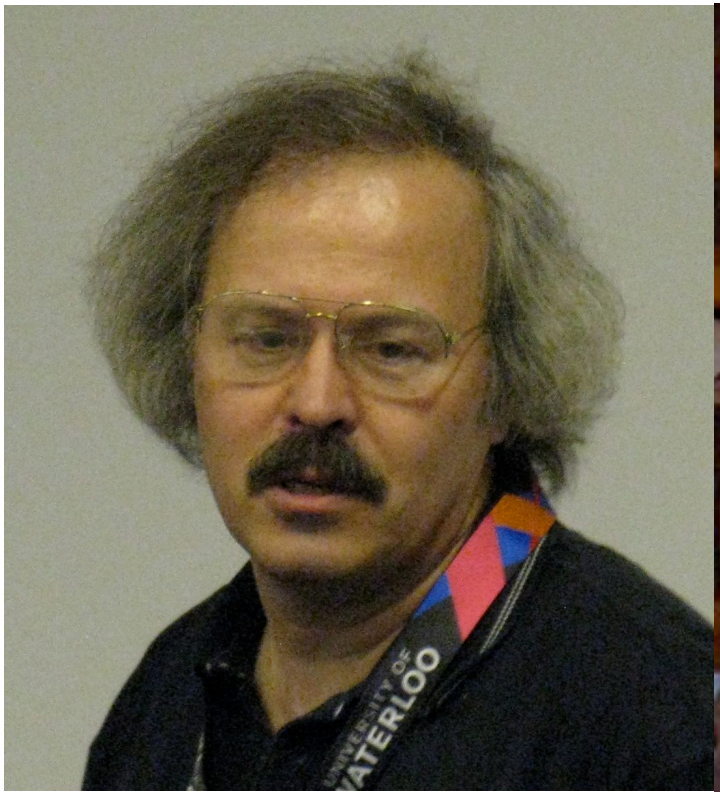
Peter and Ian after:



What did OWL ever do for us?

Tools before:

```
> (load-tkb "demo.kb" :verbose T)
  ..........................................
  ........................
> (classify-tkb :mode :stars)
  pppppppppppppppppccpcppcccpcppcpcppcccppccpcp
  pcccccppcpcppcccp
  T
> (direct-supers 'MAN)
  (c[HUMAN] c[MALE])
>
```

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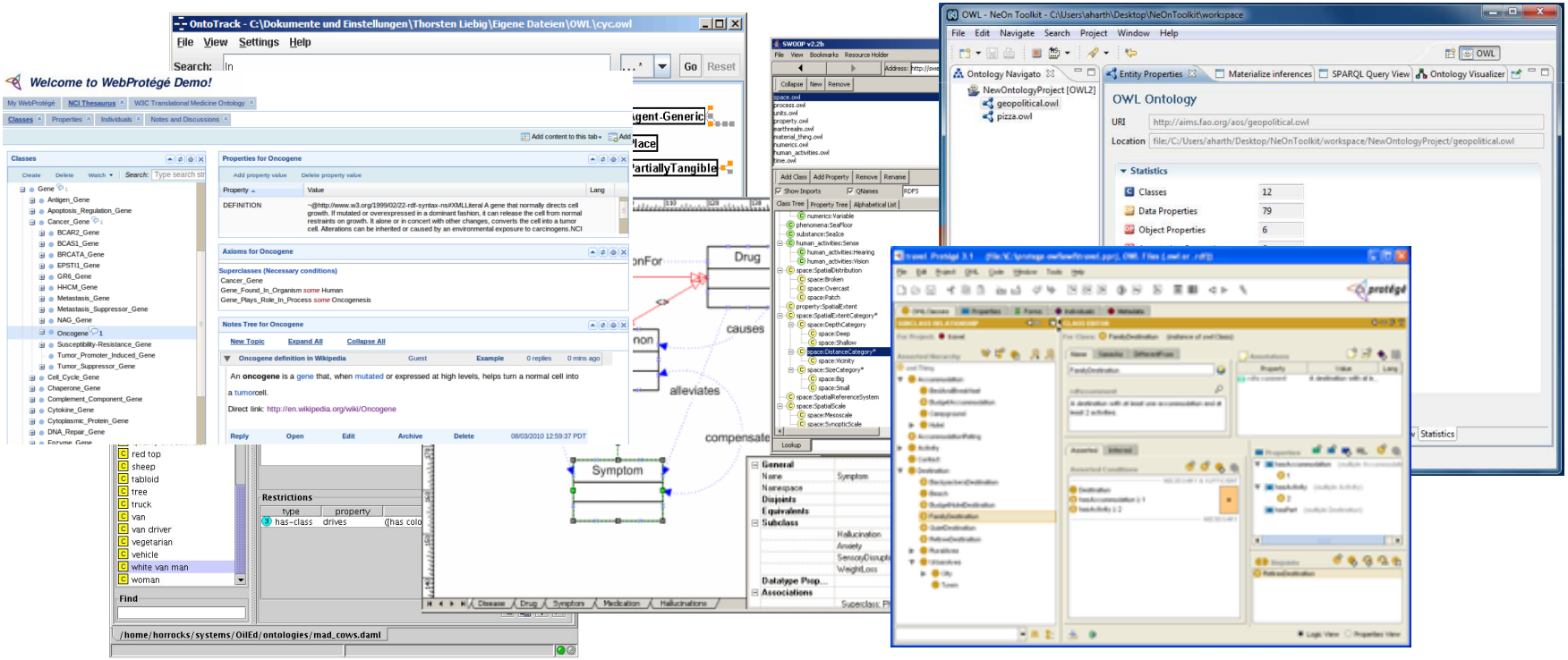

