OWL: a Reasonable Ontology Language?

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What is an Ontology?

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An explicit specification of a conceptualization

What is an Ontology?

A model of (some aspect of) the world

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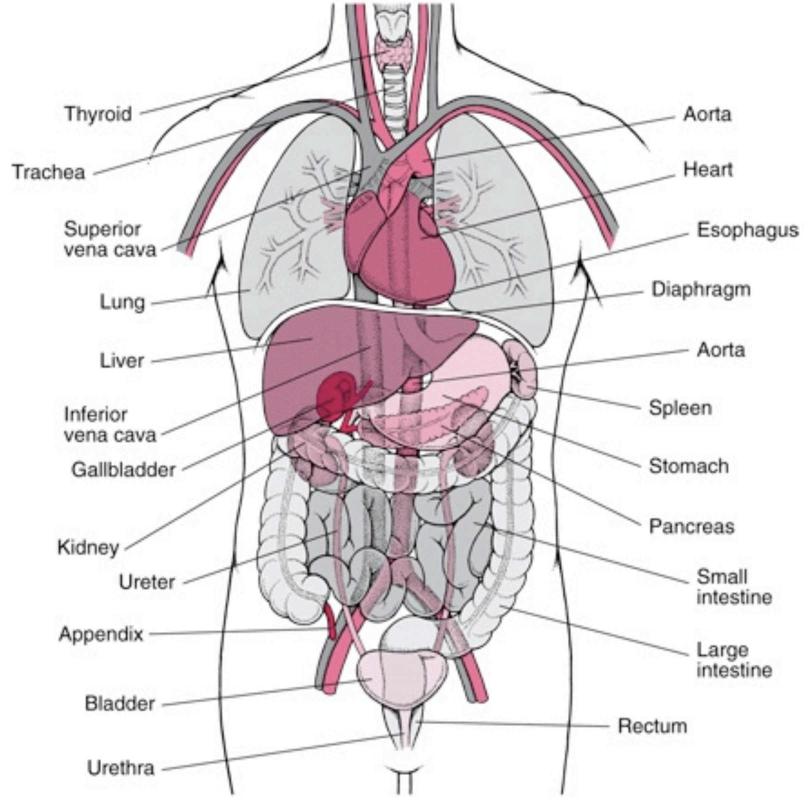
A model of (some aspect of) the world

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



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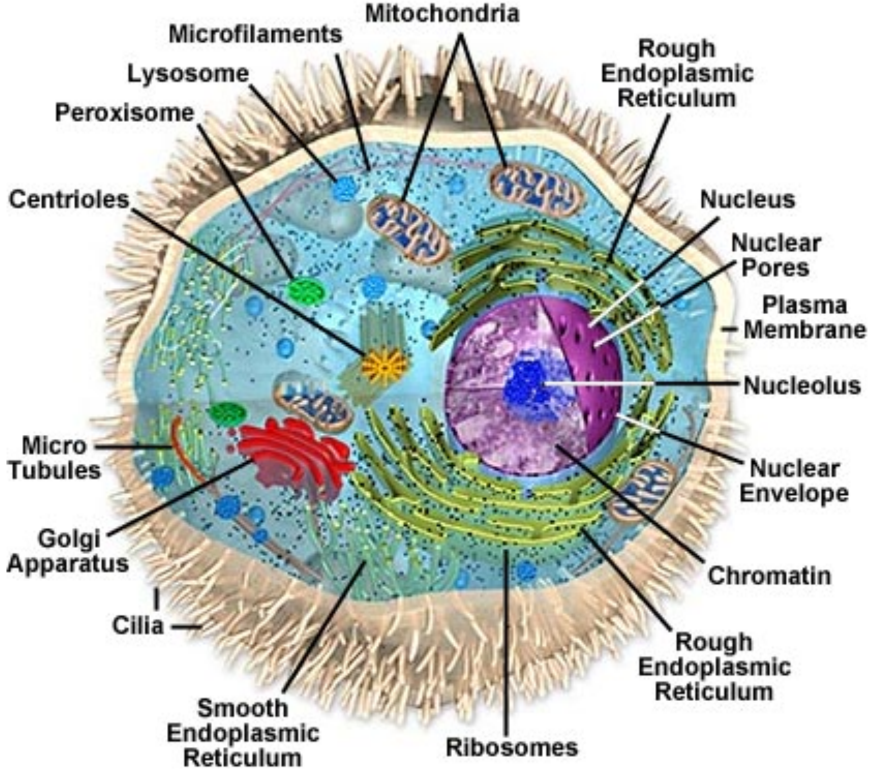

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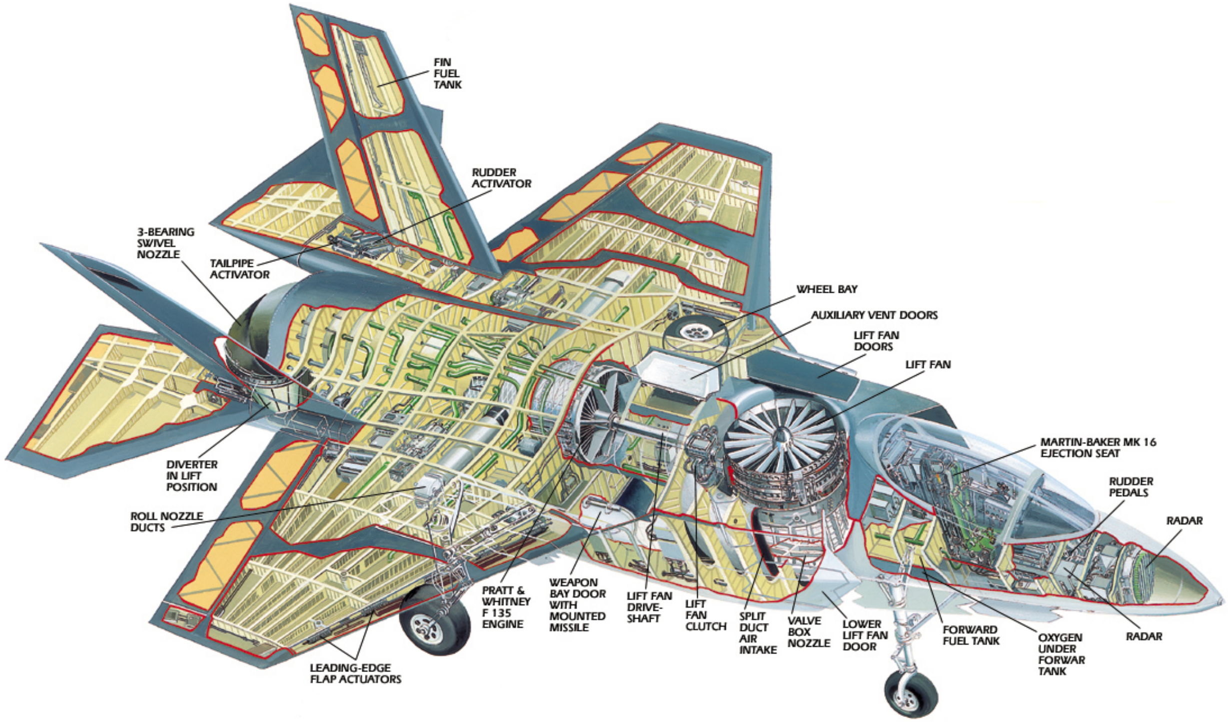

