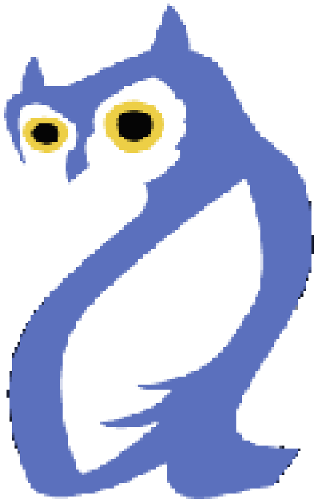
National Key Laboratory For KRistal Novel Software Technology



OWL, Patterns, & FOL

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Next:

- 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*

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

- 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

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:
$\Delta = \{v, w, x, y, z\}$

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

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

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

I_2:
$\Delta = \{v, w, x, y, z\}$

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

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

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

I_3:
$\Delta = \{v, w, x, y, z\}$

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

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

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

I_4:
$\Delta = \{v, w, x, y, z\}$

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

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

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

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 $\models$α) 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

inconsistent $\Leftrightarrow$ O $\models$ Thing Sub···Nothing

$\top \sqsubseteq \bot$ in DL

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:

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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

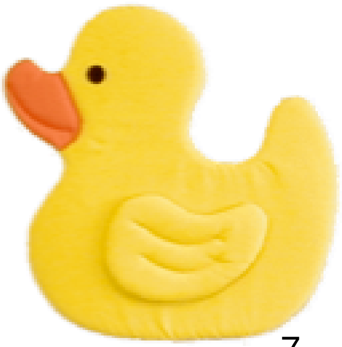
1. testing whether O is consistent; if yes, then
2. checking, for each pair A,B of class names in O plus Thing, Nothing whether O $\models$A SubClassOf B
3. checking, for each individual name b and class name A in O, whether O $\models$b:A

…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
  - *SubClassOf* axioms
  - C SubClassOf: D…any instance of C is also an instance of D
- **Necessary & Sufficient** conditions
  - *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. $O \models b:C$

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

- during your first year at NJU, you have learned a lot about FOL
- most of OWL 2 (and OWL 1) is a **decidable fragment of FOL:**

Translate an OWL ontology O into FOL using $t()$ as follows:

$$t(\mathrm{O}) = \{\forall x. t_x(C) \Rightarrow t_x(D) \mid C \text{ SubClassOf } D \in \mathrm{O}\} \cup$$
$$\{t_x(C)[x/a] \mid a : C \in \mathrm{O}\} \cup$$
$$\{r(a, b) \mid (a, b) : r \in \mathrm{O}\}$$

- …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

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

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** 凡是没有的都视为错误、
     - 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 凡是没有的都视为无法判断
     - 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

