MANCHESTER 1824

The University of Manchester

Developing Biomedical Ontologies in OWL

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with special acknowledgement to Jeremy Rogers

www.co-ode.org
www.clinical-escience.org
www.opengalen.org

NIBHI

Tools and downloads

- Protege4Alpha
  - protege.stanford.edu
  - http://protege.stanford.edu/download/prerelease-alpha/protege-bin-4.0-alpha.zip
- GraphViz - required for OWLViz
  - http://www.graphviz.org/
- Tutorial handouts and Ontologies
  - http://www.cs.man.ac.uk/~rector/tutorials/Biomed-Tutorial-2007b-dagstuhl/

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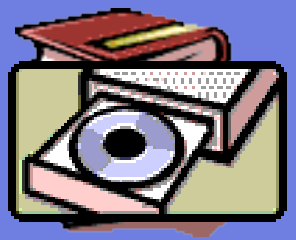
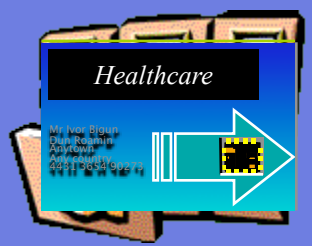
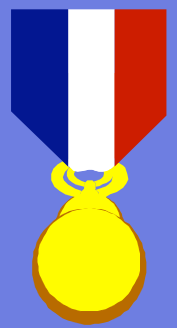
Where I come from

Clinical Terminology ← Data Entry ← Clinical Record ← Clinical research & Decision Support ← Best Practice







GALEN Ontologies & Description logics → Data Entry → Electronic Health Records → Clinical research → Decision Support & Knowledge Presentation → **Best Practice**

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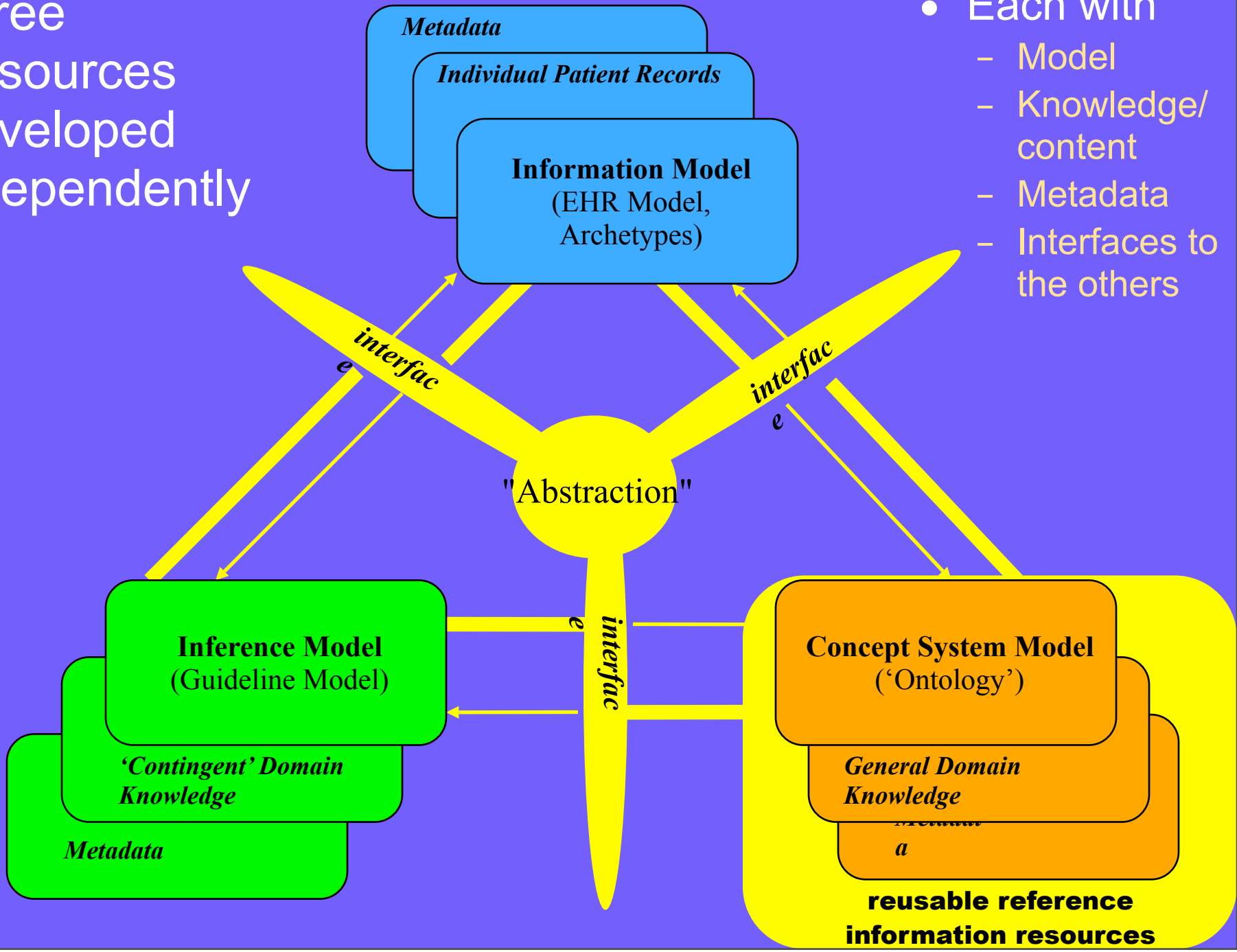
“Ontologies” in Information Systems

- What information systems can say and how - “Models of Meaning”
  - Mathematical theories - although usually weak ones
    - evolved at the same time as Entity Relation and UML style modelling
- Managing Scalabilty / complexity - “Knowledge driven systems”
  - Housekeeping tools for expert systems
    - Organising complex collections of rules, forms, guidelines, ...
- Interoperability
  - The common grounding information needed to achieve communication
  - Standards and terminology
- Communication with users
  - Document design decisions
- Testing and quality assurance
  - sufficient constraints to know when it breaks
  - Empower users to make changes safely
- ... but ***“They don’t make the coffee”***
  - ***just one component of the system / theory***

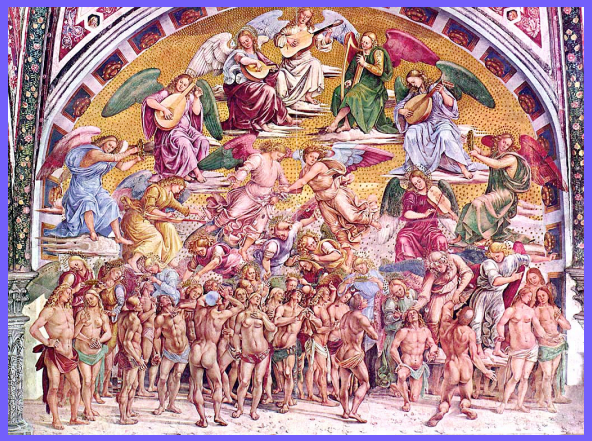
Three Resources Developed independently



- Each with
  - Model
  - Knowledge/ content
  - Metadata
  - Interfaces to the others

By way of User Centred Design

Knowledge Representation / ontologies was a solution, not a goal



- Solution space
  - Ontologies
  - Information Models
  - Logics
  - Rules
  - Frames
  - Planners
  - Logic programming
  - Bayes nets
  - Decision theory
  - Fuzzy sets
  - Open / closed world
- Problem space
  - Answer questions
  - Advising on actions
  - Hazard monitoring
  - Creating forms
  - Discovering resources
  - Constraint actions
  - Assess risk
  - …

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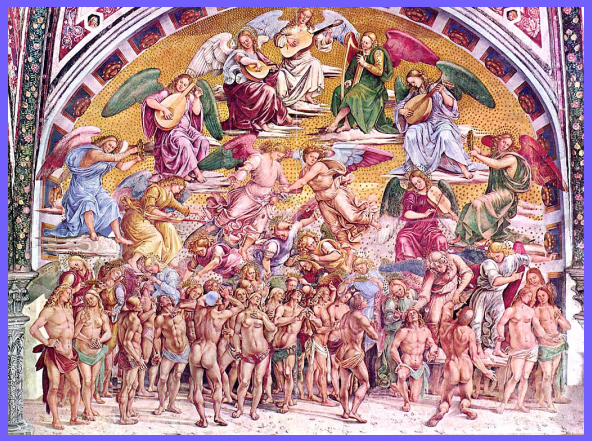

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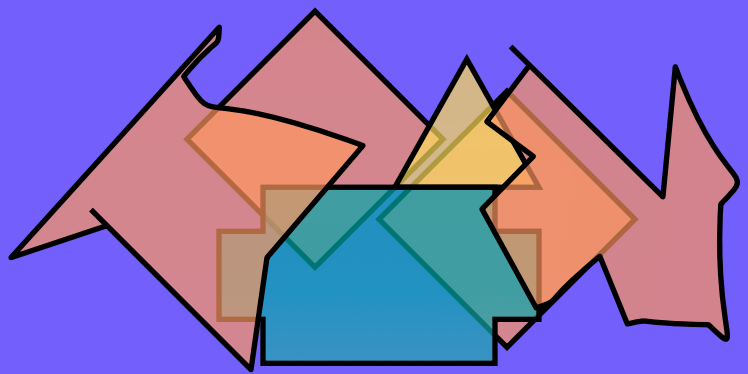
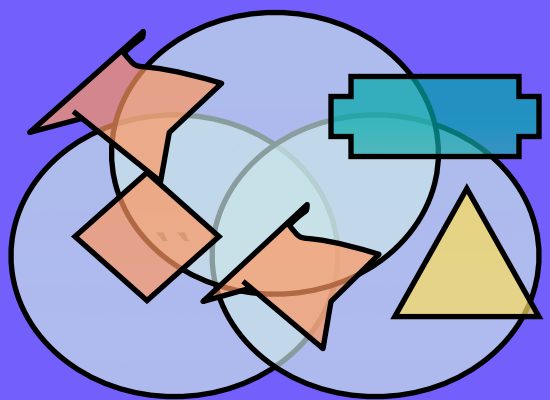
Problem space & solution space

Problem space



Guidelines, Patterns, Tools

Solution space



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Some Recent User Experiences

- Two companies building clinical systems
  - Intelligent forms creation and constraint management
    - Mastering a combinatorial explosion of ≥10^7
  - Workshops, Training and subcontracting
- NHS National Programme for IT:
  - Additional constraints to UML and between UML and terminology/ontology
    - Different implementation of the standard don't fit
  - Managing SNOMED
    - Large ≥450K ters DL based terminology
- Biologists research groups
  - Pathways
  - Epidemiology / Clinical Trials
  - Normalisation of Gene Ontology
  - Discovery of Phosphatases and other Protein activity
  - Animal behaviour and biological images
-

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Topics for today

- Normalisation & Why Classify?
  - Why use a computable subset of logic?
- Modularisation - doing it in layers
- Anatomy, parts and Disorders
  - Pneumonitis and pneumonias
  - A disorders of the lung
- Quantities and Units
- Normal, NonNormal & Pathological
  - Using negation

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Why use a Classifier?

- To *compose* concepts
  - Allow *conceptual lego*
- To avoid *combinatorial explosions*
  - Keep bicycles from exploding To manage *polyhierarchies*
  - Adding abstractions (“axes”) as needed
  - *Normalisation*
    - Untangling
      - labelling of “kinds of is-a”
- To manage *context*
  - Cross species, Cross disciplines, Cross studies
- To check *consistency* and *help users find errors*

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Assertion:

The arrival of computable logic-based ontologies/OWL gives new opportunities to make ontologies more manable and modular

- Let the ontology authors
  - create discrete modules
  - describe the links between modules
- Let the logic reasoner
  - Organise the result
- Let users see the consequences of their actions
  - Very few people can do logic well
    - And almost none quickly

Fundamental problems:

Enumeration doesn't scale

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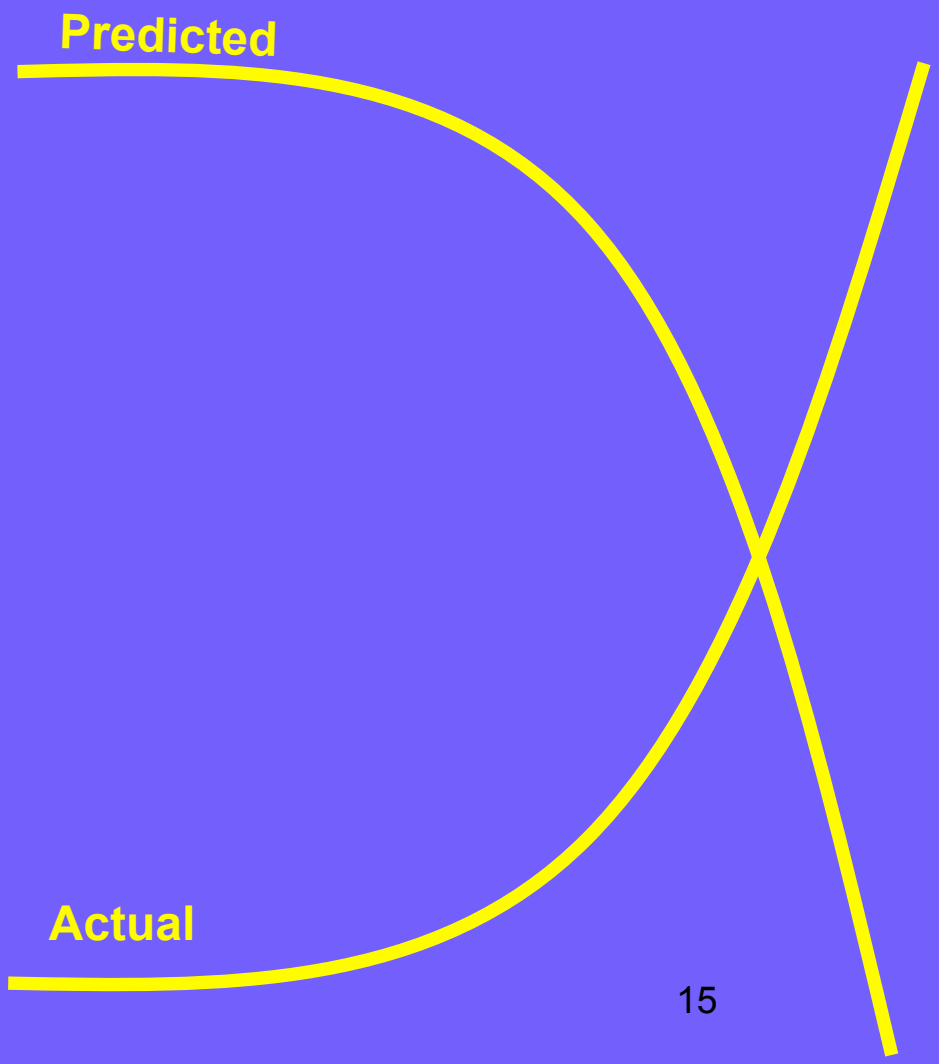
The scaling problem: The combinatorial explosion

- It keeps happening!
  - "Simple" brute force solutions do not scale up!

- Conditions x sites x modifiers x activity x context→
  - *Huge number of terms to author*
  - *Software CHAOS*



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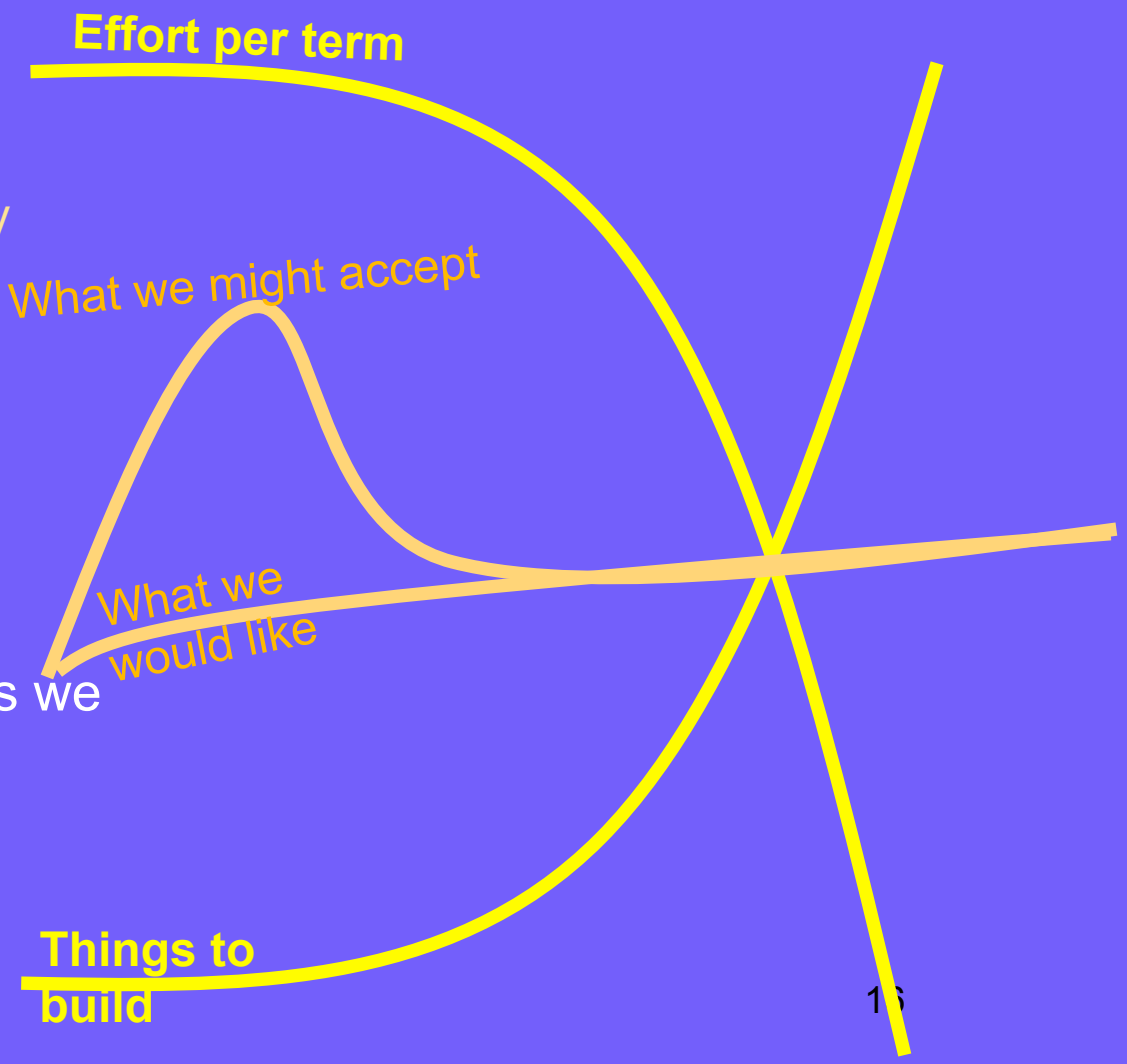
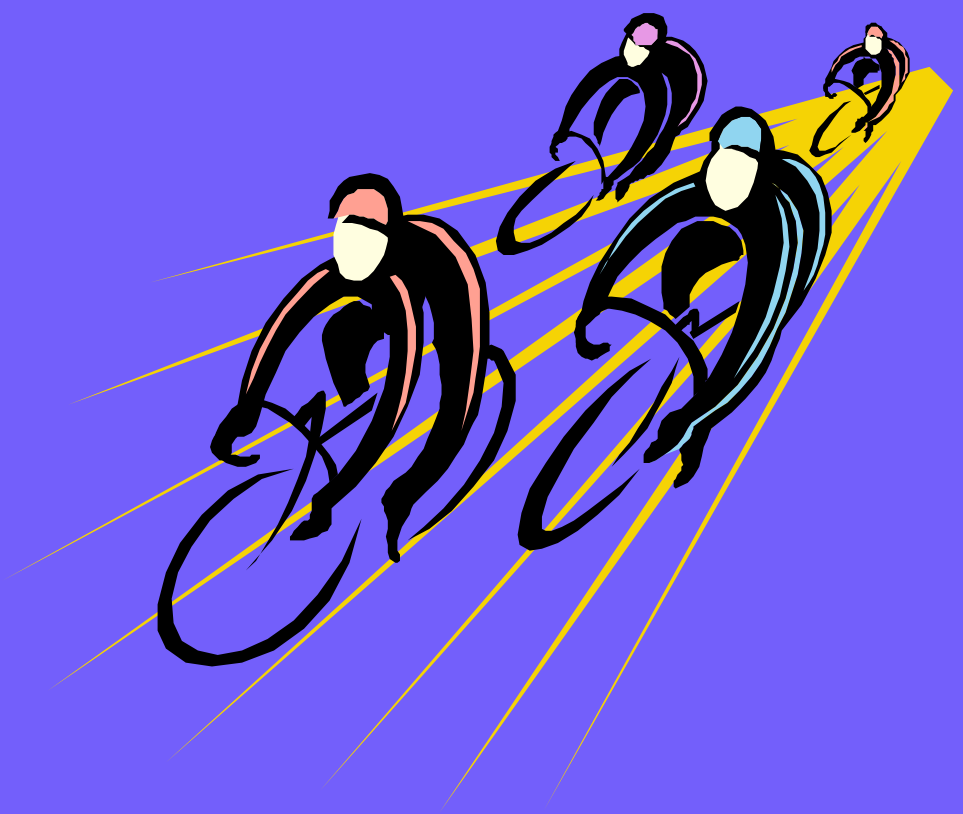
Combination of things to be done & time to do each thing