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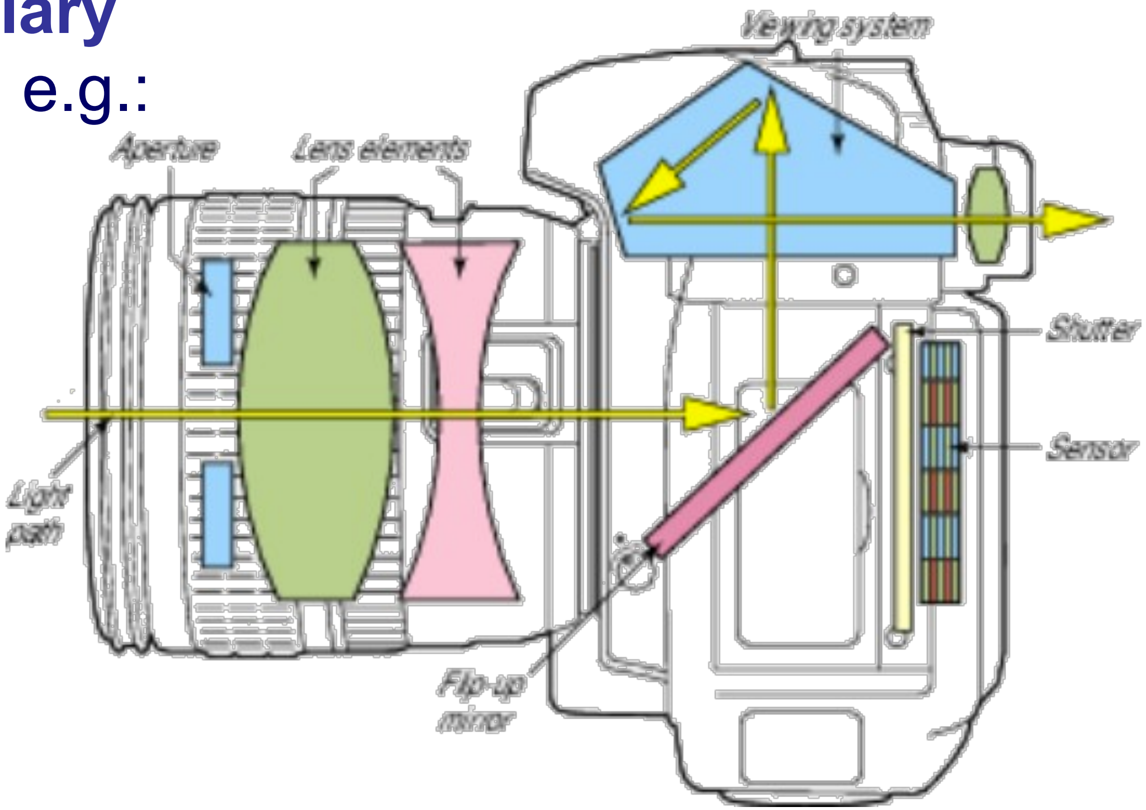

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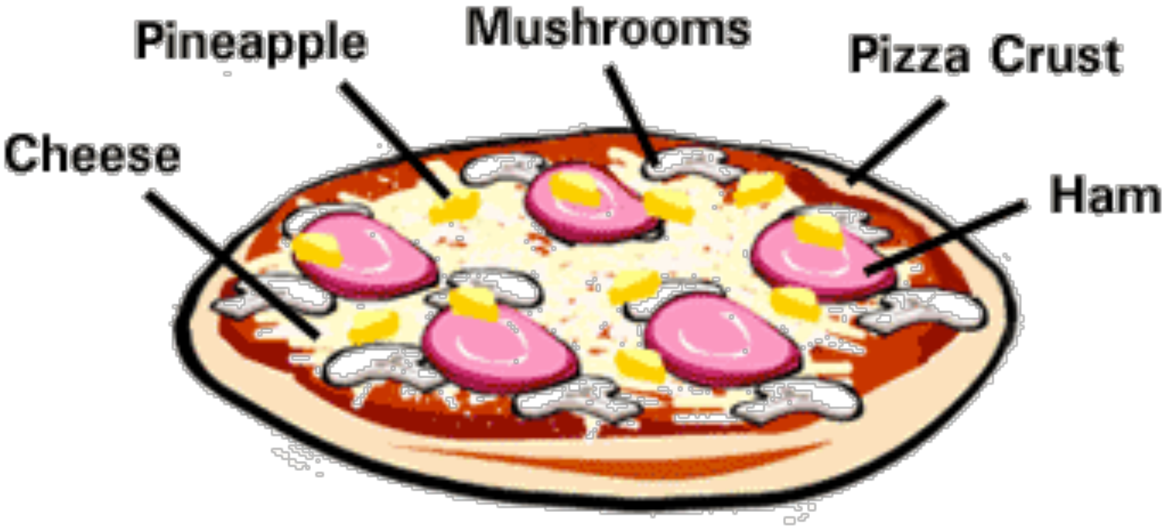
  - Cellular biology
  - Aerospace
  - Photography
  - Pizzas
  - …



What is an Ontology?

