# Foundations of the Semantic Web: Ontology Engineering

Building Ontologies 1

Alan Rector & colleagues

1

## Goals for this module: for you

- Be able to implement an ontology representation in OWL-DL
  - Be able to elicit a conceptualisation
  - Be able to formulate an ontology representation
  - Be able to implement the ontology representation in OWL-DL
    - Or be able to say you can't
    - To understand the limits of OWL-DL ontologies
  - Be able to test the resulting ontology implementation
  - Be ready to apply ontology representations in any of several use cases
    - In one week, we can't build the applications…
      …but to build an ontology is only a means to building applications
      - Without applications ontologies are pointless

2

## Goals for this Module: For us

- Still experimental – we need your feedback
  - Feedback
    - On tools – we treat this as a User Centred Design experiment
      - Please be patient
        - The good news is they are getting better
    - On the course
      - Did the content work for you?
      - What other content would you like?
      - Balance of labs and lecture
      - Content of labs
    - For the Semantic Web Best Practice Working Group
  - New ideas

3

## Mechanics - reminder

- Assessment
  - 30% lab
  - 30% Mini project
  - 40% Exam
- All labs to be handed in by number electronically – see lab handout
- Deadline – 2 weeks after end of course

4

## Ontologies and Ontology Representations

- "Ontology" – a word borrowed from philosophy
  - But we are necessarily building logical systems
    - "Physical symbol systems"
      - Simon, H. A. (1969, 1981). *The Sciences of the Artificial,* MIT Press
- "Concepts" and "Ontologies"/ "conceptualisations" in their original sense are psychosocial phenomena
  - We don't really understand them
- "Concept representations" and "Ontology representations" are engineering artefacts
  - At best approximations of our real concepts and conceptualisations (ontologies)
    - And we don't even quite understand what we are approximating

5

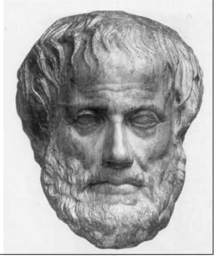
## Ontologies and Ontology Representations (cont)

- Most of the time we will just say "concept" and "ontology" but whenever anybody starts getting religious, remember…
  - ***It is only a representation!***
    - We are doing engineering, not philosophy – although philosophy is an important guide
- *There is no one way!*
  - But there are consequences to different ways
    - and there are wrong ways
      - and better or worse ways for a given purposes
  - *The test of an engineering artefact is whether it is fit for purpose*
    - Ontology representations are engineering artefacts

6

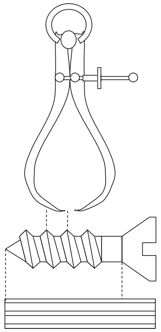
## What Is An Ontology?

- Ontology (Socrates & Aristotle 400-360 BC)
- The study of being
- Word borrowed by computing for the explicit description of the conceptualisation of a domain:
  - concepts
  - properties and attributes of concepts
  - constraints on properties and attributes
  - Individuals (often, but not always)
- An ontology defines
  - a common vocabulary
  - a shared understanding



## Measure the world…*quantitative models*

*(not ontologies)*

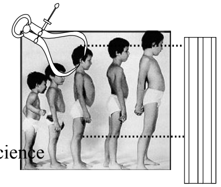


- Quantitative
  - Numerical data:
    - 2mm, 2.4V, between 4 and 5 feet
  - Unambiguous tokens
  - Main problem is accuracy at initial capture
  - Numerical analysis (e.g. statistics) well understood
- Examples:
  - How big is this breast lump?
  - What is the average age of patients with cancer ?
  - How much time elapsed between original referral and first appointment at the hospital ?

8

# describe the our understanding of the world - *ontologies*

- Qualitative
  - Descriptive data
    - Cold, colder, blueish, not pink, drunk
  - Ambiguous tokens
    - What's wrong with being drunk ?
      - Ask a glass of water.
  - Accuracy poorly defined
  - Automated analysis or aggregation is a new science
- Examples
  - Which animals are dangerous ?
  - What is their coat like?
  - What do animals eat ?