- Terms and forms needed
  - Increases exponentially
- Effort per term or form
  - Must decrease to compensate
- To give the effectiveness we want
  - Or might accept



The exploding bicycle

- 1972 ICD-9 (E826) 8
- READ-2 (T30..) 81
- READ-3 87
- 1999 ICD-10 ……



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1999 ICD10: 587 codes

- V31.22 Occupant of three–wheeled motor vehicle injured in collision with pedal cycle, person on outside of vehicle, nontraffic accident, while working for income
- W65.40 Drowning and submersion while in bath–tub, street and highway, while engaged in sports activity
- X35.44 Victim of volcanic eruption, street and highway, while resting, sleeping, eating or engaging in other vital activities

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Defusing the exploding bicycle:
500 codes in pieces

- 10 things to hit…
  - Pedestrian / cycle / motorbike / car / HGV / train / unpowered vehicle / a tree / other
- 5 roles for the injured…
  - Driving / passenger / cyclist / getting in / other
- 5 activities when injured…
  - resting / at work / sporting / at leisure / other
- 2 contexts…
  - In traffic / not in traffic

V12.24 Pedal cyclist injured in collision with two- or three-wheeled motor vehicle, unspecified pedal cyclist, nontraffic accident, while resting, sleeping, eating or engaging in other vital activities

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Conceptual Lego… it could be...

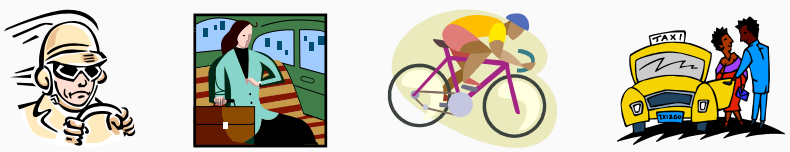
Structured Data Entry

File Edit Help

Cycling Accident

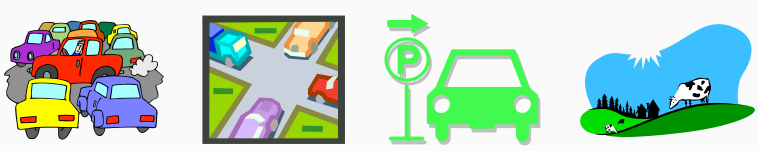
What you hit

Your Role



Activity

Location



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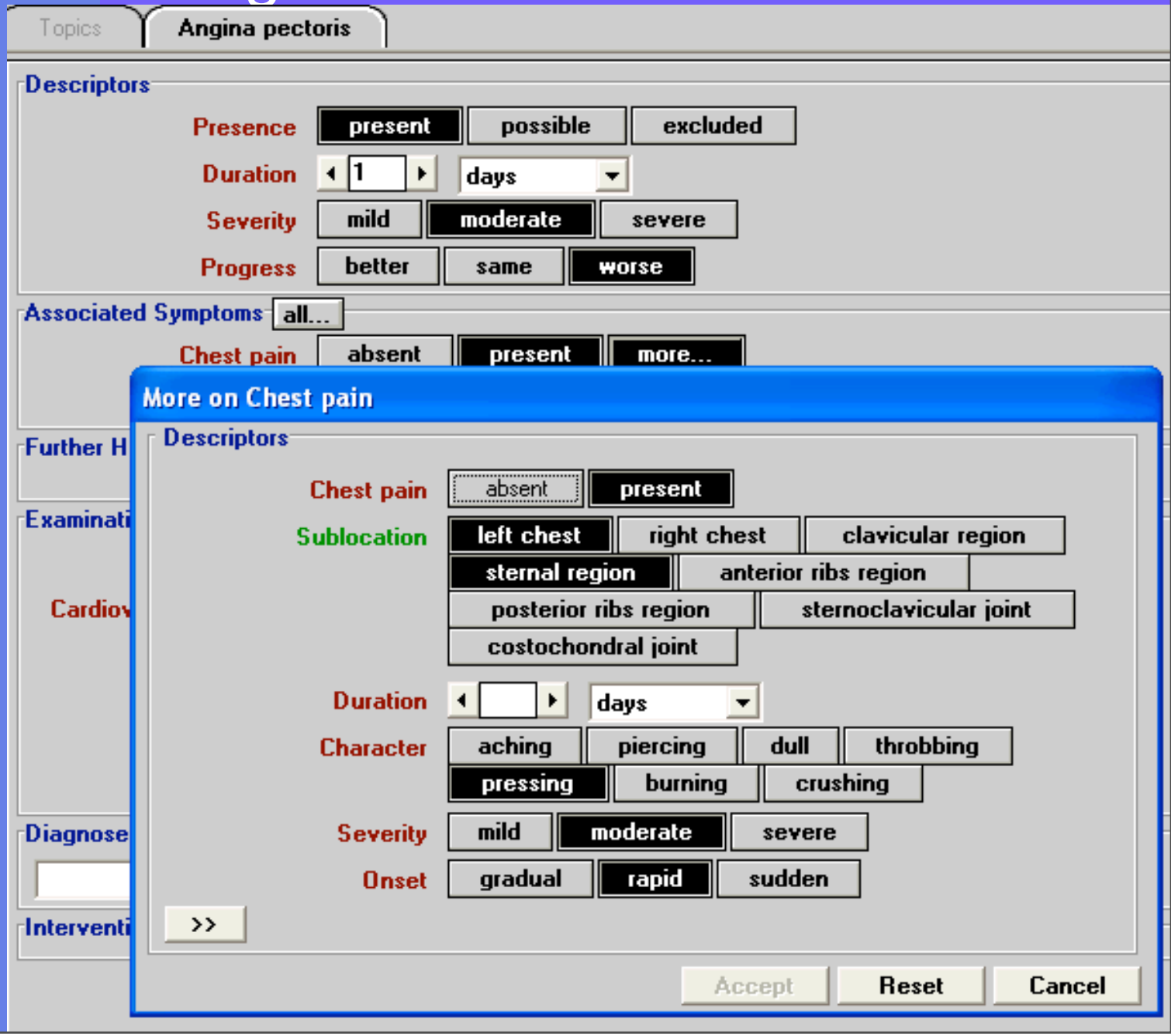
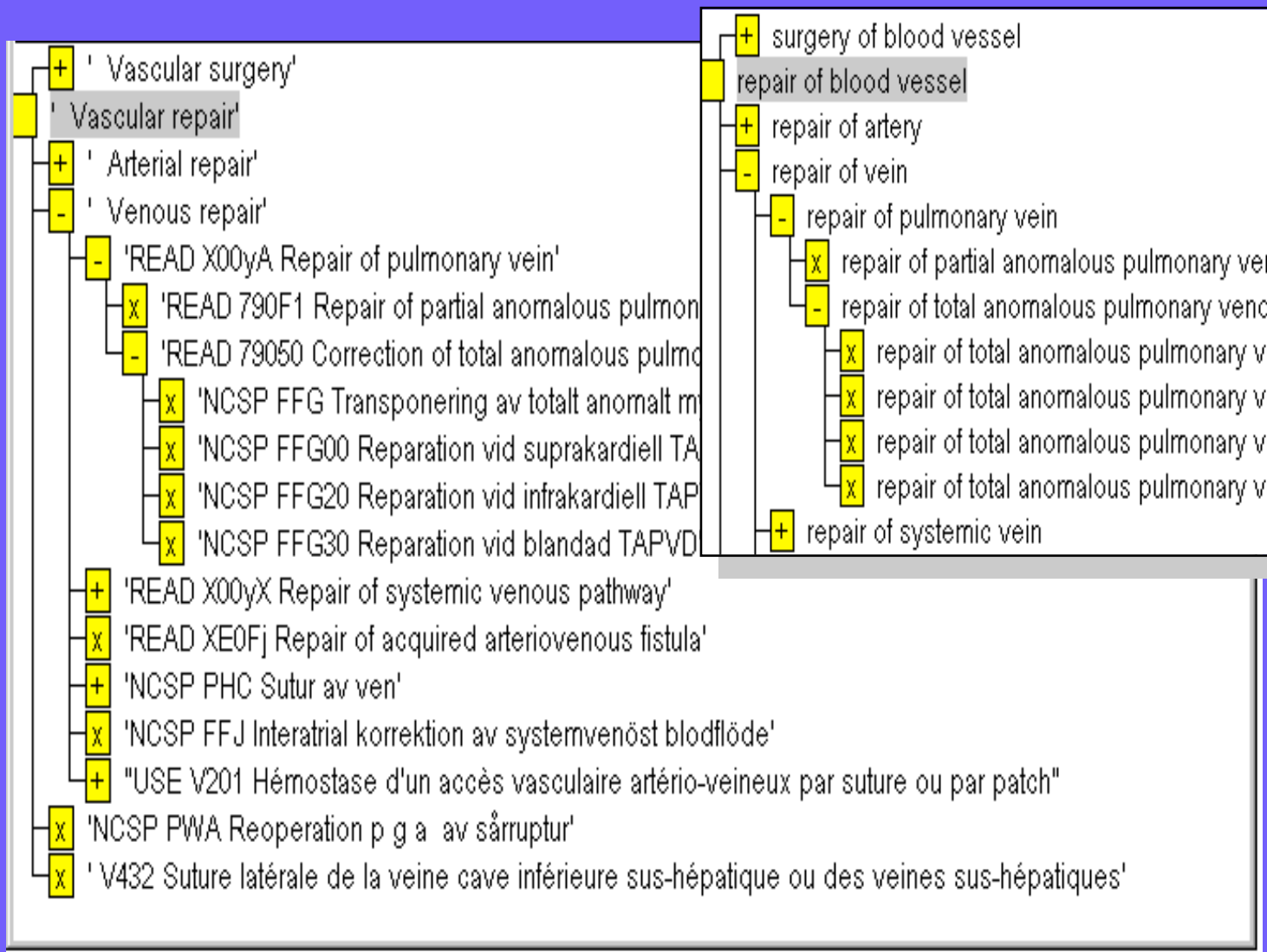
Intelligent Forms



Integrating rather than Cross Mapping



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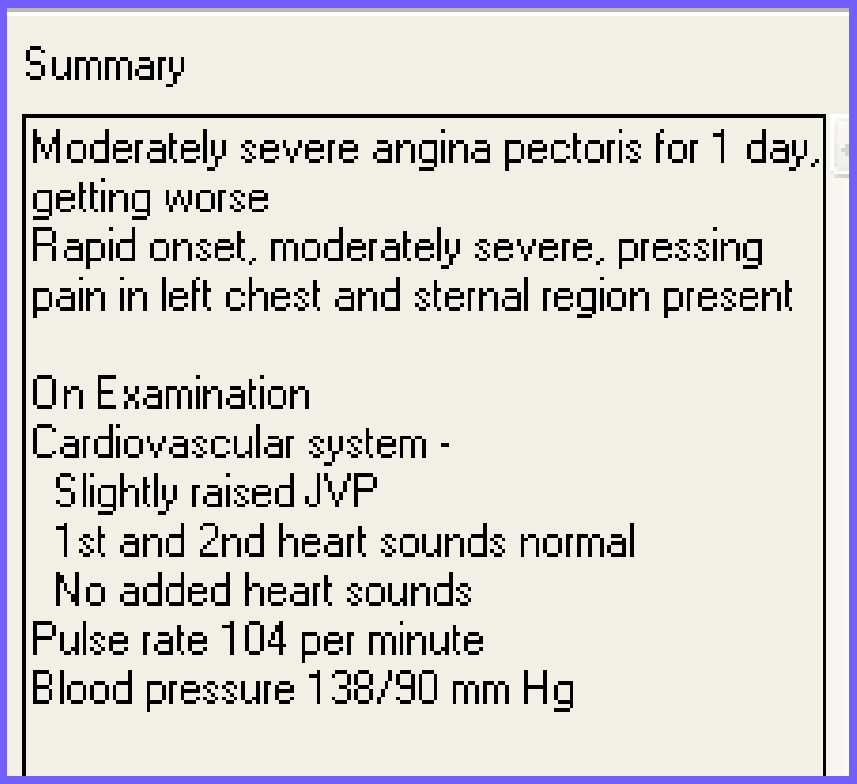
And generate it in language



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Supports Loosely coupled distributed ontology development

global cycle & work at centre

From 80% central/global effort to 10% central/global effort

From authoring to meta-authoring

User effort cut by 75% compared with manual methods
Mostly in reduced committee meetings & arguments

The means: Logic as the clips for "Conceptual Lego"

hand

extremity

body

chronic

acute

abnormal

normal

ischaemic

deletion

polymorphism

mucus

gene

protein

polysacharide

cell

expression

Lung

infection

inflammation

bacterium

virus

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Logic as the clips for "Conceptual Lego"

"***SNPolymorphism*** of ***CFTRGene*** causing ***Defect in MembraneTransport*** of ***Chloride Ion*** causing ***Increase*** in ***Viscosity*** of ***Mucus*** in ***CysticFibrosis***…"

"***Hand*** which is ***anatomically normal***"

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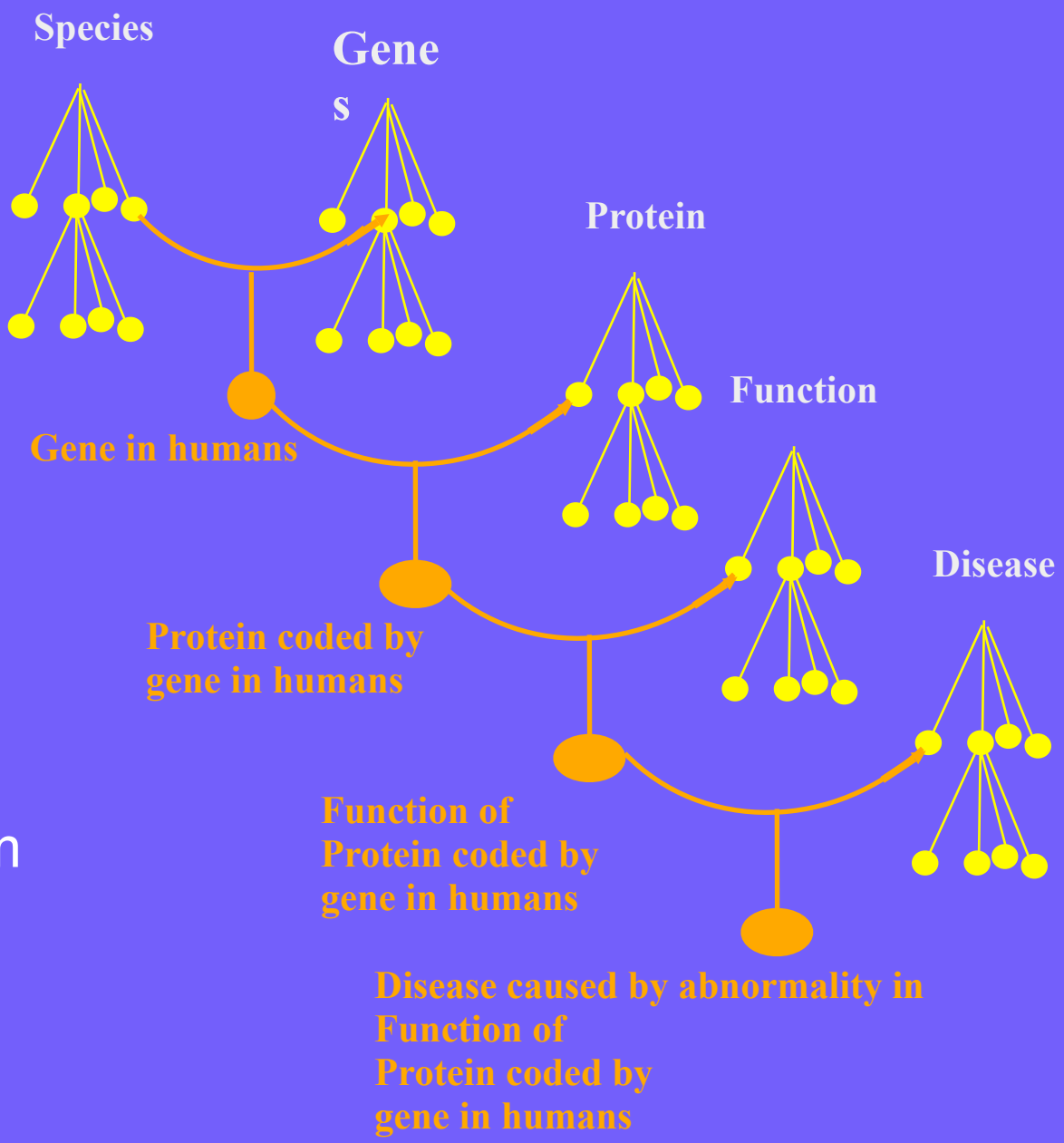
Build complex representations from modularised



