University of Southampton

Ontology Design Patterns

COMP6256 Knowledge Graphs for AI Systems

Dr Nicholas Gibbins – nmg@ecs.soton.ac.uk

University of Southampton

Design Patterns

Patterns are general, reusable solutions to commonly occurring problems

- Concept originated with Christopher Alexander's work on architecture
- Popularised in software engineering by the "gang of four"
- Subject of study by the knowledge engineering community

Design Patterns for the Semantic Web

N-ary relations

- How can we say more about a relation instance?
- How do we represent an ordered sequence of relations?

Value partitions and value sets

- How do we represent a fixed list of values?

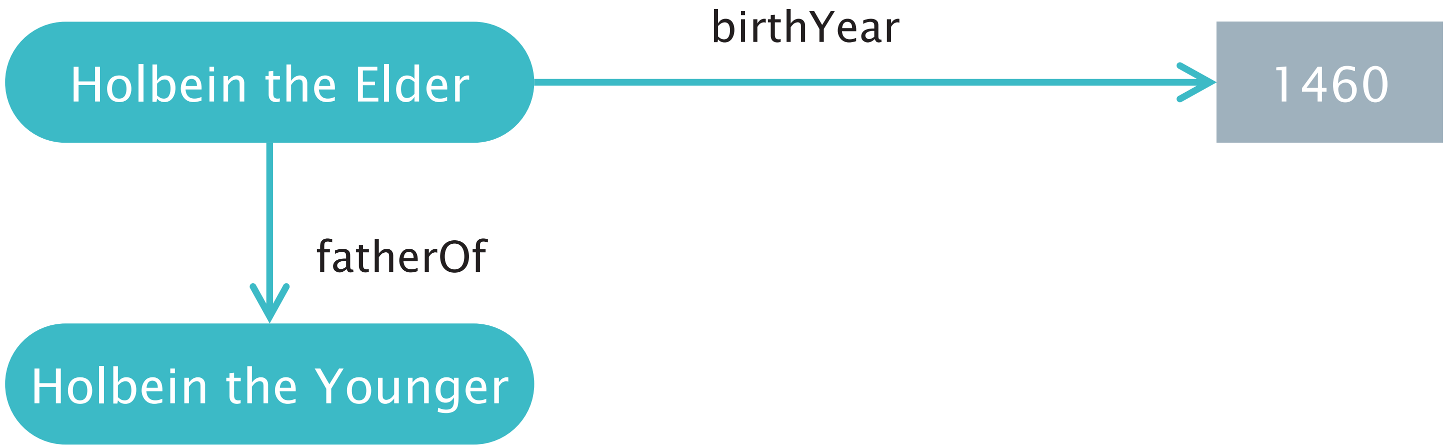
Part-whole hierarchies

- How do we represent hierarchies other than the subclass hierarchy?

N-ary Relations

Binary Relations

In RDF and OWL, binary relations link two individuals, or an individual and a value