9

# Light and Heavy expressivity

A matter of rigour and representational expressivity

- Lightweight
  - Concepts, atomic types
  - Is-a hierarchy
  - Relationships between concepts
- Heavyweight
  - Metaclasses
  - Type constraints on relations
  - Cardinality constraints
  - Taxonomy of relations
  - Reified statements
  - Axioms
  - Semantic entailments
  - Expressiveness
  - Inference systems

10

[Deborah McGuinness, Stanford]

# So what is an ontology?

Catalog/ ID

Thesauri

Formal Is-a

Frames (properties)

General Logical constraints

Terms/ glossary

Informal Is-a

Formal instance

Value restrictions

Disjointness, Inverse, partof

*Gene Ontology*

*Mouse Anatomy*

*Arom*

*EcoCyc*

*TAMBIS*

*PharmGKB*

11

[Mike Uschold, Boeing Corp]

# A semantic continuum

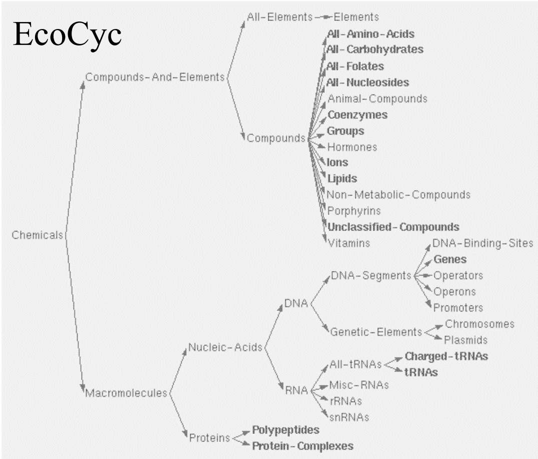
Pump: "a device for moving a gas or liquid from one place or container to another"

(pump has (superclasses (…))

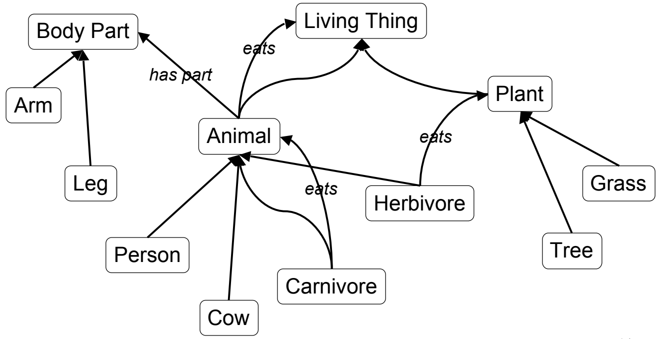
| Shared human consensus | Text descriptions | Semantics hardwired; used at runtime | Semantics processed and used at runtime |
|---|---|---|---|
| Implicit | Informal (explicit) | Formal (for humans) | Formal (for machines) |

Further to the right means:
- Less ambiguity
- More likely to have correct functionality
- Better inter-operation
- Less hardwiring
- More robust to change
- More difficult

