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OWL, Patterns, & FOL
COMP62342

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A reminder: quotations and citations

- **Citations** [4] inform us where you got an idea/approach/result/technique/term…from
    - **Reference** its source when you *take* an idea/result/example/…
- **Quote marks** "…" inform us where you got a phrase/sentence/paragraph from
    - **Quote** when you *take* a sentence & reference its source!
      …even if it's *only* 1 sentence or a short poem on your mom's birthday card!

So far, we have looked at

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

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*

Left-overs from last week

OWL 2 Semantics: an interpretation satisfying … (2)

- 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 $(x^I, y^I) \in R^I$

From Last Week

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:
  - ✓ 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

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From Last Week

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)

From Last Week

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 ∪ {n:A} is consistent (where n doesn't occur in O)
3. b is an instance of A in O iff O ∪ {b:not(A)} is not consistent
4. O entails A SubClassOf B iff O ∪ {n:A and not(B)} is inconsistent

From Last Week

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

- O is **coherent** if every class name that occurs in O is satisfiable w.r.t 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 $O \models$ 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

OWL and First Order Logic

- in COMP60332, 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:

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

- …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 tx(C) a formula in 1 free variable?
3. translate O6 to FOL
4. …what do you know 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

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)

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://www.sciencedirect.com/science/article/pii/S1570826808000413

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✓Deepen your semantics: OWL & FOL & …

- Design **Patterns** in OWL
    - local ones
    - partonomies
- Design **Principles** in OWL:
    - multi-dimensional modelling &
    - post-coordination
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    - 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 or appear within an ontology
- The most common is
  - atomic SubClassOf axioms,
    i.e. SubClassOf axioms with class **names** on both sides
  - … but they get much more complex than that
- Usually, we're referring to **syntactic** patterns:
  - how axioms are written,
  - but remember "axioms" are inferred as well as written

Patterns and design patterns

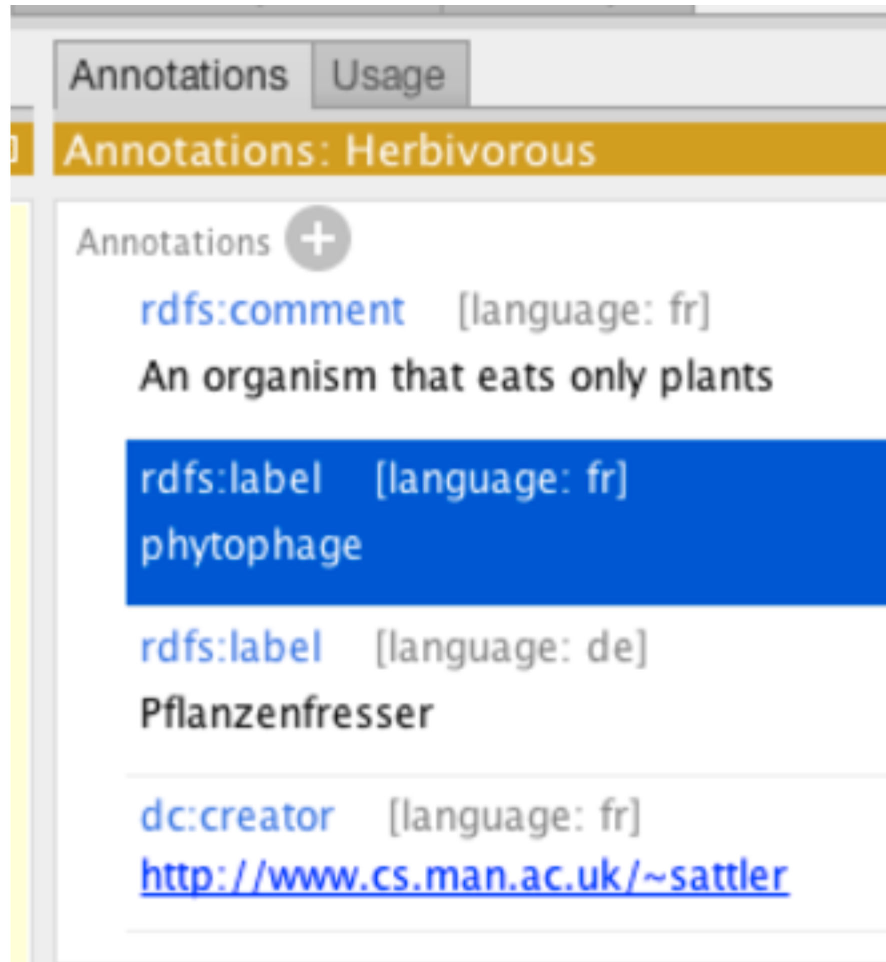
- **Software Design Patterns** are
  - well accepted solutions for common issues met in software construction

- **Ontology Design Patterns** ODPs are the same:
  - 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**