The properties birthYear and fatherOf are binary relations

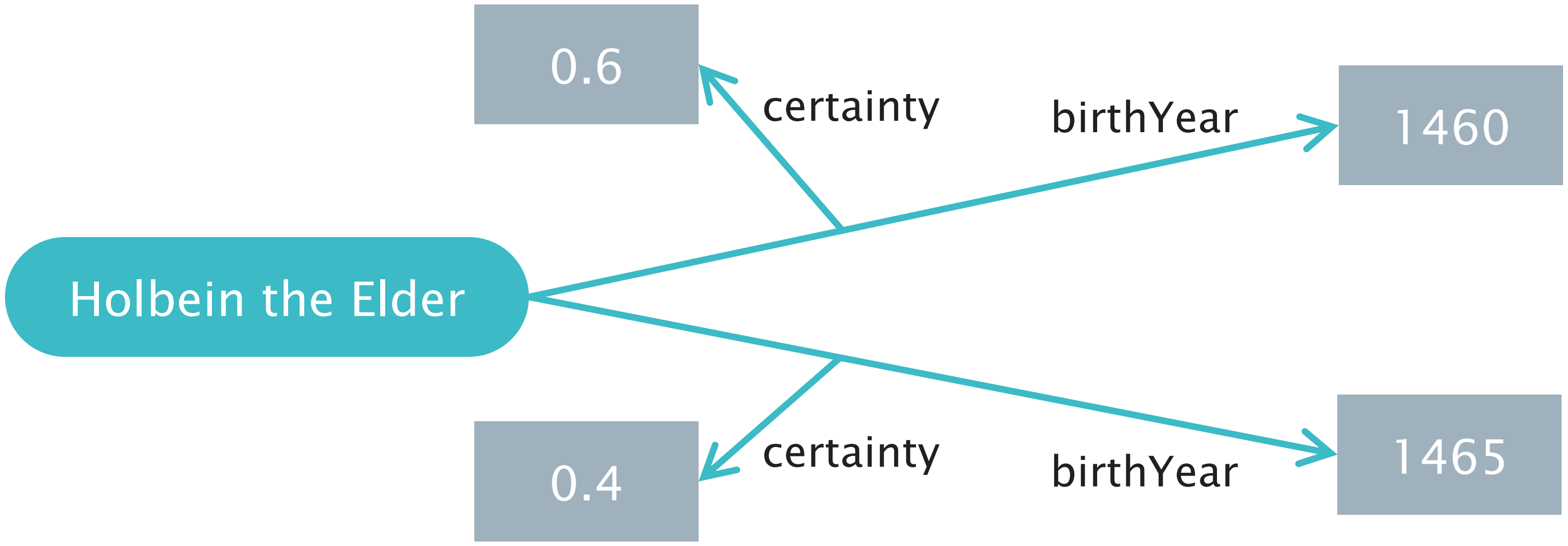
Relations with Additional Information

In some cases, we need to associate additional info with a binary relation

- e.g. certainty, strength, dates

For example, Holbein the Elder's date of birth is unconfirmed

- He was born in either 1460 or 1465
- How can we represent this uncertainty?



N-ary Relations

N-ary relations link an individual to more than a one value

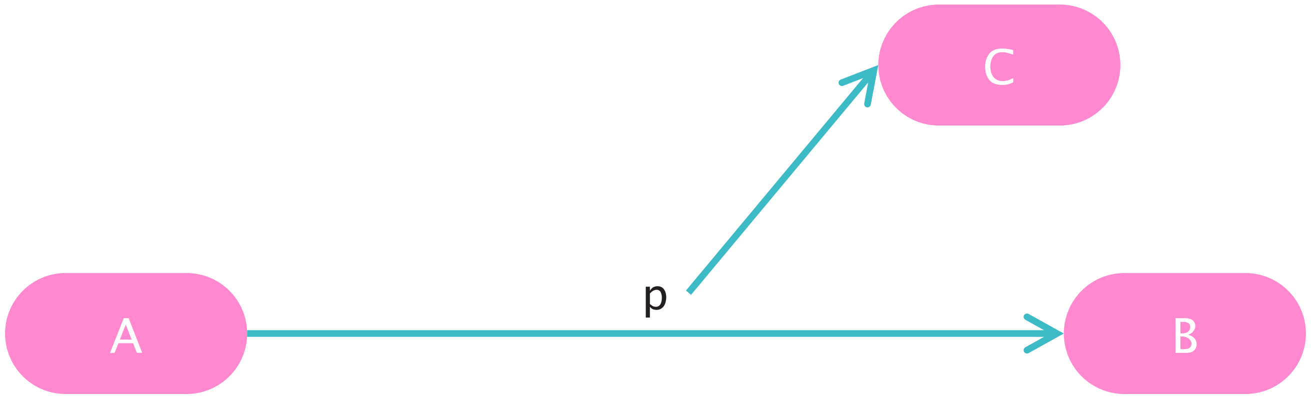
Possible use cases:

1. A relation needs additional info
   e.g. a relation with a rating value
2. Two binary relations are related to each other
   e.g. body_temp (high, normal, low), and trend (rising, falling)
3. A relation between several individuals
   e.g. someone buys a book from a bookstore
4. Linking from, or to, an ordered list of individuals
   e.g. an airline flight visiting a sequence of airports

Pattern 1: Reified Relation

To represent additional information about a relation:

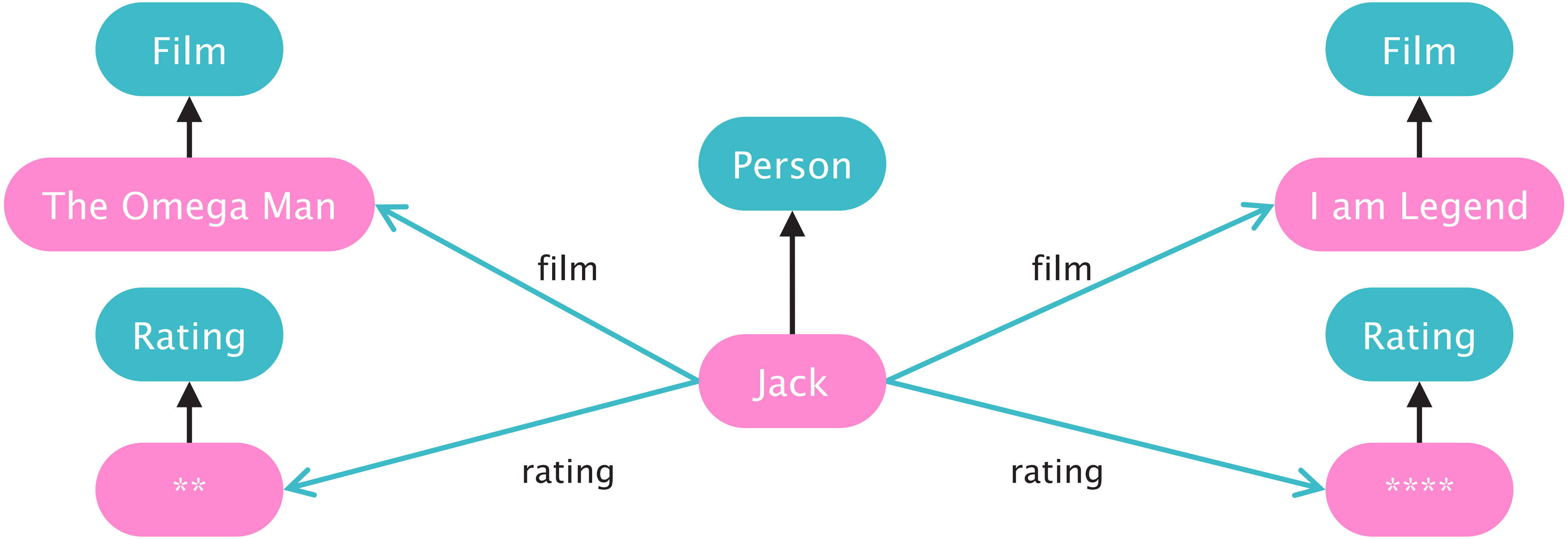
- Create a new class to represent the relation
- Individuals of this class are instances of the relation
- Relation class can have additional properties to describe more information about the relation