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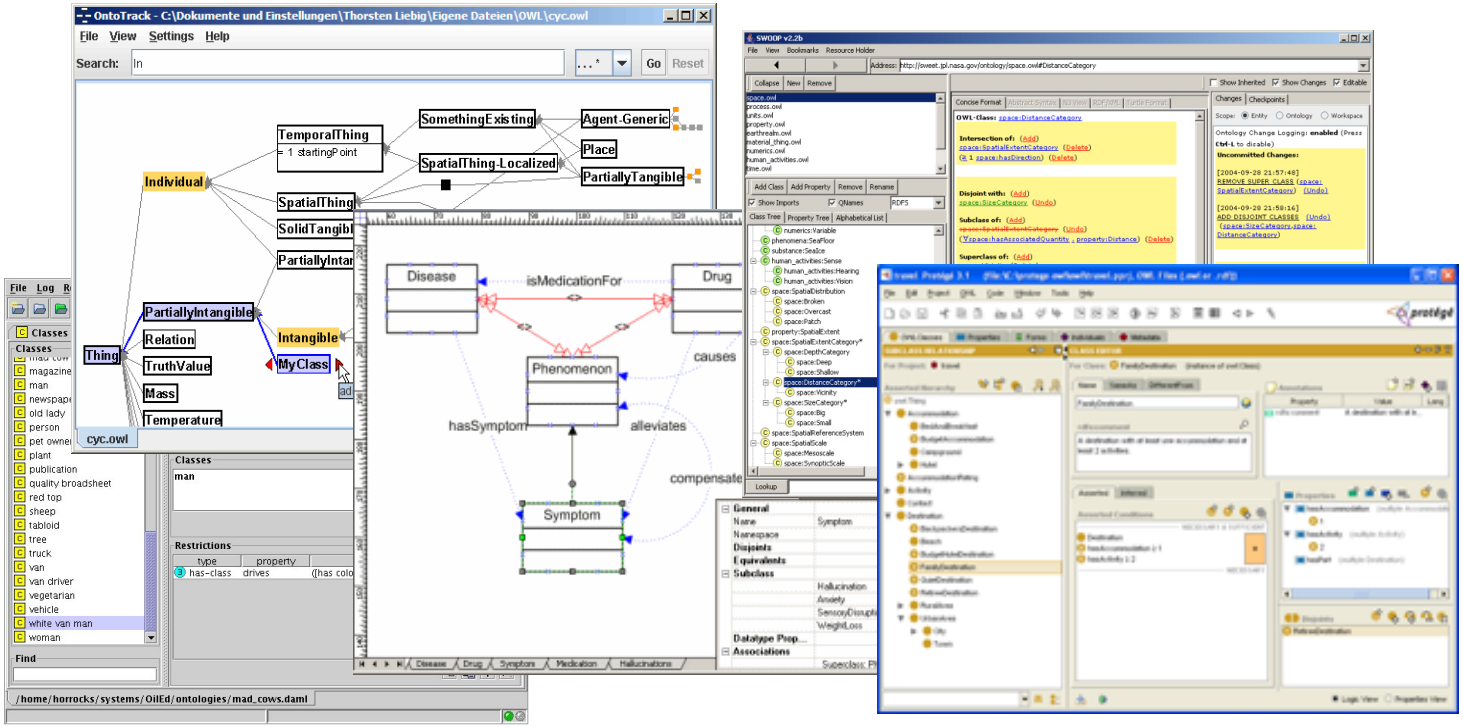

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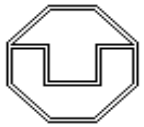

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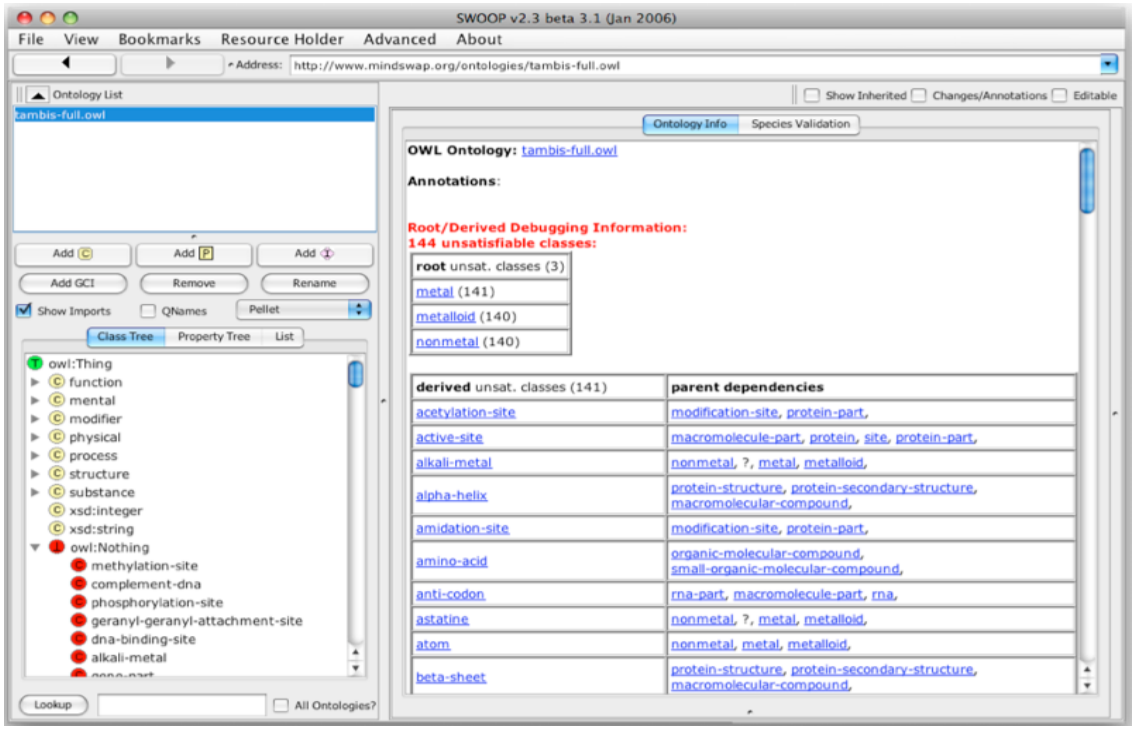
- Editors/development environments
- Reasoners
- Explanation, justification and pinpointing