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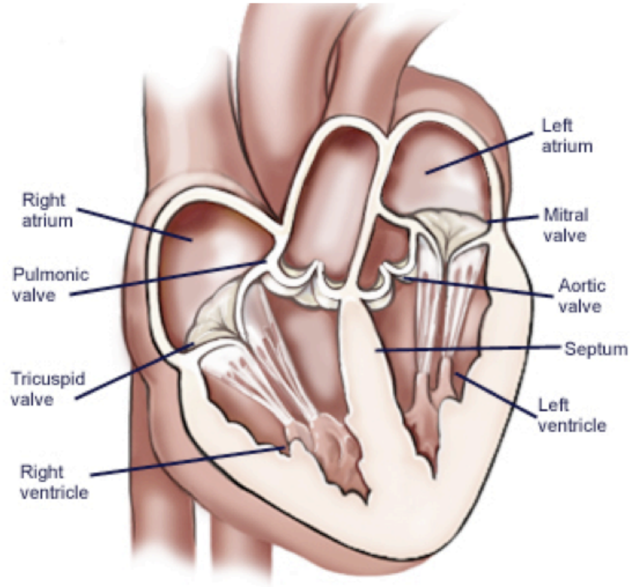
- Introduces **vocabulary** relevant to domain
- Specifies *relative* **meaning** (aka semantics) of terms

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



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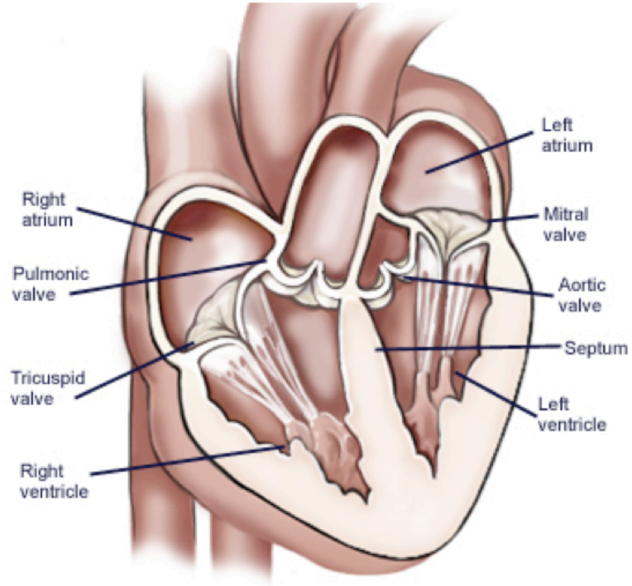
- **Formalised** e.g. using suitable logic

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



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?

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

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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    “Patients suffering from Vascular Disease”
  - Query expansion/navigation/refinement
  - Incomplete and semi-structured data
  - ...

More “intelligent” applications

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- Ontology-based **Information Systems**
  - View of data that is independent of logical/physical schema
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THE SEMANTIC WEB

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

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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**

$$\begin{aligned}\mathsf{Heart} \sqsubseteq\ & \mathsf{MuscularOrgan} \sqcap \\ & \exists \mathsf{isPartOf}.\mathsf{CirculatorySystem}\end{aligned}$$

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

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 $\mathcal{L}(v) \longrightarrow \mathcal{L}(v) \cup \{C_1, C_2\}$.
$\sqcup$-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 $\mathcal{L}(v) \longrightarrow \mathcal{L}(v) \cup \{E\}$ 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 $\mathcal{L}(v_2) \longrightarrow \mathcal{L}(v_2) \cup \{C\}$.
$\forall_+$-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 $\mathcal{L}(v_2) \longrightarrow \mathcal{L}(v_2) \cup \{\forall r'.C\}$.
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 $\{C, \dot\neg C\} \cap \mathcal{L}(v_2) = \emptyset$ then $\mathcal{L}(v_2) \longrightarrow \mathcal{L}(v_2) \cup \{E\}$ for some $E \in \{C, \dot\neg C\}$.
$\geqslant$-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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- Well defined (model theoretic) **semantics**
- **Formal properties** well understood (complexity, decidability)
- Practical **reasoning algorithms**
- Effective **implemented systems**

What did OWL ever do for us?

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Ontologies before:

Name	Original Language	defined	primitive	artificial	$\sum$	defined	primitive
		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?

Tools before:

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

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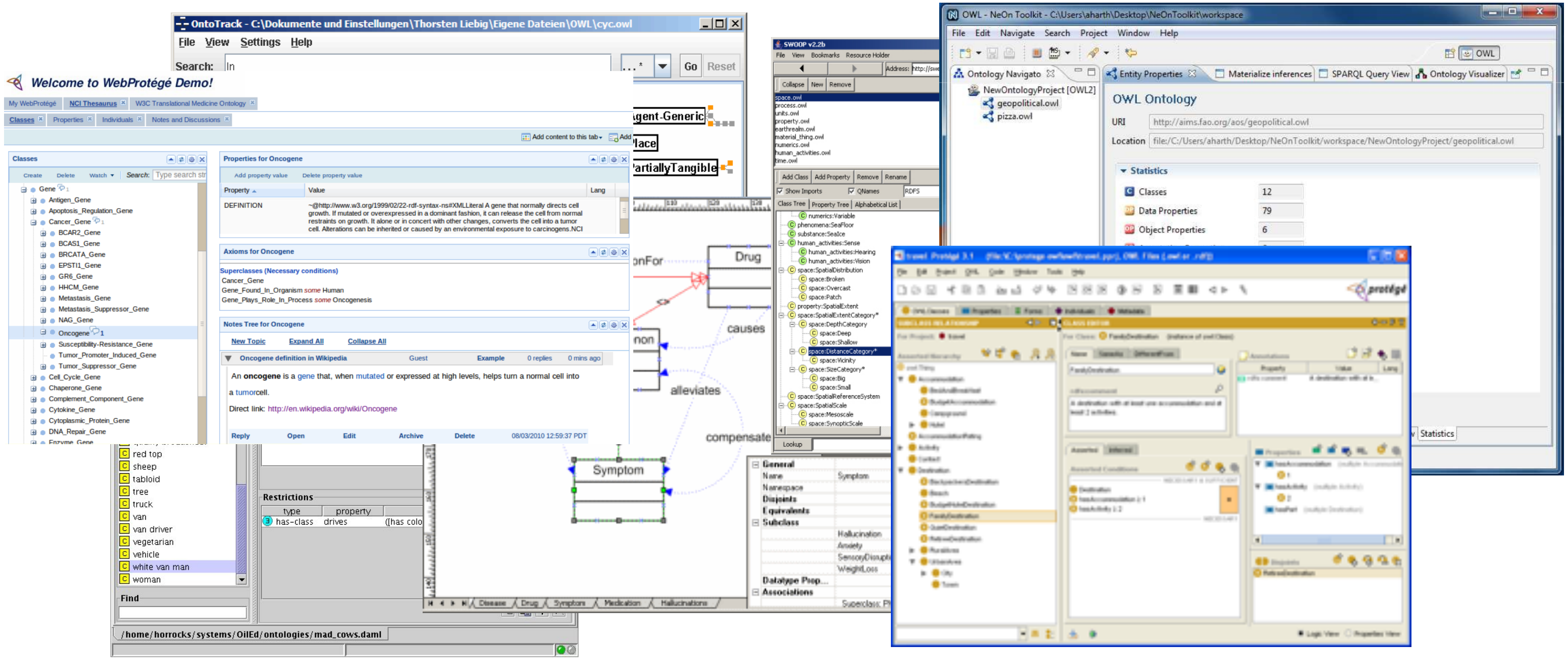
Tools after:



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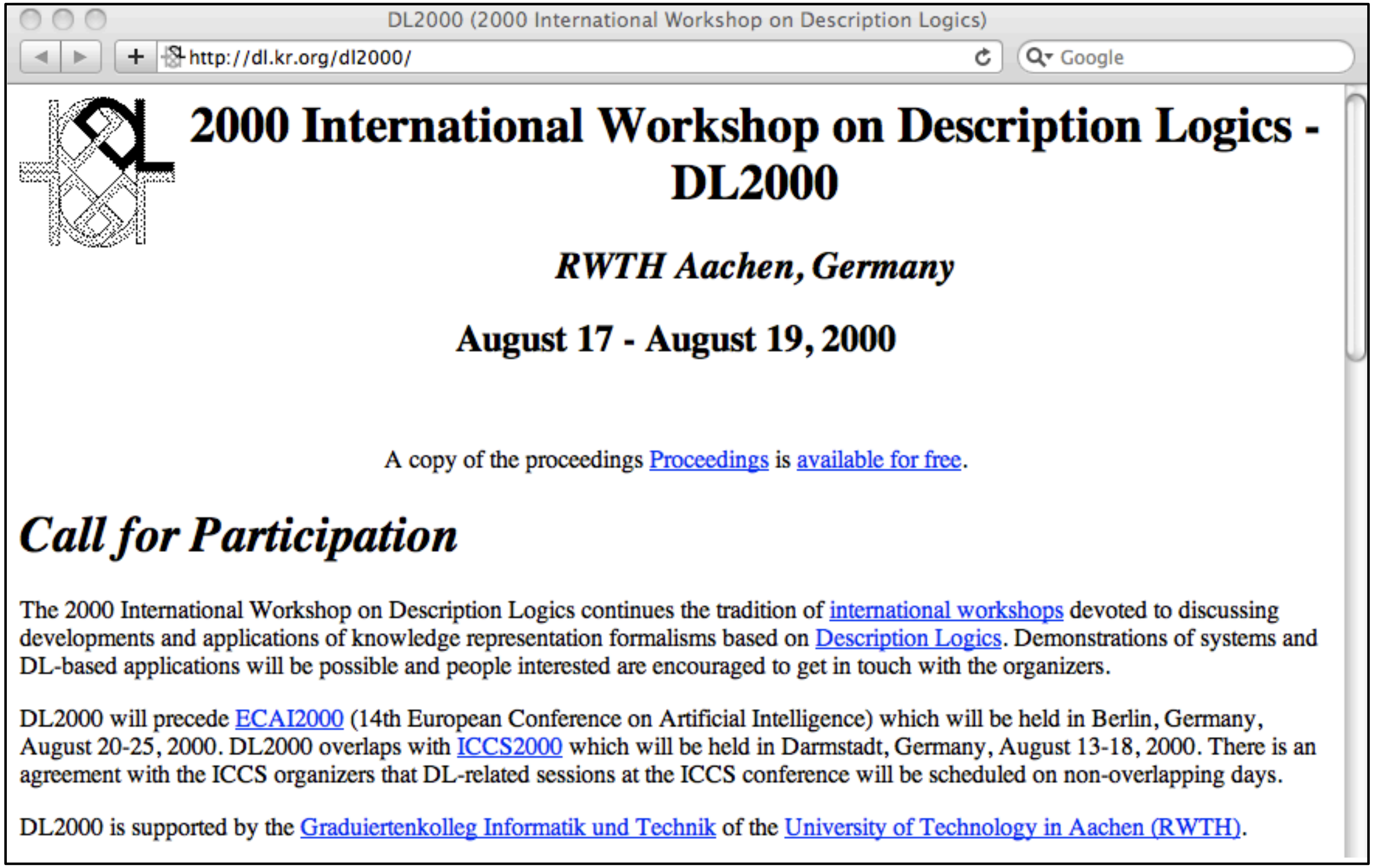
"**Profile**" before:



DL2000 (2000 International Workshop on Description Logics)

http://dl.kr.org/dl2000/

2000 International Workshop on Description Logics - DL2000

RWTH Aachen, Germany

August 17 - August 19, 2000

A copy of the proceedings Proceedings is available for free.

Call for Participation

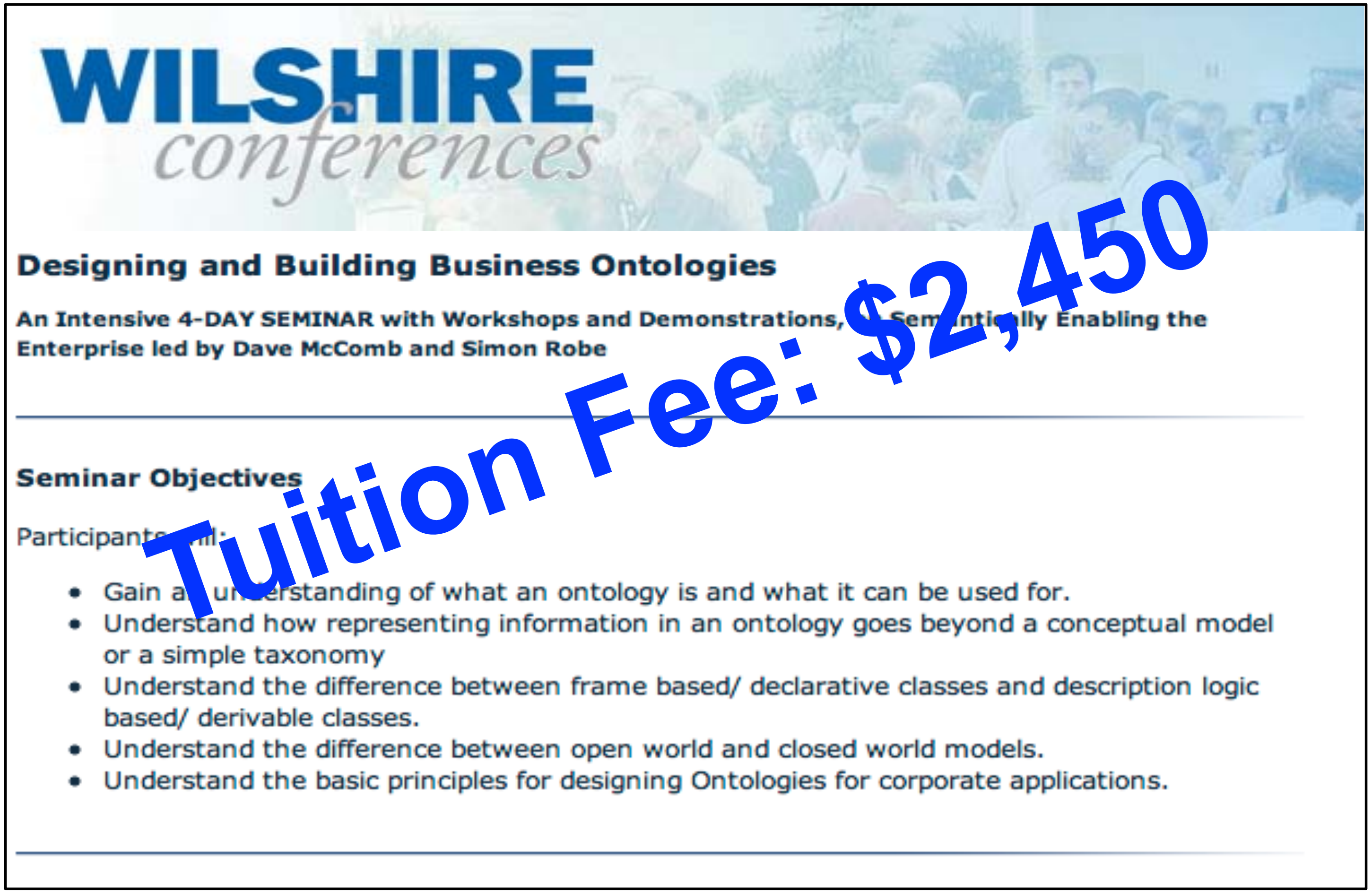
The 2000 International Workshop on Description Logics continues the tradition of international workshops devoted to discussing developments and applications of knowledge representation formalisms based on Description Logics. Demonstrations of systems and DL-based applications will be possible and people interested are encouraged to get in touch with the organizers.