12



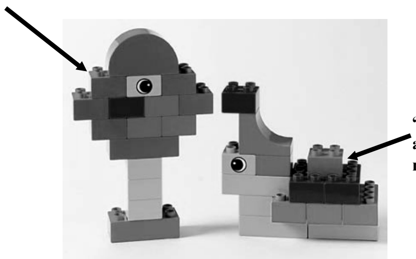

# A simple ontology: Animals






# Logic-based Ontologies: Conceptual Lego: A BioInformatics View

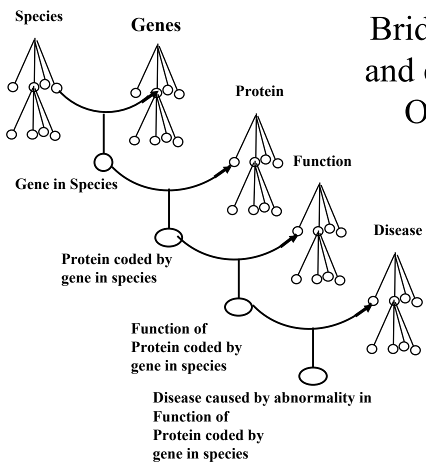
"SNPolymorphism of CFTRGene causing Defect in MembraneTransport of ChlorideIon causing Increase in Viscosity of Mucus in CysticFibrosis…"



**"Hand which is anatomically normal"**

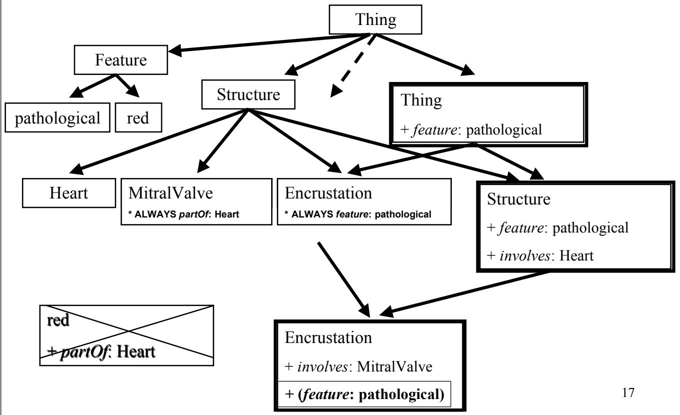


# Bridging Scales and context with Ontologies



## Logic Based Ontologies: A crash course

**Primitives** **Descriptions** **Definitions** **Reasoning** **Validating**




17

## Why Develop an Ontology?

- To share common understanding of the structure of descriptive information
  - among people
  - among software agents
  - between people and software
- To enable reuse of domain knowledge
  - to avoid "re-inventing the wheel"
  - to introduce standards to allow interoperability

18

## Why build an ontology

- Interworking and information sharing
  - Providing a well organised controlled vocabulary
- Indexing complex information
  - "Knowledge is fractal"
    - Ontologies are fractal
      - Self similar structure at every level of granularity (detail)
- Combat combinatorial explosions
  - The exploding bicycle
    - "Conceptual Lego"
      - A "dictionary and grammar" instead of a "phrasebook"

19

## Ontology Examples

- Taxonomies on the Web
  - Yahoo! categories
- Catalogs for on-line shopping
  - Amazon.com product catalog
- Dublin Core and other standards for the Web
- Domain independent examples
  - Ontoclean
  - Sumo

20

## Upper Ontologies

- Ontology Schemas
  - High level abstractions to constrain construction
    - e.g. There are “Objects” & “Processes”
  - Highly controversial
    - Sumo, Dolce, Onions, GALEN, SBU,…
  - Needed when you work with many people together
  - NOT in this tutorial – a different tutorial

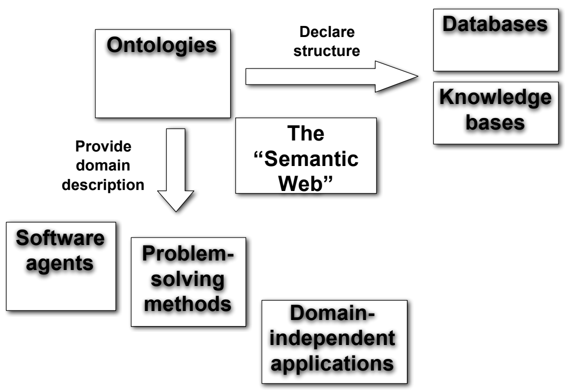
21

## Domain Ontologies

- Concepts specific to a field
  - Diseases, animals, food, art work, languages, …
  - The place to start
    - Understand ontologies from the bottom up
      - Or middle out
- Levels
  - Top domain ontologies – the starting points for the field
    - Living Things, Geographic Region, Geographic_feature
  - Domain ontologies – the concepts in the field
    - Cat, Country, Mountain
  - Instances – the things in the world
    - Felix the cat, Japan, Mt Fuji

