OWL, Patterns, & FOL
COMP62342

Sean Bechhofer
sean.bechhofer@manchester.ac.uk
Uli Sattler
uli.sattler@manchester.ac.uk

So far, we have looked at

- operational knowledge of OWL (Pizza)
- KR in general, its roles
- KA and competency questions
- formalising knowledge
- the semantics of OWL

Today:

- Deepen your semantics: OWL & FOL & …
- Design **Patterns** in OWL
  - local ones
  - partonomies
- Design **Principles** in OWL:
  - multi-dimensional modelling
  - PIMPS - an upper level ontology
  - post-coordination
- **Automated reasoning** about OWL ontologies:
  - a tableau-based algorithm to make
  - …implicit knowledge explicit
  - …our know KR *actionable*

Left-overs from last week:
More on OWL Semantics

OWL 2 Semantics: an interpretation satisfying … (2)

From Last Week

- An interpretation I **satisfies an axiom α** if
  - α = C SubClassOf: D and $C^I \subseteq D^I$
  - α = C EquivalentTo: D and $C^I = D^I$
  - α = P SubPropertyOf: S and $P^I \subseteq S^I$
  - α = P EquivalentTo: S and $P^I = S^I$
  - …
  - α = x Type: C and $x^I \in C^I$
  - α = x R y and $(x^I, y^I) \in R^I$

Check
OWL 2 Direct Semantics
for more!!!

- I **satisfies an ontology O** if I satisfies every axiom α in O
  - If I satisfies O, we call I a **model of** O
- See how the axioms in O *constrain* interpretations:
  - ✓ the more axioms you add to O, the fewer models O has
- …they do/don't hold/are(n't) satisfied in an ontology
  - in contrast, a class expression C **describes a set** C^I in I

OWL 2 Semantics: an interpretation satisfying … (2)

- An interpretation I **satisfies an axiom**
  - C **SubClassOf**: D if $C^I \subseteq D^I$
  - C **EquivalentTo**: D if $C^I = D^I$
  - P **SubPropertyOf**: S if $P^I \subseteq S^I$
  - P **EquivalentTo**: S if $P^I = S^I$
  - …
  - x **Type**: C if $x^I \in C^I$
  - x R y if $(x^I, y^I) \in R^I$

Check
OWL 2 Direct Semantics
for more!!!

- I **satisfies an ontology O** if I satisfies every axiom A in O
  - If I satisfies O, we call I a **model of** O
- See how the axioms in O *constrain* interpretations:
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- …they do/don't hold/are(n't) satisfied in an ontology
  - in contrast, a class expression C **describes a set** C^I in I

Draw & Match Models to Ontologies!

O1 = {}

O2 = {a:C, b:D, c:C, d:C}

O3 = {a:C, b:D, c:C, b:C, d:E}

O4 = {a:C, b:D, c:C, b:C, d:E
D SubClassOf C}

O5 = {a:C, b:D, c:C, b:C, d:E
a R d,
D SubClassOf C,
D SubClassOf
S some C}

O6 = {a:C, b:D, c:C, b:C, d:E
a R d,
D SubClassOf C,
D SubClassOf
S some C,
C SubClassOf R only C }

I_1:
Δ = {v, w, x, y, z}

C^I = {v, w, y}
D^I = {x, y} E^I = {}

R^I = {(v, w), (v, y)}
S^I = {}

a^I = v b^I = x
c^I = w d^I = y

I_2:
Δ = {v, w, x, y, z}

C^I = {v, w, y}
D^I = {x, y} E^I = {y}

R^I = {(v, w), (v, y)}
S^I = {}

a^I = v b^I = x
c^I = w d^I = y

I_3:
Δ = {v, w, x, y, z}

C^I = {x, v, w, y}
D^I = {x, y} E^I = {y}

R^I = {(v, w), (v, y)}
S^I = {}

a^I = v b^I = x
c^I = w d^I = y

I_4:
Δ = {v, w, x, y, z}

C^I = {x, v, w, y}
D^I = {x, y} E^I = {y}

R^I = {(v, w), (v, y)}
S^I = {(x,x), (y,x)}

a^I = v b^I = x
c^I = w d^I = y

OWL 2 Semantics: Entailments etc. (3)

Let O be an ontology, α an axiom, and A, B classes, b an individual name:

- O is **consistent** if there exists some model I of O
  - i.e., there is an interpretation that satisfies all axioms in O
  - i.e., O isn't self contradictory
- O **entails** α (written $O \models \alpha$) if α is satisfied in all models of O
  - i.e., α is a consequence of the axioms in O
- A is **satisfiable** w.r.t. O if $O \not\models$ A SubClassOf Nothing
  - i.e., there is a model I of O with $A^I \neq \{\}$
- b is an **instance of** A w.r.t. O (written $O \models$ b:A) if $b^I \subseteq A^I$ in every model I of O

Theorem:

1. O is consistent iff $O \not\models$ Thing SubClassOf Nothing
2. A is satisfiable w.r.t. O iff $O \cup$ {n:A} is consistent (where n doesn't occur in O)
3. b is an instance of A in O iff $O \cup$ {b:not(A)} is not consistent
4. O entails A SubClassOf B iff $O \cup$ {n:A and not(B)} is inconsistent

OWL 2 Semantics: Entailments etc. (3) ctd

Let O be an ontology, α an axiom, and A, B classes, b an individual name:

- O is **consistent** if there exists some model I of O
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- b is an **instance of** A w.r.t. O if $b^I \subseteq A^I$ in every model I of O

Classifying O is a reasoning service consisting of

1. testing whether O is consistent; if yes, then
2. checking, for each pair A,B of class names in O plus Thing, Nothing whether $O \models$ A SubClassOf B
3. checking, for each individual name b and class name A in O, whether $O \models$ b:A

…and returning the result in a suitable form: O's **inferred class hierarchy**

A side note: Necessary and Sufficient Conditions

- **Classes** can be described in terms of *necessary* and *sufficient* conditions.
  - This differs from some frame-based languages where we only have necessary conditions.
- **Necessary** conditions

  Constraints/Background knowledge
  - *SubClassOf* axioms
  - C SubClassOf: D…any instance of C is also an instance of D
- **Necessary & Sufficient** conditions

  Definitions
  - *EquivalentTo* axioms
  - C EquivalentTo: D…any instance of C is also an instance of D and vice versa, any instance of D is also an instance of C
- Allows us to perform automated **recognition** of individuals,

  i.e. O ⊧ b:C

If it looks like a duck and walks like a duck, then it's a duck!

OWL and Other Formalisms:
First Order Logic
Object-Oriented Formalisms

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OWL and First Order Logic

- in COMP60332 or elsewhere, you have learned a lot about FOL
- most of OWL 2 (and OWL 1) is a **decidable fragment of FOL:**

Translate an OWL ontology $\mathcal{O}$ into FOL using $t()$ as follows:

$$
\begin{aligned}
t(\mathcal{O}) = & \{\forall x.t_x(C) \Rightarrow t_x(D) \mid C \textsf{ SubClassOf D} \in \mathcal{O}\} \cup \\
& \{t_x(C)[x/a] \mid a\colon C \in \mathcal{O}\} \cup \\
& \{r(a,b) \mid (a,b)\colon r \in \mathcal{O}\}
\end{aligned}
$$

- …we assume that we have replaced each axiom C EquivalentTo D in O with C SubClassOf D, D SubClassOf C
- …what is $t_x(C)$?

OWL and First Order Logic

Here is the translation $t_x()$ from an OWL ontology into FOL formulae in one free variable

$$
\begin{aligned}
t_x(A) &= A(x), & t_y(A) &= A(y),\\
t_x(\textsf{not C}) &= \neg t_x(C), & t_y(\textsf{not C}) &= \ldots,\\
t_x(C\ \textsf{and D}) &= t_x(C) \wedge t_x(D), & t_y(C\ \textsf{and D}) &= \ldots,\\
t_x(C\ \textsf{or D}) &= \ldots, & t_y(C\ \textsf{or D}) &= \ldots,\\
t_x(r\ \textsf{some C}) &= \exists y.r(x,y) \wedge t_y(C), & t_y(r\ \textsf{some C}) &= \ldots,\\
t_x(r\ \textsf{only C}) &= \ldots, & t_y(r\ \textsf{only C}) &= \ldots.
\end{aligned}
$$

Exercise:

1. Fill in the blanks
2. Why is $t_x(C)$ a formula in 1 free variable?
3. Translate O6 to FOL
4. …have you heard about the **2 variable fragment of FOL**?