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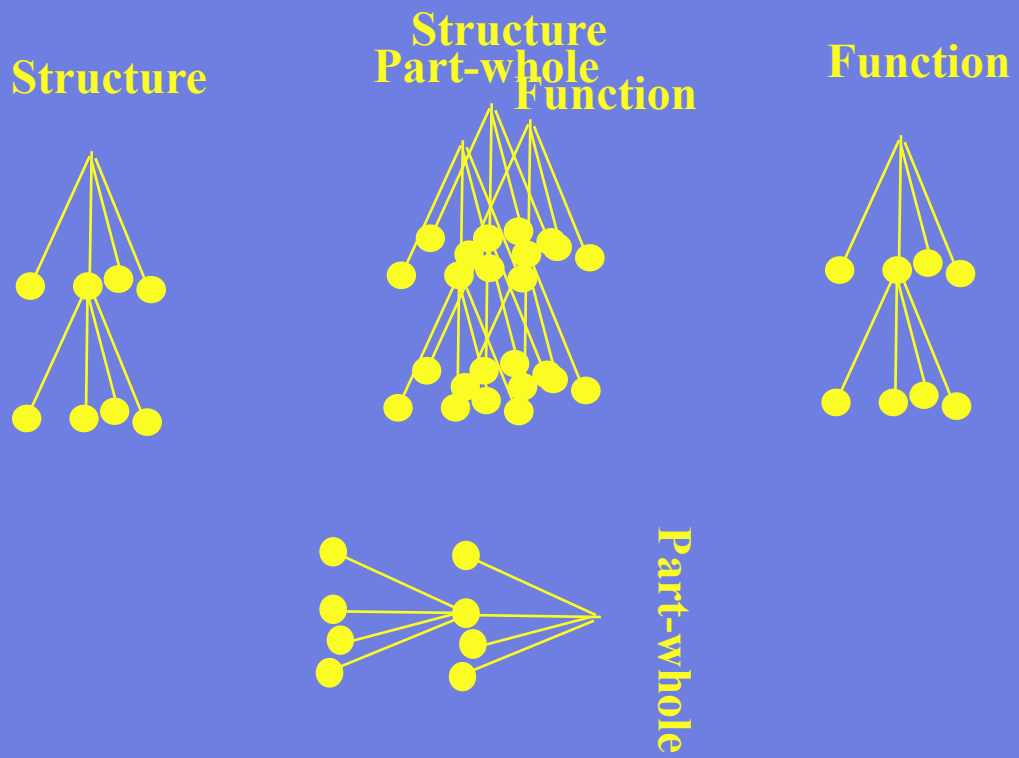
Normalising (untangling) Ontologies



Rationale for Normalisation

- Maintenance
  - Each change in exactly one place
    - No “Side effects”
- Modularisation
  - Each primitive must belong to exactly one module
    - *If a primitive belongs to two modules, they are not modular.*
    - *If a primitive belongs to two modules, it probably conflates two notions*
  - Therefore concentrate on the *“primitive skeleton”* of the domain ontology
- Parsimony
  - Requires fewer axioms

Normalisation and Untangling

Let the reasoner do multiple classification

- Tree
  - Everything has just one parent
    - A ‘strict hierarchy’
- Directed Acyclic Graph (DAG)
  - Things can have multiple parents
    - A ‘Polyhierarchy’
- Normalisation
  - Separate primitives into disjoint trees
  - Link the trees with restrictions
    - Fill in the values

Untangling and Enrichment

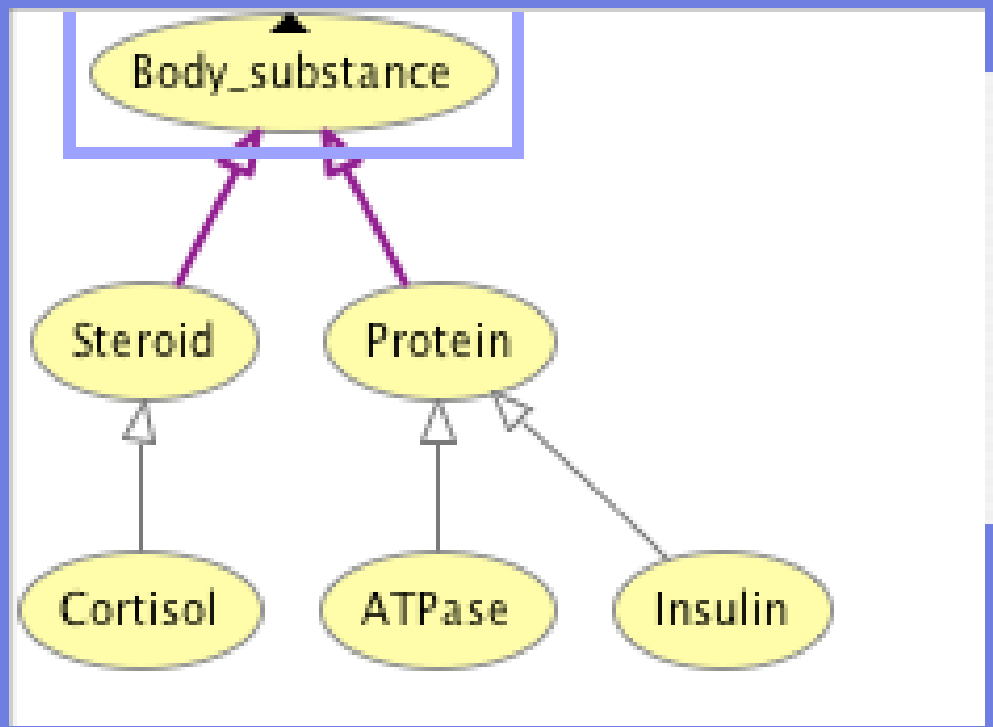
Using a classifier to make life easier

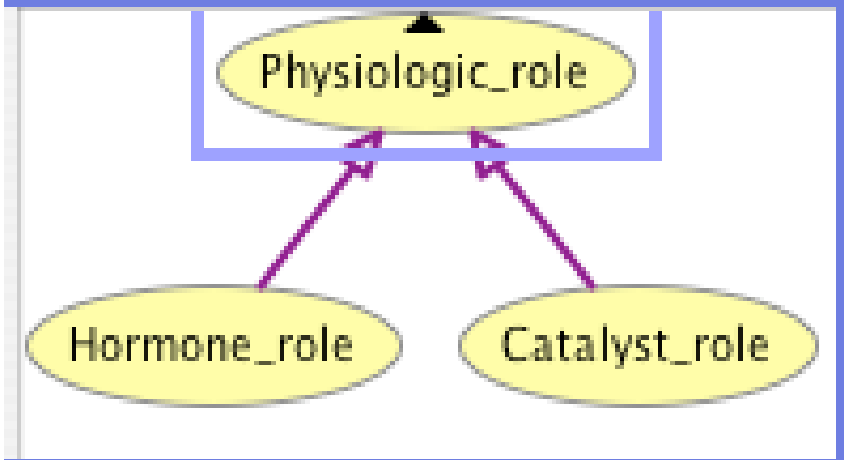
- Substance
- - Protein
- - - Insulin
- - - ATPase
- Steroid
- - Cortisol

- PhsioloicRole
- - HormoneRole
- - CatalystRole

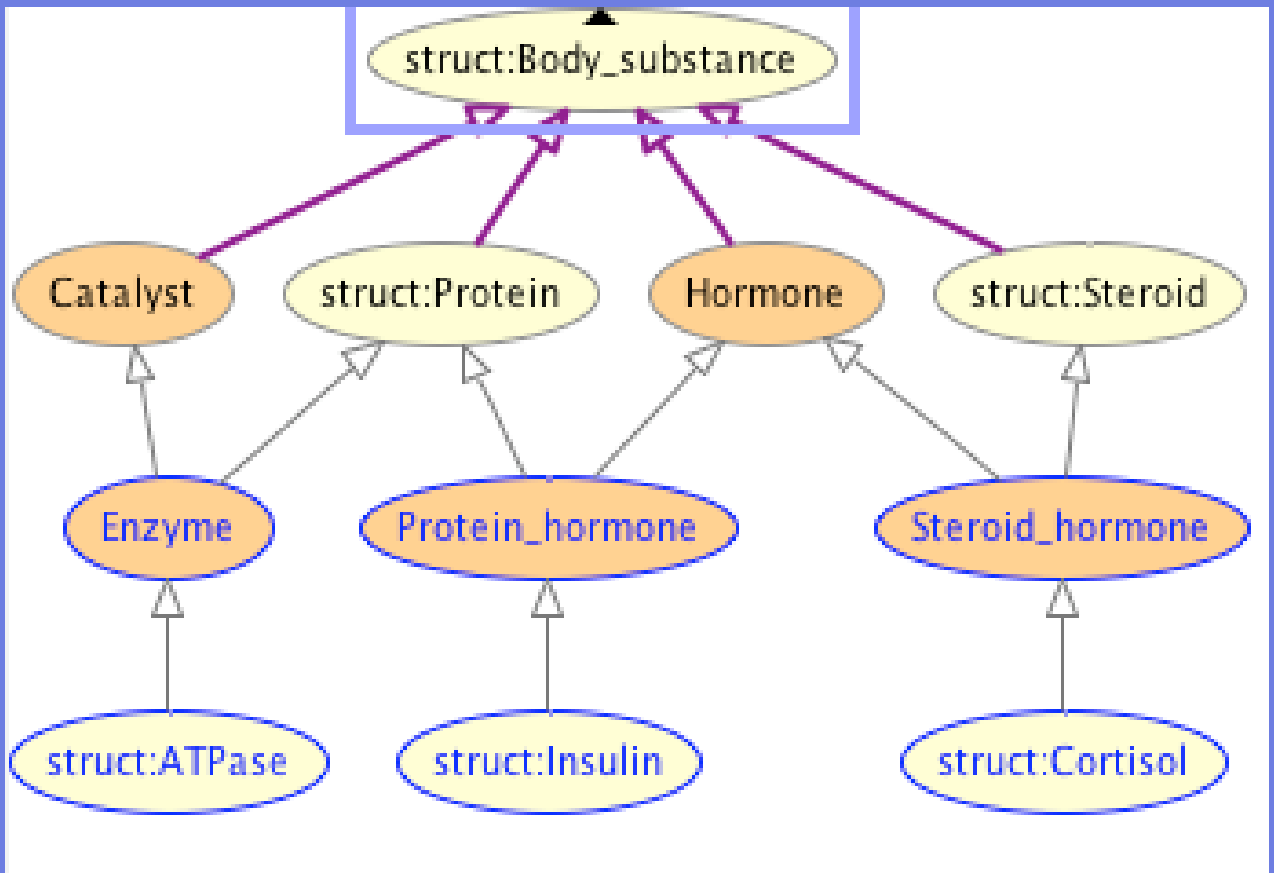
Substance
- Protein
- - ProteinHormone
- - - Insulin
- - Enzyme
- - - ATPase
- Steroid
- - SteroidHomone^
- - - Cortisol
-Hormone
- - ProteinHormone^
- - - Insulin^
- - SteroidHormone^
- - - Cortisol^
- Catalyst
- - Enzyme^
- - - ATPase^

Modularised into structure and function ontologies

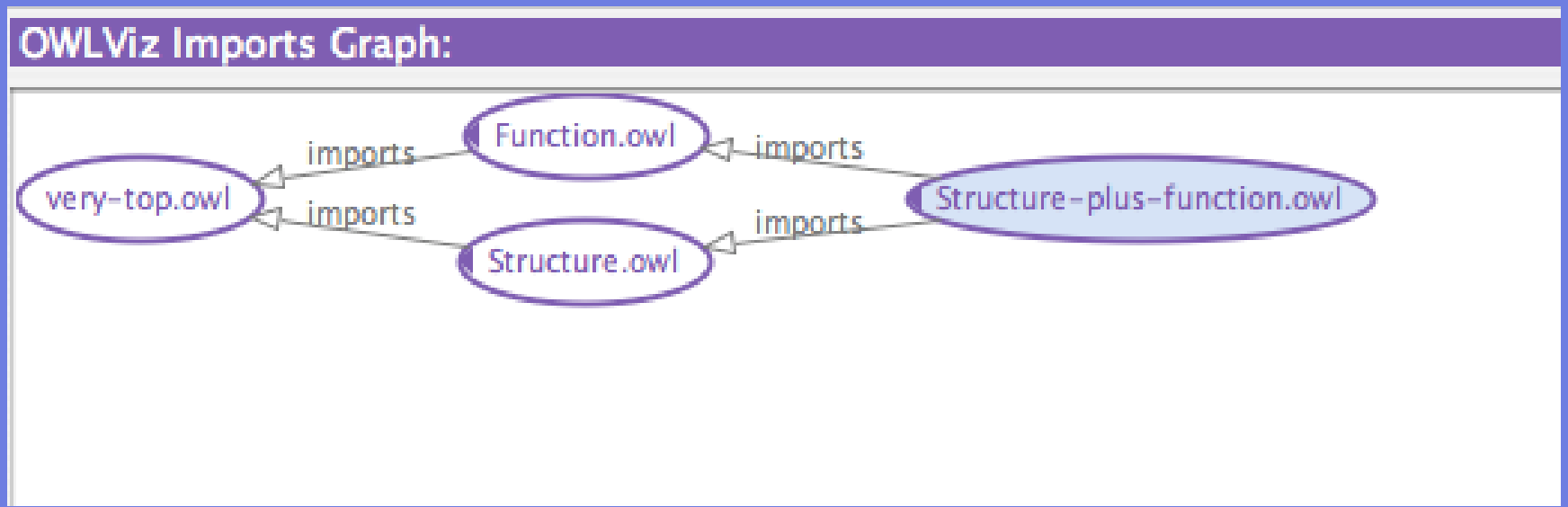




Unified ontology after classification



Module Structure



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Normalisation: Criterion 1 The skeleton should consist of disjoint trees

- *Every primitive concept should have exactly one primitive parent*
  - All multiple hierarchies the result of inference by reasoner

Normalisation Criterion 2: *No hidden changes of*

- *Each branch should be homogeneous and logical*
  ("Aristotelian")
  - Hierarchical principle should be subsumption
    - Otherwise we are "lying to the logic"
  - The criteria for differentiation should follow consistent principles in each branch
    eg. structure *XOR* function *XOR* cause

Normalisation Criterion 3

Distinguish "Self-standing" and "Refining" Concepts
"Qualities" vs Everything else

- Self-standing concepts
  - Roughly Welty & Guarino's "sortals"
    - *person, idea, plant, committee, belief,…*
- Refining concepts – depend on self-standing concepts
    - *mild|moderate|severe, hot|cold, left|right,…*
  - Roughly Welty & Guarino's non-sortals
  - Closely related to Smith's "fiat partitions"
  - Usefully thought of as Value Types by engineers
- For us an engineering distinction…

Normalisation Criterion 3a

Self-standing primitives should be globally disjoint & open

- Primitives are atomic
  - If primitives overlap, the overlap conceals implicit information
- A list of self-standing primitives can never be guaranteed complete
  - How many kinds of person? of plant? of committee? of belief?
  - Can't infer: Parent & $\neg sub_1$ &…& $\neg sub_{n-1}$ → sub_n
- Heuristic:
  - Diagnosis by exclusion about self-standing concepts should *NOT* be part of 'standard' ontological reasoning

Normalisation Criterion 3b

Refining primitives should be <u>locally</u> disjoint & closed

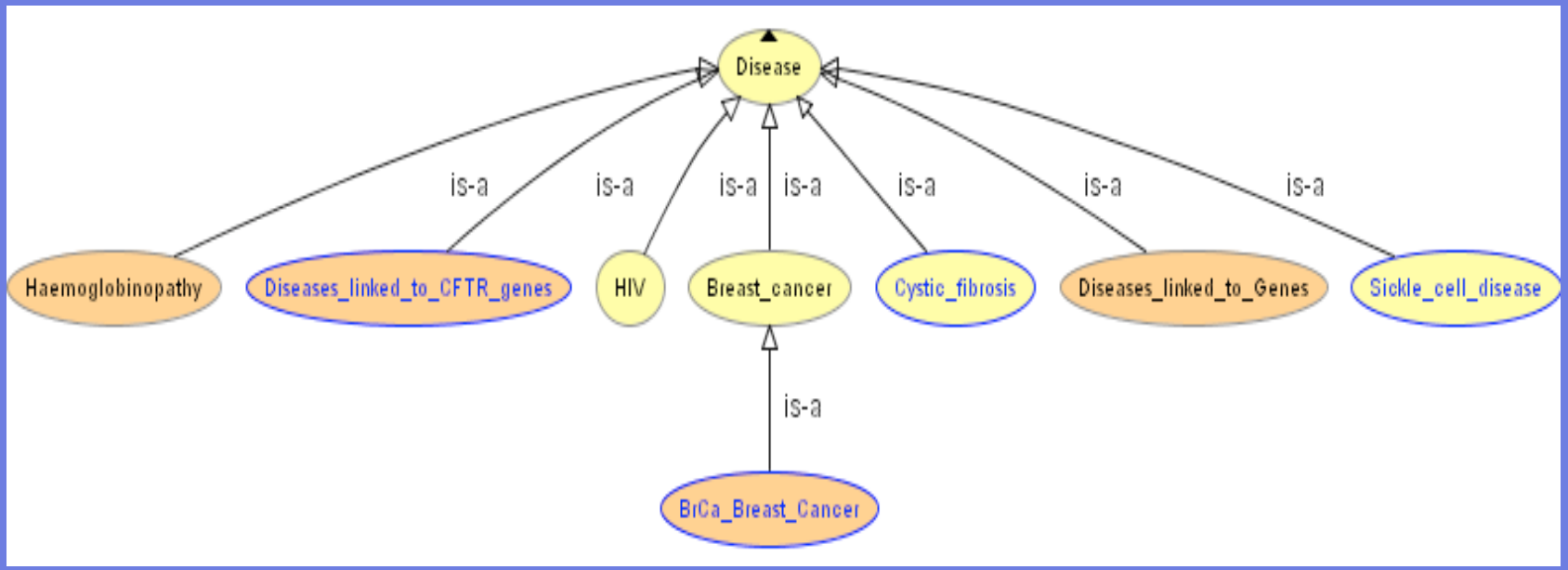
- individual values must be disjoint
  - but can be hierarchical
    - e.g. “very hot”, “moderately severe”
- Each list can be guaranteed to be complete
  - Can infer Parent & ¬sub_1 &…& ¬sub_{n-1} → sub_n
- Value types themselves need not be disjoint
  - “being hot” is not disjoint from “being severe”
    - Allowing Valuetypes to overlap is a useful trick, e.g.
      - restriction has_state someValuesFrom (severe and hot)