22

## An Ontology should be just the Beginning




23

## Ontology Technology

- “Ontology” covers a range of things
  - Controlled vocabularies – e.g. MeSH
    - Linguistic structures – e.g. WordNet
  - Hierarchies (with bells and whistles) – e.g. Gene Ontology
  - Frame representations – e.g. FMA
  - Description logic formalisms – Snomed-CT, GALEN, OWL-DL based ontologies
  - Philosophically inspired e.g. Ontoclean and SUMO

24

## OWL
## The Web Ontology Language

- W3C standard
- Collision of DAML (frames) and Oil (DLs in Frame clothing)
- Three 'flavours'
  - OWL-Lite –simple but limited
  - OWL-DL – complex but deliverable (real soon now)
  - OWL-Full – fully expressive but serious logical/computational problems
    - Russel Paradox etc etc
  - All layered (awkwardly) on RDF Schema
- Still work in progress – see Semantic Web Best Practices & Deployment Working Group (SWBP)

25

## Description Logics

- What the logicians made of Frames
  - Greater expressivity and semantic precision
    - Compositional definitions
      - "Conceptual Lego" – define new concepts from old
- To allow automatic classification & consistency checking
  - The mathematics of classification is tricky
    - Some seriously counter-intuitive results
      - The basics are simple – devil in the detail

26

## Description Logics

- Underneath:
  - computationally tractable subsets of first order logic
- Describes relations between Concepts/Classes
  - Individuals secondary
    - ***DL Ontologies are NOT databases!***

27

## Description Logics:
## A brief history

- Informal Semantic Networks and Frames (pre 1980)
  - Wood: *What's in a Link*; Brachman *What IS-A is and IS-A isn't*.
- First Formalisation (1980)
  - Bobrow *KRL*, Brachman: *KL-ONE*
- All useful systems are intractable (1983)
  - Brachman & Levesque: *A fundamental tradeoff*
    - Hybrid systems: T-Box and A-Box
- All tractable systems are useless (1987-1990)
  - Doyle and Patel: *Two dogmas of Knowledge Representation*

28

# A brief history of KR

- 'Maverick' incomplete/intractable logic systems (1985-90)
  - GRAIL, LOOM, Cyc, Apelon, …,
- Practical knowledge management systems based on frames
  - Protégé
- The German School: Description Logics (1988-98)
  - Complete decidable algorithms using tableaux methods (1991-1992)
  - Detailed catalogue of complexity of family – "alphabet soup of systems"
- Optimised systems for practical cases (1996-)
- Emergence of the Semantic Web
  - Development of DAML (frames), OIL (DLs) → DAML+OIL → OWL
    - **Development of Protégé-OWL**
    - **A dynamic field – constant new developments & possibilities**

29

# And beware Ontologies are not databases!

- Ontologies are (mostly) about the classes –
  - Can be used to represent database aspects of ***schemas***
    - *What must be true of any database consistent with the schema*
  - The Terminology
    - *What must be true of any concept consistent with the ontology*
  - The "T-Box" – for "terminology box"
- Limited functionality for individuals ('instances')
  - Primarily to help define classes
    - The class of John's shirts, The class of cities in Japan
  - To describe individuals use
    - A database
    - Triple representation (RDF or Topic Maps)
    - An instance store
    - Perhaps with an ontology as the schema
  - Open world instead of closed world
    - Individuals in ontologies (The "A-Box") poorly understood and very high computational complexity