O6 = {a:C, b:D, c:C, b:C, d:E
a R d,
D SubClassOf C,
D SubClassOf
S some C,
C SubClassOf R only C }

Object Oriented Formalisms

Many formalisms use an “object oriented model” with

- **Objects/Instances/Individuals**
  - Elements of the domain of discourse
  - e.g., “Bob”
  - Possibly allowing descriptions of classes
- **Types/Classes/Concepts**
  - to describe sets of objects sharing certain characteristics
  - e.g., “Person”
- **Relations/Properties/Roles**
  - Sets of pairs (tuples) of objects
  - e.g., “likes”

- Such languages are/can be:
  - Well understood
  - Well specified
  - (Relatively) easy to use
  - Amenable to machine processing

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Object Oriented Formalisms

OWL can be said to be object-oriented:

- Objects/Instances/**Individuals**
  - Elements of the domain of discourse
  - e.g., “Bob”
  - Possibly allowing descriptions of classes
- Types/**Classes/**Concepts
  - to describe sets of objects sharing certain characteristics
  - e.g., “Person”
- Relations/**Properties**/Roles
  - Sets of pairs (tuples) of objects
  - e.g., “likes”

- *Axioms* represent background knowledge, constraints, definitions, …
- Careful: SubClassOf is similar to **inheritance** but **different**:
  - inheritance can usually be over-ridden
  - SubClassOf can’t
  - in OWL, ‘multiple inheritance’ is normal

Other KR systems

- Protégé can be said to provide a **frame-based view** of an OWL ontology:
  - it gathers axiom by the class/property names on their left
- DBs, frame-based or other KR systems may make assumptions:
  1. **Unique name assumption**
     - Different names are always interpreted as different elements
  2. **Closed domain assumption**
     - Domain consists only of elements named in the DB/KB
  3. **Minimal models**
     - Extensions are as small as possible
  4. **Closed world assumption**
     - What isn't entailed by O isn't true
  5. **Open world assumption:** an axiom can be such that
     - it's entailed by O or
     - it's negation is entailed by O or
     - none of the above

Question: which of these does
- OWL make?
- a SQL DB make?

Other KR systems: Single Model -v- Multiple Model

Multiple models:

- Expressively powerful
  - Boolean connectives, including **not, or**
- Can capture incomplete information
  - E.g., using **or**, **some**
- Monotonic: adding information preserves entailments
- Reasoning (e.g., querying) is often complex: e.g.,reasoning by case
- Queries may give counter-intuitive results in some cases

Single model:

- Expressively weaker (in most respects)
- – No negation or disjunction
- Can't capture incomplete information
- Often non-monotonic: adding information may invalidate entailments
- Reasoning (e.g., querying) is often easy
- Queries may give counter-intuitive results in some cases

Complete details about OWL

- here, we have concentrated on some **core** features of OWL, e.g., no
  - domain, range axioms
  - SubPropertyOf, InverseOf
  - datatype properties
  - …
- we expect you to look these up!

- OWL is defined via a **Structural Specification**
- http://www.w3.org/TR/owl2-syntax/
- Defines language independently of concrete syntaxes
- Conceptual structure and abstract syntax
  - UML diagrams and functional-style syntax used to define the language
  - Mappings to concrete syntaxes then given.
- The structural specification provides the foundation for implementations (e.g. OWL API as discussed later)

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OWL Resources

- The OWL Technical Documentation is all available online from the W3C site.

  http://www.w3.org/TR/owl2-overview/

  All the OWL documents are relevant; we recommend in particular the
    - Overview
    - Primer
    - Reference Guide and
    - Manchester Syntax Guide

- Our Ontogenesis Blog at
- http://ontogenesis.knowledgeblog.org/

Today:

✓Deepen your semantics: OWL & FOL & …

- Design **Patterns** in OWL
    - local ones
    - partonomies
- Design **Principles** in OWL:
    - multi-dimensional modelling
    - post-coordination
    - PIMPS - an upper level ontology
- **Automated reasoning** about OWL ontologies:
    - a tableau-based algorithm to make
    - …implicit knowledge explicit
    - …our know KR *actionable*

Patterns of axioms

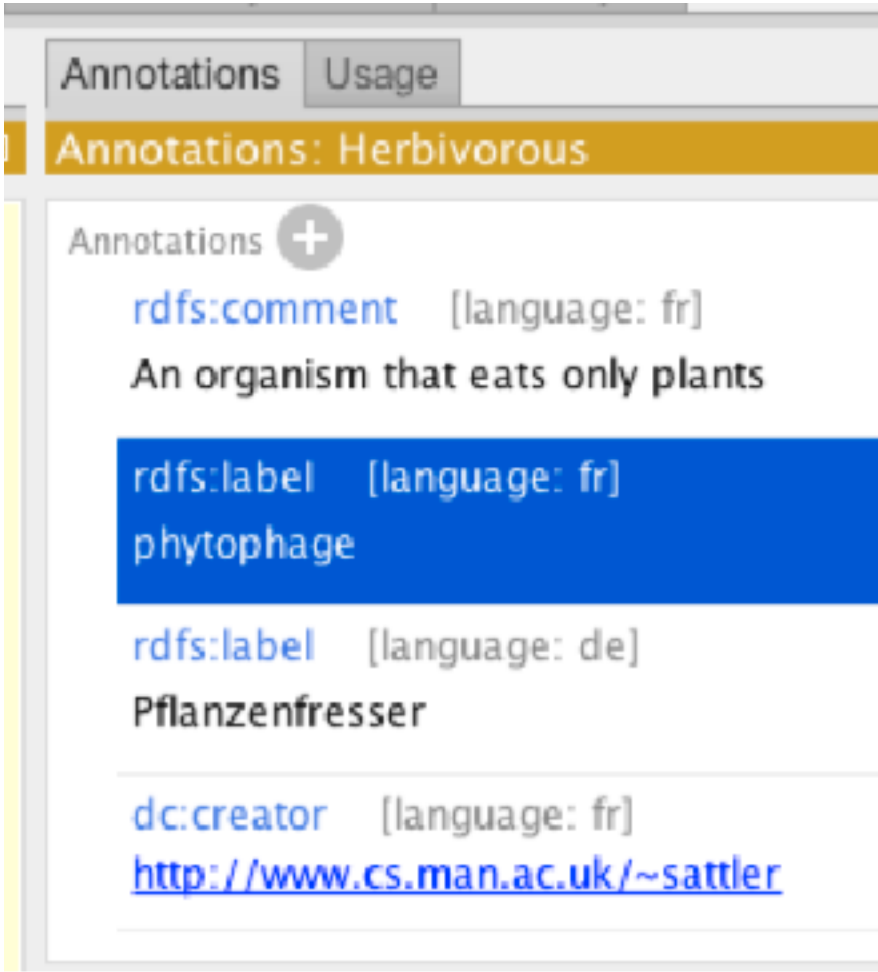
- An **axiom pattern** is
  - a recurring regularity in how axioms are used in an ontology
- The most common is
  - atomic SubClassOf axioms,
    i.e. *A SubClassOf B* where A, B are class **names**
  - … but they get much more complex than that
- Usually, we're referring to **syntactic** patterns:
  - how axioms are written,
  - but remember "axioms" are entailed as well as written

Patterns and **Design** patterns

- **Software Design Patterns** are
  - well accepted solutions for common issues met in software construction
- **Ontology Design Patterns** ODPs are similar:
  - well accepted solutions for common issues met in ontology construction
  - but ontology engineers have barely agreed on well accepted problems, let alone their solutions
- ODPs often depend on one's philosophical stance …
  we'll mostly talk about *patterns* as recurring regularities of asserted axioms

Coding style: term normalisation

- Is a sort of pattern…
- What we want is:
  - **Class** names:
    - singular nouns with
    - initial capital letter,
    - spaces via CamelCase
  - **Individual** names:
    - all lower case,
    - spaces indicated by _
  - **Property** names:
    - initial lower case letter,
    - spaces via CamelCase
    - usually start with “is” or “has”
- All classes and individuals have a label, creator, description **annotation property**



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Term normalisation ⊆ applied naming convention

- A **naming convention** determines
  - what words to use, in
  - which order and
  - what one does about symbols and acronyms
- Adopt one
  - for both labels and URI fragments
- Having a label is a “good practice”

“Glucose transport” vs “transport of glucose”