Term normalisation ⊆ applied naming convention

- A **naming convention** determines
  - what words to use, in
  - which order and
  - what one does about symbols and acronyms

"Glucose transport" vs "transport of glucose"

- Adopt one
  - for both labels and URI fragments
  - both for the URI fragment and for the label
- Having a label is a "good practice"

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”
  - Vinegared Rice is not Sushi, but “part of Sushi” of “Sushi Ingredient”

- Card sorting and the three card trick can help you here
- More on this later when we talk about upper level ontologies

Types of axiom patterns

- **Domain modelling patterns**: How to organise the axioms describing a domain
- Works both in the
  - large: the whole ontology – and in the
  - small: how to describe a class/type of sushi
- **Language patterns**: Used to
  - take advantage of language features or
  - work around something missing in a language
- The latter are used in the former

A first Axiom Pattern: the **Property Closure Pattern**

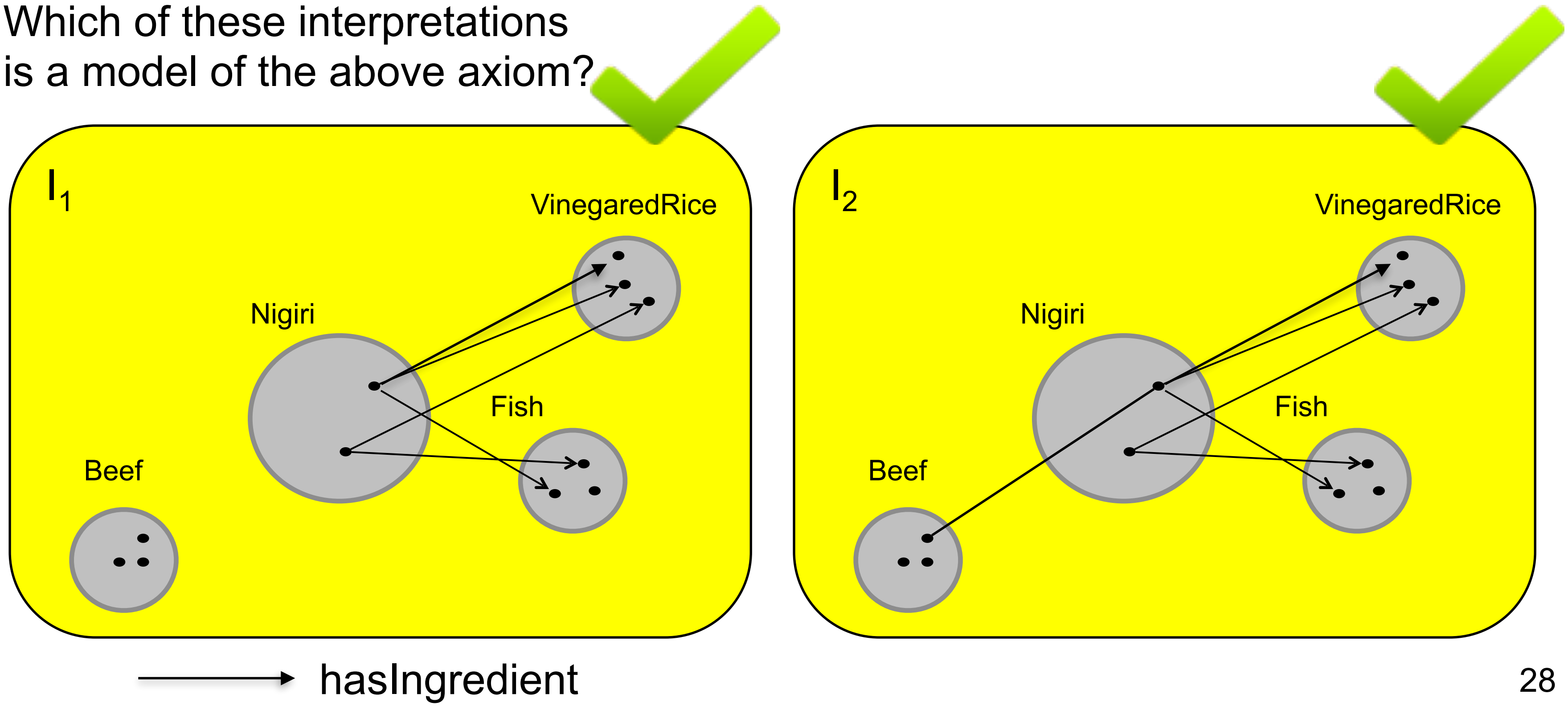
Class: Nigiri
    SubClassOf Sushi,
        hasIngredient **some** VinegaredRice,
        hasIngredient **some** Fish