DL2000 will precede ECAI2000 (14th European Conference on Artificial Intelligence) which will be held in Berlin, Germany, August 20-25, 2000. DL2000 overlaps with ICCS2000 which will be held in Darmstadt, Germany, August 13-18, 2000. There is an agreement with the ICCS organizers that DL-related sessions at the ICCS conference will be scheduled on non-overlapping days.

DL2000 is supported by the Graduiertenkolleg Informatik und Technik of the University of Technology in Aachen (RWTH).

What did OWL ever do for us?

“**Profile**” after:



Designing and Building Business Ontologies

An Intensive 4-DAY SEMINAR with Workshops and Demonstrations, Semantically Enabling the Enterprise led by Dave McComb and Simon Robe

Seminar Objectives

Participants will:

- Gain an understanding of what an ontology is and what it can be used for.
- Understand how representing information in an ontology goes beyond a conceptual model or a simple taxonomy
- Understand the difference between frame based/ declarative classes and description logic based/ derivable classes.
- Understand the difference between open world and closed world models.
- Understand the basic principles for designing Ontologies for corporate applications.

What did OWL ever do for us?

Applications before:

What did OWL ever do for us?

Applications after:

What did OWL ever do for us?

Applications after:

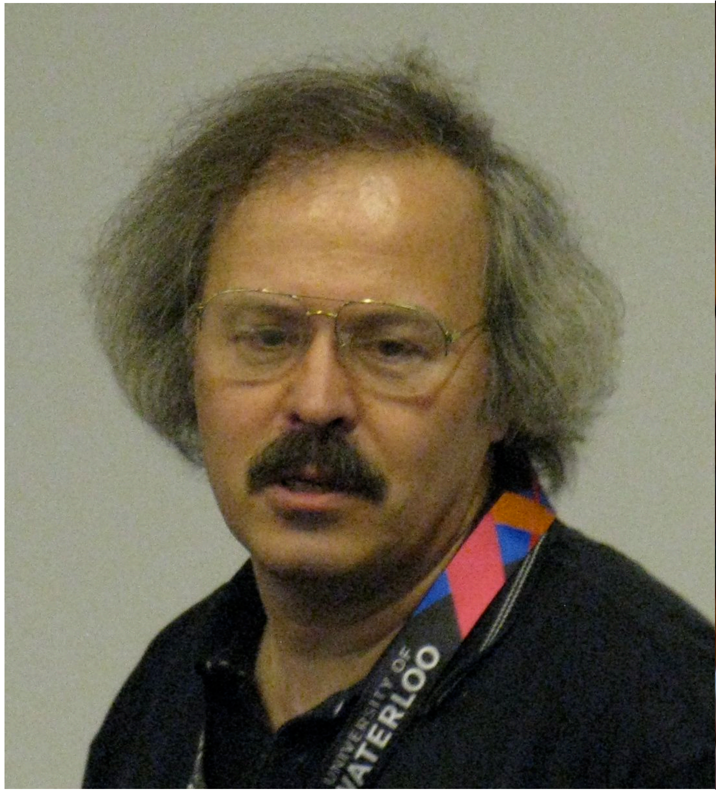
- eScience, eCommerce, geography, engineering, defence, …
- Major impact in healthcare and life sciences
- Mainstream technology supported by, e.g., ORACLE 11g
- Increasing impact in business applications

What did OWL ever do for us?

Peter and Ian before:

What did OWL ever do for us?

Peter and Ian after:



Where We Are Now

- OWL (2) ontology language a W3C **standard**
- OWL (2) based on **AI research** (in particular DLs)
- Wide range of **tools and infrastructure** now available
- **High profile** applications
- Support from **mainstream technology** vendors

So everybody's happy?

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Of course not!

It’s Too Complicated

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It is too complicated, and users will never understand it or be able to use it!