Normalisation Criterion 4 Axioms

- *No axiom should denormalise the ontology*

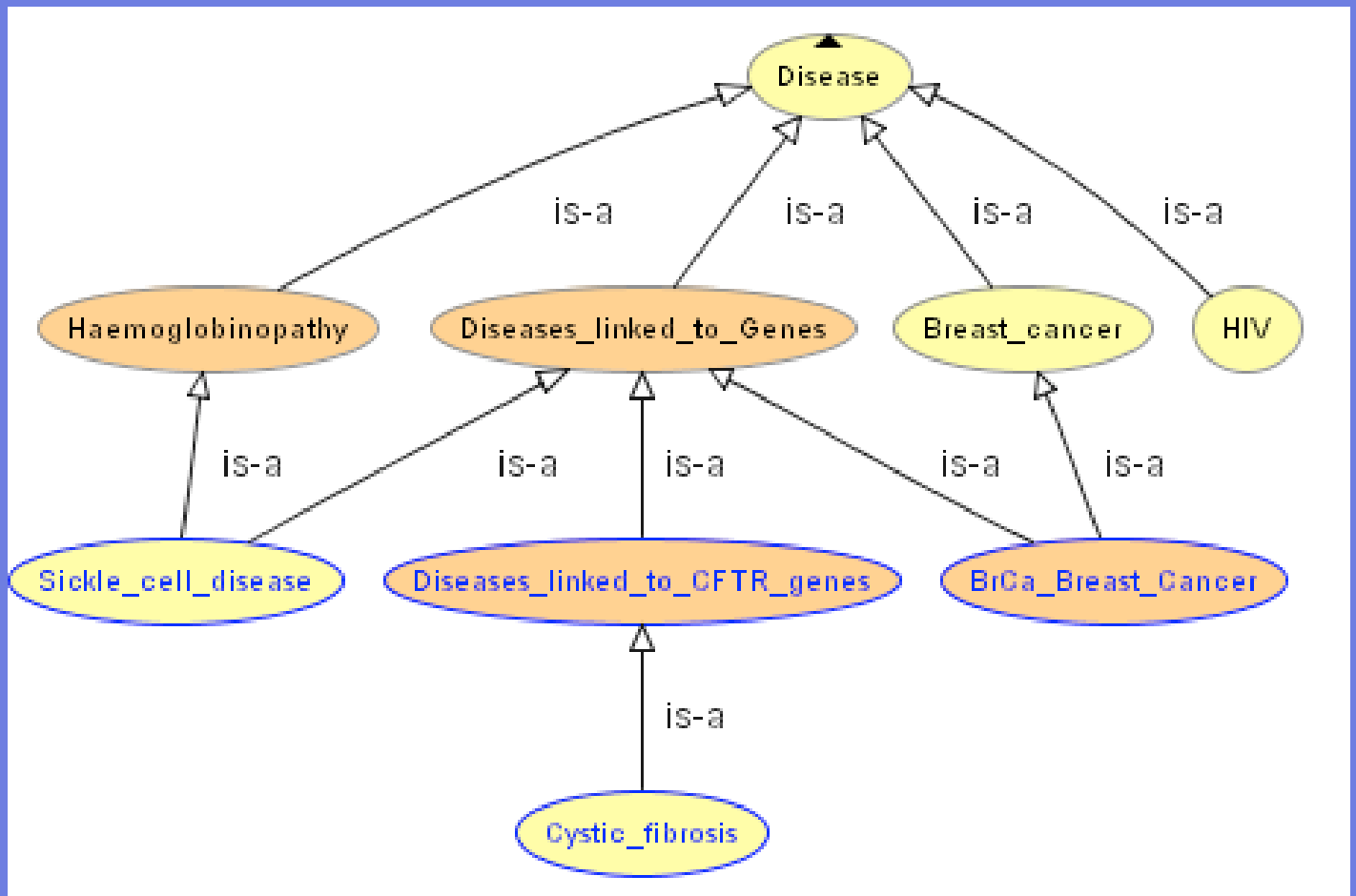
  No axiom should imply that a primitive is part of more than one branch of primitive skeleton
  - If all primitives are disjoint, any such axioms will make that primitive unsatisfiable
    - A partial test for normalisation:
      - *Create random conjunctions of primitives which do not subsume each other.*
      - *If any are satisfiable, the ontology is not normalised*

A real example: Build a simple treee

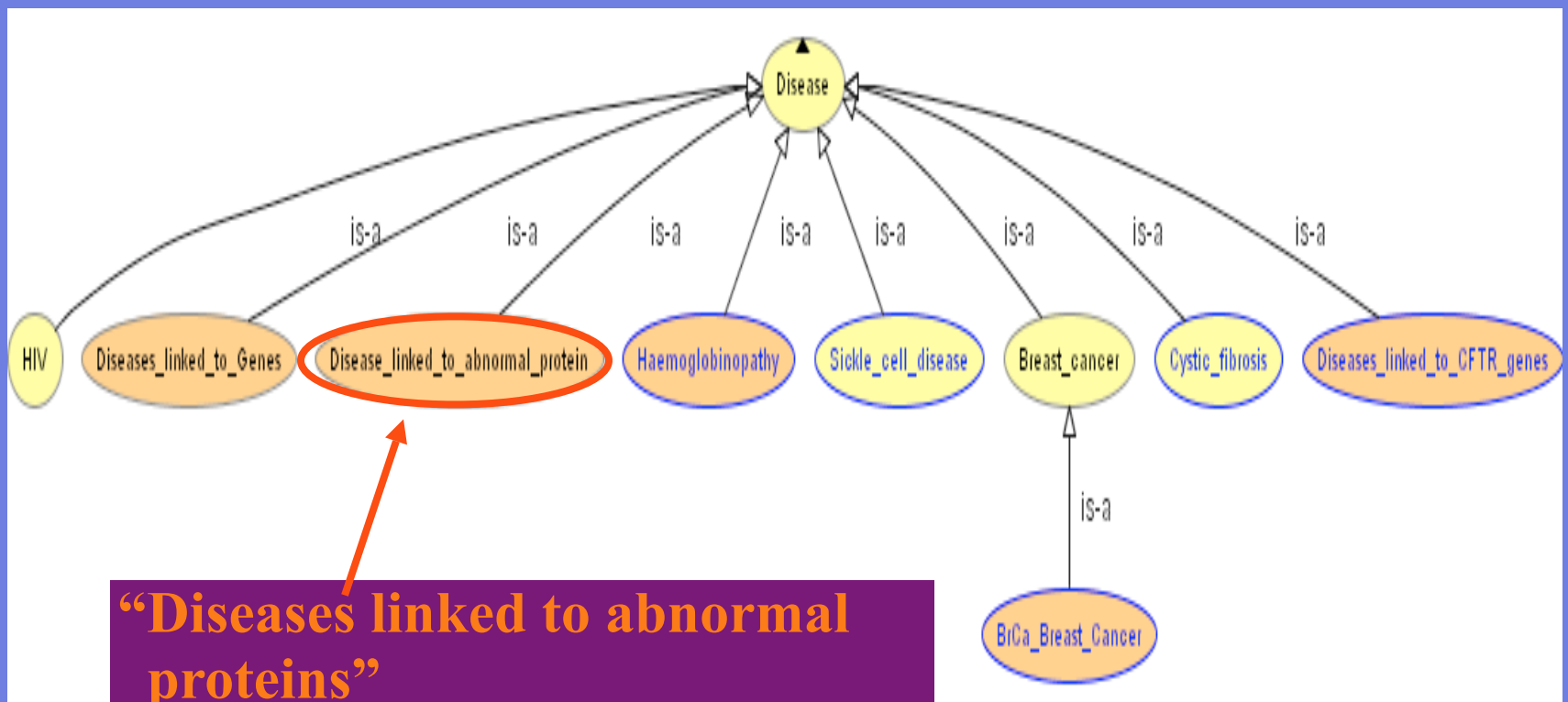


easy to maintain

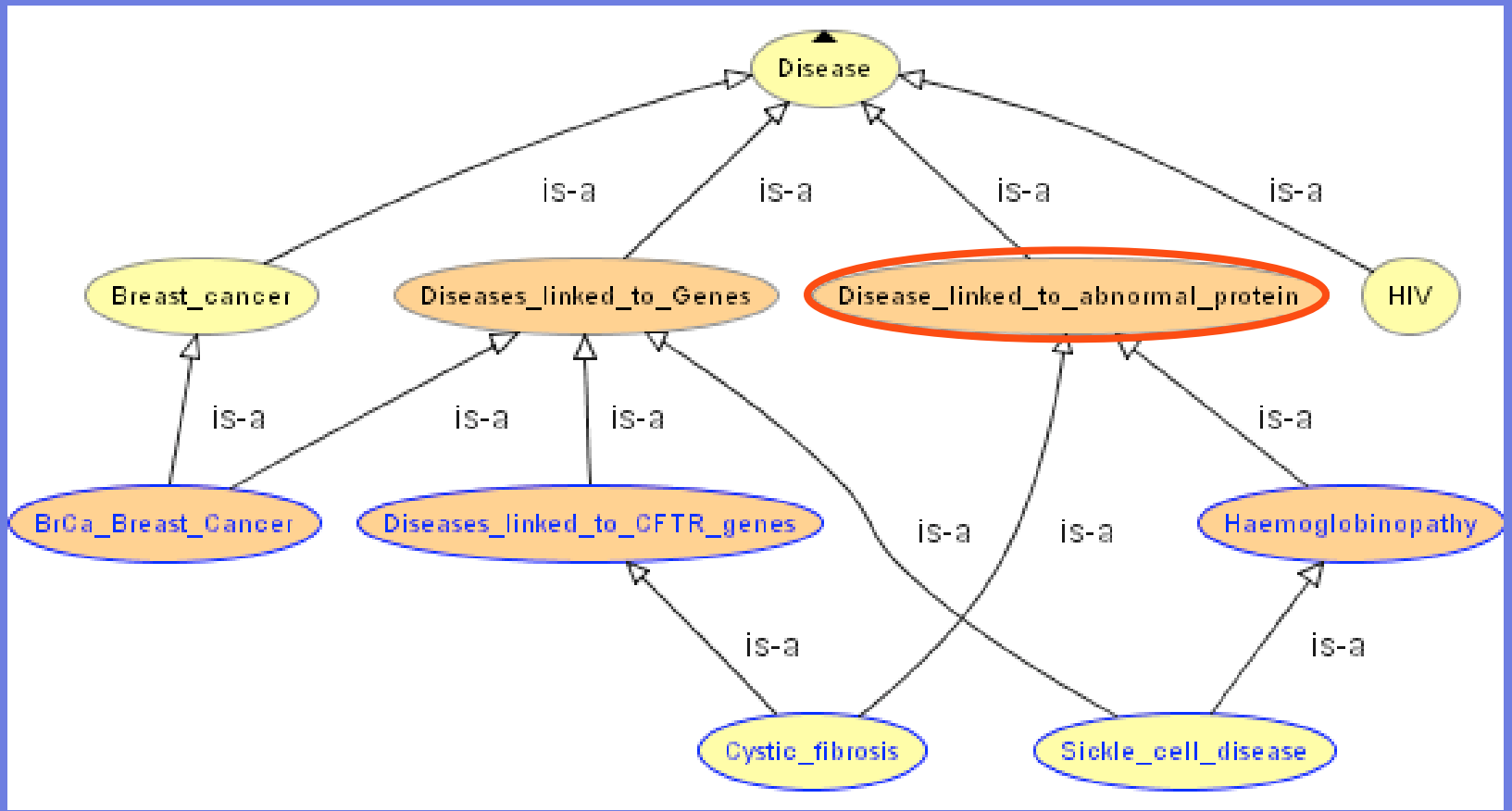
Let the classifier organise it



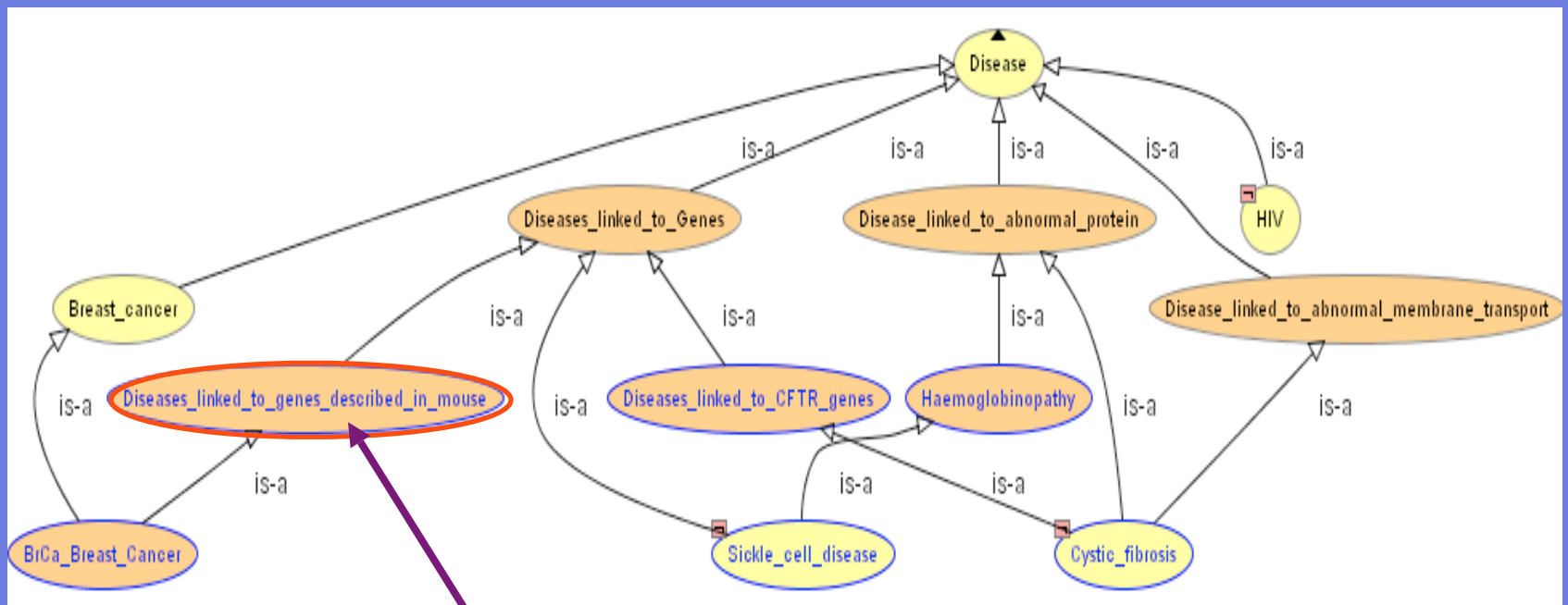
If you want more abstractions,



And let the classifier work again



And again – even for a quite different category



"Diseases linked genes described in the mouse"

Summary: Why Normalise? Why use a Classifier?

- To *compose* concepts
  - Allow *conceptual lego*
- To manage *polyhierarchies*
  - Adding abstractions (“axes”) as needed
  - *Normalisation*
    - Untangling
      - *labelling of “kinds of is-a”*
- To avoid *combinatorial explosions*
  - Keep bicycles from exploding
- To manage *context*
  - Cross species, Cross disciplines, Cross studies
- To check *consistency* and *help users find errors*

Now: How to do it in OWL - *A quick review*

- Existential qualifiers (SOME)
- Universal qualifiers (ONLY)
- Open World Assumption
  - Negation as inconsistency (”unsatisfiability”)
    - What is neither provable nor provably false is unspecified (”unknown”)

- Load infections-only.owl
    - Trivially simply model for illustration only
  - Define a bacterial infection
  - Define a viral infection
  - Define a mixed (bacterial-viral) infection

Bacterial infection

- *Any* infection caused by *some* bacterium

- Note that it is a defined (equivalent) class.

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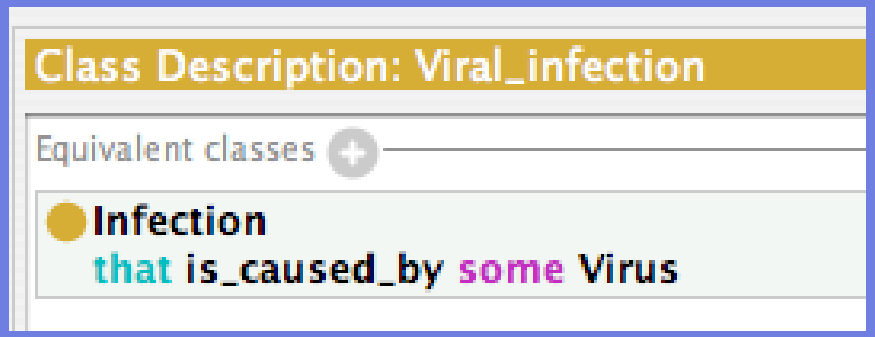
Viral infection



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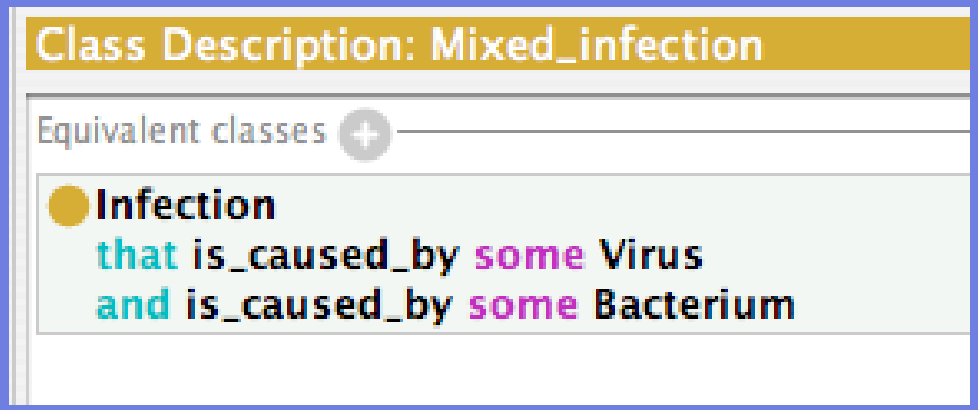
Mixed infection



- How will bacterial infection, viral infection, and mixed infection classify?
  - Run the classifier and see

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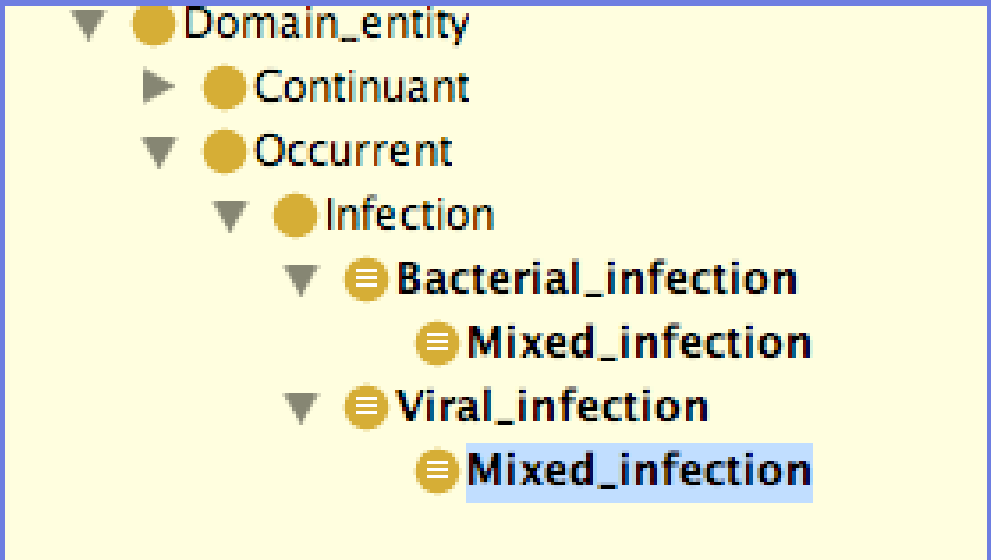
After classification



Why?