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

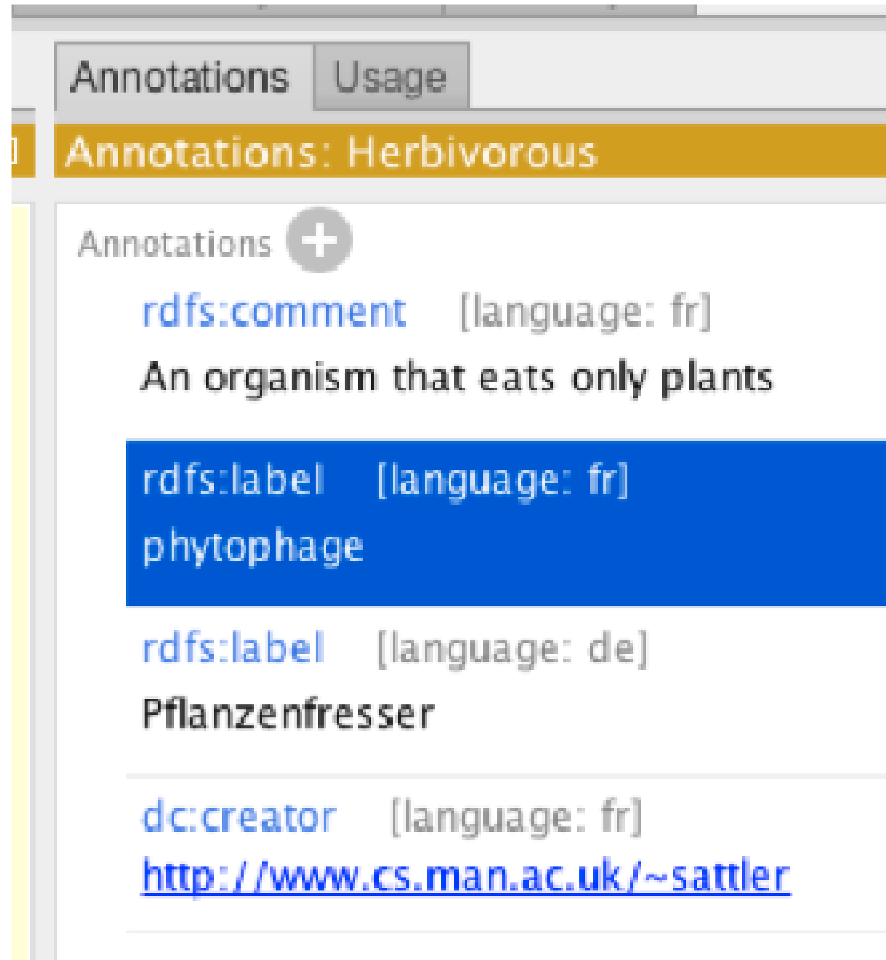
- **Software Design Patterns** are
  - well accepted solutions for common issues met in software construction

- **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, 首字母大写
    - spaces via CamelCase
  - **Individual** names:
    - all lower case, 小写 .
    - 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 $\subseteq$ 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