See http://ontogenesis.knowledgeblog.org/948 for an introduction

How good names help modelling

- The help understanding relationships between terms: for example,
  - Thigh, shin, foot and toe are not “leg”, but “leg part”
  - Slice of tomato, tomato sauce, and tomato puree are not “Tomato” but “Tomato based product”
  - Eggs, milk, honey are not meat or animal, but “Animal Product”
  - Pizza base is not Pizza, but “part of Pizza” of “Pizza Ingredient”

- **Card sorting** and **the three card trick** can help you here

Types of axiom patterns

- **Naming Patterns**
  - see term normalisation, naming convention

- **Logical patterns** (also known as Language Patterns)
  axioms to
  - take advantage of language features or
  - work around something missing in a language

- **Content Patterns** (also known as Domain modelling patterns):
  axioms to describe certain phenoma/concepts in a domain
  - Works both in the
    - large: the whole ontology
    - small: how to describe a class/type of furniture

1st Logical Pattern: the **Property Closure Pattern**

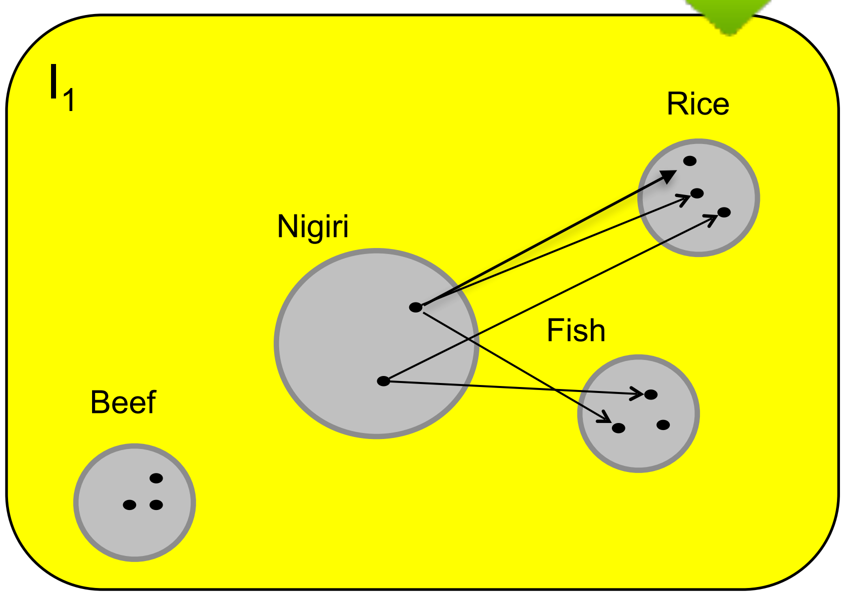
Class: Nigiri
SubClassOf Sushi,
hasIngredient **some** Rice,
hasIngredient **some** Fish

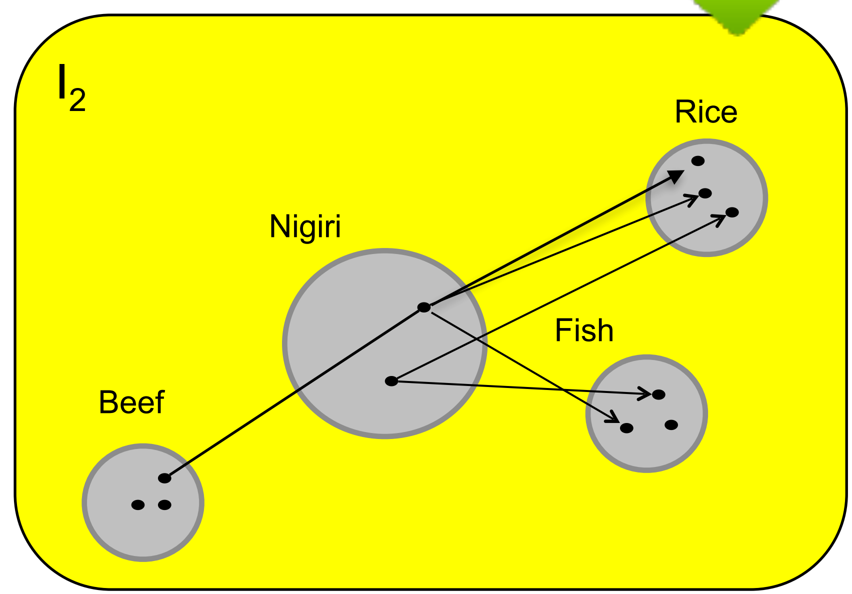
- Does Nigiri contain rice?
- Does Nigiri contain fish?
- Does Nigiri contain beef?

1st Logical Pattern: the **Property Closure Pattern**

Class: Nigiri
SubClassOf Sushi,
hasIngredient **some** Rice,
hasIngredient **some** Fish

Which of these interpretations is a model of the above axiom?



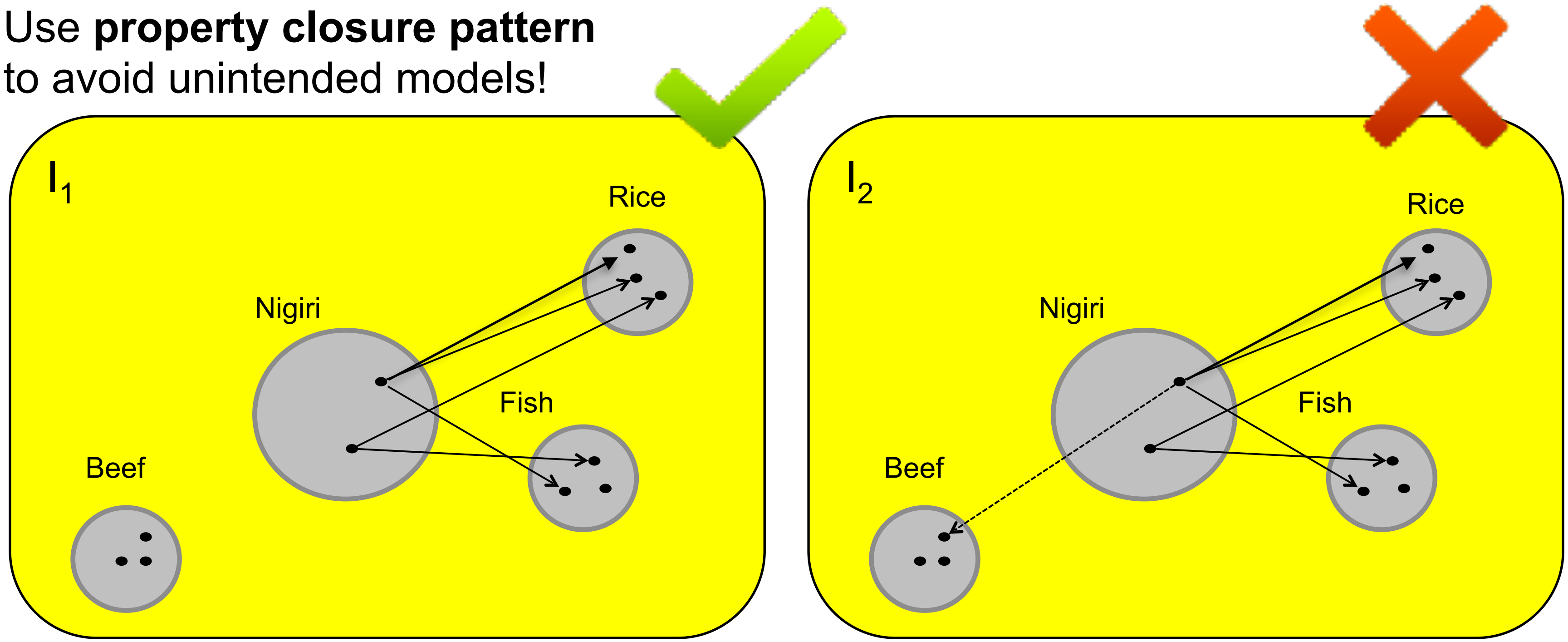


→ hasIngredient

1st Logical Pattern: the **Property Closure Pattern**

Class: Nigiri
SubClassOf Sushi,
hasIngredient **some** Rice,
hasIngredient **some** Fish,
hasIngredient **only** (Fish or Rice)

Use **property closure pattern**
to avoid unintended models!



→ hasIngredient

OWL's Open World Assumption (OWA)

- Unless we have 'constrained' something it **may** be possible
  - e.g., for Nigiri to have ingredients other than rice & fish
- This behaviour is as "open world assumption"
  - OWL makes OWA

Class: Nigiri
SubClassOf Sushi,
hasIngredient **some** Rice,
hasIngredient **some** Fish

$\mathcal{O} \models$ Nigiri SubClassOf hasIngredient some Rice?