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

A first Axiom Pattern: the **Property Closure Pattern**

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

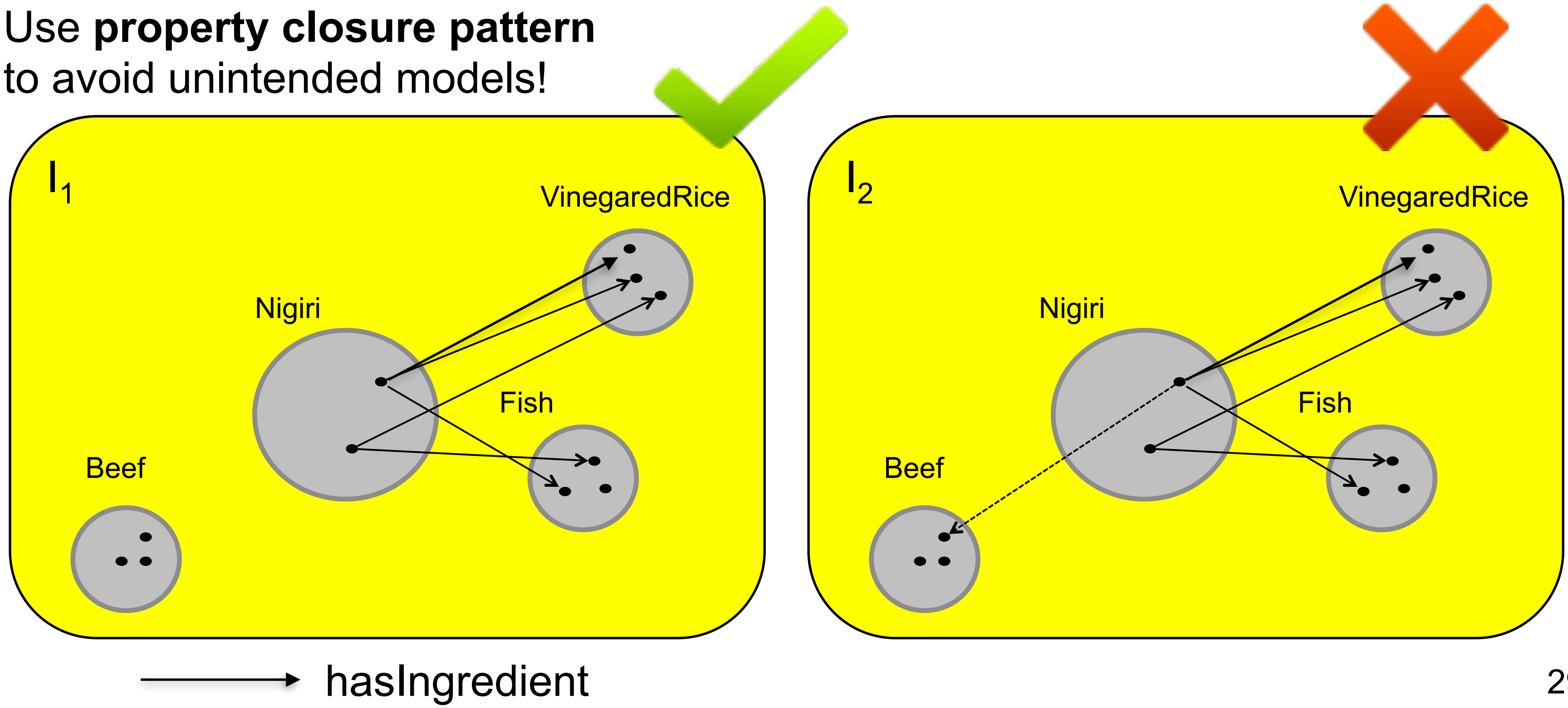
Which of these interpretations is a model of the above axiom?



A first Axiom Pattern: the Property Closure Pattern

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

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



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 VinegaredRice,
                hasIngredient some Fish
```

- For
  - the answer to "Does Nigiri have beef as ingredient" is "Maybe/Don't know"

```
DisjointClasses: VinegaredRice, Fish, Beef
Class: Nigiri
        SubClassOf Sushi,
                hasIngredient some VinegaredRice,
                hasIngredient some Fish,
                hasIngredient only (Fish or VinegaredRice)
```

- For
  - the answer to "Does Nigiri have beef as ingredient" is "No"!

A first Axiom Pattern: the **Property Closure Pattern**

- In summary, 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)
```

A second Axiom Pattern: the **Covering Axiom 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
- 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!

More information on closing patterns….