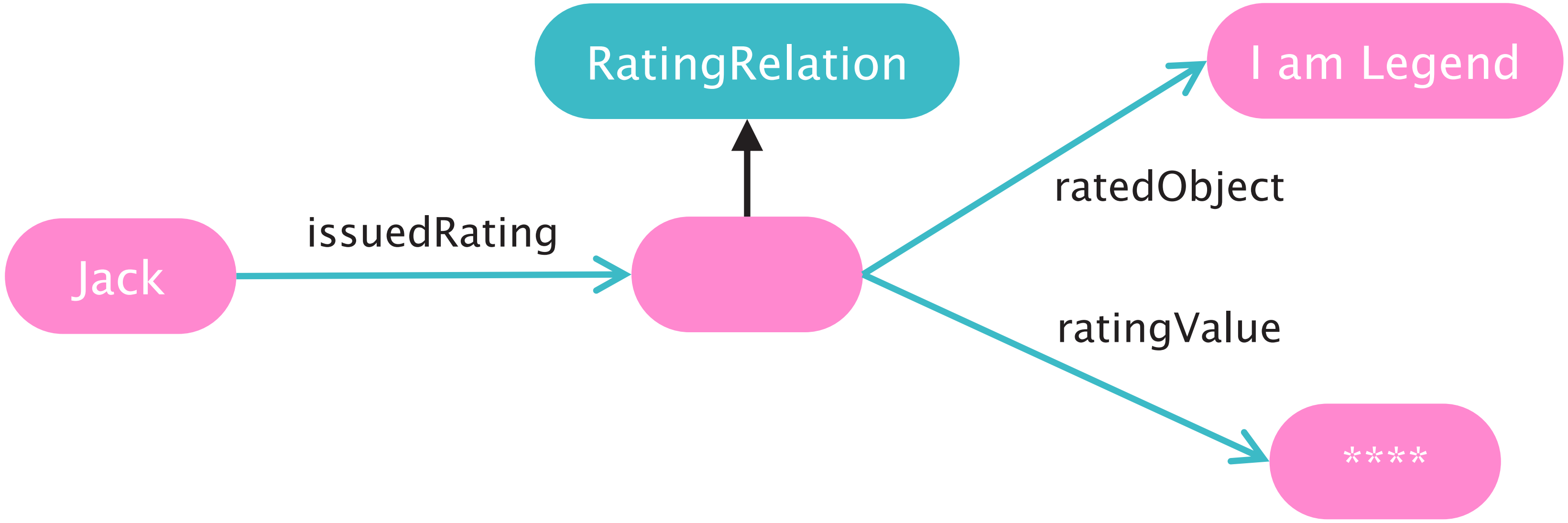
Use case 1: additional information

Jack has given the film ‘I Am Legend’ a four-star rating

- We need to represent a quantitative value to describe the rating relation



Use case 1: additional information

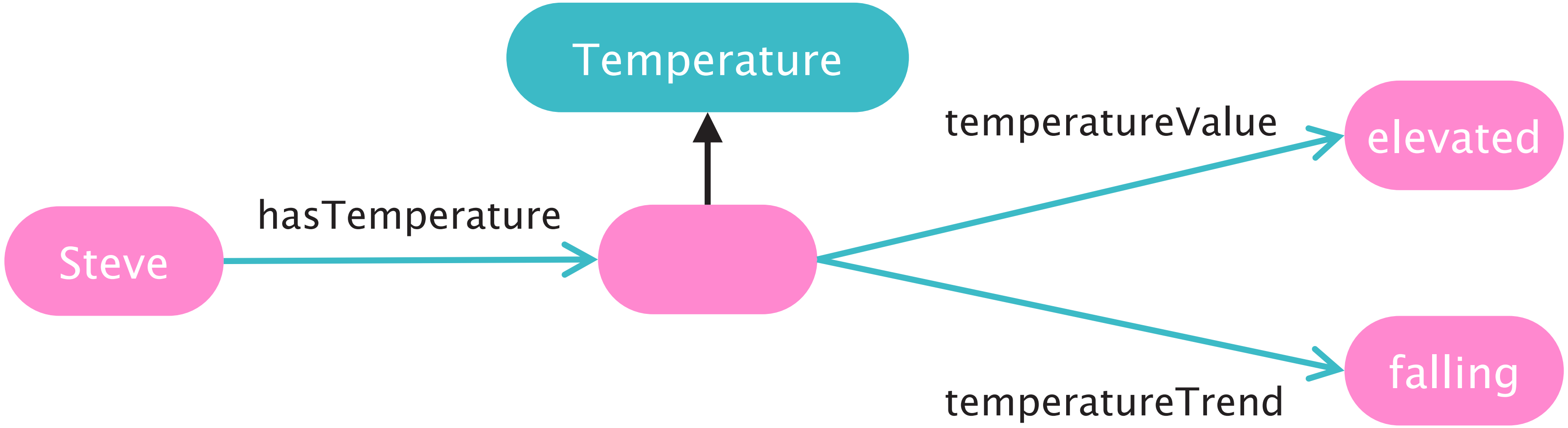


$$\text{Person} \sqsubseteq \forall \text{issuedRating.RatingRelation}$$
$$\text{RatingRelation} \sqsubseteq \exists \text{ratedObject.Film} \sqcap \leq 1 \text{ ratedObject}$$
$$\text{RatingRelation} \sqsubseteq \forall \text{ratingValue.Rating} \sqcap \leq 1 \text{ ratingValue}$$