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- Many people are now using it!
- Naive users can manage with a small subset (c.f. SQL, MS-Word, ...)
- “Lite” subsets only useful if they confer some computational advantage

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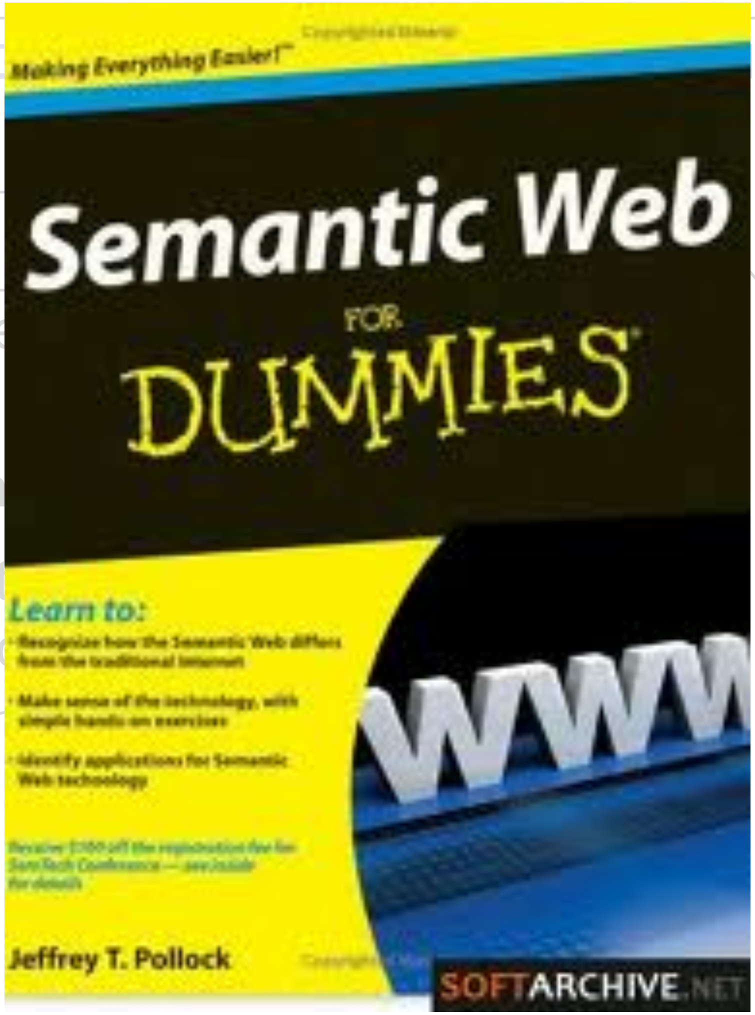

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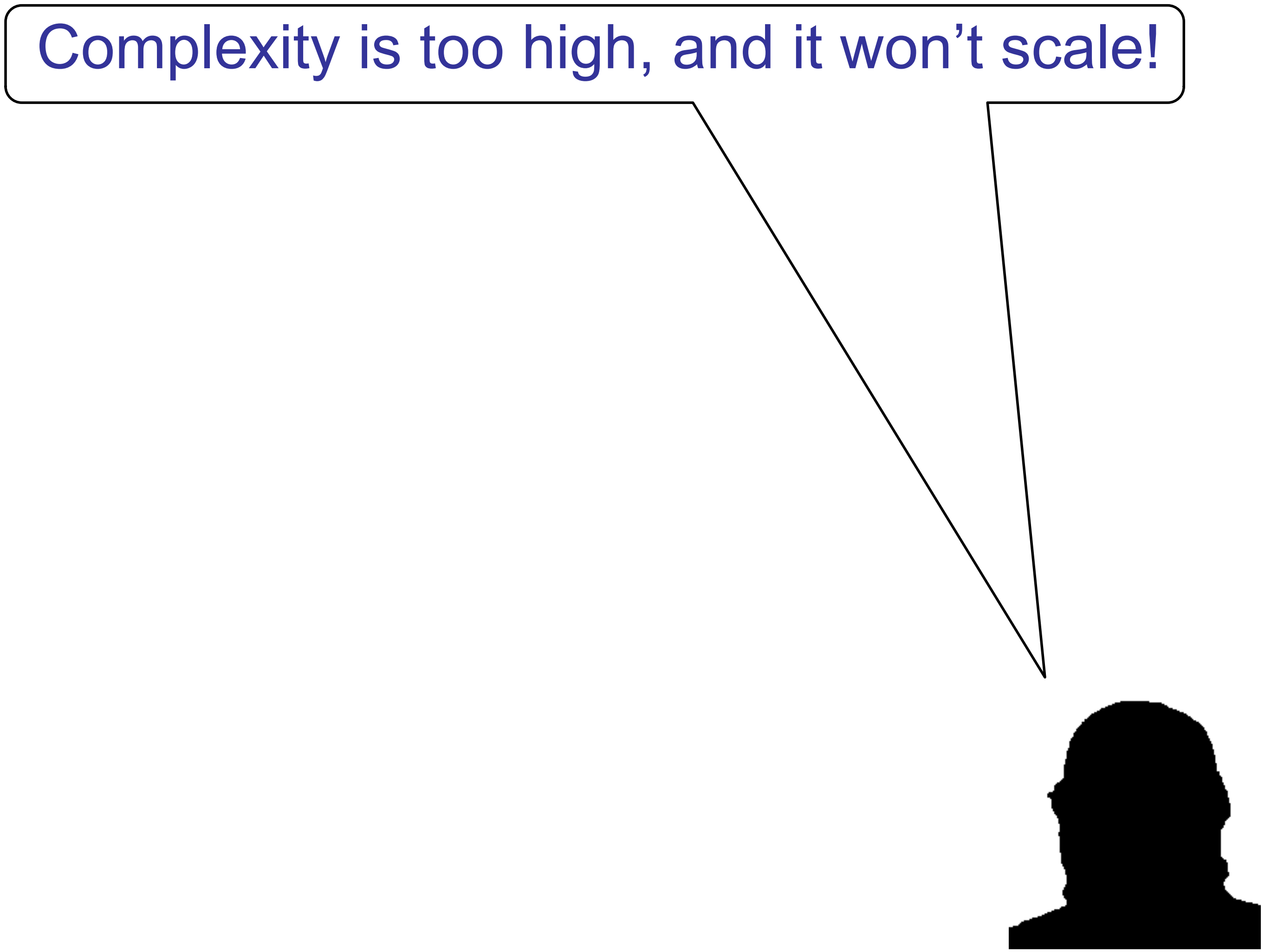

It’s Too Complex

Complexity is too high, and it won’t scale!

- What do we mean by “scale”?

  Reasoning with whole web doesn’t make sense

- Even so, scalability is a real problem

  $\mathcal{SROIQ}$ satisfiability/subsumption is 2NEXPTIME-complete

It’s Too Complex

Thanks to: Arthur Gordon, Alison Gurlitz, Stephen Lam and Eugene Moy

It's Too Complex

So is OWL reasoning doomed to failure?