30

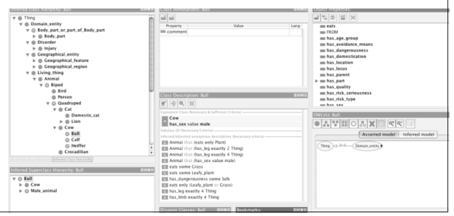
# Approach

- Design patterns
  - Analogous to Java design patterns
    - Standard ways to do things
      - Someday they will be supported by tools, but today you have to do it yourself
  - Being codified by Semantic Web Best Practice Working Group
- Elephant traps
  - Common errors & misconceptions
    - Especially those that seem to work at first
- Foundations of knowledge representation
  - 200 to 2000 years of experience & mistakes you need not repeat
- Common dilemmas & tradeoffs
  - Things for which we don't have a perfect answer

31

# Protégé OWL: New tools for ontologies

- Transatlantic collaboration
- Implement robust OWL environment within PROTÉGÉ framework
  - Version 4-A1pha - complete rewrite
  - You will be guinea pigs - and we will have human facts folk seeing what problems you have
  - New ideas for debugging, visualisation, ontology management, etc.



## Protégé-OWL & CO-ODE

- Joint work: Stanford & U Manchester +
  Southampton & Epistemics
  - Please give us feedback on tools – mailing lists & forums at:
    - **protege.stanford.edu**
    - **www.co-ode.org**
- Don't beat your head against a brick wall!
  - Look to see if others have had the same problem; If not…
  - ***ASK!***
    - ***We are all learning.***

33

## OWL-DL & Classification

- Not all of OWL-DL can yet be implemented
  - We will deal mostly with what can be classified using Racer or FaCT++
  - Not all of the things that are implemented scale successfully
    - All classifiers are worst-case exponential (or worse)
- FaCT++
  - Classifier being developed here
    - Dmitry Tsarkov/Ian Horrocks
- Pellet
  - Classifier from originally MindSwap (U Maryland) www.mindswap.org but now here
    - Bijan Parsia
    - Best integrated with Protégé at the moment.
- We will try to provide warnings of things which cannot be classified or do not scale
  - But you may discover new things on your own

34

## Example Ontologies for this Module

- Pizzas
  - For the mechanics of OWL and Protégé/OWL
    - Simple – no ontological problems, just mechanics
- Animals for best practice examples and ontology building
  - The example for you to work from
    - Also for examples of parts and wholes
- The University and courses
  - Your job is to build an ontology for the University by analogy to the examples
    - with some specific help
    - Leads on to major ontological issues
- Simple Upper Ontology
  - To put it together
    - Mostly about the University

35

## Building Ontologies

- Basic Concepts and Mechanics

36

## Why it's hard (1)

- Clash of intuitions
  - Subject Matter Experts motivated by custom & practice
    - Prototypes & Generalities
  - Logicians motivated by logic & computational tractability
    - Definitions and Universals
- Transparency & predictability vs Rigour & Completeness
- Neophytes (you?) caught in the muddled middle

37

## Why it's hard (2)

- Conflation of Models
  - Meaning: Correctness of Classification & retrieval
  - Indexing: Task of discovery, search, or finding
  - Use: Task of data entry, decision support, …
  - Acquisition: Task of capturing knowledge
- Assuring quality & managing change
  - Quality assurance: Criteria for whether it is 'correct'
  - Evolution Coping with change
  - Regression testing Controlling changes & maintaining Quality

38

## Why its hard (3)

- Confusion of terminology and usage
  - Religious wars over words and assumptions
- The intersection of
  - Linguistics
  - Cognitive science
  - Software engineering
  - Philosophy
  - Human Factors
- A jumble of syntaxes

39

## Vocabulary

- "Class" ≈ "Concept" ≈ "Category" ≈ "Type"
- "Instance" ≈ "Individual"
- "Entity" ≈ "object", Class or individual
- "Property" ≈ "Slot" ≈ "Relation" ≈ "Relationtype" ≈ "Attribute" ≈ Semantic link type" ≈ "Role"
  - but be careful about "role"
    - Means "property" in DL-speak
    - Means "role played" in most ontologies
      - E.g. "doctor_role", "student role" …