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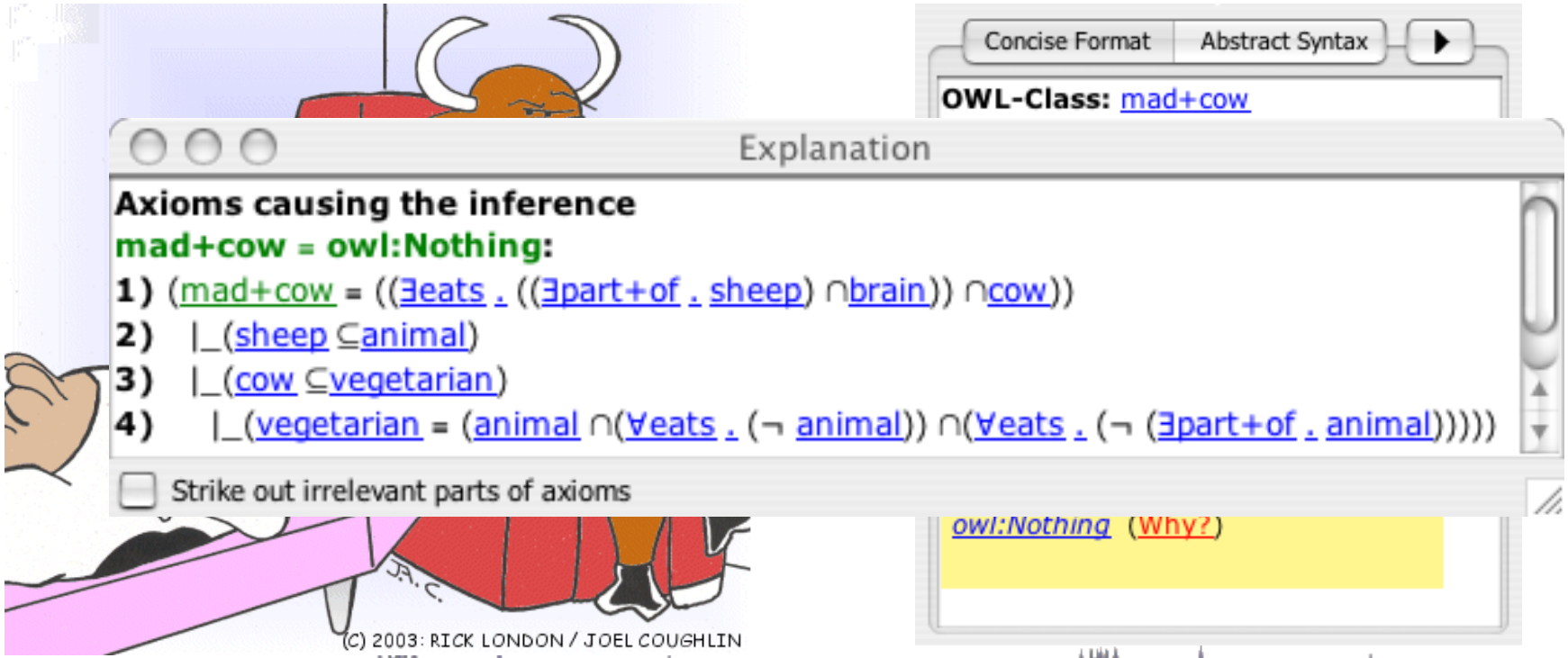

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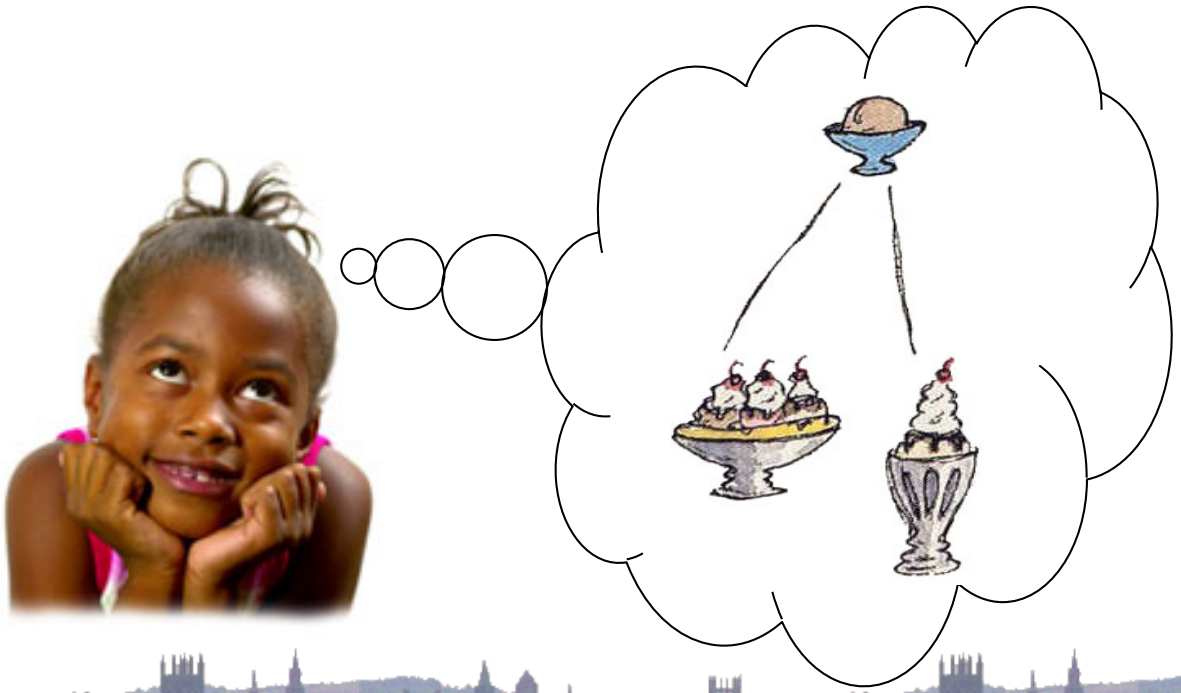

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  - expected subsumptions hold (consistent with intuitions)
  - unexpected equivalences hold (unintended synonyms)

Case Study: HCLS

- **OBO foundry** includes more than 100 biological and biomedical ontologies
- **Siemens** "actively building OWL based clinical solutions"
- OWL tools used to find and repair critical errors in ontology used at **Columbia Presbyterian**
- **SNOMED-CT** (Clinical Terms) ontology
  - used in healthcare systems of more than 15 countries, including Australia, Canada, Denmark, Spain, Sweden and the UK
  - also used by major US providers, e.g., Kaiser Permanente
  - ontology provides common vocabulary for recording clinical data