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

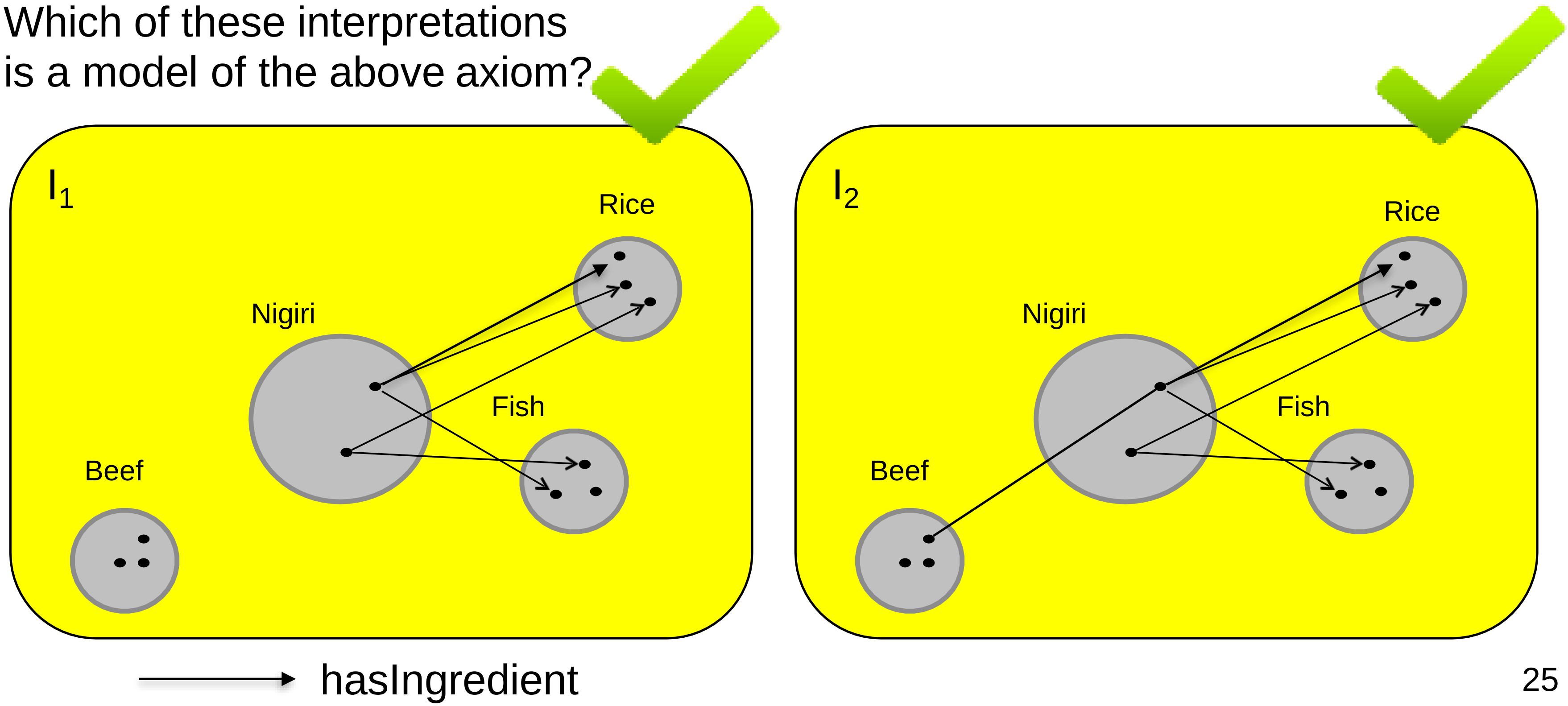
hasIngredient **some** Fish

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