Q: "Does Nigiri have beef as ingredient?"
A: "Maybe/Don't know"

DisjointClasses: Rice, Fish, Beef
Class: Nigiri
SubClassOf Sushi,
hasIngredient **some** Rice,
hasIngredient **some** Fish,
hasIngredient **only** (Fish or Rice)

$\mathcal{O} \models$ Nigiri SubClassOf hasIngredient some Rice?

Q: "Does Nigiri have beef as ingredient?"
A: "No"

1st Logical Pattern: the **Property Closure Pattern**

- In general, the property closure pattern for a property P is of the form

```
Class: A
        SubClassOf …
                P some B1,
                          ….  ,
                P some Bn,
                P only (B1 or … or Bn)
```

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2nd Logical Pattern: the **Covering Pattern**

- Say we have Class X with subclasses Yi
  - e.g., UG, MSc, MRes, PhD are all subclasses of Student

Class: Y1 **SubClassOf** X
Class: Y2 **SubClassOf** X
…
Class: Yk **SubClassOf** X

- Now we *may* want to say that
  "any individual of class X has to be an individual of some class Yi"
  - i.e., class X is *covered by* classes Y1,…,Yk
  - e.g., every Student is a UG, MSc, MRes, or PhD student
- To ensure this **coverage of** X by Y1,…Yk, we use the **covering axiom:**

Class: Y1 **SubClassOf** X
Class: Y2 **SubClassOf** X
…
Class: Yk **SubClassOf** X

Class: X **SubClassOf**: (Y1 or … or Yk)

- **Quick exercise**: translate the above axioms into FOL!

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3rd Logical Pattern: the **Partitions Pattern**

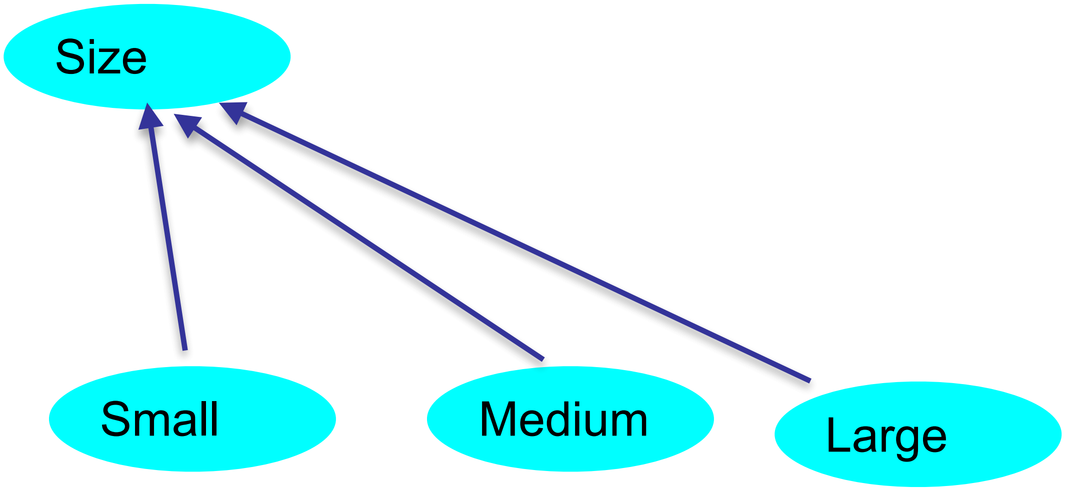
- Say we have Class X with subclasses Yi
  - e.g., UG, MSc, MRes, PhD are all subclasses of Student
- Now we *may* want to say that "no individual can be an instance 2 or more of these class Yi"
- How do we "partition" values **for properties** such as Size, Spicyness, etc:
- E.g., we want to say that a person's "Size"
  - must be one of the subclasses of Size and
  - only one of those sizes – and that
  - an individual size cannot be two kinds of size at the same time

3rd Logical Pattern: the **Partitions Pattern**

Class: Small **SubClassOf** Size
Class: Medium **SubClassOf** Size
Class: Large **SubClassOf** Size
DisjointClasses: Small, Medium, Large
Class: Size **SubClassOf** (Medium **or** Small **or** Large)

Disjoint
+ Covering

Partition

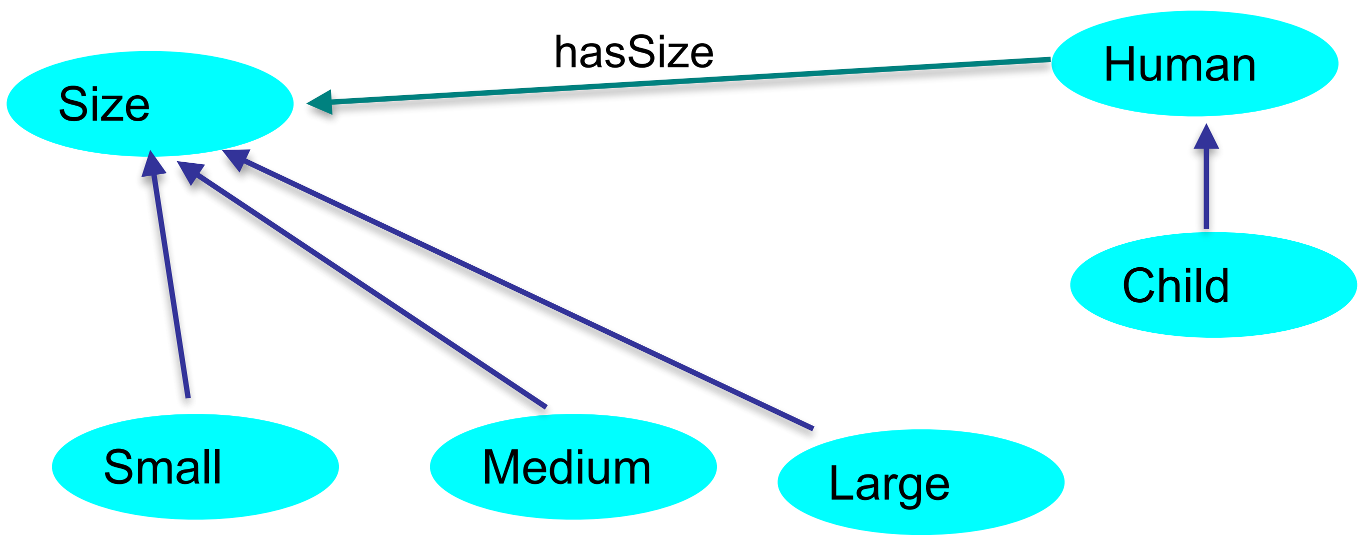


4th Logical Pattern: the **Entity Property Quality Pattern**

Class: Small **SubClassOf** Size
Class: Medium **SubClassOf** Size
Class: Large **SubClassOf** Size
DisjointClasses: Small, Medium, Large
Class: Size **SubClassOf** (Medium **or** Small **or** Large)

Property: hasSize **Characteristics**: Functional
Range: Size **Domain:** Mammal
Class: Human **SubClassOf** hasSize **some** Size
Class: Child **SubClassOf** Human **and** hasSize **only** Small

Partition Pattern



4th Logical Pattern: the **Entity Property Quality Pattern**

- Used to model descriptive features of things
  - possibly together with a value partition
- OWL elements:
  - for each feature or **quality** such as size, weight, etc:
    - **functional** property, e.g., hasSize and
    - class for its values, e.g., Size
    - link these by stating that the class is the **range** of the property
    - state to which classes these qualities
      - may apply via the **domain** of the property and
      - are necessary
- Using classes allows to make subpartitions
  - may overlap
  - may be related to concrete sizes and datatype properties
  - e.g. very large, moderately large

More information on logical patterns….