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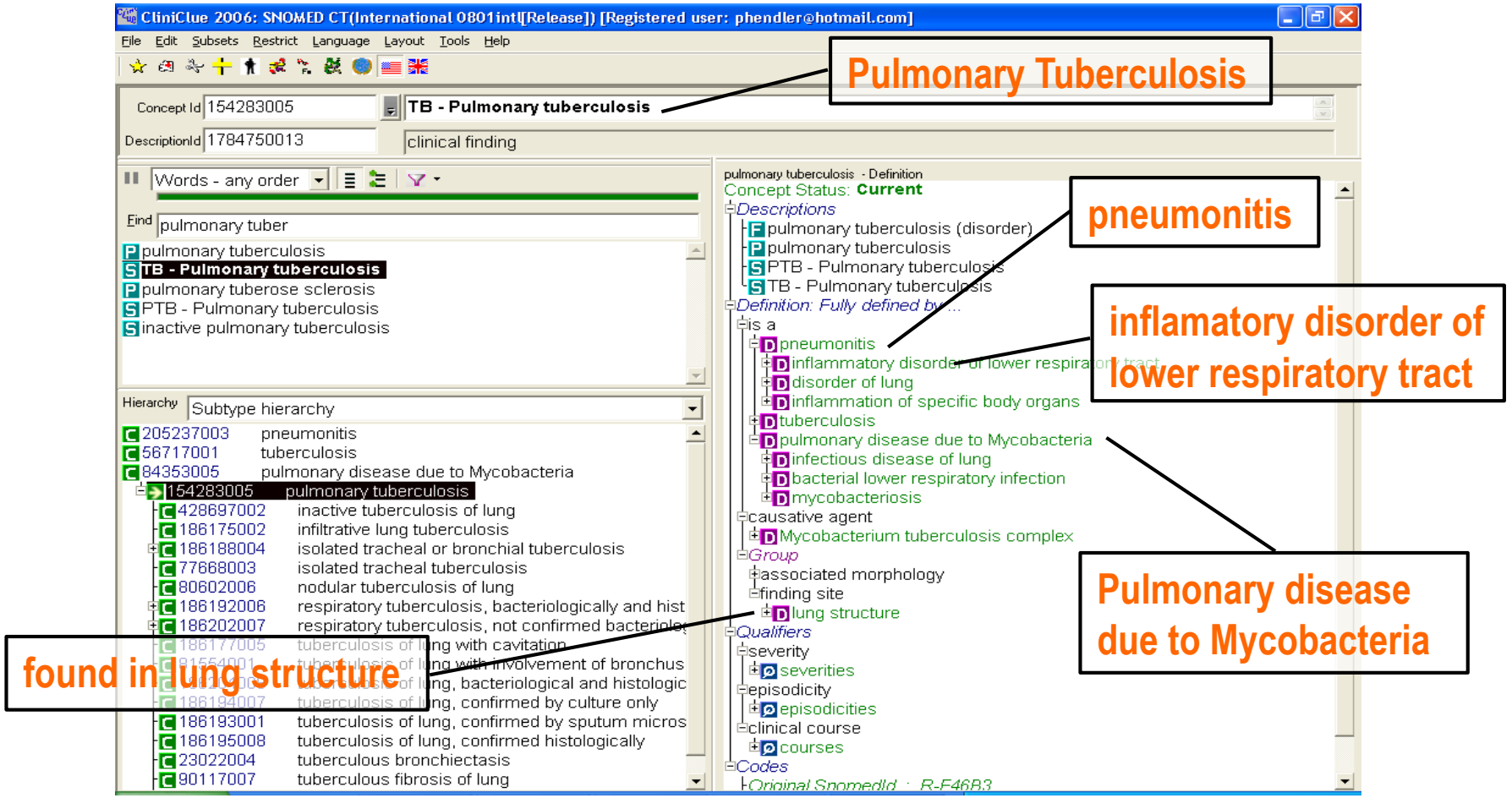

Case Study: HCLS

- **Kaiser Permanente** extending SNOMED to express, e.g.:
  - *non-viral pneumonia* (negation)
  - *infectious pneumonia* is caused by a *virus* or a *bacterium* (disjunction)
  - *double pneumonia* occurs in two *lungs* (cardinalities)
- This is easy in **SNOMED-OWL**
  - but reasoner failed to find expected subsumptions, e.g., that *bacterial pneumonia* is a kind of *non-viral pneumonia*
- Ontology highly **under-constrained**: need to add disjointness axioms (at least)
  - *virus* and *bacterium* must be disjoint

Case Study: HCLS

- Adding disjointness led to **surprising results**
  - many classes become inconsistent, e.g., *percutanious embolization of hepatic artery using fluoroscopy guidance*
- Cause of **inconsistencies** identified as class *groin*
  - *groin* asserted to be subclass of both *abdomen* and *leg*
  - *abdomen and leg* are disjoint
  - modelling of *groin* (and other similar "junction" regions) identified as incorrect

Case Study: HCLS

- Correct modelling of groin is quite complex, e.g.:
  - groin has a part that is part of the abdomen, and has a part that is part of the leg (***inverse properties***)

$$\mathsf{Groin} \sqsubseteq \exists \mathsf{hasPart}.(\exists \mathsf{isPartOf}.\mathsf{Abdomen}))$$
$$\mathsf{Groin} \sqsubseteq \exists \mathsf{hasPart}.(\exists \mathsf{isPartOf}.\mathsf{Leg})$$
$$\mathsf{hasPart} \equiv \mathsf{isPartOf}^{-}$$

  - all parts of the groin are part of the abdomen or the leg (**disjunction**)

$$\mathsf{Groin} \sqsubseteq \forall \mathsf{hasPart}.(\exists \mathsf{isPartOf}.(\mathsf{Abdomen} \sqcup \mathsf{Leg}))$$

  - ...