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

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

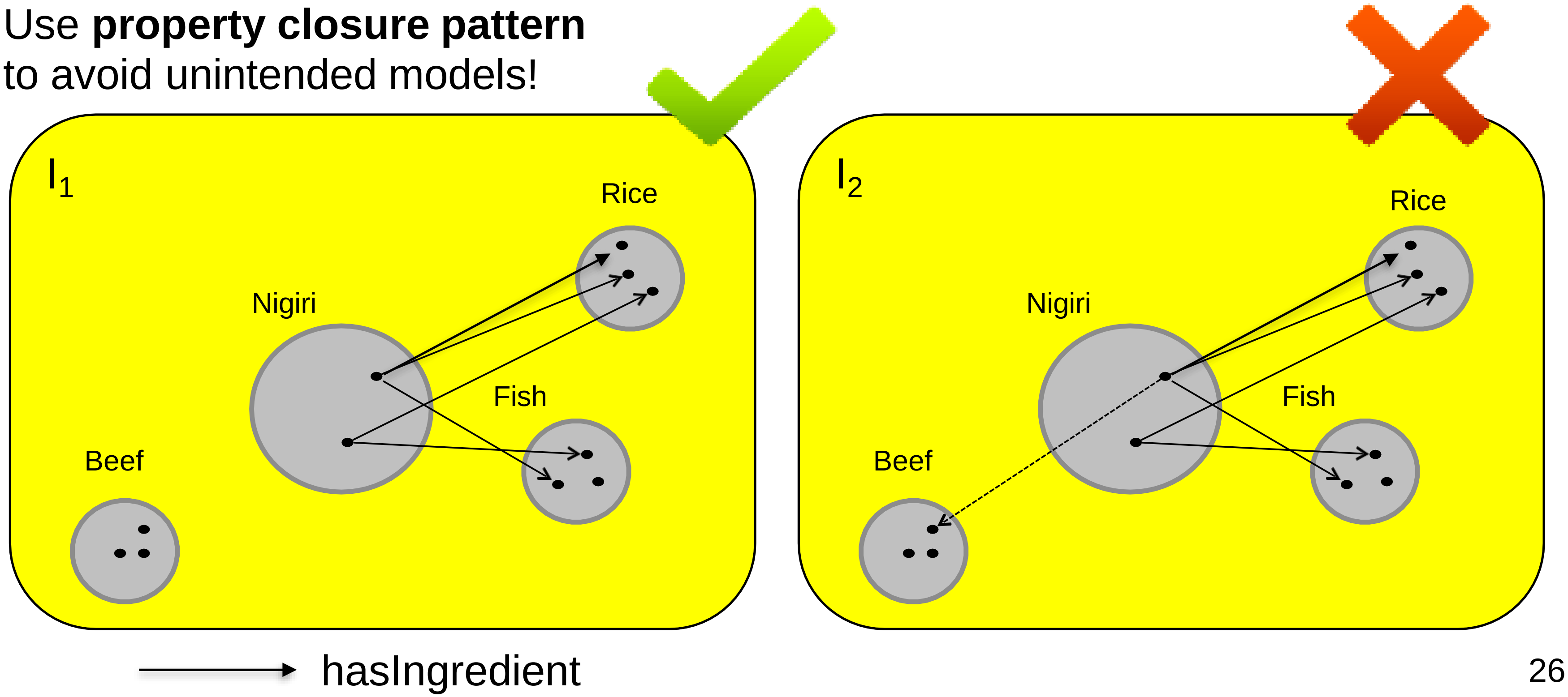
Which of these interpretations
is a model of the above axiom?