Use case 2: different aspects of a relation

Steve has a temperature which is high, but falling

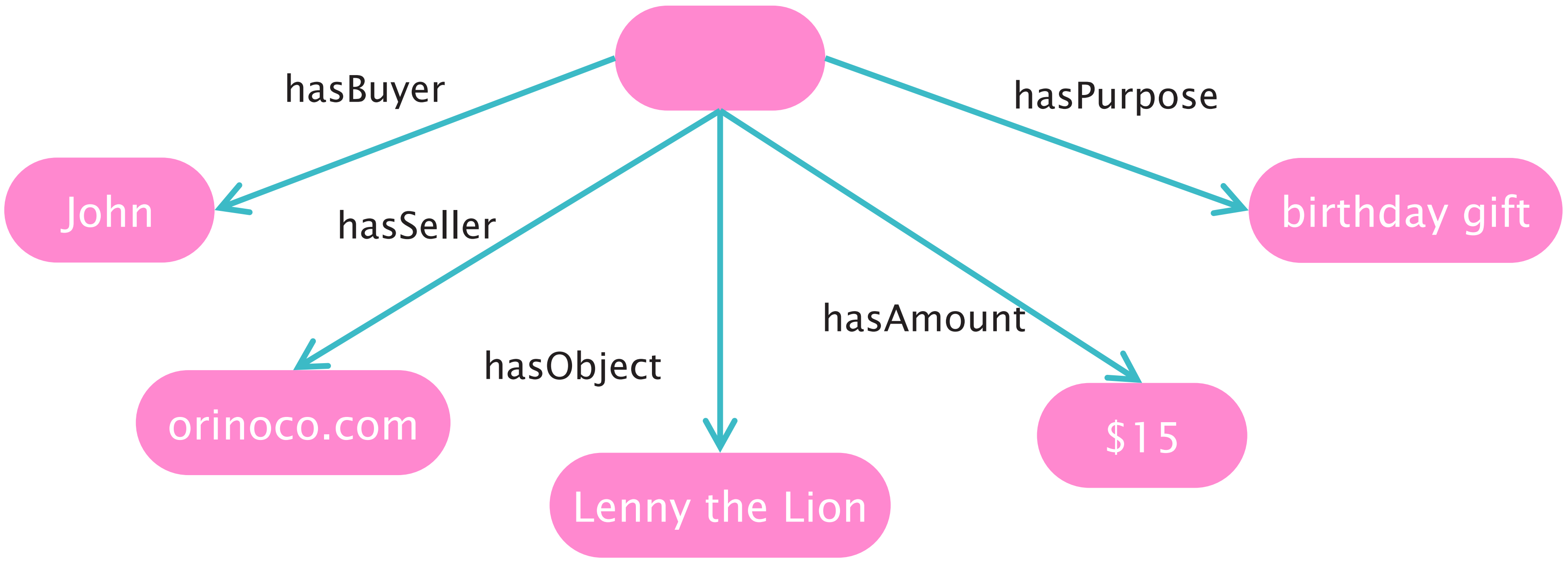
- We need to represent different aspects of the temperature that Steve has



Use case 3: no distinguished participant

John buys a “Lenny the Lion” book from orinoco.com for $15 as a birthday gift

- No distinguished subject for the relation
- i.e. no primary relation to convert into a Relation Class as in cases 1 and 2



Source: W3C

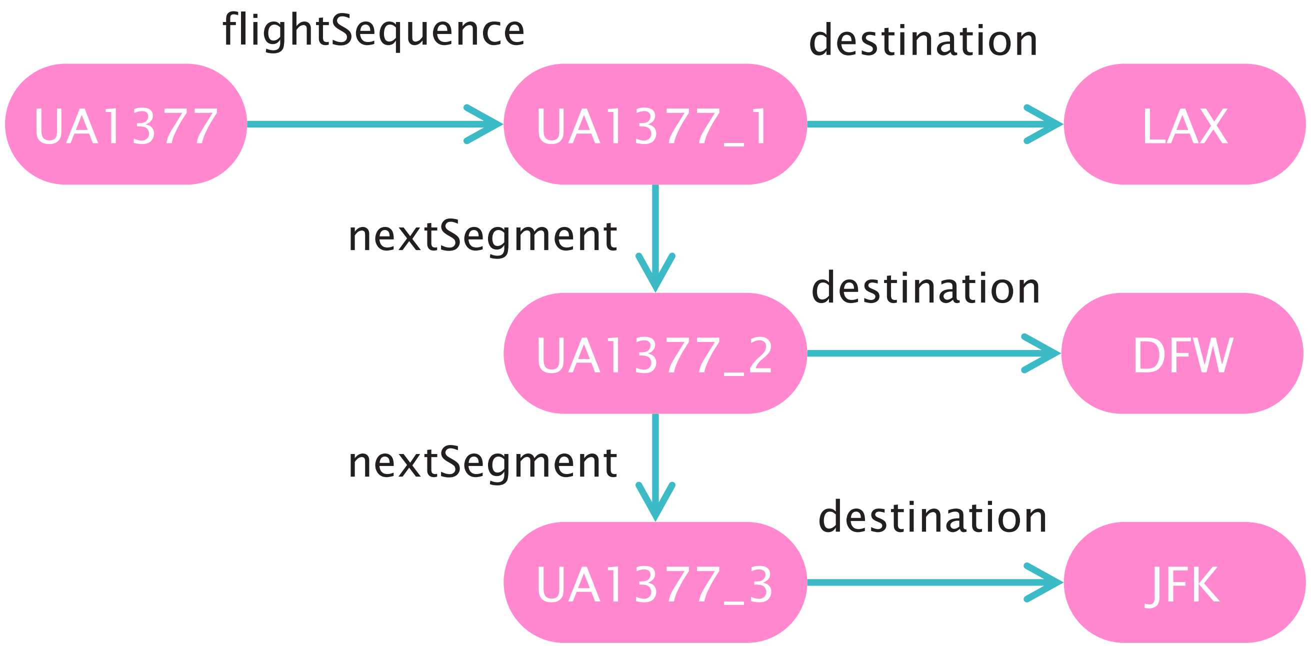
Use case 3: no distinguished participant