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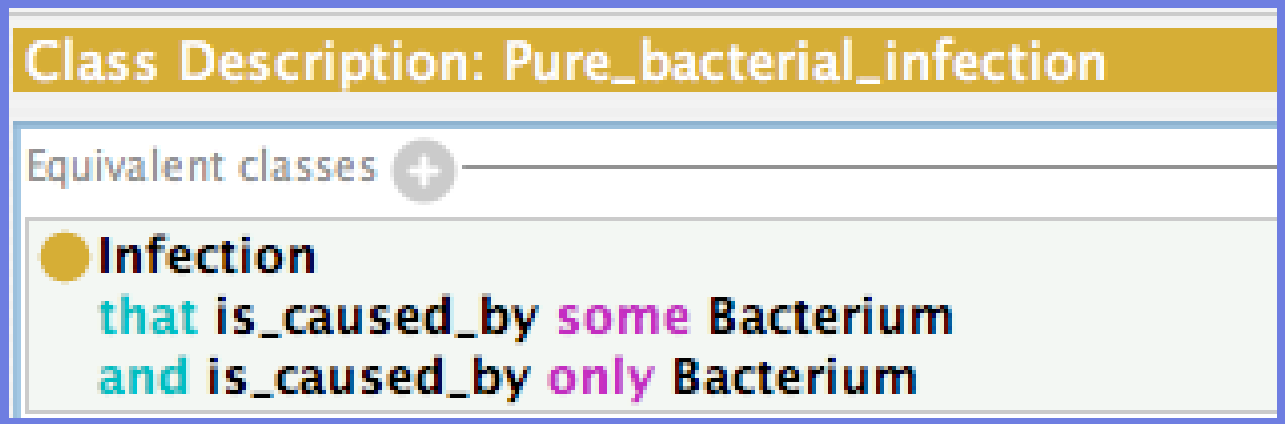
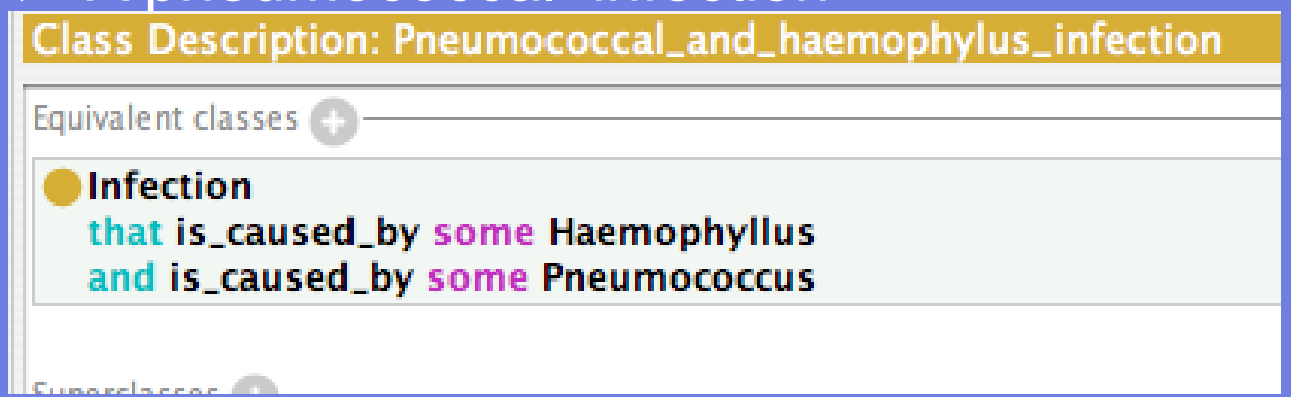
A “Pure bacterial infection”

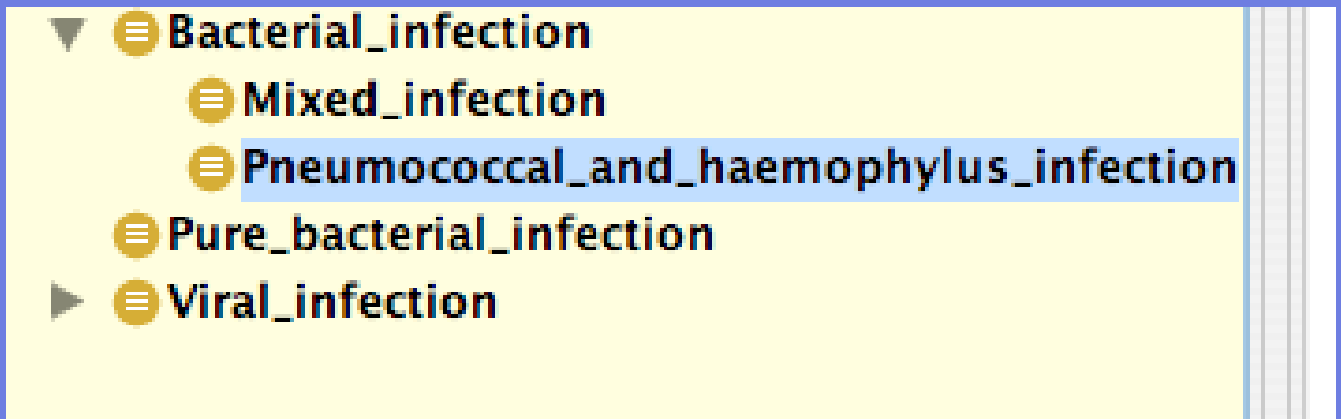


- A pneumococcal infection



- How will these classify
  - Is a pneumococcal and haemophylus infection a kind of pure bacterial infection? - Both are

Why not?



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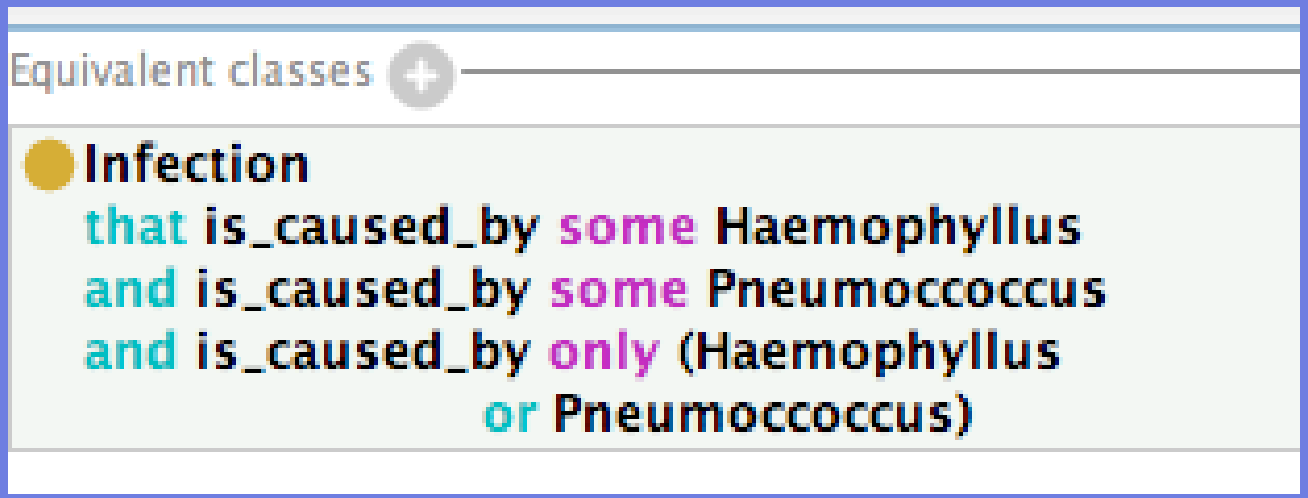
Closure Axioms



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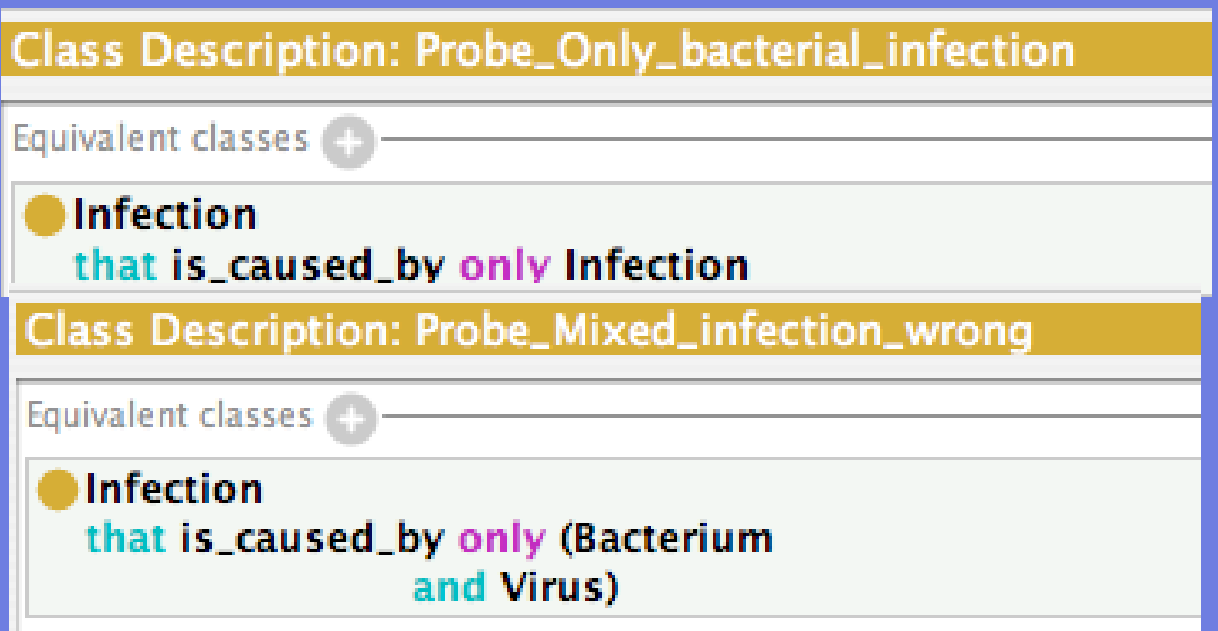
Trivial satisfiability
Two common errors



- How will these classify? Why?

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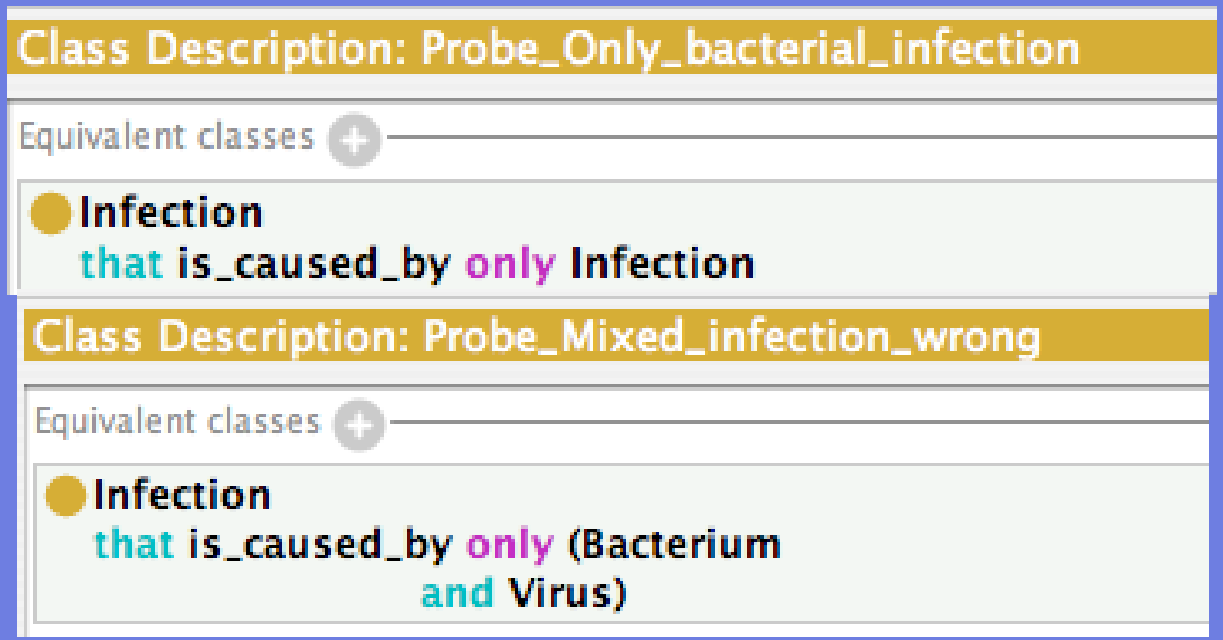
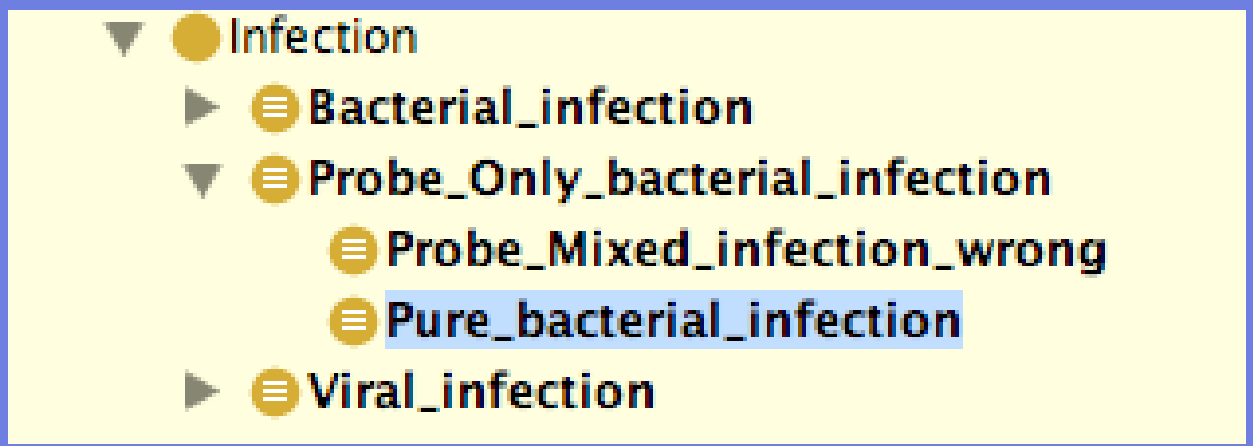
After classification (Explain it)





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Trivial satisfaction

- Bacterium and Virus are disjoint
  - Nothing is both a bacterium and a virus
    - owl:Nothing = (Bacterium AND Bottom)
- ONLY NOTHING ↔ NOT SOME THING
  - Infection THAT is_caused_by ONLY Nothing = Infection THAT NOT (is_caused_by SOME Thing)
- ONLY does not mean SOME
  - Infection THAT is_caused_by ONLY Bacterium = Infection THAT NOT (is_caused_by SOME NOT Bacterium)
    - *No cause given. There may be a cause, as long as it is a*
- Therefore:
  An infection not caused by anything is a kind of infection not caused by anything except bacteria.
  - Check definition for “Pure bacterial infection”

Modularisation: *towards assembling ontologies from reusable fragments*

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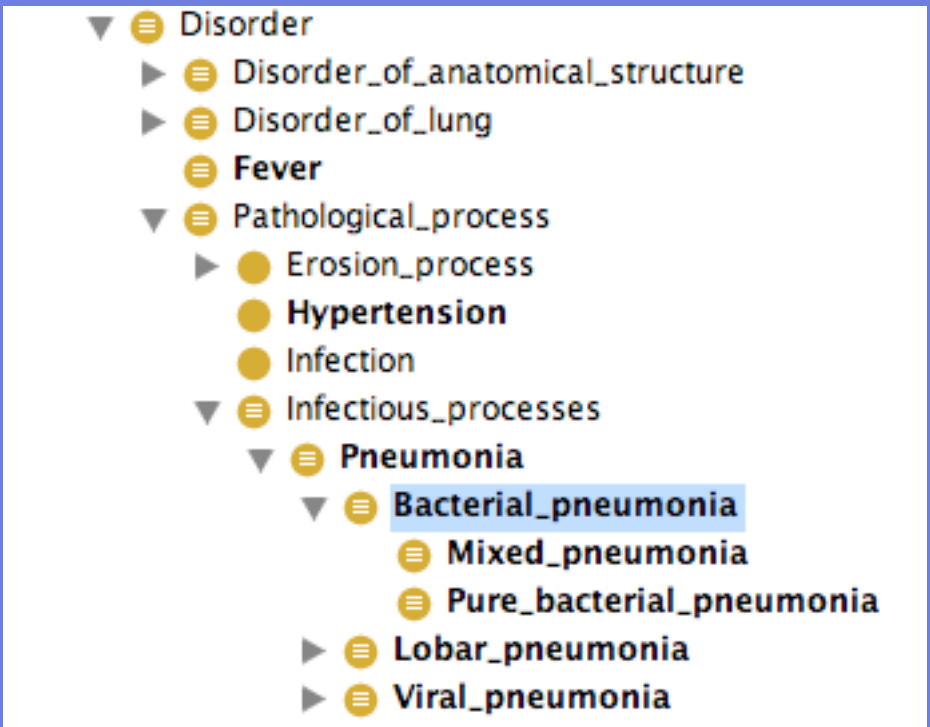
Why use modules

- Re-use
  - e.g. annotations, quantities, upper ontologies
- Coherent extensions
  - Localisation & Views
    - Local normal ranges, value sets, etc. under generic headings
  - Experimentation and add ins
    - e.g. add in tutorial examples without corrupting basic structure
- Logical separation
  - e.g. avoid confusing medicine and medical records
- ...but managing modularised ontologies is more work
  - More things to remember.
  - More things to get wrong

Modules and imports

- Key notions:
  - "Base URI" - the identifier for the ontology
    - In the form of a URI but really just an ID
      - ***Used by the import mechanism to identify the module***
  - Physical location
    - Where the module is actually stored.
      - *usualy your local directory for this version of the ontology*
- Our conventions:
  - Ontologies stored as sets of modules in a single directory
  - "Start-Here.owl" tells you what to load and load everything else.
  - The "Active ontology" is the one you are editing
    - Active ontology items are shown in bold

Items from active ontology are in bold



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Protege-OWL import mechanism

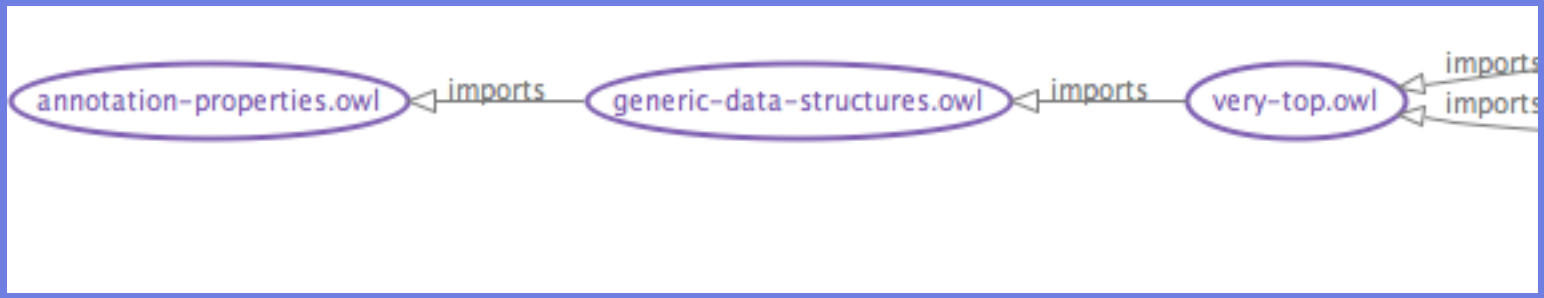
- Importer looks for a file with the correct identifying “Base URI”
  - Written into the header of the XML
  - NOT the physical location
- Order of search
  - (Specified file)
  - The local directory
  - Local libraries
  - Global libraries
  - The internet at the site indicated by the Base URI