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!



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

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

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

- For
  - the answer to "Does Nigiri have beef as ingredient" is "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)
```

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)

不存在某个 $a \in X$
且 $a \notin Y_i$ $(i=1,\dots,k)$

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

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”

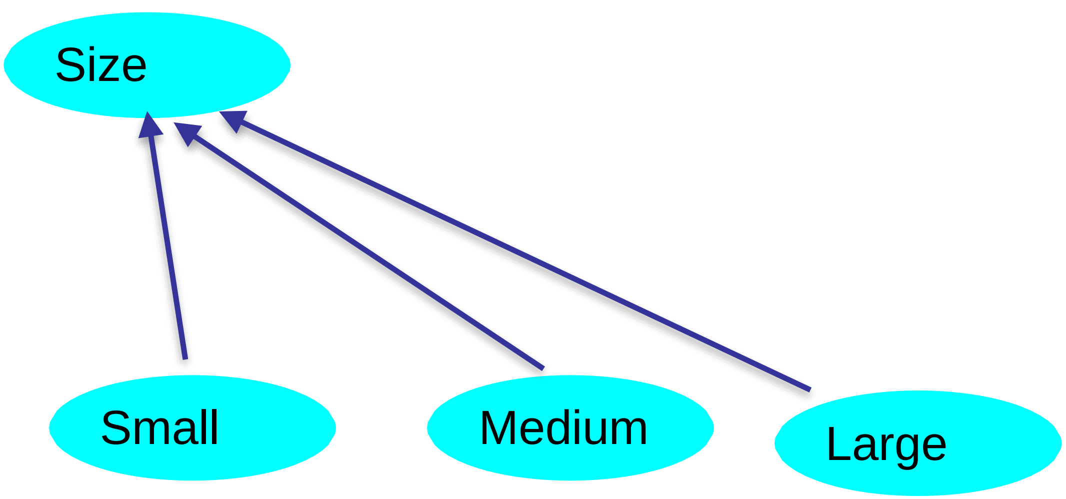
- How do we “partition” values **for properties** such as Size, Spicyness, etc:
- E.g., we want to say that a person’s “Size”
  - must be one of the subclasses of Size and
  - only one of those sizes – and that
  - an individual size cannot be two kinds of size at the same time

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

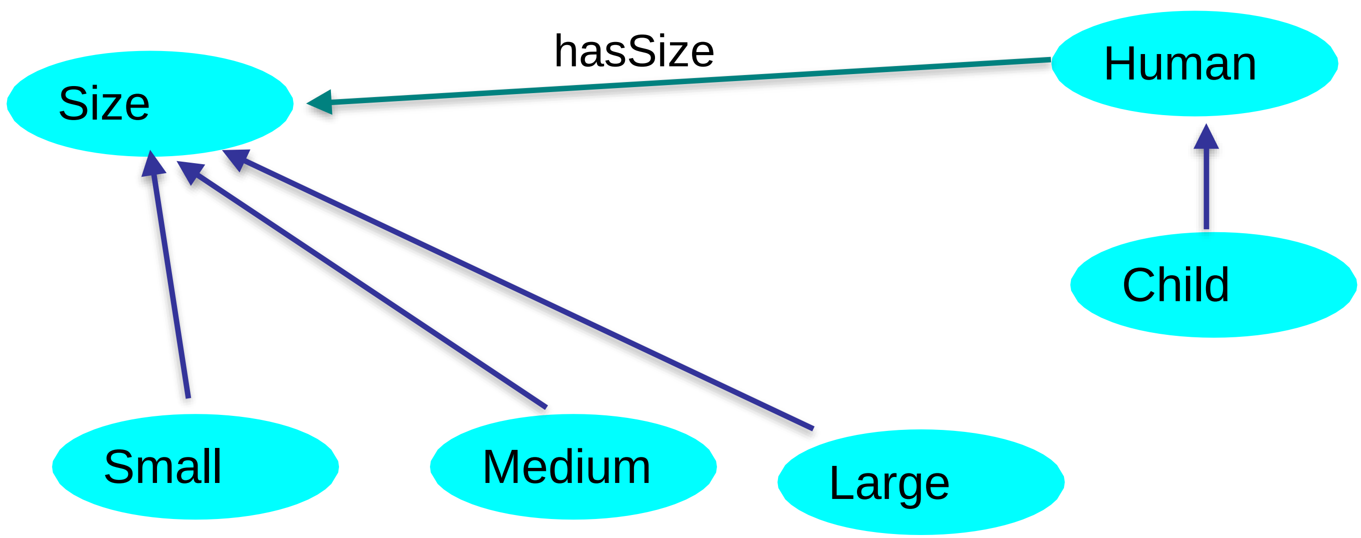
Partition



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