40

## Syntaxes

- Three official syntaxes + Protégé-OWL syntax
  - Abstract syntax-- -Specific to OWL
  - *N3 ----------------* -*OWL & RDF*
    -*used in all SWBP documents*
  - XML/RDF ------- -very verbose, not for human consumption
  - *"German DL"----* -*very concise, symbolic*
  - First order logic - - complete but more powerful than DL
  - *Manchester Syntax---- - Intuitive keywords and infix notation*
- This tutorial uses simplified abstract syntax
  - someValuesFrom → ***some*** ∃
  - allValuesFrom → ***only*** ∀
  - intersectionOf → AND ⊓
  - unionOf → OR ⊔
  - complementOf → NOT ¬
  - complete ***definition*** ***necessary & sufficient***
  - partial ***description*** ***necessary***
- Protégé/OWL can generate all syntaxes except German



## Why its hard (4)

- Clash with vocabulary and practice of related software disciplines
- Most OO analysis produces a set of templates
  - E.g. a Java Class is a template for a Java object
    - Nothing is permitted until there is a place for it in the template
- OWL is a way of specifying constraints
  - The criteria for being a member of a class
    - Everything is permitted until ruled out by a constraint



## **Clash with intuitions of related fields**

- Object Oriented Programming
  - Java,a C++, Smalltalk, etc.
    - But OO programming is not knowledge representation
- Object Oriented Design (Databases )
  - But data models are not ontologies either
    - Although UML is often a good starting point
      - Additional a-logical issues
        - » Difference between attributes and relations
        - » Issues of life cycle and handling of aggregation
        - » Notion of an instance
        - » Implicitly "closed world"
- Frame based systems, Semantic Nets,… Traditional AI
  - Where it all started but real differences
- RDF(S), Topic Maps and other node-and-arc symbolisms
  - "What's in a link?"
  - The battles in standards committees continue



## **Summary of Approach**
## **Steps in developing an Ontology (1)**

1. Establish the purpose
   - Without purpose, no scope, requirements, evaluation,
2. Informal/Semiformal knowledge elicitation
   - Collect the terms
   - Organise terms informally
   - Paraphrase and clarify terms to produce informal concept definitions
   - Diagram informally
3. Refine requirements & tests

**Summary of Approach**
**Steps in implementing an Ontology (2)**

4. Implementation
   - Develop normalised schema and skeleton
   - Implement prototype recording the *intention as a paraphrase*
     - Keep track of what you meant to do so you can compare with what happens
       - Implementing logic-based ontologies is programming
   - Scale up a bit
     - Check performance
   - Populate
     - Possibly with help of text mining and language technology
5. Evaluate & quality assure
   - Against
   - Include tests for evolution and change management
   - Design regression tests and "probews"
6. Monitor use and evolve
   - ***Process not product!***

45

## If this were three modules…

1. Knowledge elicitation and analysis
   - A quick overview
2. **Implementation**
   - **A solid introduction**
3. Evolution, ontology alignment, and management
   - Left for another module
     - But a major motivation for the methods taught in this module
       - Normalisation and documentation of intentions

46

## Plan of Labs

- Lab 1 – the mechanics of OWL in Protégé Owl
  - The pizza example
- Lab 2 – Ontology building the life cycle
  - A more realistic example
  - Start building the University example
    - On the pattern of the lecture example of animals
- Lab 3
  - Problems and tricks of the trade
  - DL problems (IH)
- Lab 4
  - More on patterns and parts and whole
- Lab 5
  - Upper ontologies and clarification of the mini project

47

## More Reasons

- To make domain assumptions explicit
  - easier to change domain assumptions (consider a genetics knowledge base)
  - easier to understand and update legacy data
- To separate domain knowledge from the operational knowledge
  - re-use domain and operational knowledge separately (e.g., configuration based on constraints)
- To manage the combinatorial explosion

48