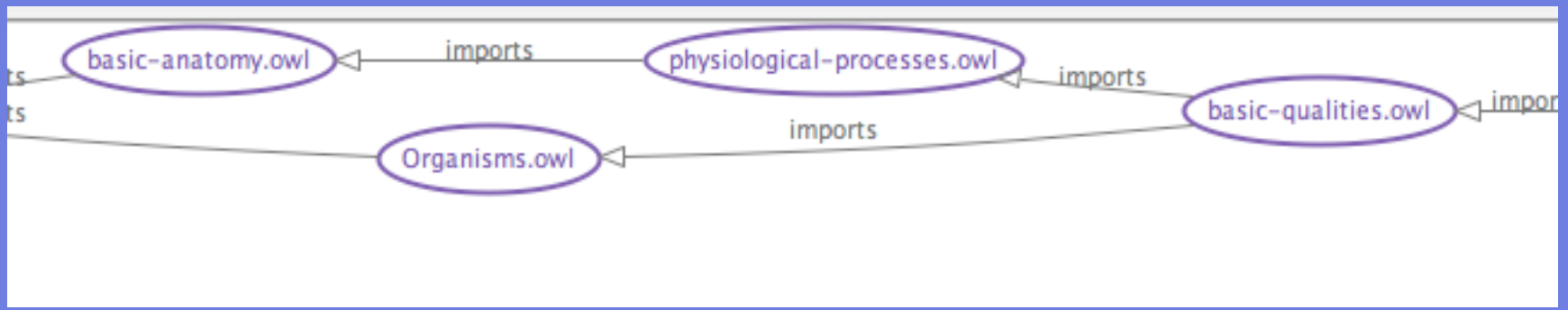
If you can, load the tutorial ontology nowontology/

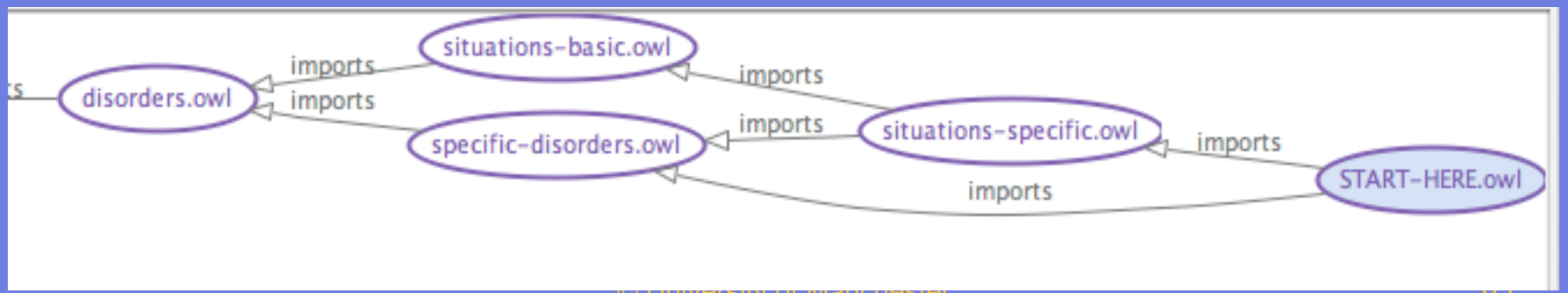
- Open .../biomedical-tutorial-2007/Start-Here.owl

Typical pattern

Views→Ontology views→OwlViz Imports







Module list

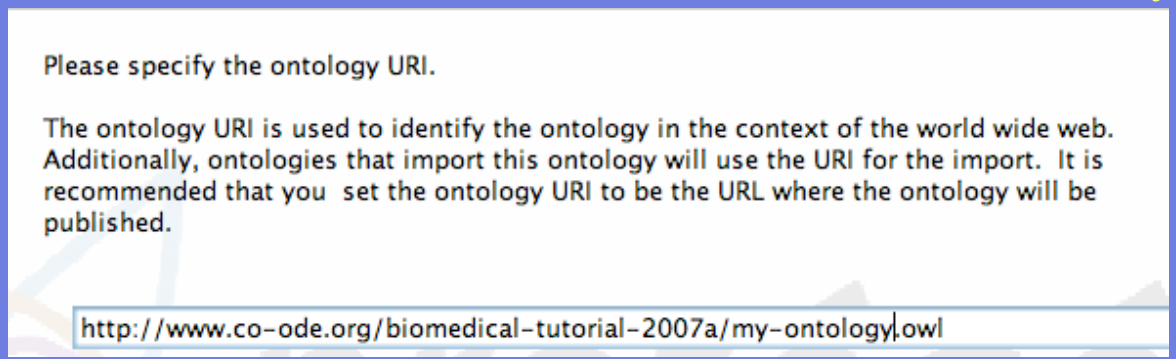
- Annotation - the annotation properties needed
- generic-data-structures -
  - quantities & numbers
- very-top - the upper ontology
  - in this case adapted for biomedicine
- Anatomy, Physiology, Biochemistry, Organism
  - The main topics
- Qualities
  - The basic qualities of those topics
- Disorders
  - General patterns for disorders
- Specific disorders
  - Examples for this tutorial
- Situations
  - Disorders in context of patients and observations

Anatomy and Disorders

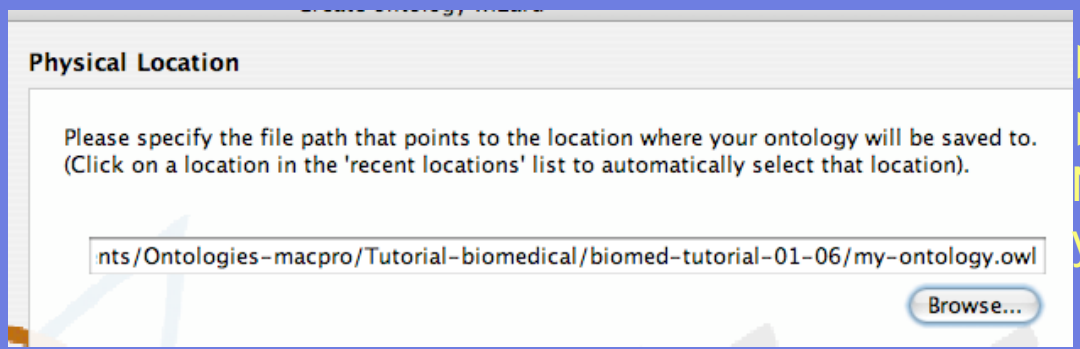
- Disorders have a locus in an anatomical structure of physiological process
  - Disorder has_locus SOME Anatomical_structure
- Disorders are anything which is described as pathological
  - has_normality_quality SOME Pathological
    - To be explained in detail late
- Parts and wholes
  - A whole field “mereology”
  - Multiple views - functional / cinician’s view different from structural / anatomist’s view.

Examples

- Backup your ontology directory
- Make “disorders.owl” the active ontology
- Create a new ontology in the same frame named “my-disorders”
  - File new
  - When pop-up asks about a new frame say NO
  - When asked for a name edit the end of the URI to “my-ontology.owl”



  - When asked where to store it, browse to your current directory



  - Press finish
  - NB This does NOT save your ontology!

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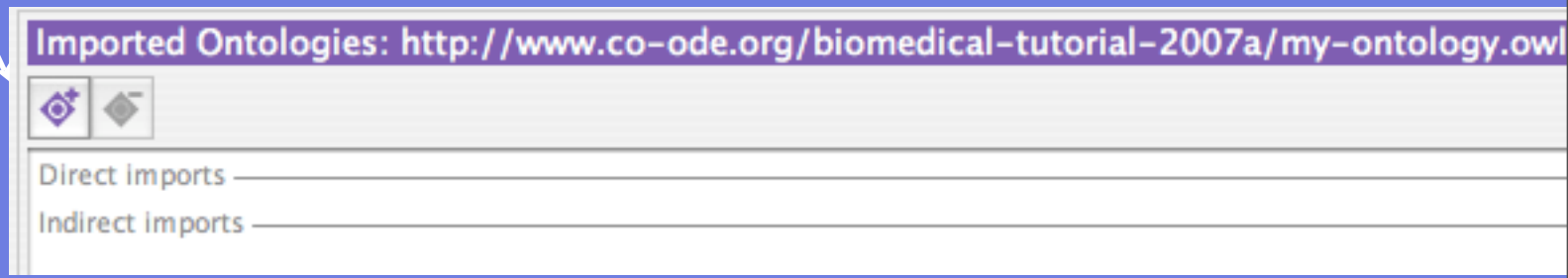
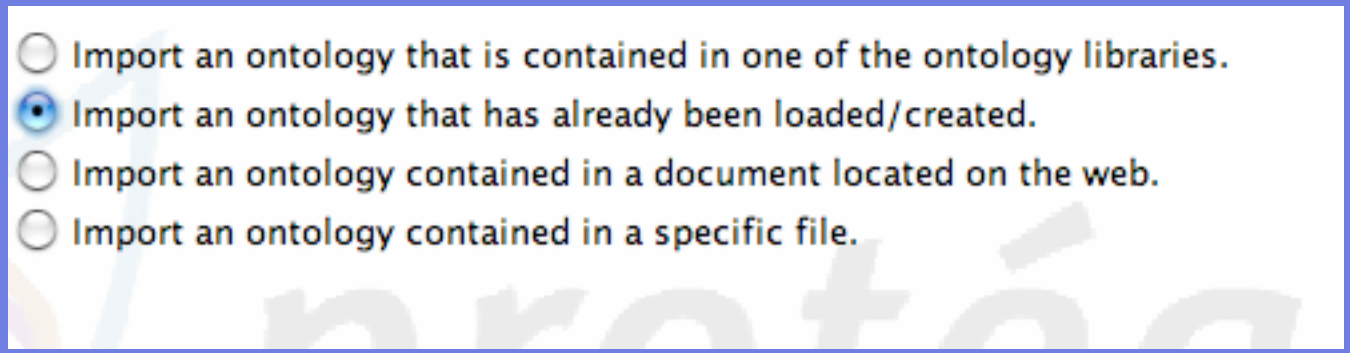
Import disorders.owl

- Go to the Active Ontology Tab
- Click the plus icon for imported ontologies



- Select import an ontology that has already been loaded



- Select disorders.owl and press finish

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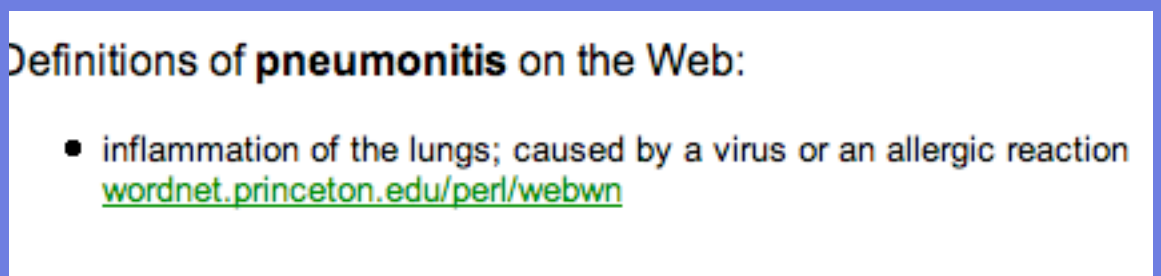
Task: Make Pneumonitis and Pneumonias in various variations

- Question 1: What is “Pneumonia” and what is “Pneumonitis”
  - Look it up
    - e.g. Google define: pneumonitis



- Write your own paraphrases:
- “Pneumonitis” is an “Inflammation of the lungs”
- “Pneumonia” is an “inflammation of the lungs caused by an infection”
- Many definitions on the web, but this summarises them for our purposes.

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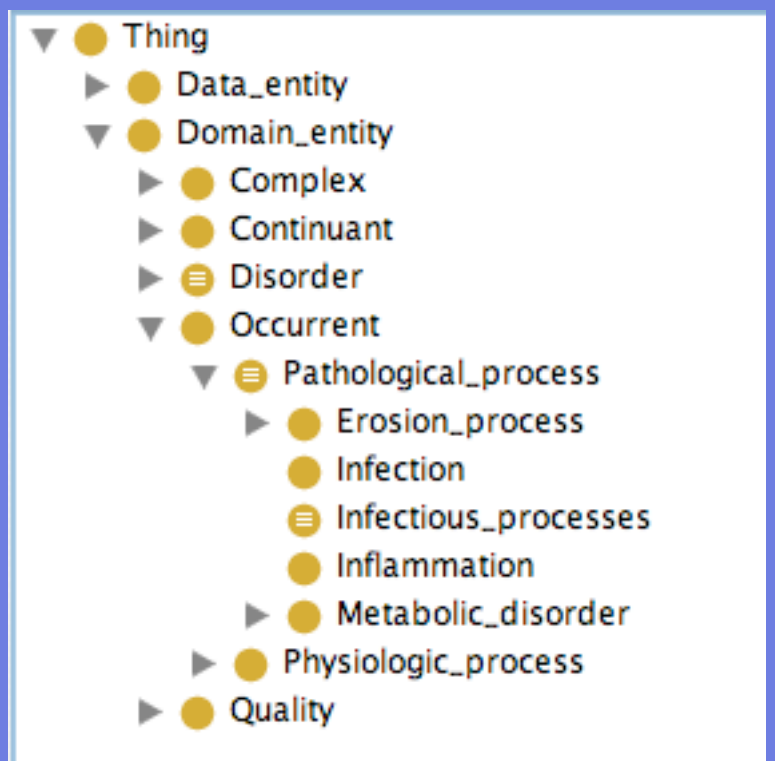
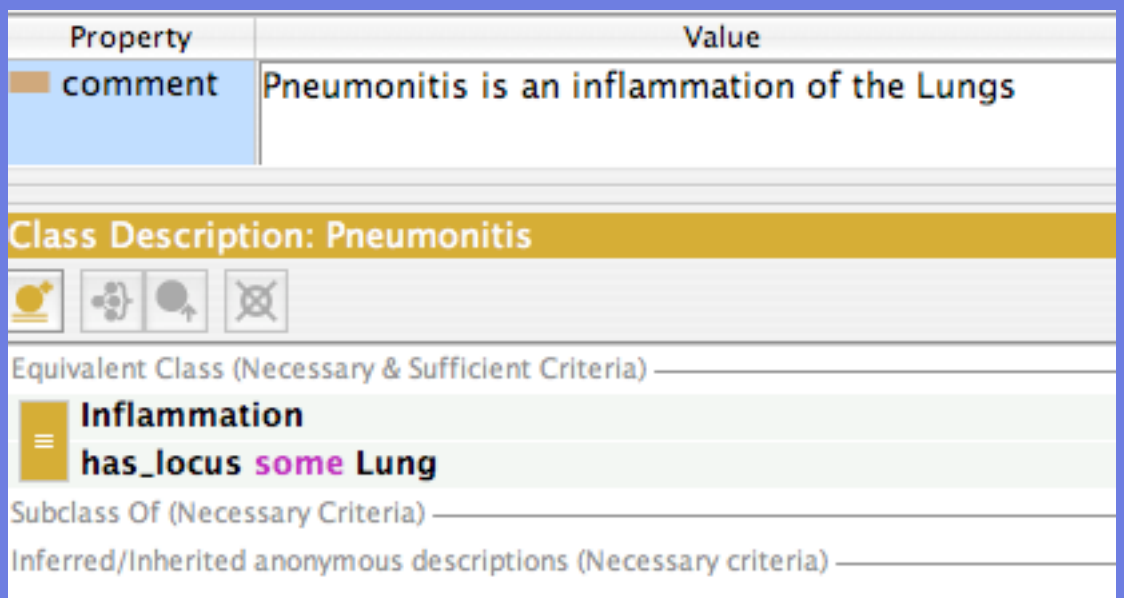
First defintion of pneumonitis

- "Inflammation of the lung"
  - Find Inflammation
    - CTRL or CMND F in class hierarchy



Create “Pneumonitis”

- Create a new subclass of Inflammation
  - In the comment box type something like “Pneumonitis” = “Inflammation of lung”
    - ALWAYS add a free text paraphrase of what you are modelling
  - Add the restriction
    - has_locus SOME Lung
  - Make it a defined class
    - CTRL/CMD-D.