- http://ontogenesis.knowledgeblog.org/1001
- Lots of short, accessible articles about ontology stuff

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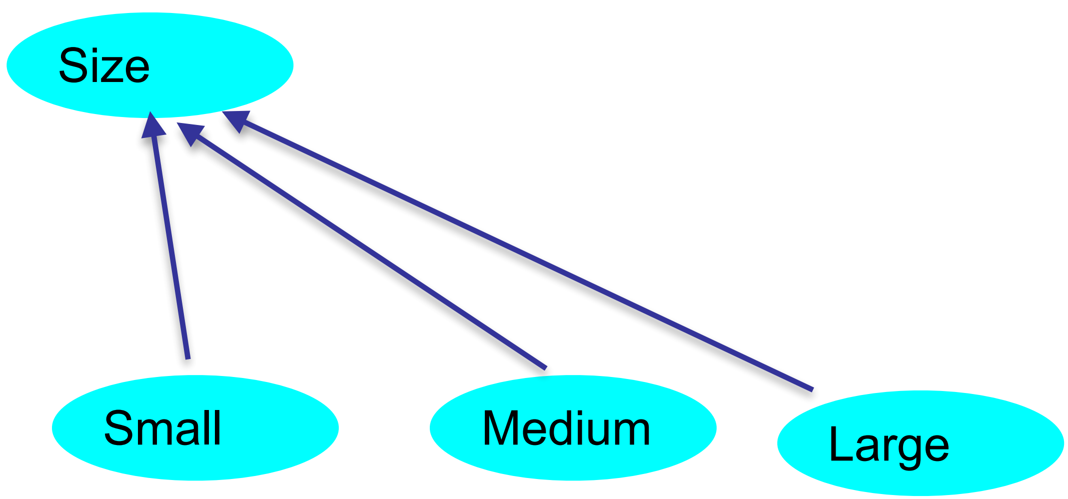
A third Axiom Pattern: the (Value) **Partitions Pattern**

- 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

A third Axiom Pattern: the (Value) **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)

Disjointness
+ Covering
Partition



A fourth Axiom Pattern: the **Entity Property Quality Pattern**

Class: Small **SubClassOf** Size
Class: Medium **SubClassOf** Size
Class: Large **SubClassOf** Size