$$\text{Purchase} \sqsubseteq \exists\, \text{hasBuyer}.\text{Person} \sqcap = 1\ \text{hasBuyer}$$
$$\text{Purchase} \sqsubseteq \exists\, \text{hasSeller}.\text{Company} \sqcap = 1\ \text{hasSeller}$$
$$\text{Purchase} \sqsubseteq \exists\, \text{hasObject}.\text{Object}$$
$$\text{Purchase} \sqsubseteq \forall\, \text{hasAmount}.\text{Quantity} \sqcap = 1\ \text{hasAmount}$$
$$\text{Purchase} \sqsubseteq \forall\, \text{hasPurpose}.\text{Purpose}$$

Pattern 2: Sequence of arguments

United Airlines, flight 1377 visits the following airports: LAX, DFW, and JFK

- For such an example, we need to represent a sequence of arguments



Pattern 2: Sequence of arguments

$\top \sqsubseteq \forall\, \text{flightSequence}^{-}.\, \text{Flight}$	(flightSequence rdfs:domain Flight)
$\top \sqsubseteq \forall\, \text{flightSequence}.\, \text{FlightSegment}$	(flightSequence rdfs:range FlightSegment)
$\top \sqsubseteq\, \leq 1\ \text{flightSequence}$	(flightSequence is functional)
$\top \sqsubseteq \forall\, \text{nextSegment}^{-}.\, \text{FlightSegment}$	(nextSegment rdfs:domain FlightSegment)
$\top \sqsubseteq \forall\, \text{nextSegment}.\, \text{FlightSegment}$	(nextSegment rdfs:range FlightSegment)
$\top \sqsubseteq\, \leq 1\ \text{nextSegment}$	(nextSegment is functional)
$\top \sqsubseteq \forall\, \text{destination}^{-}.\, \text{FlightSegment}$	(destination rdfs:domain FlightSegment)
$\top \sqsubseteq \forall\, \text{destination}.\, \text{Airport}$	(destination rdfs:range Airport)

$\text{FlightSegment} \sqsubseteq\, = 1\ \text{destination} \sqcap \leq 1\ \text{nextSegment}$
$\text{FinalFlightSegment} \equiv \text{FlightSegment} \sqcap = 0\ \text{nextSegment}$

Value Partitions and Value Sets

Descriptive Features

Descriptive features are quite common in ontologies:

- Size = {small, medium, large}
- Risk = {dangerous, risky, safe}
- Health status = {good health, medium health, poor health}

Also called “qualities”, “modifiers” and “attributes”