Case Study: HCLS

What we learned:

- Ontology engineering is **error prone**
  - errors of omission (e.g., disjointness) and commission (e.g., modelling of groin)
- **Expressive features** of OWL are sometimes needed
- Sophisticated tool support is **essential**
  - handling ontologies of this size is challenging
  - domain experts (and logicians!) often need help to understand the (root) cause of both inconsistencies and non-subsumptions
  - surprising and unexplained (non-) inferences are frustrating for users and may cause them to lose faith in the reasoner

Case Study: BBC

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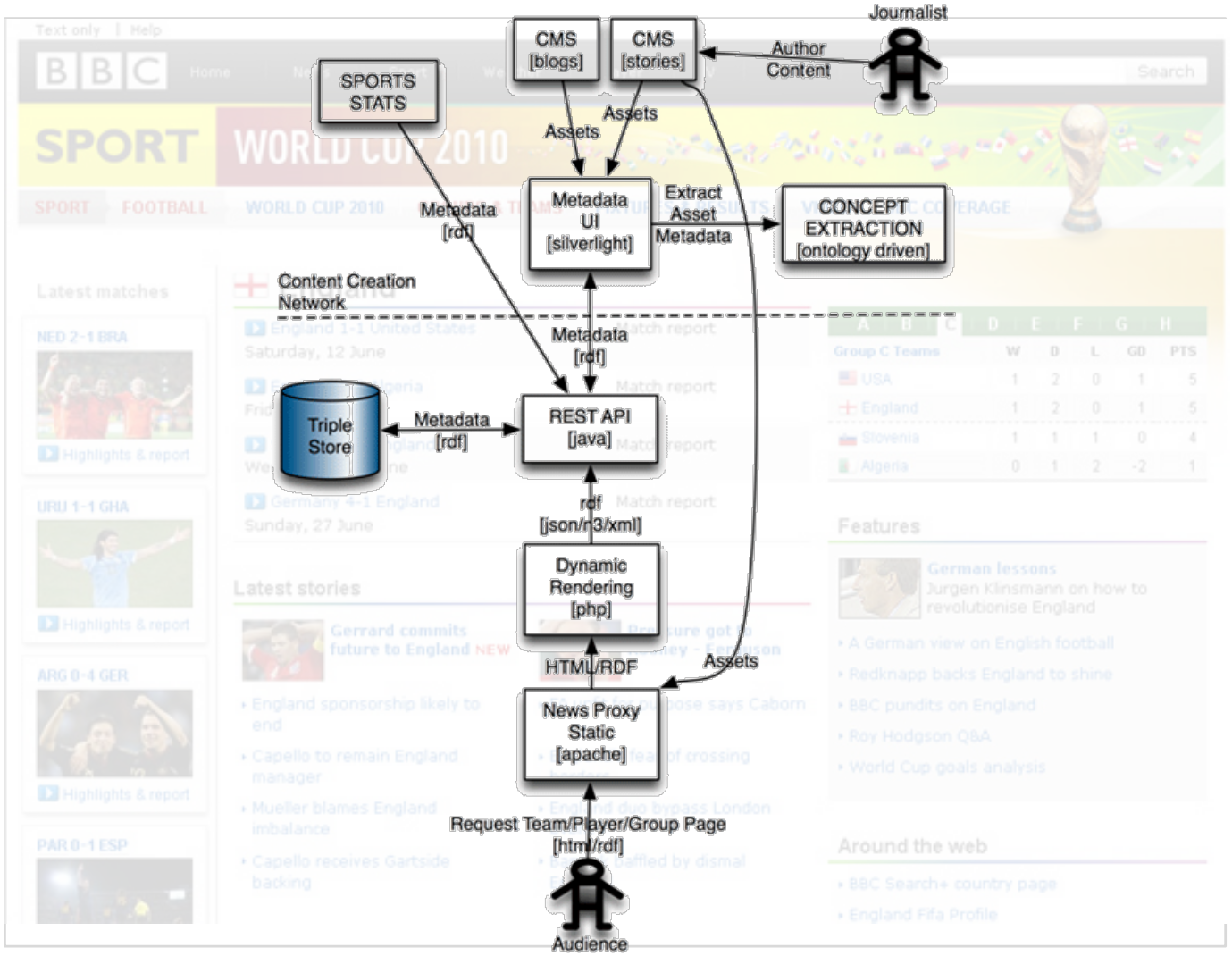

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$$\text{John} : \text{Patient} \sqcap \exists \text{suffersFrom}.\text{HeartDisease}$$

$$+$$

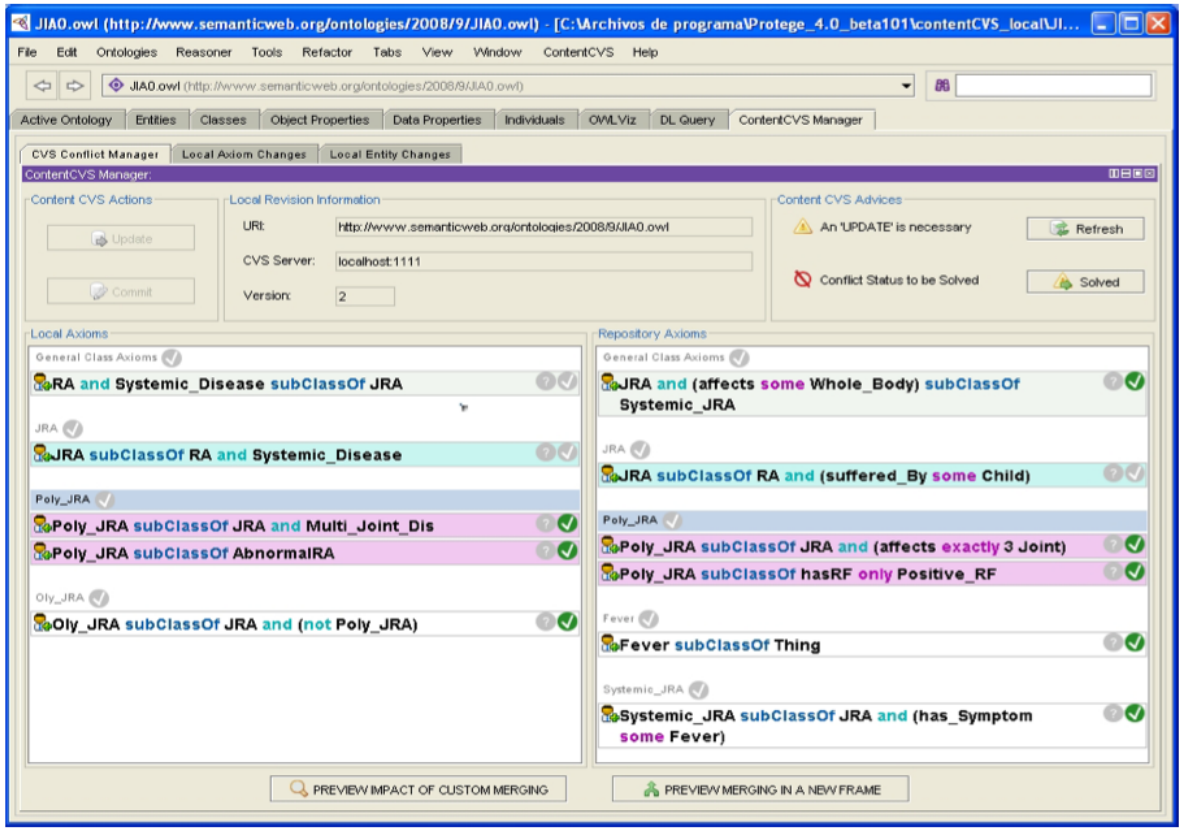
$$\begin{aligned} \text{Heart} &\sqsubseteq \text{MuscularOrgan} \sqcap \exists \text{isPartOf}.\text{CirculatorySystem} \\ \text{HeartDisease} &\equiv \text{Disease} \sqcap \exists \text{affects}.\text{Heart} \\ \text{VascularDisease} &\equiv \text{Disease} \sqcap \exists \text{affects}.(\exists \text{isPartOf}.\text{CirculatorySystem}) \end{aligned}$$