- Have a look at
  - http://www.w3.org/TR/swbp-specified-values/
  - http://ontogenesis.knowledgeblog.org/1499
  - http://ontogenesis.knowledgeblog.org/1001
  - Lots of short, accessible articles about ontology stuff

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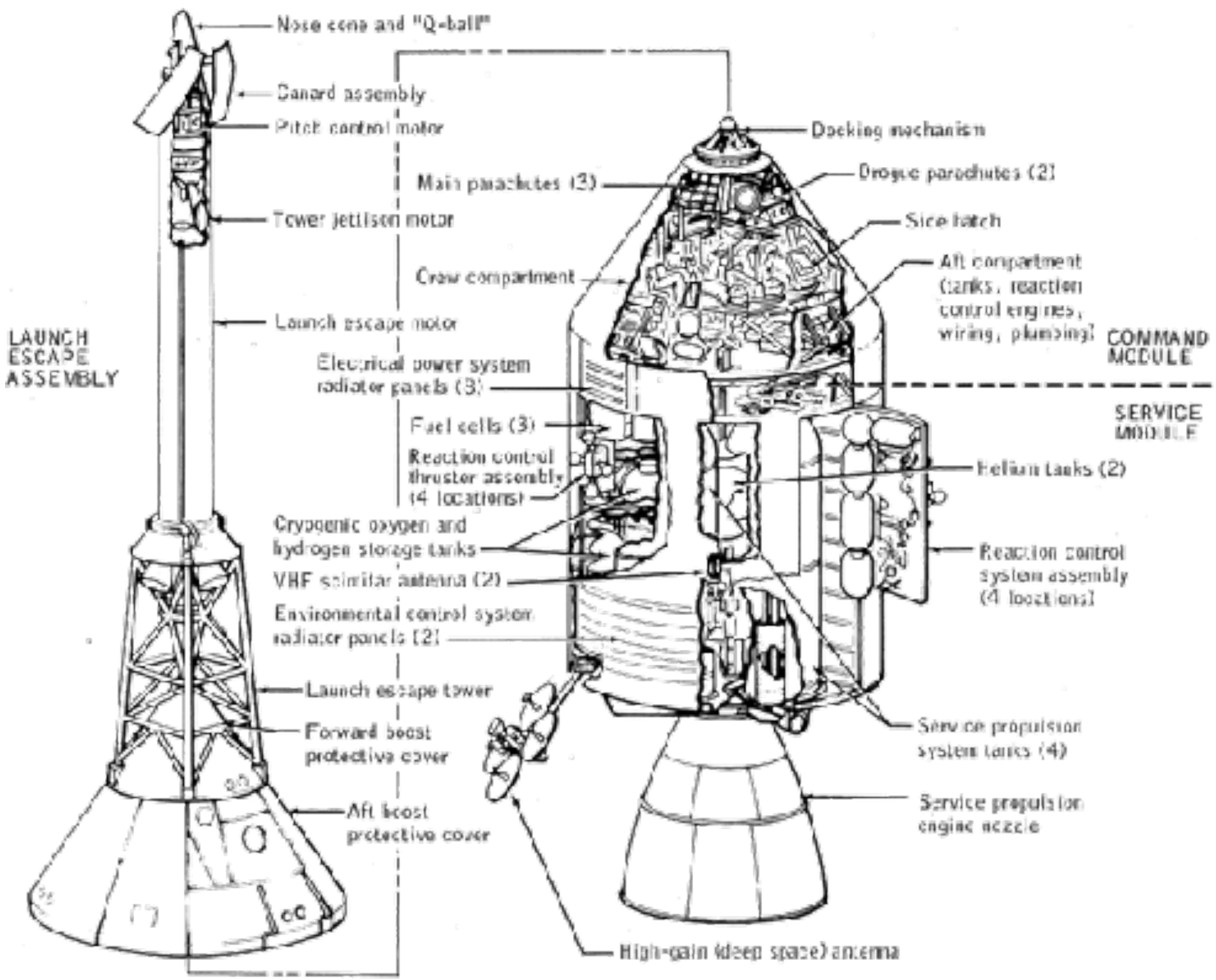
Partonomies:
Parts and Wholes

Towards Content Patterns: Composition, Parts and Wholes



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Composition or Aggregation

- Describing a **whole** by means of its **parts,** e.g.,

  AppleCake is a Cake that has parts that are Apple

- Is *hasPart* one or more relations?
  - If more, what are the primary composition relationships?
- What inferences can we make?
- What might we have in our representation languages to support this?

http://www.flickr.com/photos/hartini/2429653007

- **Mereonomy** is the study of **parts, wholes,** and their relations

Parts & wholes: examples

Toothbrush — Bristles

Shopping Trolley — Wheels

Car — Iron

Cappuccino — Milk

Kilometer — Meter

England — Manchester

Forest — Tree

Pie — Slide of Pie

Book — Chapter

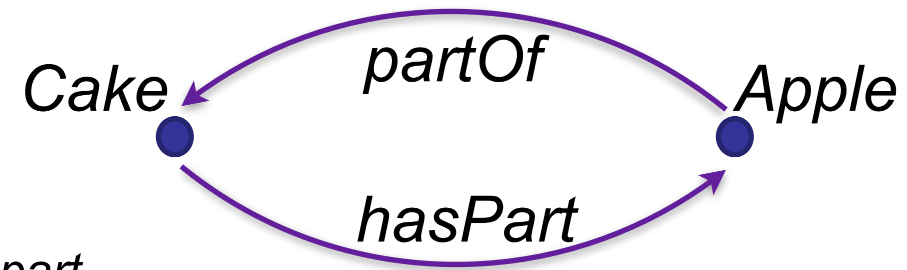
University of Manchester — You

http://www.flickr.com/photos/aramisfirefly/4585596077

- These are different kinds of composition, with different
  - characteristics
  - properties.
- Confusing them may result in incorrect (or undesirable) inferences.

Is part of versus *has part*

- Of course *is part of* is a **different** relation than *has part*
  - my hand *is part of* me but
  - ~~my hand *has part* me~~



- But *is part of* is the **inverse of** *has part*
  - Protégé makes it easy to say this
  - Not declaring this may cause loss of entailments/inferences
- Semantics: If P is the inverse of Q in $\mathcal{O}$, then for any model $\mathcal{I}$ of $\mathcal{O}$, any x, y in Δ: $(x, y) \in P^{\Delta}$ iff $(y, x) \in Q^{\Delta}$

More on Inverse Properties

- Be careful about what you can/cannot infer around inverse relationships:
- …for example:

Property: hasPart
  InverseOf: isPartOf
Class: Car
  SubClassOf: Vehicle and
    (hasPart **some** Engine)
    (hasPart **exactly 4** Wheel)
Class: Broken
  SubClassOf: Device **and** (isPartOf **only** Broken)

  - does this ontology entail that

Engine **SubClassOf** (isPartOf **some** Car)?
Car **and** (hasPart **some** Broken) **SubClassOf** Broken?

Possible Properties of Part-Whole Relations

- See [Winston, Chaffin, Herrmann1987] and [Odell 1998]
- **functional**:
  - Does the part bear a functional or structural relationship to the whole? Are they in specific temporal/special position to support this functionality?
  - e.g., engine-car, wheel-bicycle
  - Odell calls this “configurational”
- **homeomerous** (homeomeric):
  - Is the part the same *kind of thing* as the whole?
  - e.g., the North-West of England, a slice of bread
- **invariant** (separable)
  - Can the part be separated from the whole (without destroying it)?
  - e.g., a hair of me, the bell of my bicycle
  - often difficult since it involves *identity*
  - e.g. if you remove my arm, I am still me?

1. P-W-R: isComponentOf

- holds between
  - a component and
  - an integral object
  - i.e., a configuration of parts and a whole
- used for a particular arrangement (not just haphazard)

functional
non-homeomeric
separable

- Bristles - toothbrush
- Scene - film
- Handle - CarDoor

- Functional: ripping handle off car door affects functionality (of both)
- Non-homeomeric: handle & door are different kinds of things
- Separable: ripping handle off car door is possible

2. P-W-R: isIngredientOf

- holds between
  - material and
  - object that’s made of this material

non-functional
non-homeomeric
non-separable

- Milk - Capuccino
- Flour - Bread

- Functional: milk is “anywhere” in the cappuccino
- Non-homeomeric: cappuccino and milk are different kinds of things
- Non-separable: can’t take milk out of cappucino/flour out of bread

3. P-W-R: isPortionOf

- holds between
  - a portion and
  - an object

non-functional
homeomeric
separable

- Almost like Material-Object, but parts are *the same kinds of thing* as whole
- aka Slice, helping, segment, lump, drop etc.