- High complexity doesn't mean that ***bad*** performance is guaranteed
  - Just that we can't guarantee ***good*** performance
- Highly optimised implementations (may) work well in practice
- Main problem is relatively low "**robustness**"
  - Optimisations exploit features of *typical* ontologies
  - Small changes in ontology can lead to large changes in performance – "it worked OK yesterday"
- Large **data sets** may also be problematical
- Users/applications can choose tractable subsets (**profiles**) if greater scalability and/or robustness is needed

It’s Too Complex

OWL 2 profiles:

- **OWL 2 EL**
  - polynomial (combined) complexity
  - highly effective “one pass” classification algorithms
- **OWL 2 RL**
  - polynomial (combined) complexity
  - convenient rule-extended database implementation
- **OWL 2 QL**
  - AC^0 (data) complexity (< logspace)
  - highly scalable query rewriting implementation

It should have been based on ....*

* Insert favourite logic/KR-formalism

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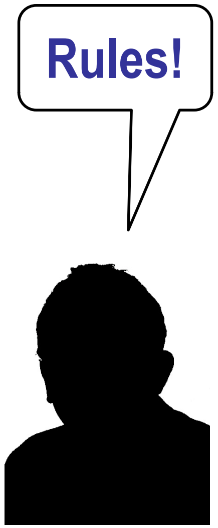

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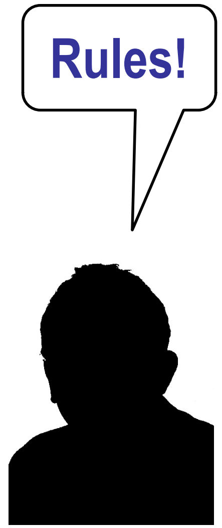
- ✔ More natural/intuitive and easy to understand
- ✔ Can describe arbitrary relational structures
- ✔ UNA and CWA semantics is more intuitive/appropriate
- ✔ Better scalability



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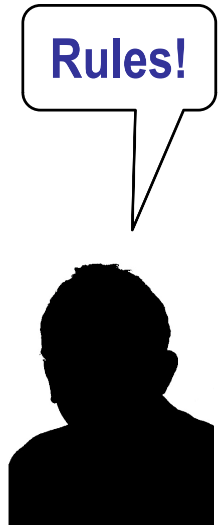
- ✘ Less natural/intuitive and easy to understand
- ✘ Can't describe unbounded structures
- ✘ UNA and CWA inappropriate in Web setting
- ✘ Poor at dealing with incomplete information



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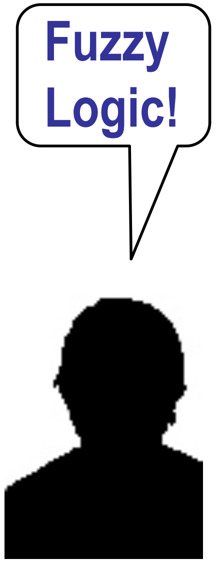
- ✔ Information may also be vague/noisy, e.g., the Web
- ✔ Strictly extends “crisp” languages (1 = true; 0 = false)



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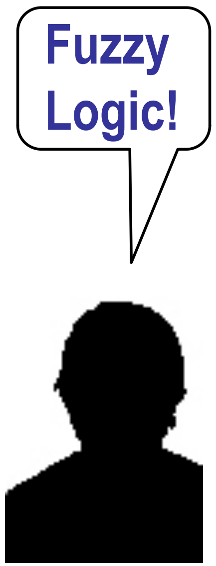
- ✔ Strictly extends “crisp” languages (1 = true; 0 = false)

- ✘ Developing ontologies may be more difficult
- ✘ How will fuzzy values be determined/agreed?
- ✘ Reasoner implementations still prototypical
- ✘ Practicality still an open question



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- ✔ Undecidability not important

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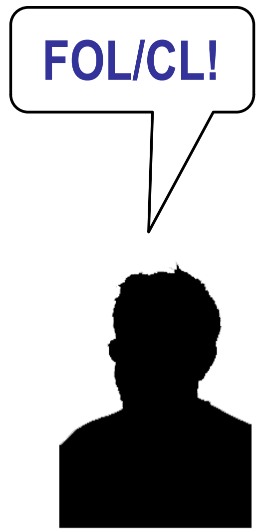

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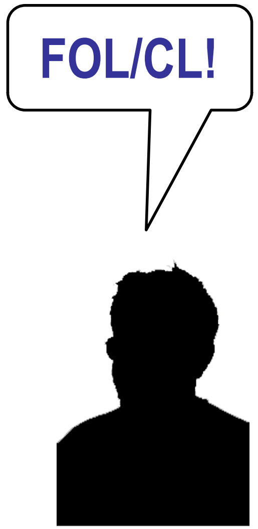
- ✘ Reasoners are *much* less robust
- ✘ Poor at proving non-subsumption (normal case)
- ✘ Difficult to recognise subsets
- ✘ Incomplete answers typically used in unsound way



* Insert favourite logic/KR-formalism

Undecidability -v- High Complexity

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- Can think of undecidable as a very high complexity class
  - Result is very low robustness of reasoner performance

Users have to make do with imperfect tests which sometimes fail to yield results" ... "analogous to 404 errors on the Web

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- But in practice
  - Even SOTA FOL theorem provers are not very effective for non-theorems/non-subsumption
  - Vast majority tests are non-subsumptions, so answer to most tests is “don’t know” (almost every link gives a 404 error)
  - Users expect/demand (fast and) complete reasoning; otherwise they simply won’t use the reasoner

Incompleteness -v- Incorrectness

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  - and incomplete reasoners often don’t even distinguish

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Isn’t this just negation as failure?

- Absolutely not!
  – Failure in NAF means failure of entailment

    $\neg\phi$ is true if ϕ is not entailed

  – It doesn’t mean failure of an incomplete reasoner to prove that ϕ is entailed
  – Treating “don’t know” as “no” is simply **incorrect**

It’s Not Expressive Enough

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I need to express ....,* which I can’t express in OWL

* Insert favourite expressive feature

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- ✔ There are many things that can't be expressed in OWL
- ✔ Some of them would certainly be very useful

* Insert favourite expressive feature

It’s Not Expressive Enough

I need to express ....,* which I can’t express in OWL

- ✔ There are many things that can’t be expressed in OWL
- ✔ Some of them would certainly be very useful

- ✘ It’s too complicated
- ✘ It’s too complex
- ✘ It should have been based on ....