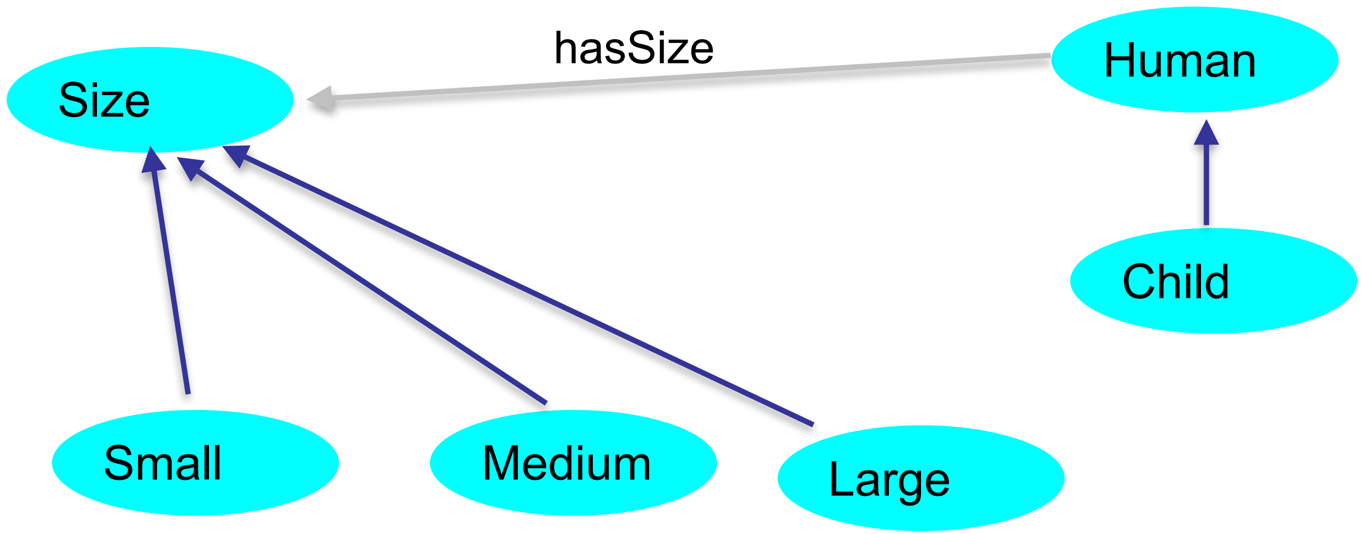
DisjointClasses: Small, Medium, Large

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

Property: hasSize **Characteristics**: Functional
Range: Size **Domain:** Mammal

Class: Human **SubClassOf** hasSize **some** Size

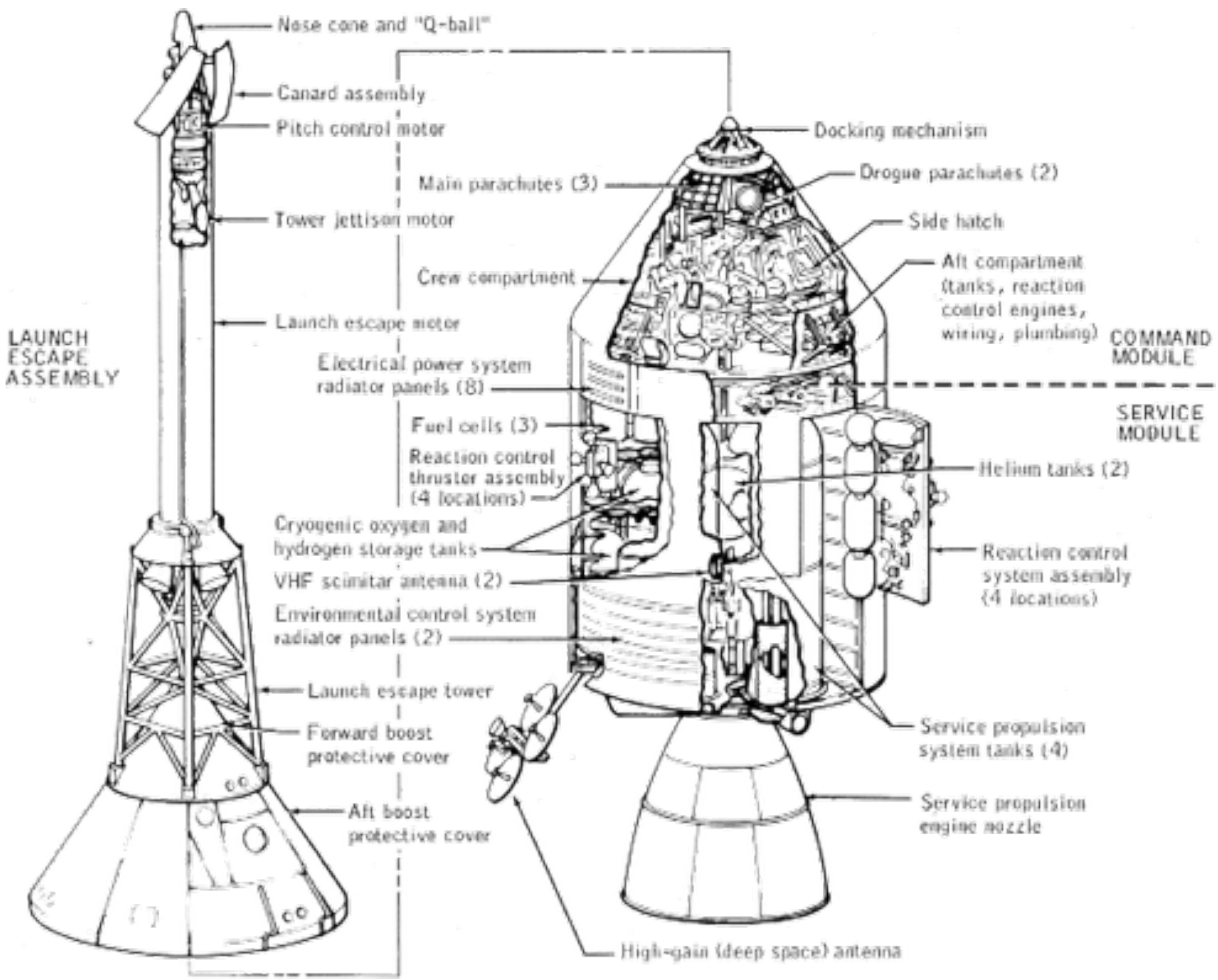
Class: Child **SubClassOf** Human **and** hasSize **only** Small



A fourth Axiom 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., has_size 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 apply
      - via the **domain** of the property and
      - where they 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
- Have a look at
  - http://www.w3.org/TR/swbp-specified-values/
  - http://ontogenesis.knowledgeblog.org/1499

Beyond Axiom Patterns: Composition, Parts and Wholes



Composition or Aggregation

- Describing a **whole** object by means of its **parts**
  - treating complex things as a single object

- What are the primary composition relationships?
- What inferences can we make?
- What might we have in our representation languages to support this?

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

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

Parts & wholes: Some examples

- Bristles are part of a toothbrush
- Wheels are part of a shopping trolley
- A car is partly iron
- Milk is part of a cappuccino
- A meter is part of a kilometer
- Manchester is part of England
- A tree is part of a forest
- A slice of pie is part of the pie
- A book chapter is part of a book
- I am part of the University of Manchester

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

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

Properties of Composition

- [Winston, Chaffin, Herrmann1987] and [Odell 1998] identify core properties:
- **functional**:
  - Does the part bear a functional or structural relationship to the whole?
  - e.g., engine-car, wheel-bicycle
- **homeomerous**:
  - Is the part the same kind of thing as the whole?
  - e.g., the North-West of England, a slice of bread
- **invariant**:
  - Can the part be separated from the whole?
  - e.g., a hair of me, the bell of my bicycle

- …next, we discuss *natural* combinations of these that give rise to interesting **part-whole relations**
- **…**and don't confuse P-W-Rs with is-a/SubClassOf:
  - engine is part of car, but not 'is-a'!