- SliceOfBread - Bread
- SomeChocolate - Chocolate

- Non-functional: slices can be anywhere, and don't affect function of whole
- Homeomeric: slide & bread are both bread
- Separable: can cut a slice of bread

4. P-W-R: isSpatialPartOf

- holds between
  - a place and
  - its surrounding area

non-functional
homeomeric
non-separable

- Like Portion-Object, parts are same kind of things as whole
- Unlike Portion-Object, parts cannot be removed

- Manchester - England
- Peak - a mountain

5. P-W-R: isMemberOf

- holds between
  - a thing and
  - a unit/collection of these things

non-functional
non-homeomeric
separable

- Tree - Forest
- Employee - Union
- Ship - Fleet
- I - University of Manchester

- there’s also a non-separable variant “Member - Partnership”:
- e.g., Stan - StanAndLaurel

Summary of Odell's Compositional Relationships

	Functional	Homeomeric	Separable
Component-Integral isComponentOf	Y	N	Y
Material-Object isIngredientOf	N	N	N
Portion-Object isPortionOf	N	Y	Y
Place-Area	N	Y	N
Member-Bunch	N	N	Y
Member-Partnership	N	N	N

P-W-Rs ≠ *Non Compositional Relationships*

- Topological inclusion
  - I am in the lecture theatre
- Classification inclusion
  - Catch 22 is a Book
  - It’s an instance of Book, not a part of it, so not Member-Bunch
- Attribution
  - Properties of an object can be confused with composition
  - Height of a Lighthouse isn’t part of it
- Attachment
  - Earrings aren’t part of Ears
  - Toes are part of Feet
  - Sometimes attachments are parts, but not always
- Ownership
  - I have a bicycle

…a lot of modelling is about making the right distinctions and thus helping to get the right relationships between individuals

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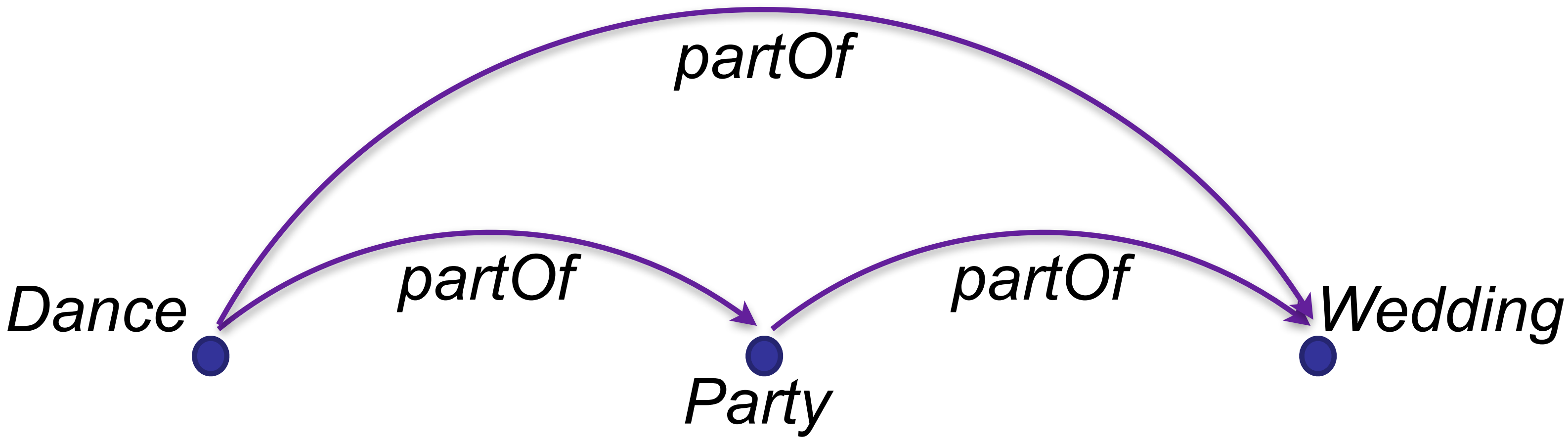
So what?
Modelling these in OWL

Transitivity

X is part of Y, Y is part of Z,
thus X is part of Z



Transitivity

X is part of Y, Y is part of Z,
thus X is part of Z

- Careful: this is only true for some/with the same kind of composition.

- Pistons part of the Engine
- Engine part of the Car
- ➡ Pistons part of the Car

- Pistons component of the Engine
- Engine component of the Car
- ➡ Pistons component of the Car

- Sean's arm component of Sean
- Sean member of School of Computer Science
- ➡ Sean's arm component of School of Computer Science
- ➡ Sean's arm member of School of Computer Science
- ➡ Sean's arm part of School of Computer Science

Transitivity

X is part of Y, Y is part of Z,
thus X is part of Z

- Careful: this is only true for some/with the same kind of composition.

- Pistons part of the Engine
- Engine part of the Car
- ➡ Pistons part of the Car

- Pistons component of the Engine
- Engine component of the Car
- ➡ Pistons component of the Car

Property: isPartOf
Characteristics: Transitive

Property: isComponentOf
SubPropertyOf: isPartOf

Property: isPortionOf
SubPropertyOf: isPartOf
Characteristics: Transitive

- Sean's arm component of Sean
- Sean member of School of Computer Science
- ➡ Sean's arm component of School of Computer Science
- ➡ Sean's arm member of School of Computer Science
- ➡ Sean's arm part of School of Computer Science

Transitivity

- In partonomies, we may want to identify **direct** parts
  - Piston *directPartOf* Engine; Engine *directPartOf* Car
  - Piston is **not** *directPartOf* Car, but is a *partOf* Car
- I want to query for all the **direct** parts of the Car, but not the direct parts of its direct parts.
  - So directPartOf **cannot** be transitive
- Solution: provide a transitive superproperty

Property: isPartOf
  Characteristics: Transitive

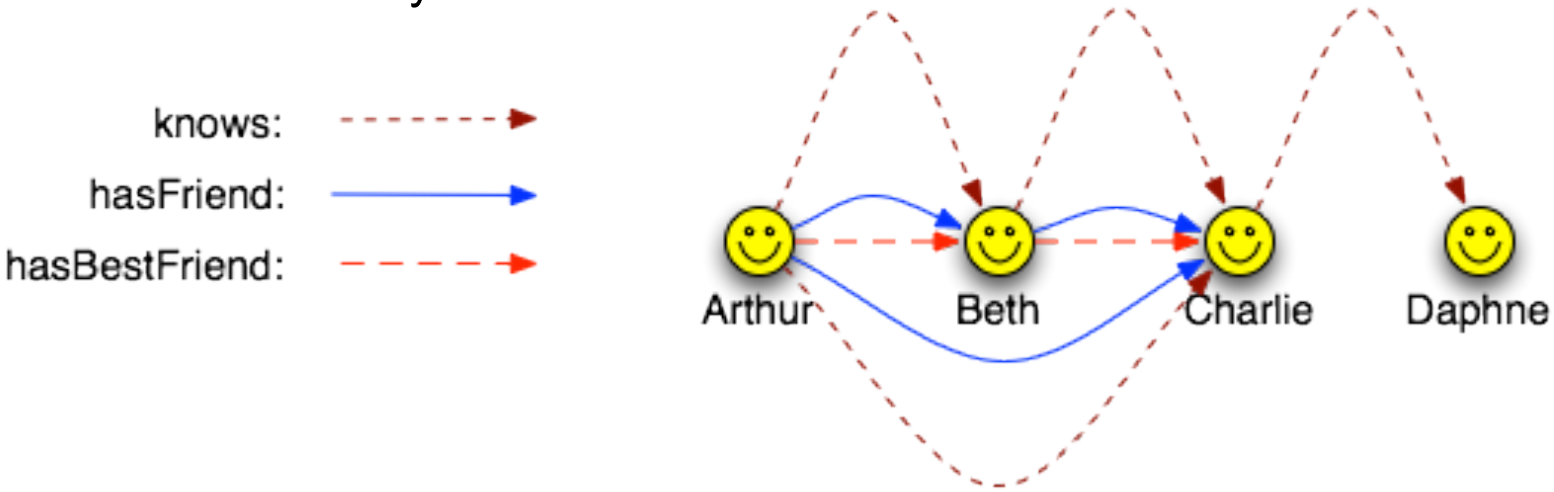
Property: isDirectPartOf
  SubPropertyOf: isPartOf

- Queries can use the superproperty to query transitive closure
- Assertions use the direct part of relationship
- A standard ontology design pattern, sometimes referred to as transitive reduction.