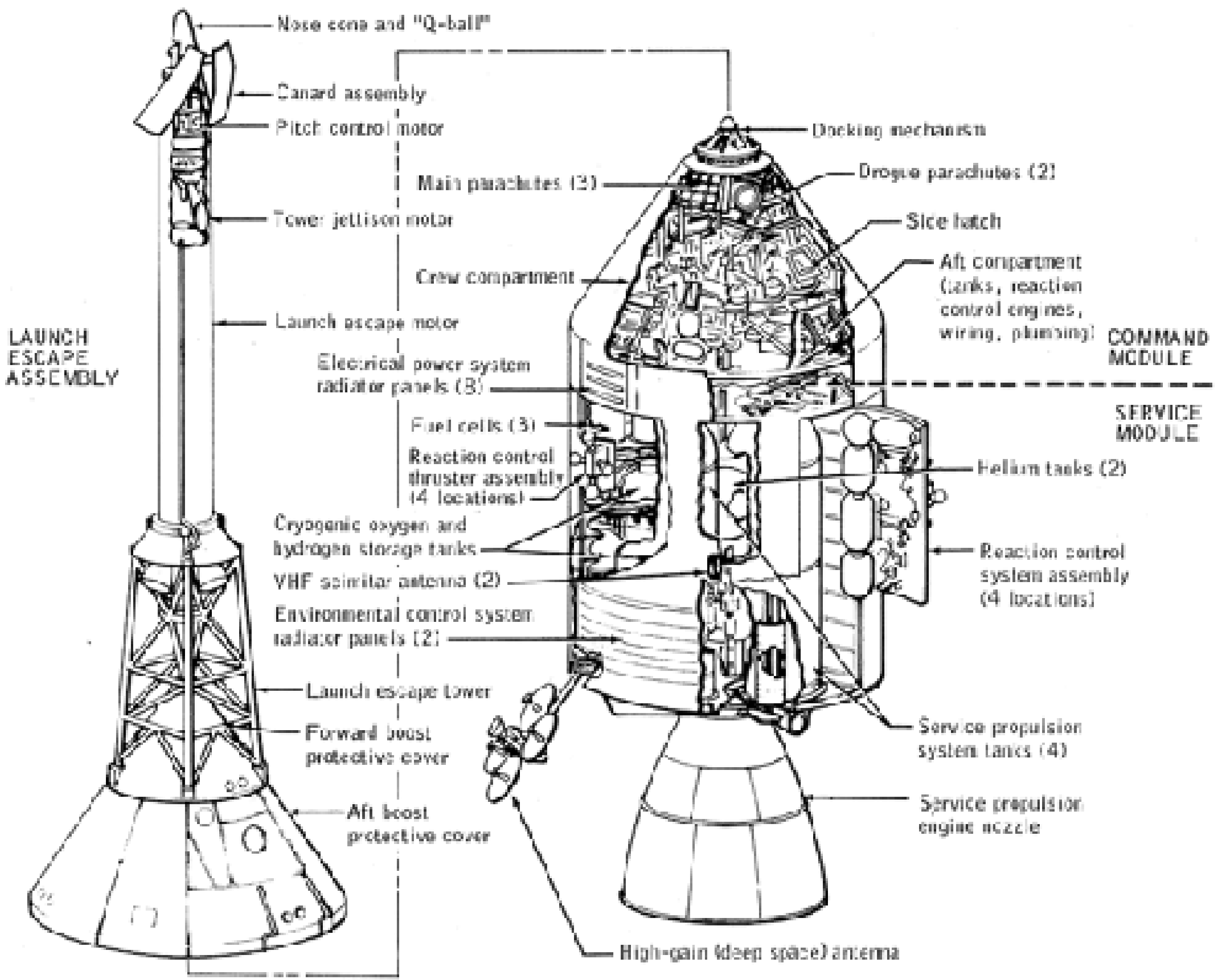
4th Logical Pattern: the **Entity Property Quality Pattern**

- 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

Towards Content Patterns: Composition, Parts and Wholes



Composition or Aggregation

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

    AppleCake is a Cake that has parts that are Apple

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

- 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?

- **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

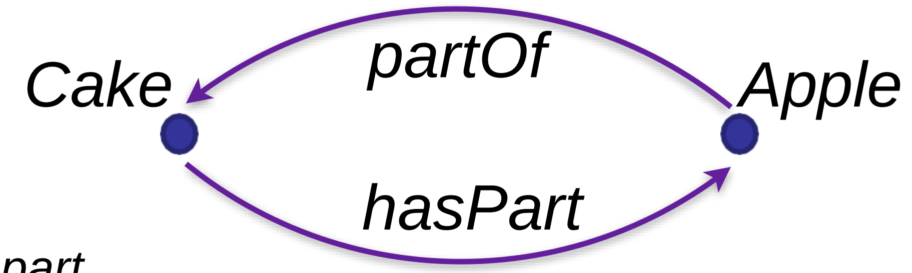
University of Manchester — You

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*
  - Protege makes it easy to say this
  - Not declaring this may cause loss of entailements/inferences

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

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

整体的一个部分

- 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 $\neq$ *Non Compositional Relationships*

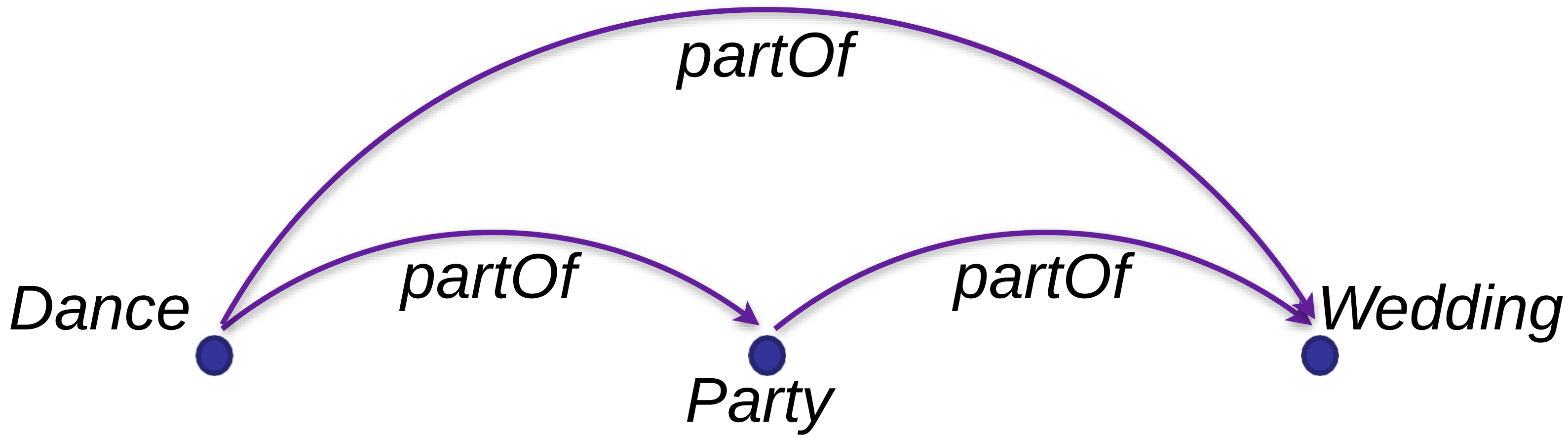
- Topological inclusion