1. P-W-R: Component-Integral Object

functional
non-homeomeric
separable

- A configuration of parts within a whole

- Bristles - toothbrush
- Scene - film

- A particular arrangement (not just haphazard)

- If components cease to support the overall pattern then different associations may arise
  - Handle ripped from a door of the car.
    - No longer a part but a piece

2. P-W-R: Material-Object

functional
non-homeomeric
non-separable

- Parts can't be removed

- Capuccino is partly milk
- Bread is partly flour

- Define what objects are made of.
- Component-Integral can be separated
  - Car without a door handle still a Car
- Material-Object can't
  - Bread without flour not bread

3. P-W-R: Portion-Object

functional
homeomeric
separable

- Almost like Material-Object, but parts are the same kinds of thing as whole

- Slice of bread is a portion of bread
- meter is part of a kilometer

- Selective inheritance of properties
- Ingredients of bread are ingredients of slice of bread
  - But with different quantities

- Slice, helping, segment, lump, drop etc.

4. P-W-R: Place-Area

functional
homeomeric
non-separable

- Unlike Portion-Object, pieces cannot be removed

- Manchester part of England
- Peak part of a mountain

- Often between places and locations.
- Pieces similar in nature.

5. P-W-R: Member-Bunch

non-functional
non-homeomeric
separable

- No requirement for a particular structural or functional relationship

- Tree part of a Forest
- Employee part of the Union
- Ship part of a Fleet
- I am part of the University of Manchester

6. P-W-R: Member-Partnership

non-functional
non-homeomeric
non-separable

- An invariant form of Member-Bunch

- Stan Laurel is part of Laurel and Hardy
- Fred and Ginger are a dancing couple

- Removal of member destroys the partnership
  - a different partnership may result

Summary of Odell’s Compositional Relationships

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

Dont’ confuse P-W-Rs with *Non Compositional Relationships* such as

- 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
  - A bicycle has wheels
  - I have a bicycle
  - A lot of modelling is about making the right distinctions and thus helping to get the right relationships between individuals

So what? Modelling these in OWL

Transitivity

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

- We might expect part-whole or composition relationships to behave transitively.
  - But this is generally only true with the same kind of composition.

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

➡ Pistons part of the Car ✔

- Sean’s arm part of Sean
- Sean part of School of Computer Science

➡ Sean’s arm part of School of Computer Science ✘

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Property: isPartOf
Characteristics: Transitive

Property: isComponentOf
SubPropertyOf: isPartOf

Property: isPortionOf
SubPropertyOf: isPartOf
Characteristics: Transitive

- Sean's arm part of Sean
- Sean part 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 shouldn't be transitive
- Solution: provide a transitive superproperty

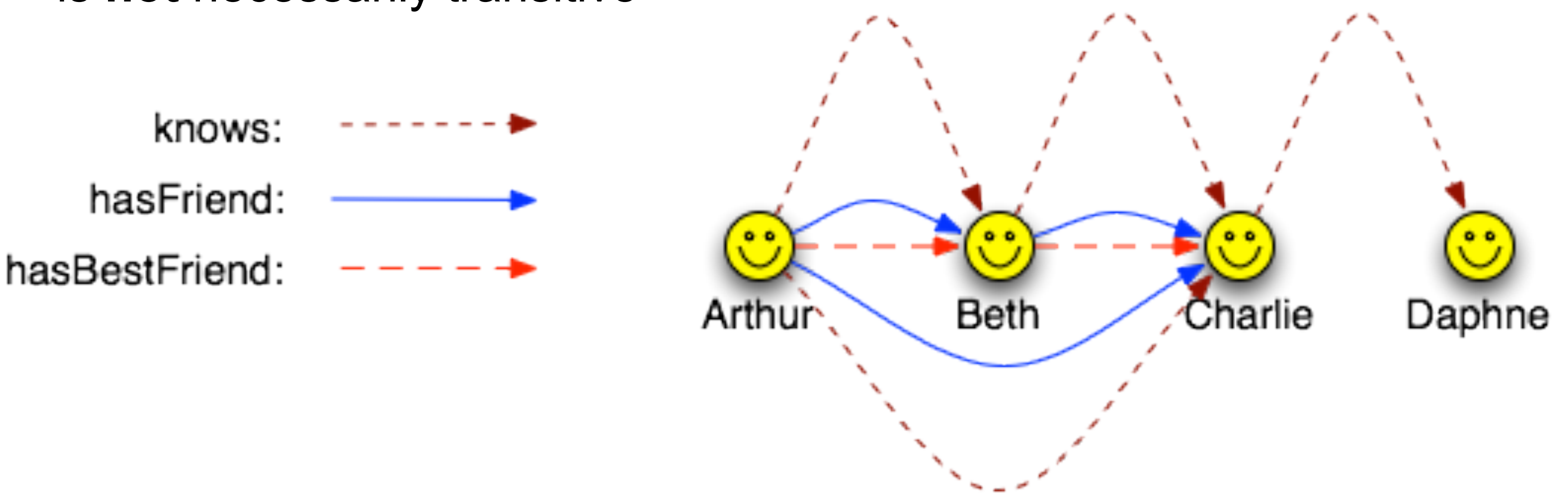
Property: isPartOf
Characteristics: Transitive
Property: isDirectPartOf
SubPropertyOf: isPartOf