Aside: Transitivity and Subproperties

- Transitive property R is one s.t. for any I model of O, any x,y,z in Δ:
  - if $(x,y) \in R^I$ and $(y,z) \in R^I$, then $(x,z) \in R^I$
  - A superproperty of a transitive property is **not** necessarily transitive
  - A subproperty of a transitive property is **not** necessarily transitive

Property: knows
Property: hasFriend
  SubPropertyOf: knows
  Characteristics: Transitive
Property: hasBestFriend
  SubPropertyOf: hasFriend



Generalised Transitivity

- Some P-W relations interact in interesting ways:

- Sean member of School of Computer Science
- School of Computer Science is a portion of the University of Manchester

➡ Sean member of School of the University of Manchester

Property: isPartOf
Characteristics: Transitive

Property: isMemberOf
SubPropertyOf: isPartOf

Property: isPortionOf
SubPropertyOf: isPartOf
Characteristics: Transitive
SubPropertyChain: isMemberOf o isPortionOf

Composition

- Composition provides a mechanism for describing a (class of) object(s) in terms of its parts
- By considering basic properties of part-whole relationships, we can
  - identify different *kinds* of relationship
  - decide where we can (or ca ty.
- Explicitly separating & relating t get correct inferences

Depends on

Property: isPartOf
 Characteristics: Transitive

Property: isLocatedIn
 SubPropertyChain: isLocatedIn o isPartOf
 Characteristics: Transitive

Class Fracture
 SubClassOf isLocatedIn **some** Bone
Class FractureOfFemur
 EquivalentTo Fracture and isLocatedIn **some** Femur
Class HeadOfFemur
 SubClassOf isPartOf **some** Femur

⊨

Fracture and *isLocatedIn* some *HeadOfFemur*

SubClassOf

FractureOfFemur

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Other Content Design Patterns

- …we just talked a lot about how to model composites
- there are many other general content design patterns:
  - how to model time, trajectories, agents, lists, development, roles (see later!), …
- and many domain dependent content design patterns:
  - how to model
    - aquatic resource observations
    - algorithm implementation execution
    - microblog entry
    - hazardous situation
    - …
- See http://ontologydesignpatterns.org/wiki/Main_Page for a long list

Design Principles in OWL:
Multi-Dimensional Modelling
&
Post-Coordination

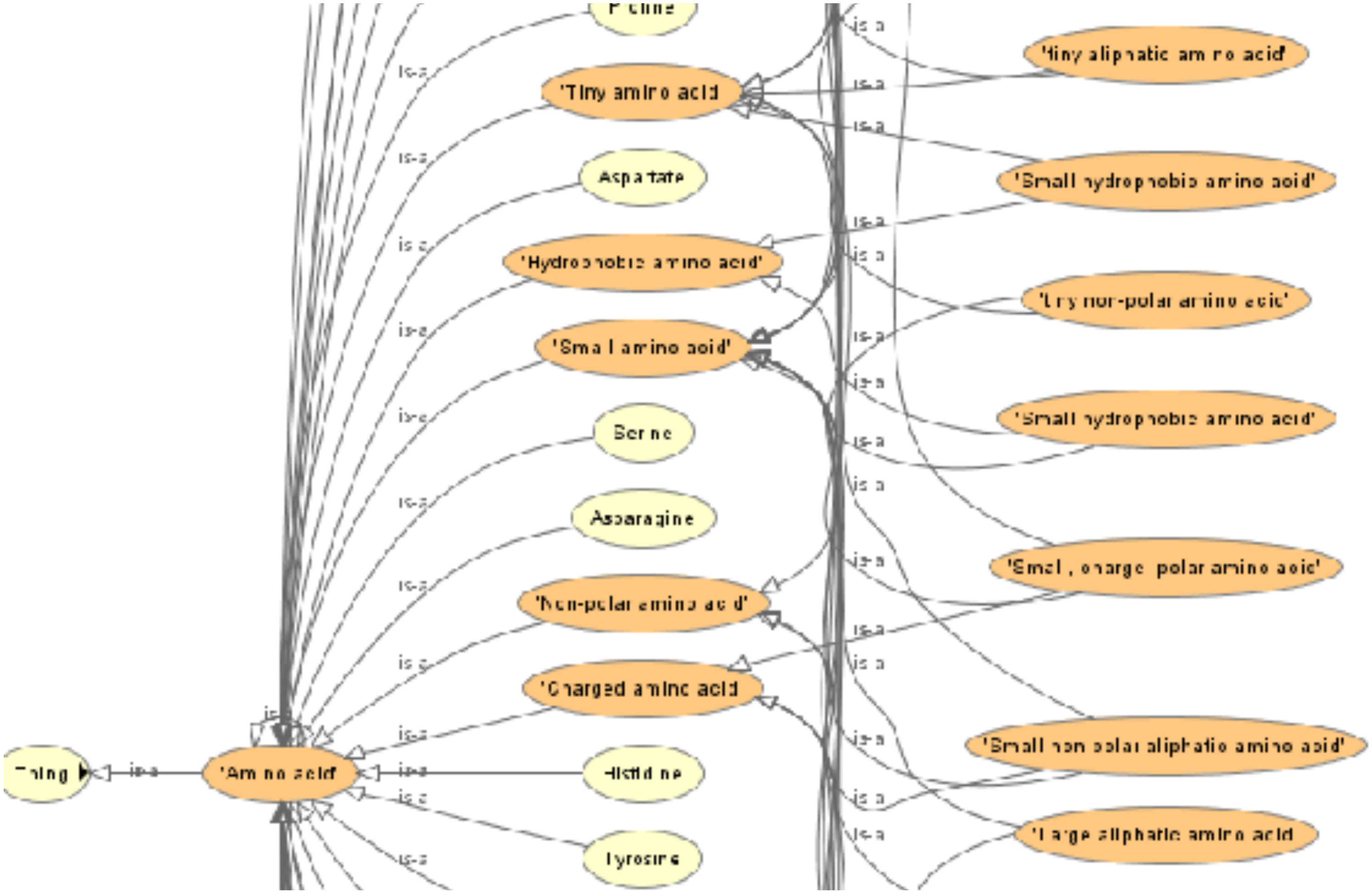
Ontology Normalisation

- An ontology covers different **kinds of things**
  - each kind can come with its (class) hierarchy!
- ➡ poly-hierarchies are the norm
- "Harry Potter and the Philosopher's stone" is a book, a
  - children's book (readers!),
  - work of fiction (literature category!)
  - written in English (language!)
  - available in paperback (form of printing/binding)
- Poly-hierarchies allow knowledge to be captured and appropriately queried
- They are difficult to build by hand
  - do we have "EnglishChildFictionPaperback" or "EnglishChildPaperbackFiction" or….
- Essentially impossible to get right and maintain
  - combinatorial explosion of terms!
- We can use OWL and automated reasoners to do the work for us
- … but how does one manage this and get it right?

Example: tangled medecine

shoulder_catches_during_movement
shoulder_feels_like_it_will_slip_out_of_place
shoulder_joint_feels_like_it_may_slip_out_of_place
shoulder_joint_pain_better_after_rest
shoulder_joint_pain_causes_difficulty_lying_on_affected_side
shoulder_joint_pain_causing_inability_to_sleep
shoulder_joint_pain_difficult_to_localize
shoulder_joint_pain_feels_better_after_normal_movement
shoulder_joint_pain_first_appears_at_night
shoulder_joint_pain_improved_by_medication
shoulder_joint_pain_improves_during_exercise__returns_later
shoulder_joint_pain_incr_by_raising_arm_above_shoulder_level
shoulder_joint_pain_increased_by
shoulder_joint_pain_increased_by_lifting
shoulder_joint_pain_increased_by_moving_arm_across_chest
shoulder_joint_pain_increased_by_reaching_around_the_back
shoulder_joint_pain_relieved_by_putting_arm_over_head
shoulder_joint_pain_sudden_onset
shoulder_joint_pain_unrelenting
shoulder_joint_pain_worse_on_rising
shoulder_joint_pain_worsens_with_extended_activity
shoulder_joint_popping_sound_heard
shoulder_joint_suddenly_gives_way
shoulder_seems_out_of_place
shoulder_seems_out_of_place__recollection_of_the_event
shoulder_seems_out_of_place_recurrent
shoulder_seems_out_of_place_which_resolved
shoulder_suddenly_locked_up

Example: “tangled” ontology of amino acids



There are several *dimensions* of classification here

- Identifiable **dimensions** are:
  - **amino acids** themselves – they have **side chains**
  - the **size** of the amino acids side chain
  - the **charge** on the side chain
  - the **polarity** of the side chain
  - The **hydrophobicity** of the side chain
- We can
  - *normalise* these into separate hierarchies then
  - put them back together again

- Our goal is to put entities into separate *trees* all formed on the same basis

Untangeling 1: separate dimensions

Charge
- Negative
- Neutral
- Positive

Polarity
- Polar
- Nonpolar

Size
- Tiny
- Small
- Medium
- Large

Hydrophobicity
- Hydrophobic
- Hydrophilic

Amino Acids
- Alanine
- Arginine
- Asparagine
- Cysteine
- Glutamate
- Glutamine
- Glycine
- Histidine
- Isoleucine
- Leucine
- Lysine
- Methionine
- Phenylalanine
- Proline
- Serine
- Threonine
- Tryptophan
- Tyrosine
- Valine