$$\models Q(\text{John}) \quad ?$$

More Tools

Major benefit of OWL has been huge increase in range and sophistication of tools and infrastructure:

- Integration and modularisation



More Tools

Major benefit of OWL has been huge increase in range and sophistication of tools and infrastructure:

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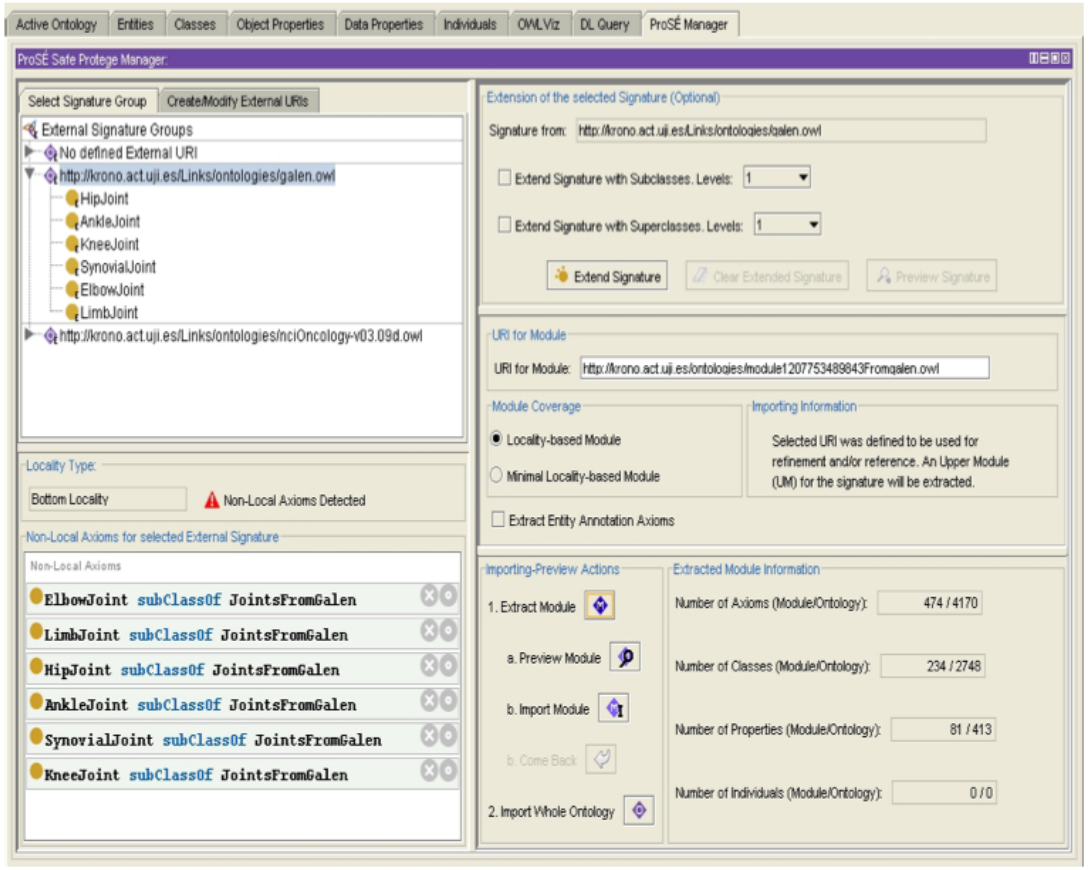

More Tools

Major benefit of OWL has been huge increase in range and sophistication of tools and infrastructure:

- Integration and modularisation
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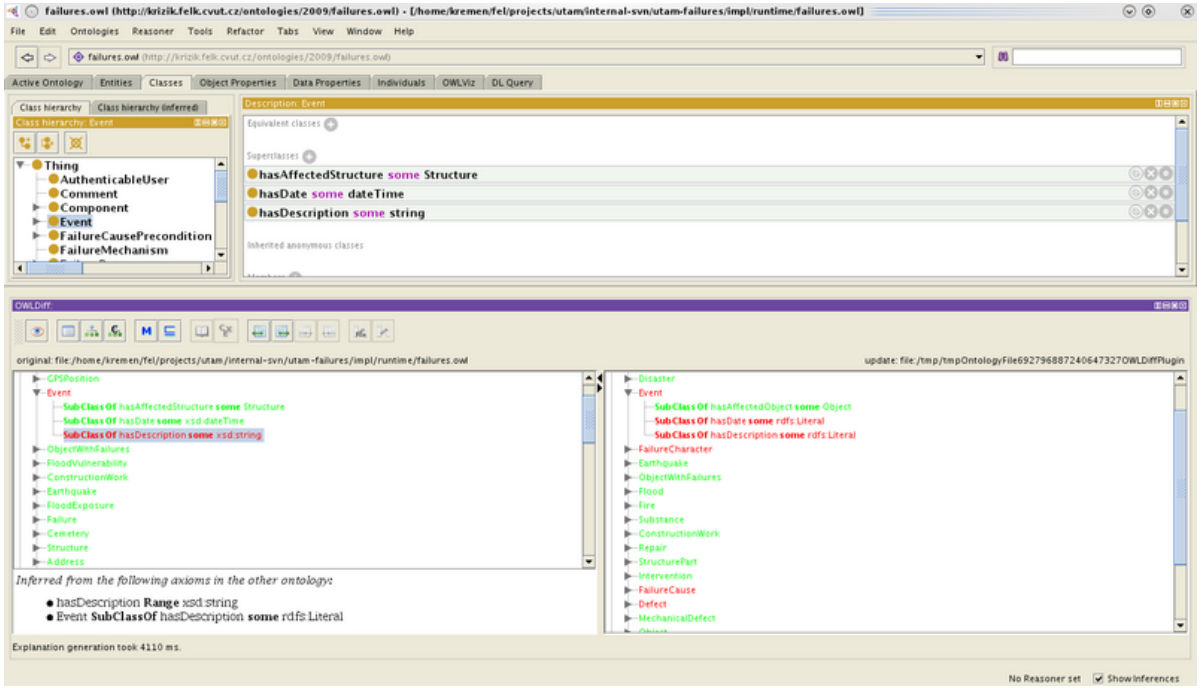
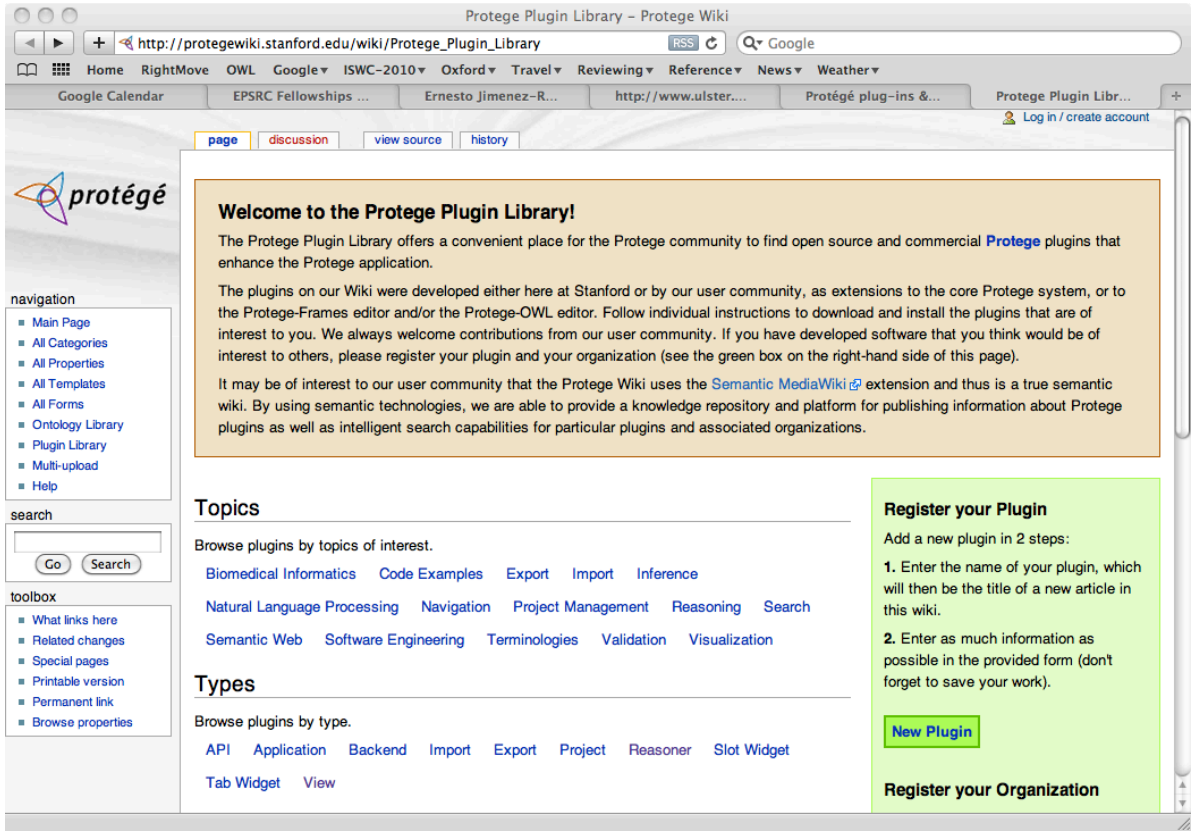
- Comparison



More Tools

Major benefit of OWL has been huge increase in range and sophistication of tools and infrastructure:

- Integration and modularisation
- Extraction
- Comparison
- Protege plugins



More Tools

Major benefit of OWL has been huge increase in range and sophistication of tools and infrastructure:

- Integration and modularisation
- Extraction
- Comparison
- Protege plugins
- APIs, in particular the **OWL API**