- 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



Aside: A note on Inverses

Property: knows
Property: hasFriend
SubPropertyOf: knows
Characteristics: Transitive
Property: isFriendOf
InverseOf: hasFriend

- OWL allows us to define inverse relationships
- If P is the inverse of Q in O, then for any I model of O, any x,y in Δ: $(x,y) \in P^I$ iff $(y,x) \in Q^I$
- Be careful about what you can infer about inverse relationships:

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

- …are all engines part of cars?
  - does this ontology entail that
    Engine **SubClassOf** (isPartOf **some** Car)?

Composition

- Composition provides a mechanism for describing
  a (class of) object(s) in terms of its parts

- By considering basic properties of this part-whole relationship, we can identify different kinds of relationship
- The different relationships then help us in identifying when, for example, we can (or can't) apply transitivity.
- Explicitly separating these in our representation can avoid incorrect/invalid inferences.

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*

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?

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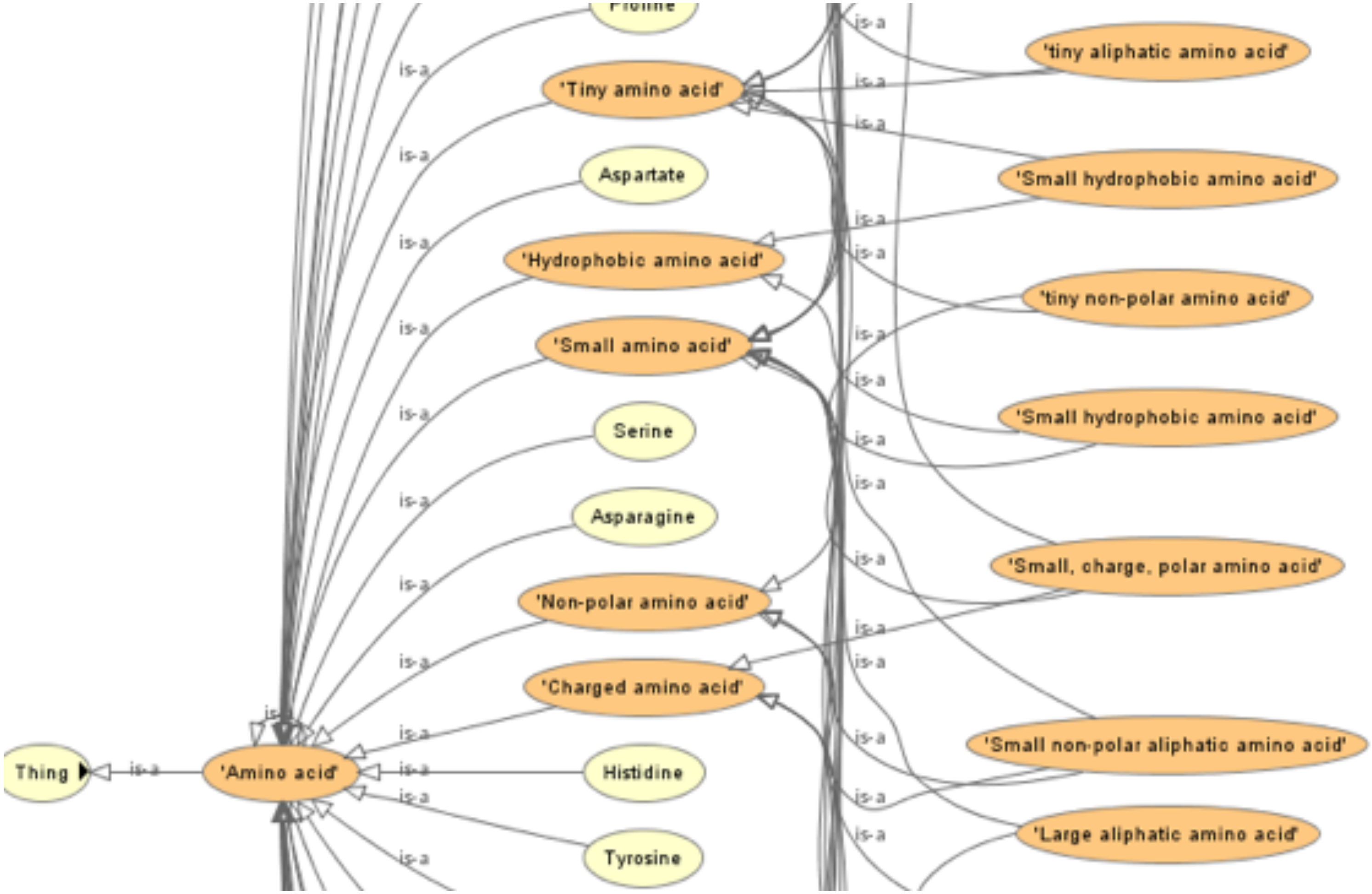
Example: tangled medecine