  - I am in the lecture theatre
- Classification inclusion
  - Catch 22 is a Book
  - It's an instance of Book, not a part of it, so not Member-Bunch
- Attribution
  - Properties of an object can be confused with composition
  - Height of a Lighthouse isn't part of it
- Attachment
  - 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

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

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- 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

Property: isPartOf
    Characteristics: Transitive

Property: isComponentOf
    SubPropertyOf: isPartOf

Property: isPortionOf
    SubPropertyOf: isPartOf
    Characteristics: Transitive

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

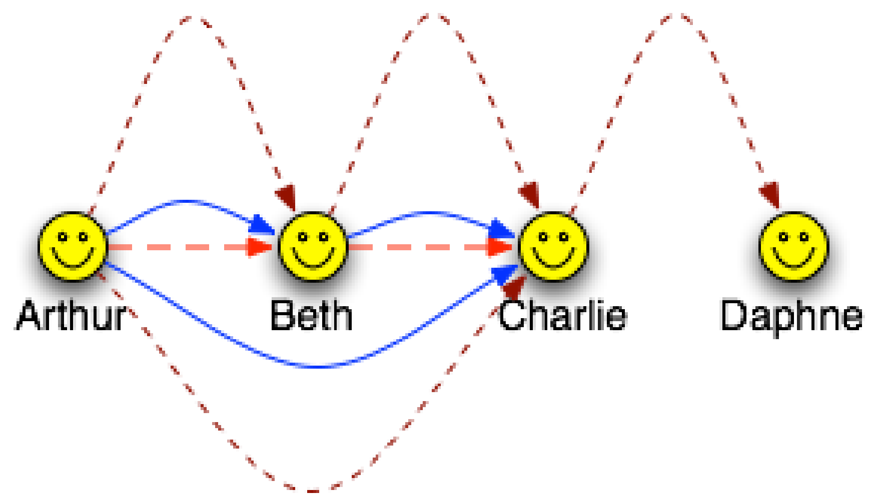
Property: isDirectPartOf
  SubPropertyOf: isPartOf

- 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

$\models$

Fracture and *isLocatedIn* some *HeadOfFemur*

SubClassOf

FractureOfFemur

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