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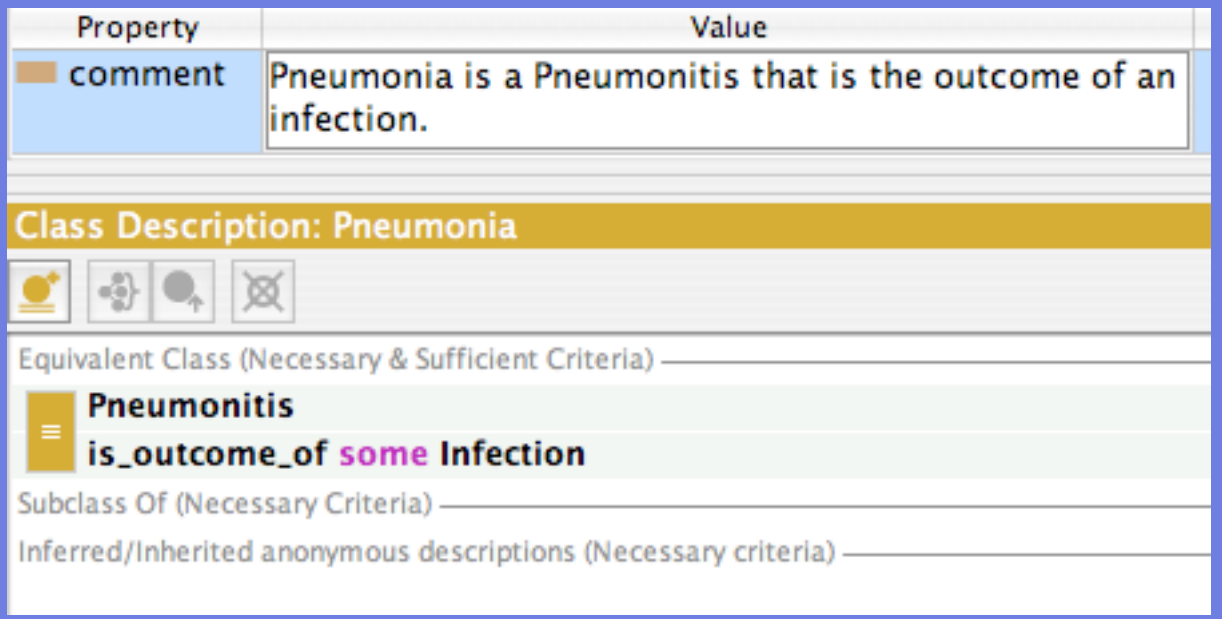
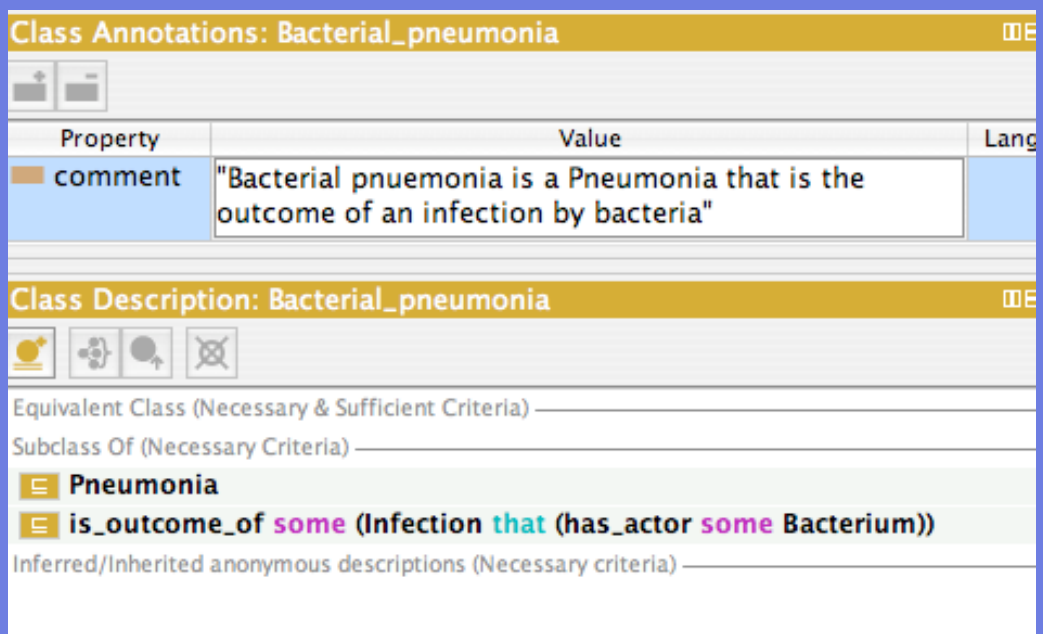
Create pneumonia

- "Pneumonia" is a pneumonitis is the outcome of an infection
  - In this ontology we use "is_outcome_of" for "cause"



Bacterial pneumonia

- First attempt
  - "Pneumonia caused by a bacteria"
- But need to rephrase to fit the ontology
  - "Pneumonia that is the outcome of an infection by bacteria"
    - In this ontology "by" translates to the property "has_actor"
      - *Processes have actors and objects*



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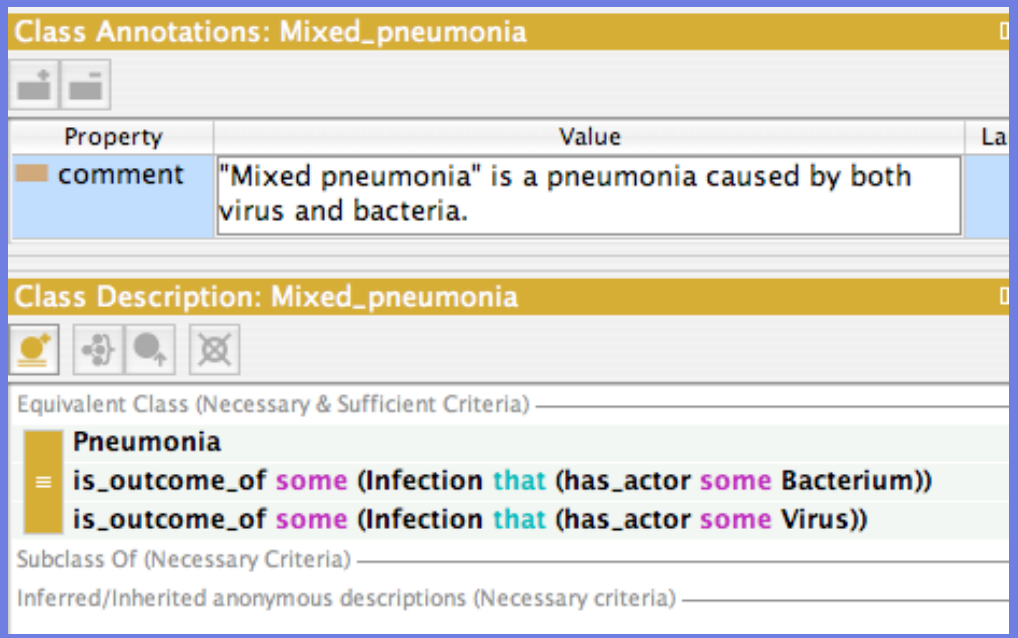
By analogy make viral pnemonia and mixed pneumonia

- Mixed pneumonia is a pneumonia that is caused by both virus and pneumonia
  - How to say this



  - WARNING
    - wrong: has_actor SOME (Virus AND Bacterium)
      - *Nothing is both a virus and a bacteria*

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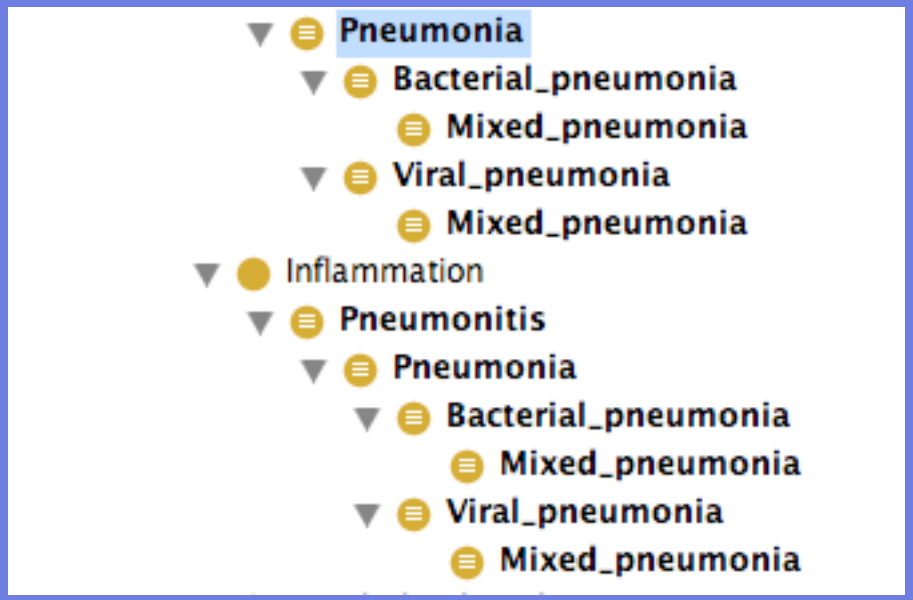
Classify and check

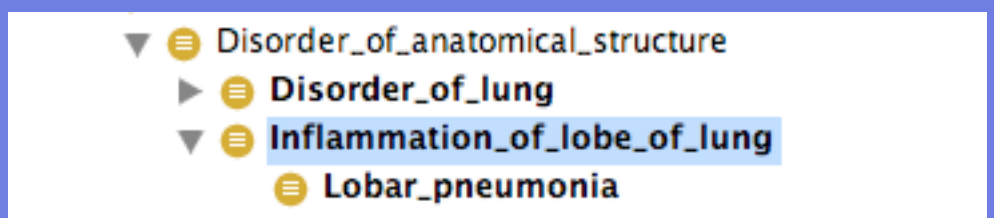
- Be sure that all classes are defined
  -  defined
  -  primitive
- To convert from primitive to defined, cmnd-d or ctrtl-d (Mac or PC)

Should get



What about “left lower lobe pneumonia”?

- First define lobar pneumonia as
  - Pneumonia that has locus in a lobe of a lung
    - “Lobe THAT is_subdivision_of SOME Lung”
- But what then is a disorder of the lung
  - Disorder THAT has_locus SOME Lung
- But what if I define an inflammation of a lobe of the lung
  - Inflammation THAT has_locus SOME (Lobe THAT is_subdivision_of SOME Lung)
  - The classifier ought to organise it for us
    - ... but it doesn’t.



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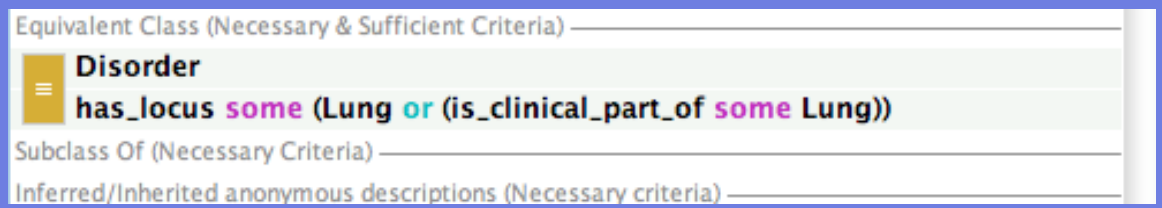
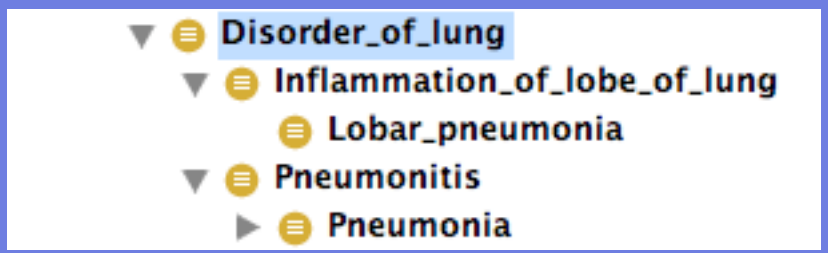
OWL means what it says

- Lobes are not lungs!
  - Our definition of lung disorder is too narrow
    - Almost always
      Disorders of parts are disorders of the whole
- A broader definition of "Disorder_of_lung"
  - Disorder THAT has_locus SOME
    (Lung OR is_clinical_part_of SOME Lung)





- Almost OK, but still Inflammation of lobe of lung is not a pneumonitis

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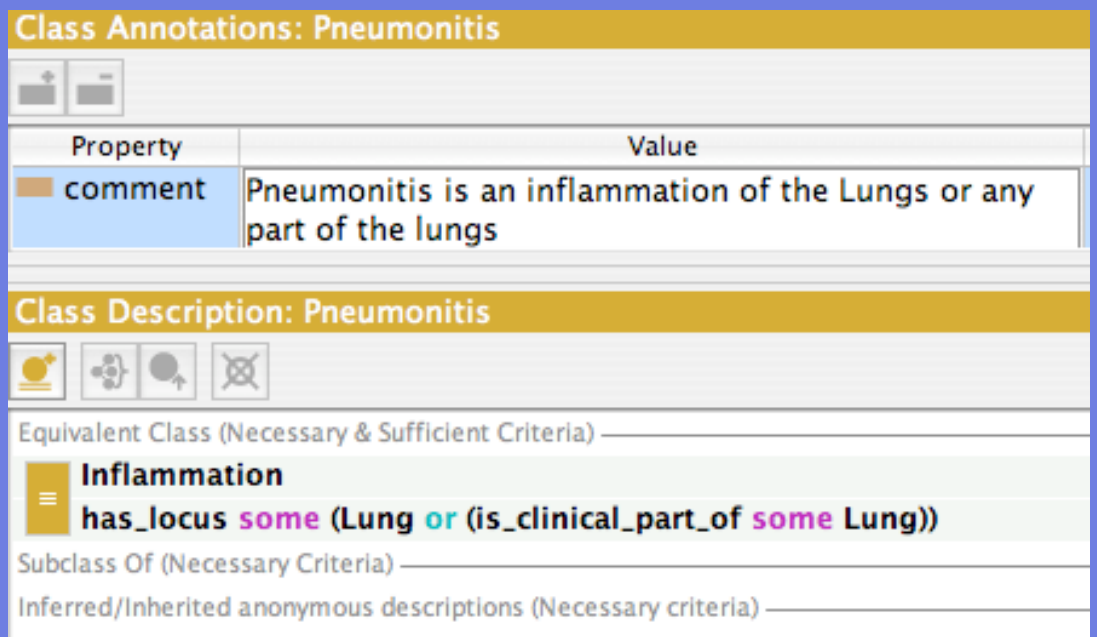
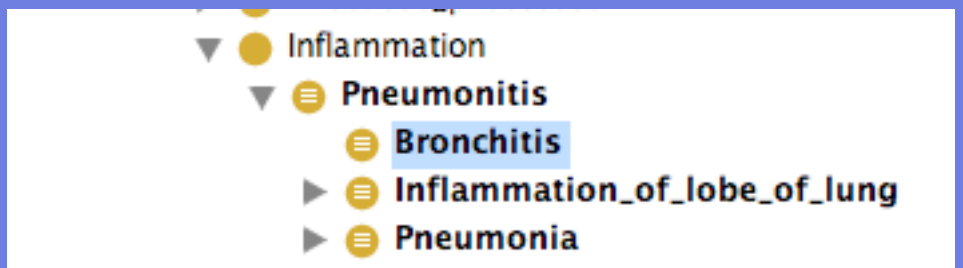
Make the pattern consistent

- Redefine Pneumonitis
  "An inflammation of the lung or any clinical part of the lung of the lung"
- 

Almost correct, but...

- What about “Bronchitis” ?
  - An inflammation of the bronchi (or any of their parts)
    - Try it and see.



- Definition of “Pneumonitis” is now too broad
- Not just any part of the lung, but the “subdivisions” of the lung
- lobes, quadrants, bases, apices, etc.

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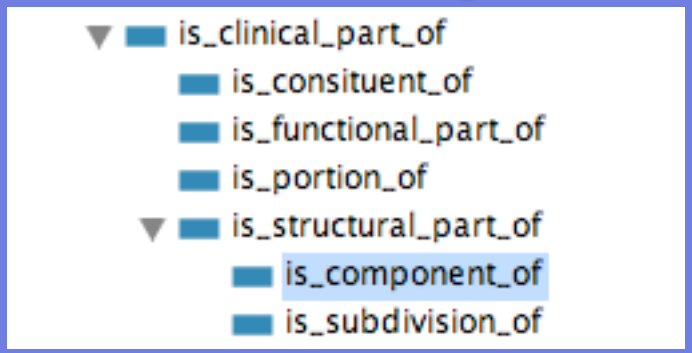
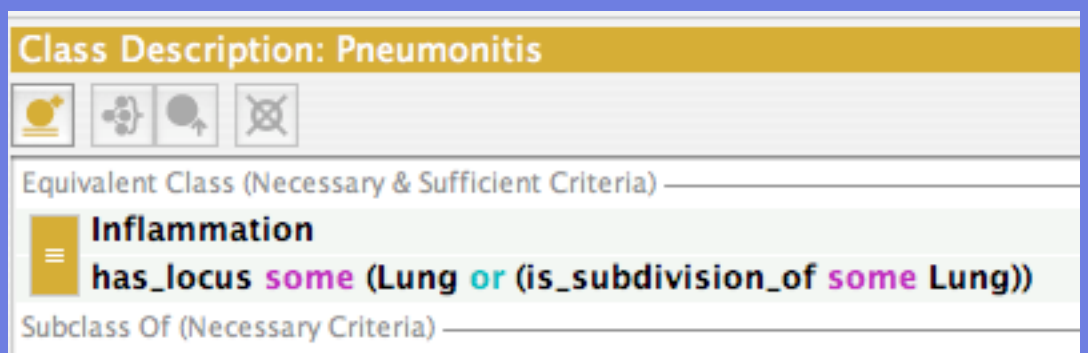
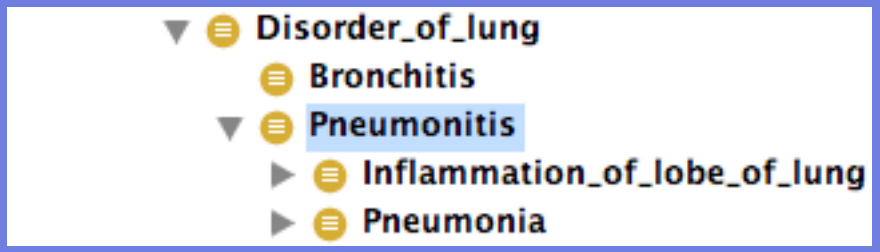
The property hierarchy allows multiple views



- The bronchus is a “component” of the lung
- The lobe is a subdivision of the lung
- Redefine pneumonitis as an inflammation of the lung or a *subdivision* of the lung
- 

Now reclassify



- Bronchitis is now a disorder of the lung (“lung disease”) but not a pneumonitis
  - As required.

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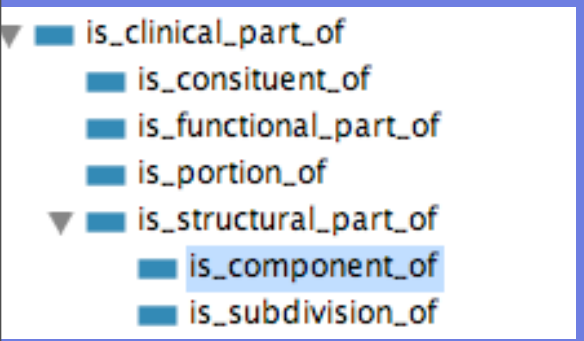
Clinical partonomy and pleuritis

- To an anatomist,
  - the pleura are different organs from the lungs
- To a clinician,
  - "Pleuritis"should be classified as a "Lung disease" or "Disorder of the lung"
    - "Pleuritis" - Inflammation of the pleura
- The Pleura
  - *function* as part of the lung
  - even though they are not *physically* part of the lung
    - The property hierarchy copes with both views.

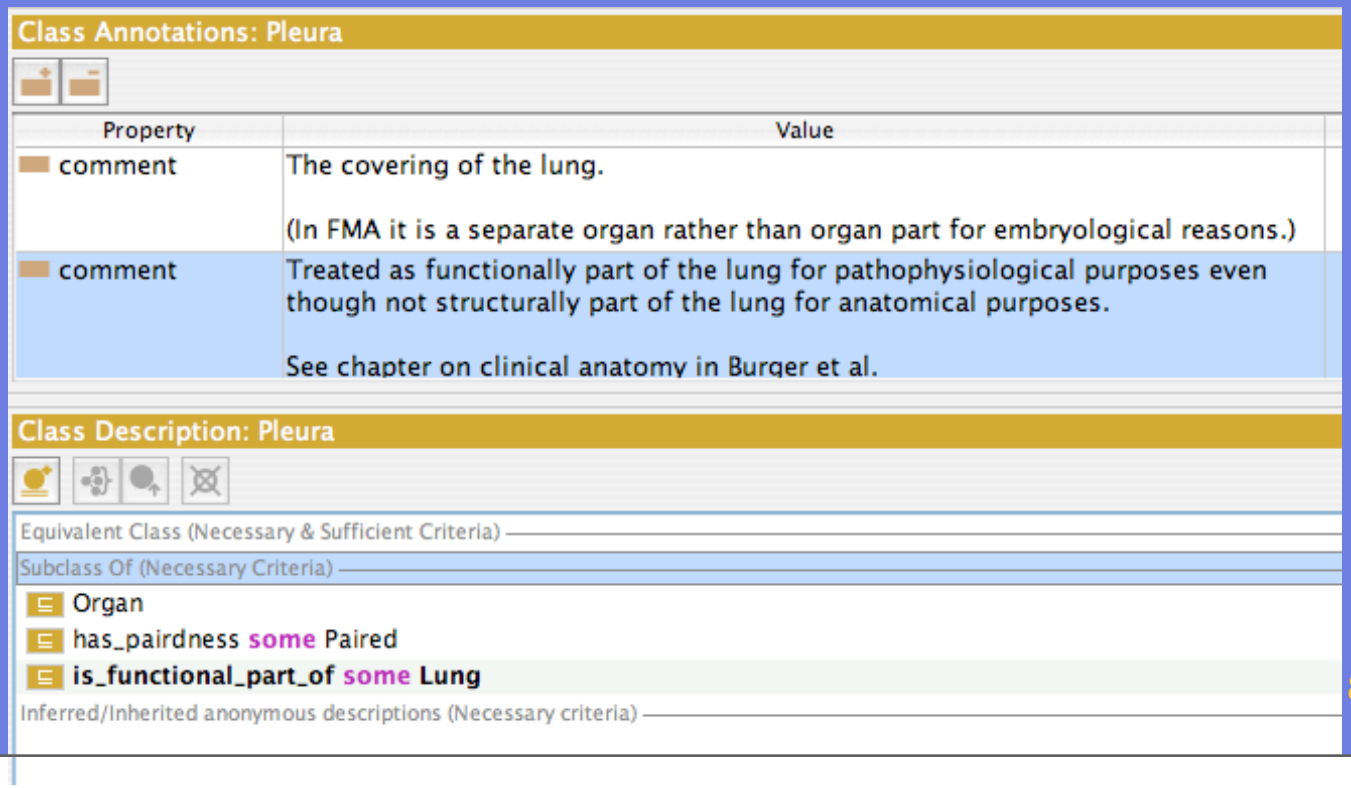


- Anything that is structurally a part of something is a clinical part of it
- Anything that is functionally a part of something is a clinical part of it
- etc.
- BUT NOT VICE VERSA.