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
- We do that compositionally via defined classes and the automated reasoners

Untangeling 2: relate dimensions using properties

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

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 **class 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!

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

PIMPS - an Upper Level Ontologies

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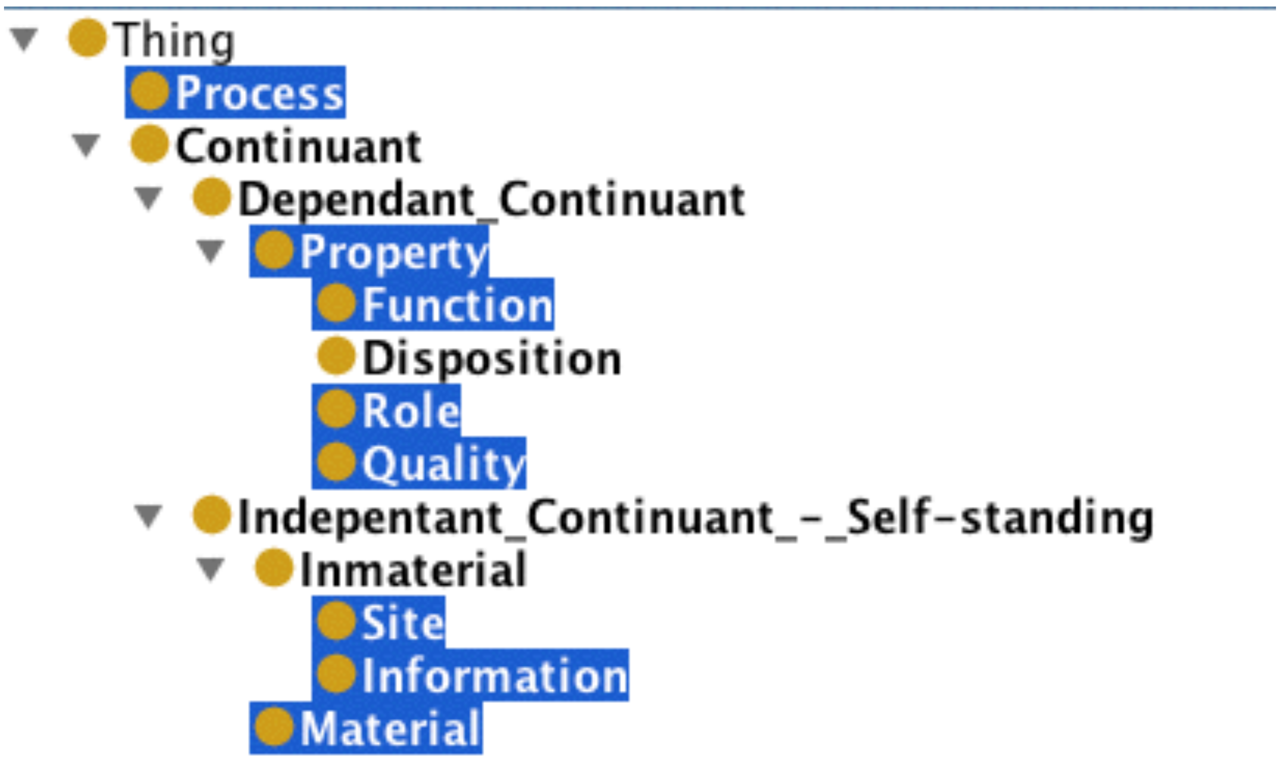
Upper Level Ontologies

- 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



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, drinking, breathing, liberation, election…
  - Lots of "-ation" and "…ing" words
- **Material**
  - Self-standing things I can "hold in my hand"
  - E.g., ball, a car, a person, a leg, a pizza, a piece of seaweed, etc etc
  - 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

PIMPS: A Simple Domain Neutral Ontology

- **Immaterial**
  - Self-standing things I can **not** “hold in my hand”
  - E.g., An idea, a goal, a 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 a material entity
  - 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
- Use property hierarchies…

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