Revision 1403 - (download) (annotate)
Fri Dec 18 17:14:37 2009 UTC (4 months, 2 weeks ago) by matthewhorridge
File size: 4711 byte(s)

```
1  package org.coode.owlapi.examples;
2
3  import org.semanticweb.owlapi.apibinding.OWLManager;
4  import org.semanticweb.owlapi.model.*;
5  import org.semanticweb.owlapi.util.DefaultPrefixManager;
6  /*
7   * Copyright (C) 2009, University of Manchester
8   *
9   * Modifications to the initial code base are copyright of their
10  * respective authors, or their employers as appropriate.  Authorship
11  * of the modifications may be determined from the ChangeLog placed at
12  * the end of this file.
13  *
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21  * MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE.  See the GNU
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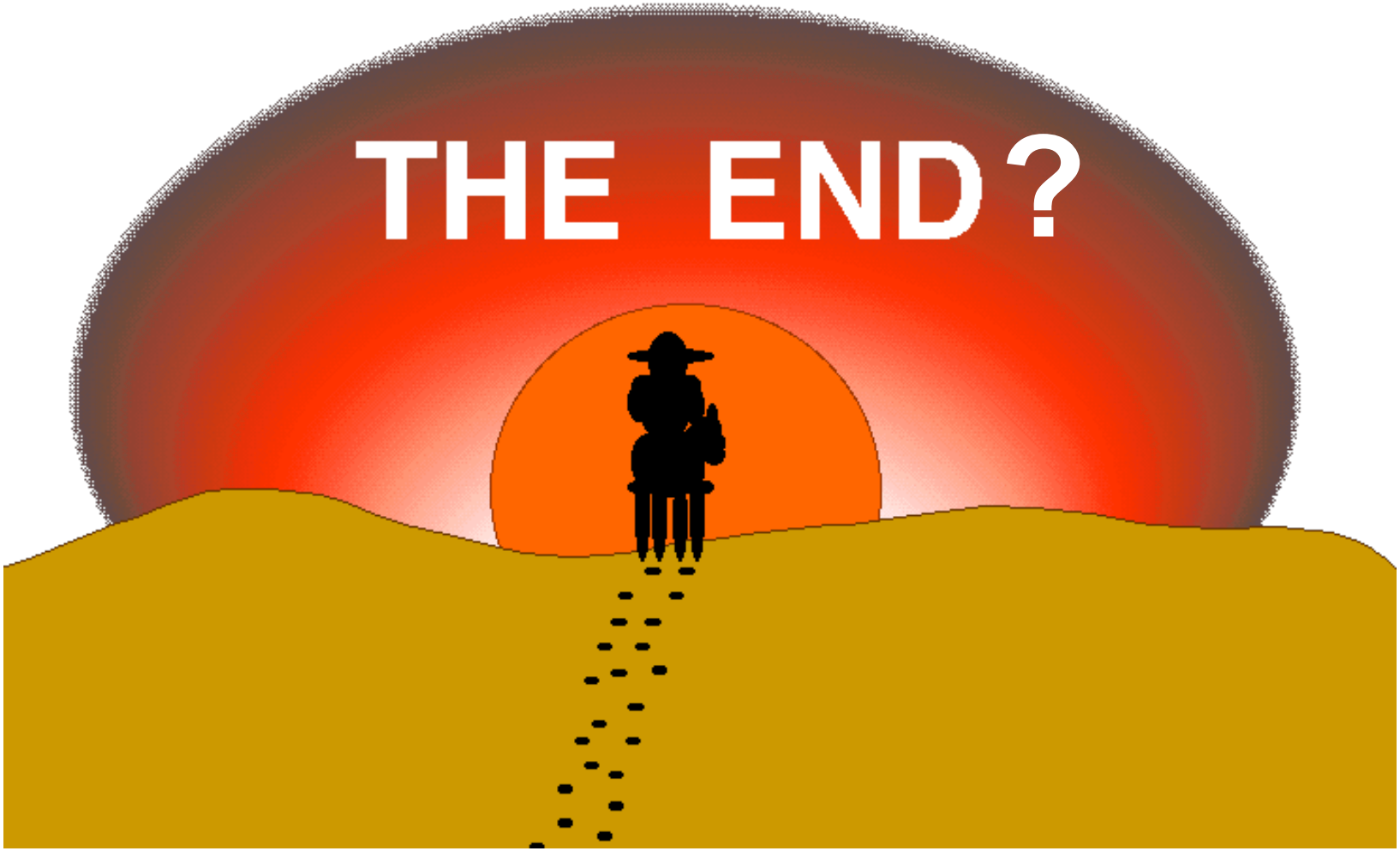
THE END?

Ongoing Research

- Query answering
  - [Kontchakov et al], [Konev et al], [Baader et al]
- Diagnosis and repair
  - [Horridge et al], [Peñaloza et al]
- Extensions
  - [Motik et al], [Artale et al]
- Optimisation/Profiles
  - [Kazakov], [Glimm et al], [Faddoul et al], [Savo et al]
- ...

Ongoing Standardisation Efforts

- Standardised query language
  - SPARQL standard for RDF
  - Currently being extended for OWL, see *http://www.w3.org/TR/sparql11-entailment/*
- RDF
  - Revision currently being considered, see *http://www.w3.org/2009/12/rdf-ws/*

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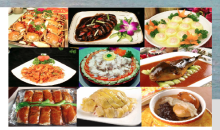

Excellent Food

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Thank you for listening

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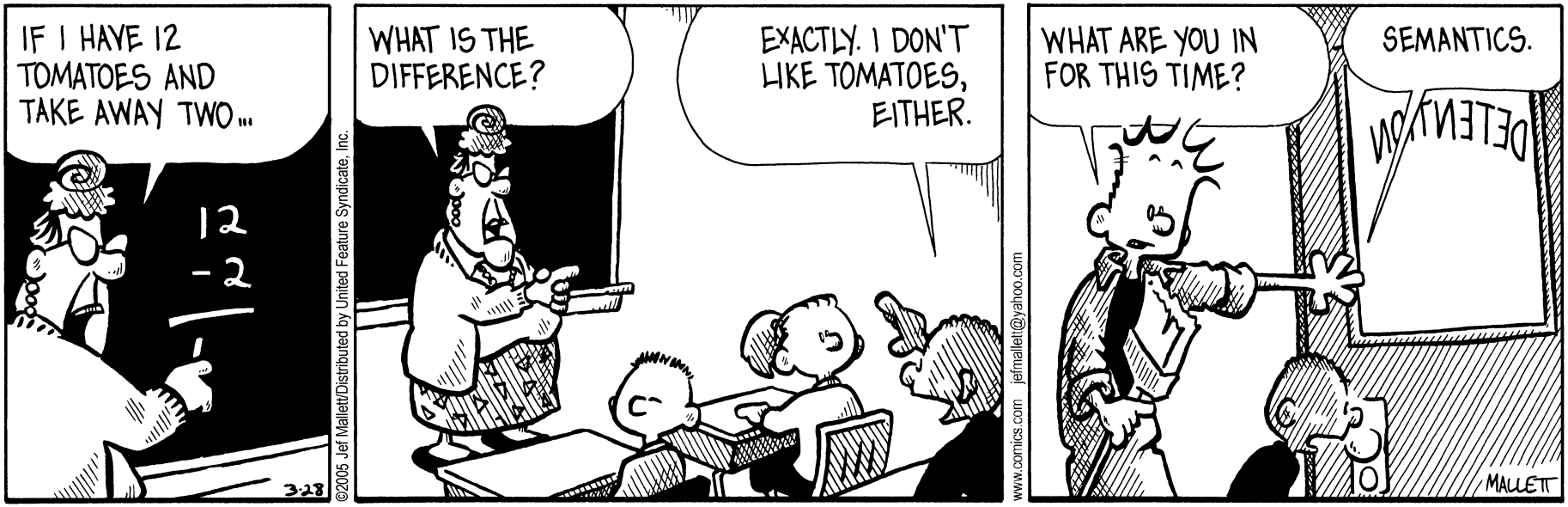

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Any questions?