Untangeling 1: separate dimensions

- Each separate dimension includes the same *kind of thing*
- Within a dimension, we don't mix
  - self-standing things, processes, modifiers (qualities)
  - our classification by, for instance, structure and then charge

Untangeling 2: relate dimensions using properties

Property: hasSize
Domain: AminoAcid
Range: Size

Property: hasPolarity
Domain: AminoAcid
Range: Polarity

Property: hasCharge
Domain: AminoAcid
Range: Charge

Property: hasHydrophobicity
Domain: AminoAcid
Range: Hydrophilic

Amino Acids
- Alanine
- Arginine
- Asparagine
- Cysteine
- Glutamate

Polarity
- Polar
- Nonpolar

Size
- Tiny
- Small
- Medium
- Large

Charge
- Negative
- Neutral
- Positive

Hydrophobicity
- Hydrophobic
- Hydrophilic

Untangeling 3: Describe **relevant** terms

Class: AminoAcid
    SubClassOf: hasSize **some** Size,
        hasPolarity **some** Polar,
        hasCharge **some** Charge,
        hasHydrophobicity **some**
            hydrophobicity

Class: Lysine
    SubClassOf: AminoAcid,
        hasSize **some** Large,
        hasCharge **some** Positive,
        hasPolarity **some** Polar,
        hasHydrophobicity **some** Hydrophilic

Amino Acids
- Alanine
- Arginine
- Asparagine
- Cysteine
- Glutamate

Polarity
- Polar
- Nonpolar

Size
- Tiny
- Small
- Medium
- Large

Charge
- Negative
- Neutral
- Positive

Hydrophobicity
- Hydrophobic
- Hydrophilic

Untangeling 3: Describe **relevant** terms

Class: LargeAminoAcid
EquivalentTo: AminoAcid
and hasSize **some** Large

Class: PositiveAminoAcid
EquivalentTo: AminoAcid
and hasCharge **some** Positive

Class: LargePositiveAminoAcid
EquivalentTo: LargeAminoAcid and PositiveAminoAcid

Amino Acids
- Alanine
- Arginine
- Asparagine
- Cysteine
- Glutamate

Polarity
- Polar
- Nonpolar

Size
- Tiny
- Small
- Medium
- Large

Charge
- Negative
- Neutral
- Positive

Hydrophobicity
- Hydrophobic
- Hydrophilic

Post-Coordination

- This poly-hierarchical/multi-dimensional modelling style in OWL allows us to use **post-coordination**
  - build class **expressions** and use them **like names**
  - i.e., we can ask a reasoner (via the OWL API)
    - for instances of (AminoAcid **and** (hasSize **some** Large)
      and (hasCharge **some** Positive))
    - whether (AminoAcid **and** (hasSize **some** Large)
      and (hasCharge **some** Neutral))
      is satisfiable w.r.t O
  - relies on OWL reasoners/tools to be able to handle class **expressions** in the same way as they handle **names**

- this saves us from having to give names to **all** combinations:
  - we can give names to **some** expressions
    - but we don't have to
    - since the reasoner can **understand** expressions!

Post-Coordination

- Multi-dimensional modelling in OWL allows us to use **post-coordination** and thus avoid tangles like this…

shoulder_catches_during_movement
shoulder_feels_like_it_will_slip_out_of_place
shoulder_joint_feels_like_it_may_slip_out_of_place
shoulder_joint_pain_better_after_rest
shoulder_joint_pain_causes_difficulty_lying_on_affected_side
shoulder_joint_pain_causing_inability_to_sleep
shoulder_joint_pain_difficult_to_localize
shoulder_joint_pain_feels_better_after_normal_movement
shoulder_joint_pain_first_appears_at_night
shoulder_joint_pain_improved_by_medication
shoulder_joint_pain_improves_during_exercise__returns_later
shoulder_joint_pain_incr_by_raising_arm_above_shoulder_level
shoulder_joint_pain_increased_by
shoulder_joint_pain_increased_by_lifting
shoulder_joint_pain_increased_by_moving_arm_across_chest
shoulder_joint_pain_increased_by_reaching_around_the_ba
shoulder_joint_pain_relieved_by_putting_arm_over_head
shoulder_joint_pain_sudden_onset
shoulder_joint_pain_unrelenting
shoulder_joint_pain_worse_on_rising
shoulder_joint_pain_worsens_with_extended_activity
shoulder_joint_popping_sound_heard
shoulder_joint_suddenly_gives_way
shoulder_seems_out_of_place
shoulder_seems_out_of_place__recollection_of_the_event
shoulder_seems_out_of_place_recurrent
shoulder_seems_out_of_place_which_resolved
shoulder_suddenly_locked_up

- if we need all these terms, we can generate them
  - automatically
  - in a principled way
  - ..and update them in case of changes!

Patterns used

- The Amino acids ontology uses these five patterns:
  - Normalisation/Multidimensional modelling
  - EPQ
  - Closure (via it's functional properties)
  - A covering axiom for all the amino acids
  - It's own pattern for amino acids

  - There is more information via
    - http://ontogenesis.knowledgeblog.org/tag/ontology-normalization
    - http://robertdavidstevens.wordpress.com/2010/12/18/an-update-to-the-amino-acids-ontology/
    - http://ontogenesis.knowledgeblog.org/1401

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PIMPS - an Upper Level Ontologies

Upper Level Ontologies

- Domain neutral description of **all** entities
- Should be able to be used to describe any domain:
  - biology, art, politics, business, medicine, …
- The basic dimensions:
  - processes and the
  - things that participate in processes
- Different ULOs differ in
  - the ontology language they use
  - their level of detail
  - their view of the world
  - etc
- Much philosophical discussion
  - …been trying since 437 BCE and still not sorted it out
- So, we'll do something simple: PIMPS

The PIMPS ontology in context

- Thing
  - Process
  - Continuant
    - Dependant_Continuant
      - Property
        - Function
        - Disposition
        - Role
        - Quality
    - Indepentant_Continuant_-_Self-standing
      - Inmaterial
        - Site
        - Information
      - Material

PIMPS: A Simple Domain Neutral Ontology

- Thing
  - **P**rocess
  - **I**mmaterial
  - **M**aterial
  - **P**roperties
    - Quality
    - Function
    - Role
    - Disposition
  - **S**ites

PIMPS: A Simple Domain Neutral Ontology

- **Process**
  - An entity that unfolds over time such that its identity changes
  - Not all of a process is present at a given time-point in that process
  - E.g., living, wedding, dying, eating, breathing, liberation, election
  - Lots of “-ation” and “…ing” words

- **Material**
  - Self-standing things I can “hold in my hand”
  - E.g., ball, car, person, leg, pizza, piece of seaweed
  - All of it exists at any one point in time
  - All of Robert exists at any point in time, even though Robert himself actually changes
  - It retains its identity

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PIMPS: A Simple Domain Neutral Ontology

- **Immaterial**
  - Self-standing things I can **not** “hold in my hand”
  - E.g., idea, goal, wish, …
  - It exists at any one point in time
  - This idea may change over time but retains its identity
- **Properties**
  - Dependant (not-self-standing) things including
    - **Quality**, e.g. Size, Weight
    - **Function**, e.g., Control, Activation, Neutralisation
    - **Role**, e.g., Catalyst, Pathogen
    - **Disposition**, e.g., HeatResistence
- **Site**
  - point or area on/of a material entity
  - e.g., the area occupied by Manchester
  - not to be confused with segments of that entity

Why use an upper level ontology?

- Consistent modelling style both within and between ontologies
- Primarily a guide to using properties consistently
  - Continuants have parts that are continuants
  - Processes have parts that are processes
  - Independent continuants hasQuality some Quality
    and playRole some Role
  - Independent continuant hasFunction some Function
  - Independent continuants participate in processes
  - Sites occupy some material entity

Today:

✓Semantic left-overs from last week

✓Deepen your semantics: OWL & FOL & …

✓Design **Patterns** in OWL

  - local ones
  - partonomies

- Design **Principles** in OWL:
  - ✓multi-dimensional modelling
  - ✓post-coordination
  - ✓PIMPS - an upper level ontology
- **Automated reasoning** about OWL ontologies:
  - a tableau-based algorithm to make
  - …implicit knowledge explicit
  - …our know KR *actionable*