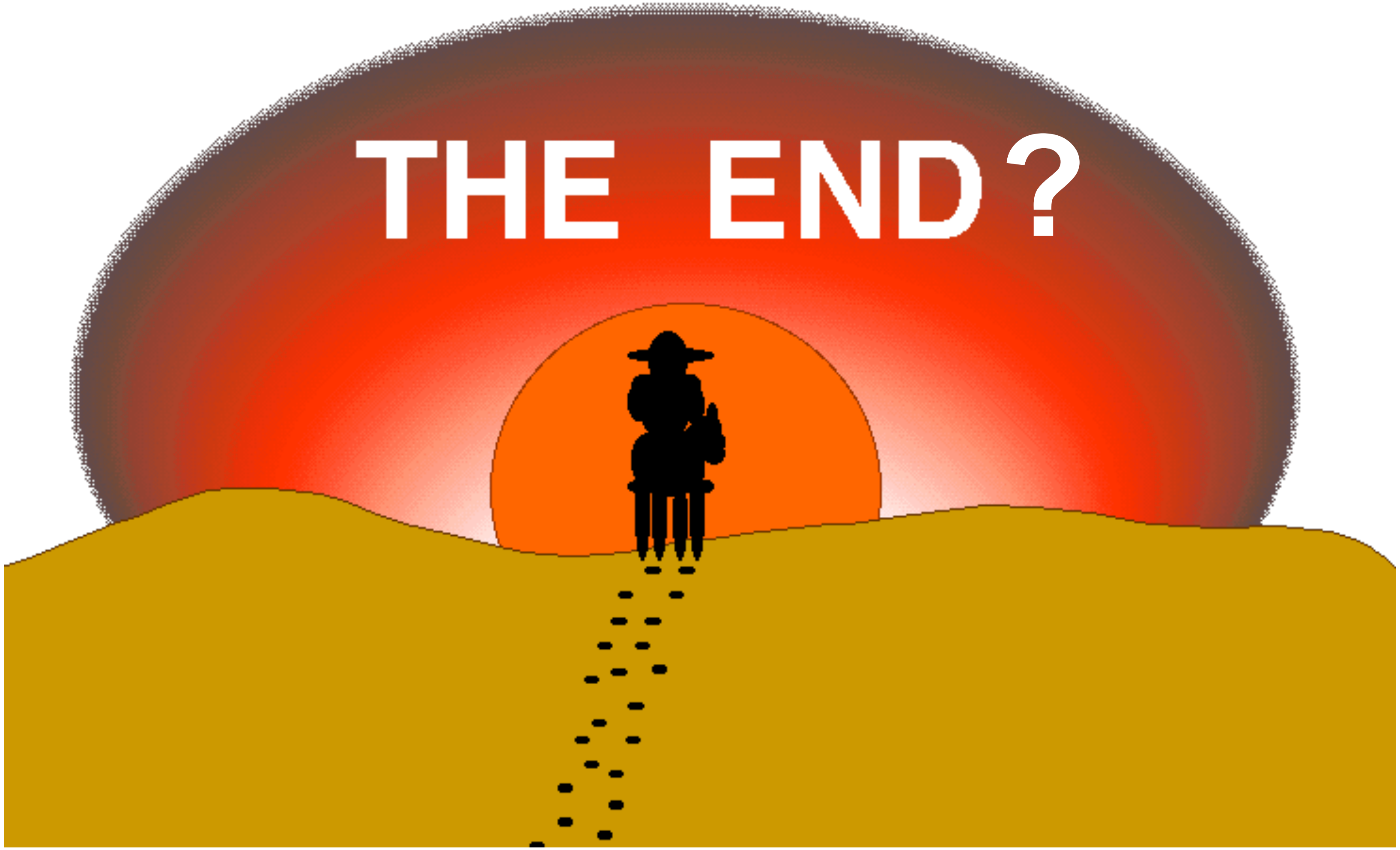
* Insert favourite expressive feature

Conclusions?

- There is no “right choice” of ontology language

  “you pays your money, and you takes your choice”

- Standardisation requires *some* choice
- Claim: OWL was a (not totally un-)reasonable choice:
  - good compromise between expressive power and robust tool performance
  - has allowed for the development of a range of tools, infrastructure and applications that could previously only have been dreamt of


THE END?

Ongoing Research

- Optimisation/Profiles
  - [Kazakov], [Glimm et al], [Faddoul et al], [Savo et al]
- 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]
- ...

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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Great Time
Fascinating City
Excellent Food
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上海交通大學
SHANGHAI JIAO TONG UNIVERSITY
IBM
Research

Thank you for listening

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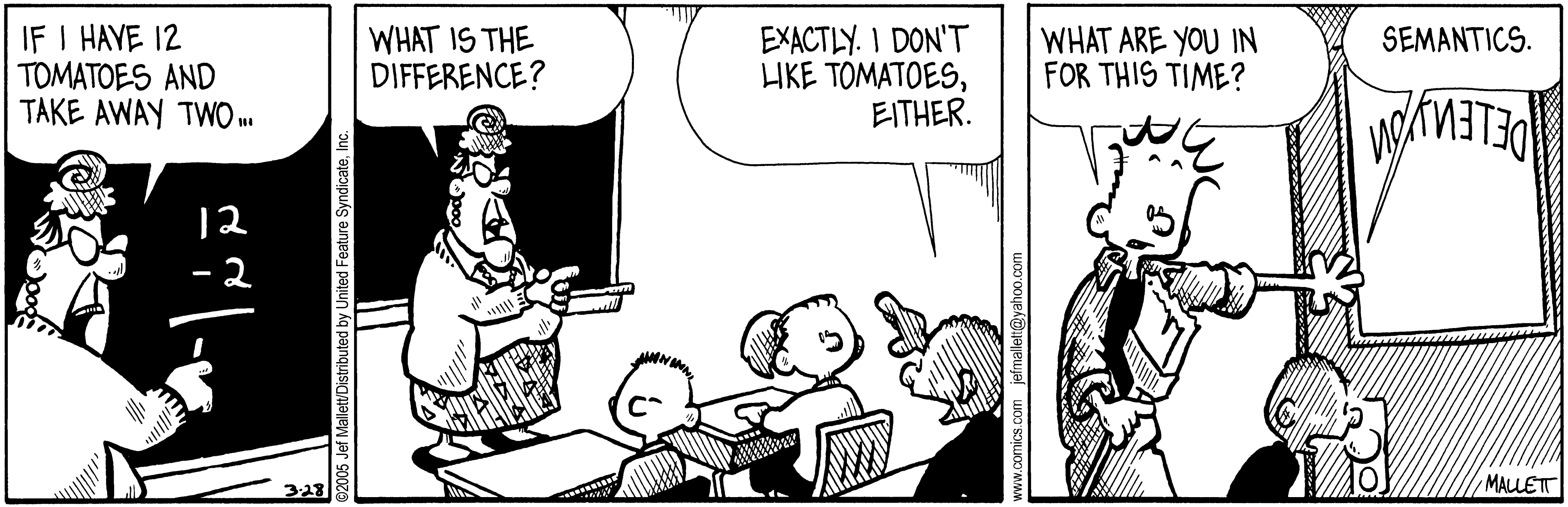

Any questions?