Also affects modularity

- We have chosen to model functional parts with physiology rather than with anatomy
  - To stick with the FMA view as far as possible in the Anatomy module.
- So we add the fact that the pleur are functionals part of the Lung in the physiologic_processes module rather than the anatomy module
  - Might even have a separate functional module
    - We can add information to a class in a new module

Additions in *physiological_processes.owl*



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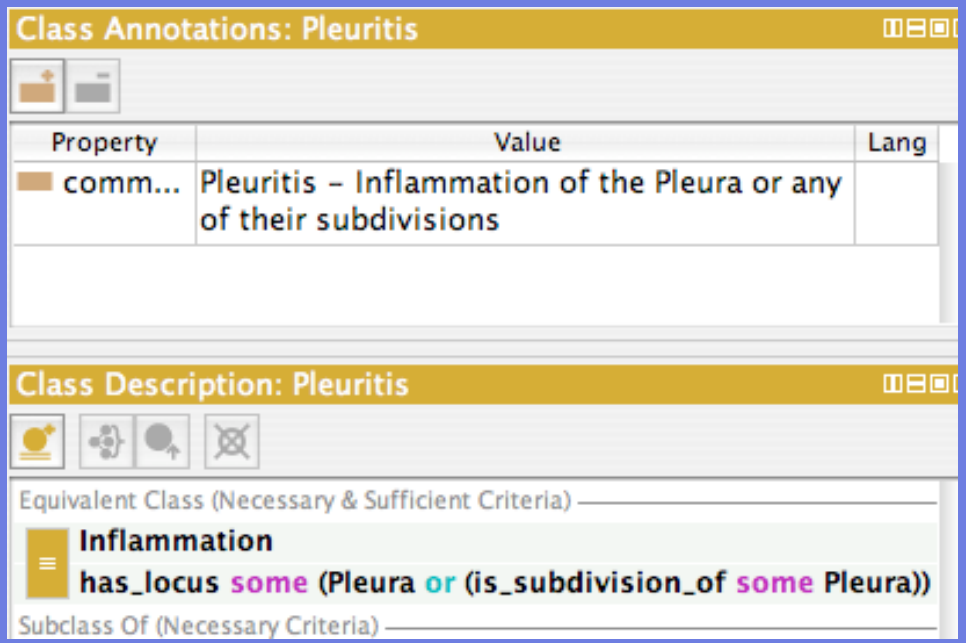
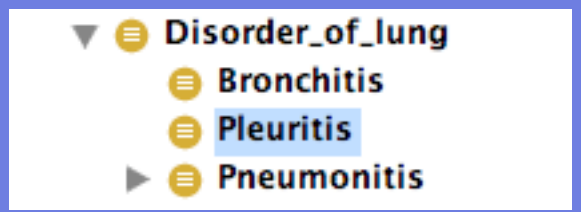
Create pleuritis and classify



- Classify and check results
  - A disorder of the lung but not a bronchitis or pneumonitis.
    - as required
      - *Anatomists & Clinicians can each have their own view*



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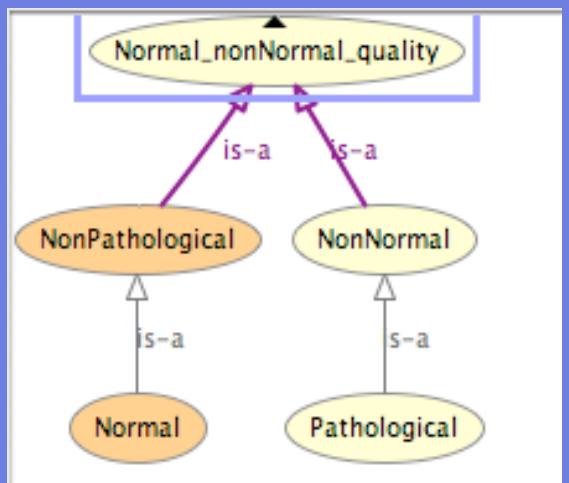
Normality and Negation

- What does it mean to be normal or abnormal?
  - To have a disease
- We implement two notions -
  - NonNormal - anything noteworthy
    - Pathological - requiring medical intervention
      - *(including "watchful waiting" or an active decision not to intervene)*
        - *GALEN used "Intrinsically pathological" but not needed in OWL*
- Basic rules
  - Pathological ➞ nonNormal
  - Normal = NOT nonNormal
  - nonPathological = NOT pathological

Normality and negation

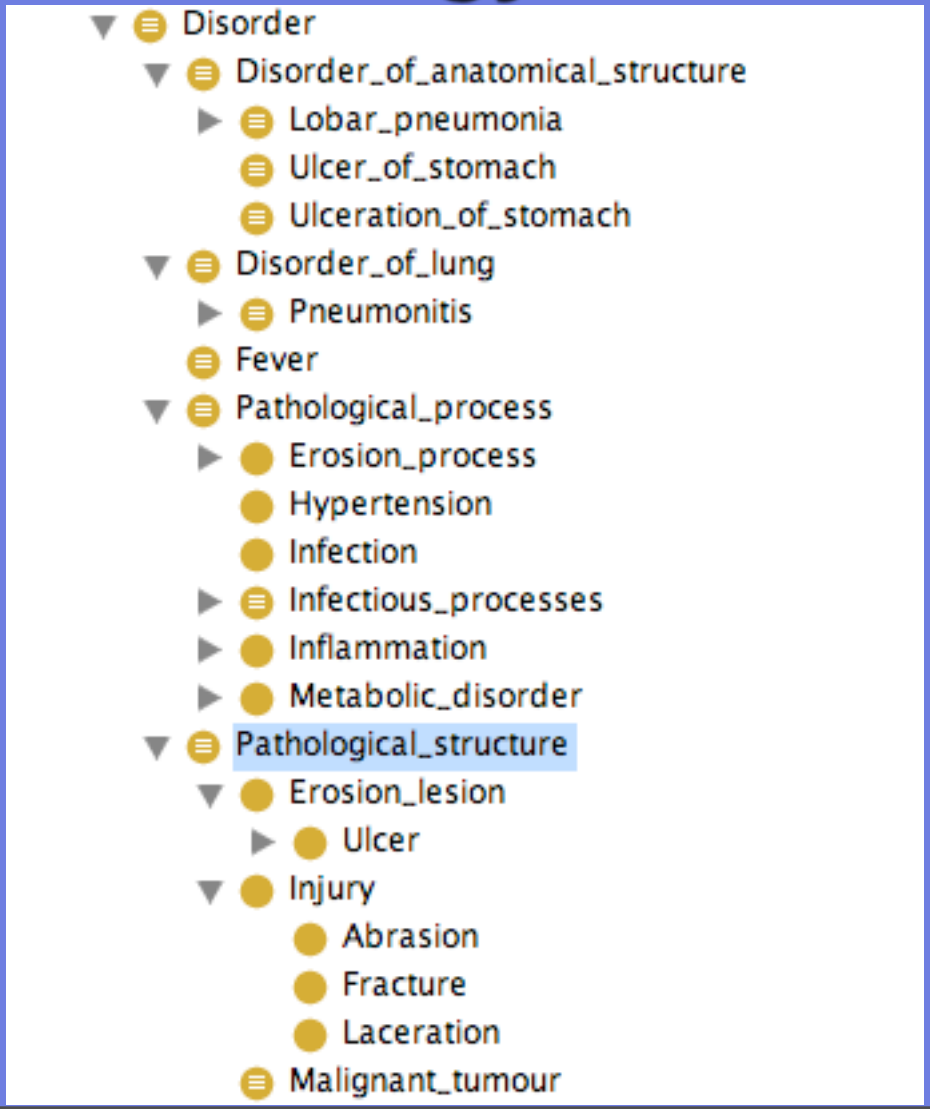
- Basic rules
  - Pathological ➞ nonNormal
  - Normal = NOT nonNormal
  - nonPathological = NOT pathological
- Remember
  - subclassOf means “necessarily implies”
    - so Pathological is a subclass of nonNormal
  - See the definitions of Normal-nonNormal_quality in disorders.owl
- Let the classifier do the work...



Defining “disease” or “disorder”

- Hard, probably futile
  - The words are used in many different ways
  - Things referred to cross ontological boundaries
    - Lesions - e.g tumours
    - Processes - e.g. infection or inflammation
    - Qualities - e.g. obstruction, malformation, elevation, ...
- Best just to say what is pathological
  - ***let the classifier gather them up***
- Also classify along multiple dimensions
  - ***include as many abstractions as are useful, no more and no less***

Example from tiny tutorial ontology



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Note

- Commented version of my_ontologies is in
  - Specific_disorders.owl
    - Make that the active ontology and compare

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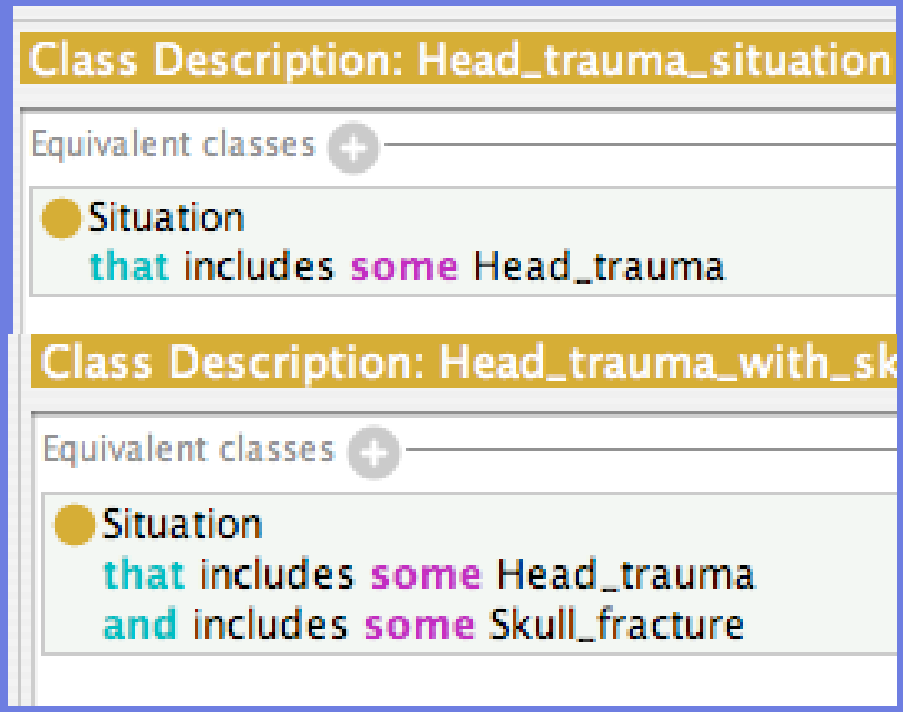
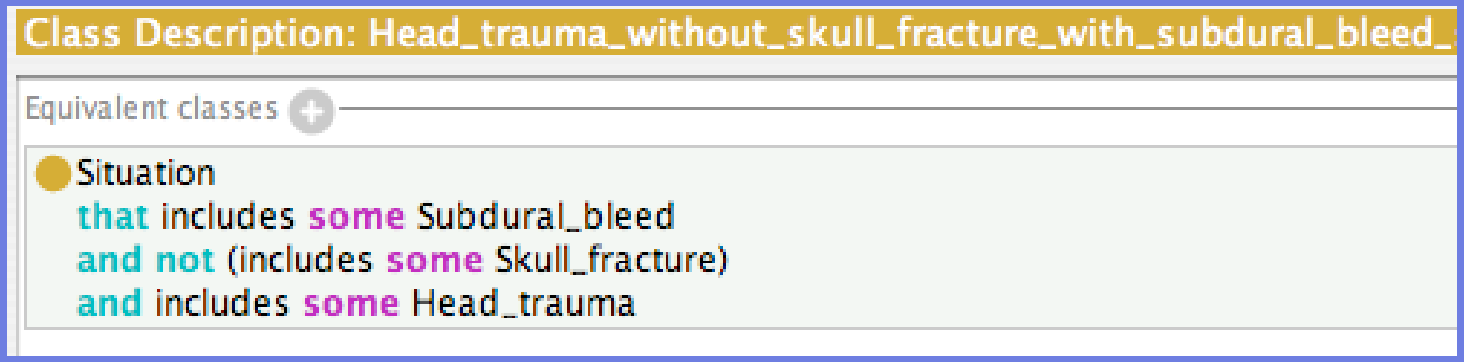
Situations & Codes

- The package unit of information in electronic health records is a “Situation”
  - A patient as observed by a clinician at a time in a setting
- Adding a code to a event in a record is to assert that the event is a instance of that kind of situation
  - The event has at least all of the assertions comprising the individual codes
  - Allows easy expression of negation and classificaiton of results with recognition of equivalence

Example: Head Trauma with/without intracranial bleeding with/ without Skull Fracture





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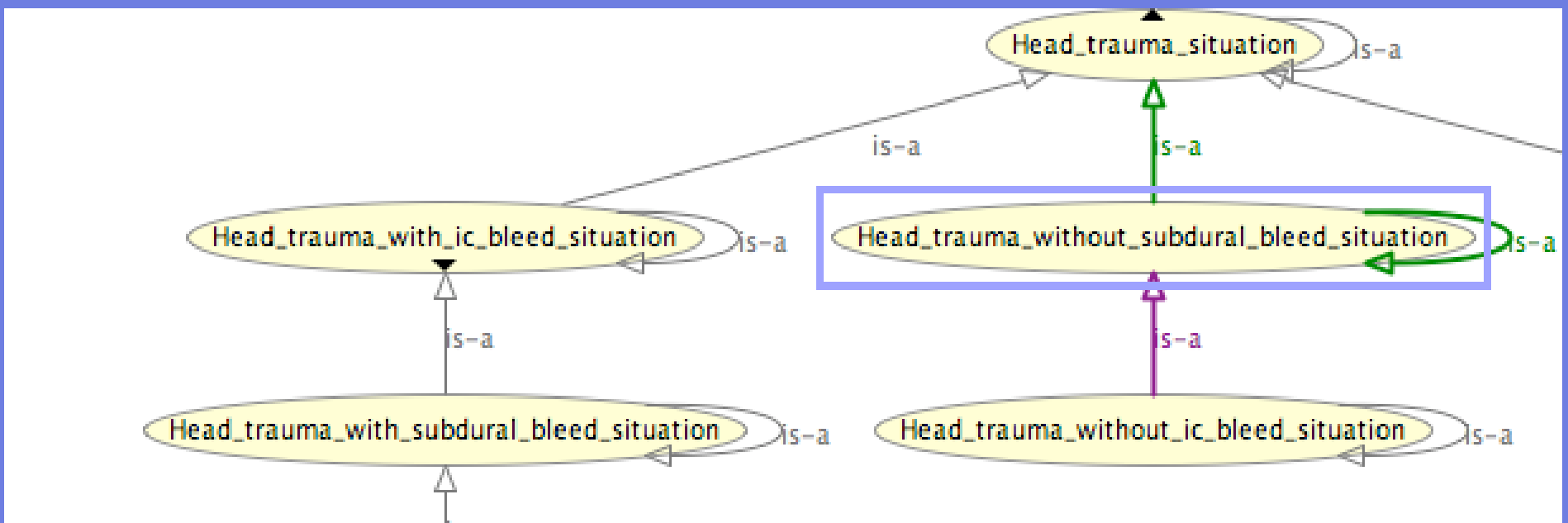
Classification - Note automatic inversion of negatives



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Summary: Building Ontologies in OWL-DL

- Start with a taxonomy of primitive classes
  - Should form pure trees
  - Remember, to make disjointness explicit
- Use definitions and the classifier to create multiple hierarchies
  - Use existential (someValuesFrom) restrictions by default
  - Things will only be classified under defined classes
- Be careful with
  - Open world reasoning
    - Use closure axioms when needed
  - “some” and “only” – someValuesFrom/allValuesFrom
  - domain and range constraints
  - making disjoint explicit

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What OWL (DL) cannot do

- A subset of first order logic with two variables
  - "Binary relational"
    - n-ary relations require "reifying" the relation
      - i.e.re-representing the property as a class
        - » See n-ary relations note at W3C SWBP
    - n-ary predicates can always be represented as binary predicates
      - subject to other limitations of OWL
  - No representation for "same"
    - The Owner is the same as the Person responsible
      - But often can manage this by property-chains
  - No representation for "All-All" statements
    - "All licensed drivers are authorised to drive all cars"
      - Known to be tractable but no implementation available
  - Representation of "optional" properties is not standardised. Options:
    - Min cardinality 0
    - Member of the domain
    - Other.
  - No representation of uncertainty
  - No representation of defaults and exceptions

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What OWL (DL) cannot do

- Limited meta-representation
  - OWL DL is strictly first order
  - OWL-Full allows higher order representations but does not support reasoning
  - OWL 1.0 annotations, but seriously impoverished
    - (Odd interaction with RDF syntax issues)
  - OWL 1.1 has puns
  - See SWBP note: *Classes as Values*
- No higher order predicates
  - OWL-DL is strictly first order
    - “Members of endagered species”
- No closed world reasoning
  - Everything must be closed exlicitly
    - Take care when transforming from databases

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Summary

- Knowledge is fractal
  - Enumeration is never ending
    - The power of logic / OWL is composition and classification
- Normalise ontologies for re-use and maintenance
  - Build DAGs (nets) out of Trees using classification
  - Use Modules to separate views and then bind them
- Diseases of the parts are diseases of the whole
  - ... but must be careful
- The property hierarchy can be used to support multiple views
- Some notions defy definition - e.g. “Disease”
  - When in doubt describe, classify and collect result bottom up
- Much more in the comments in the tutorial ontology

- and remember: ***“Ontologies are just one part of a system”***

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