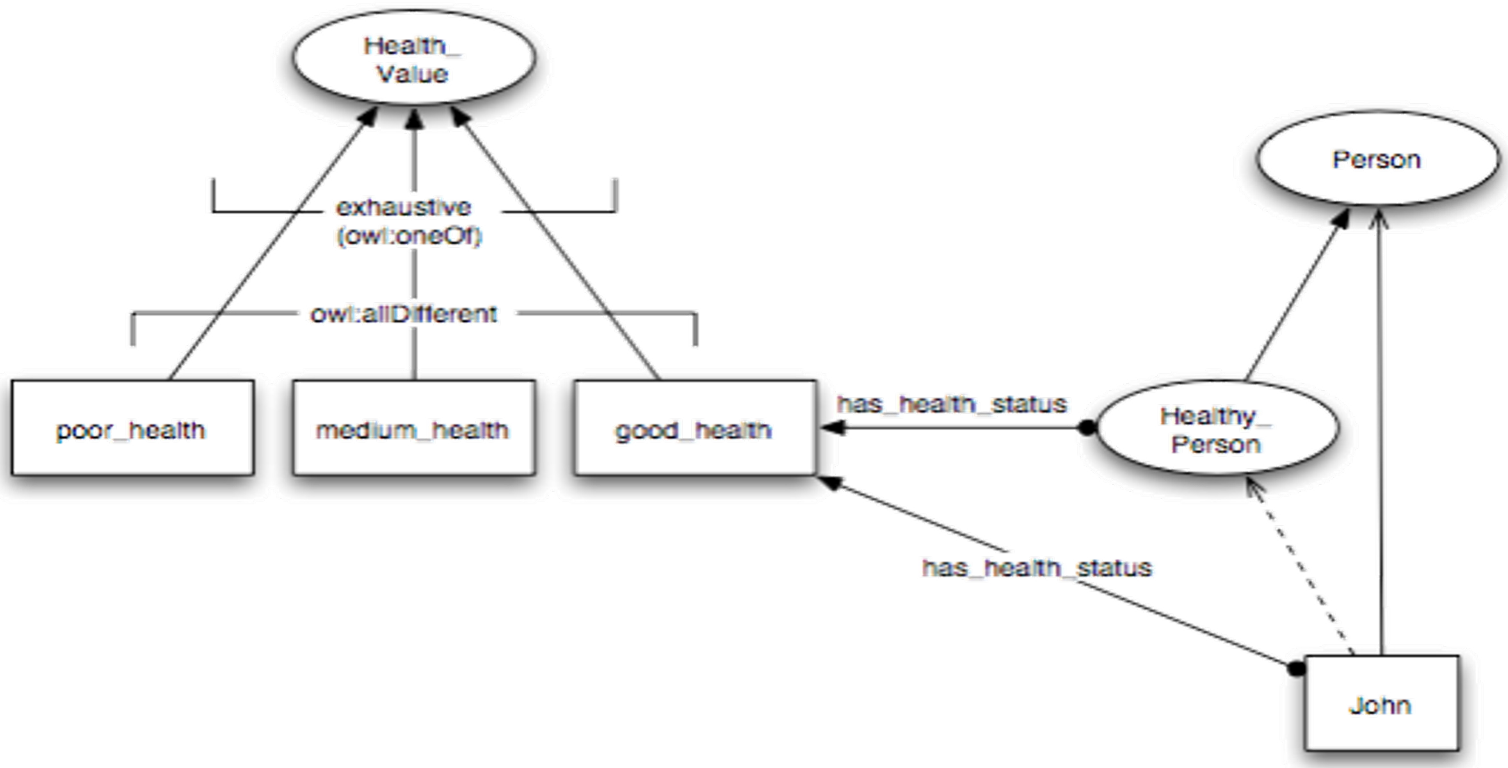
- A property can have only one value for each feature to ensure consistency

Three main approaches:

- Enumerated individuals (a value set)
- Disjoint classes (a value partition)
- Datatype values (not considered in this lecture)

Value Sets

Values of descriptive feature are individuals



Value Sets

A health value can be either poor, medium or good:

$$\text{HealthValue} \equiv \{\, \text{poorHealth}, \text{mediumHealth}, \text{goodHealth} \,\}$$

Poor, medium and good are all different from each other:

$$\text{poorHealth} \neq \text{mediumHealth}$$
$$\text{poorHealth} \neq \text{goodHealth}$$
$$\text{mediumHealth} \neq \text{goodHealth}$$

A healthy person is a person who has some health status which is the value good:

$$\text{HealthyPerson} \equiv \text{Person} \sqcap \exists \text{hasHealthStatus}.\{\, \text{goodHealth} \,\}$$

Notes on Value Sets

Need axioms to set the three health values to be different from each other

- This way, a person cannot have more than one health value at a time

Values cannot be further partitioned

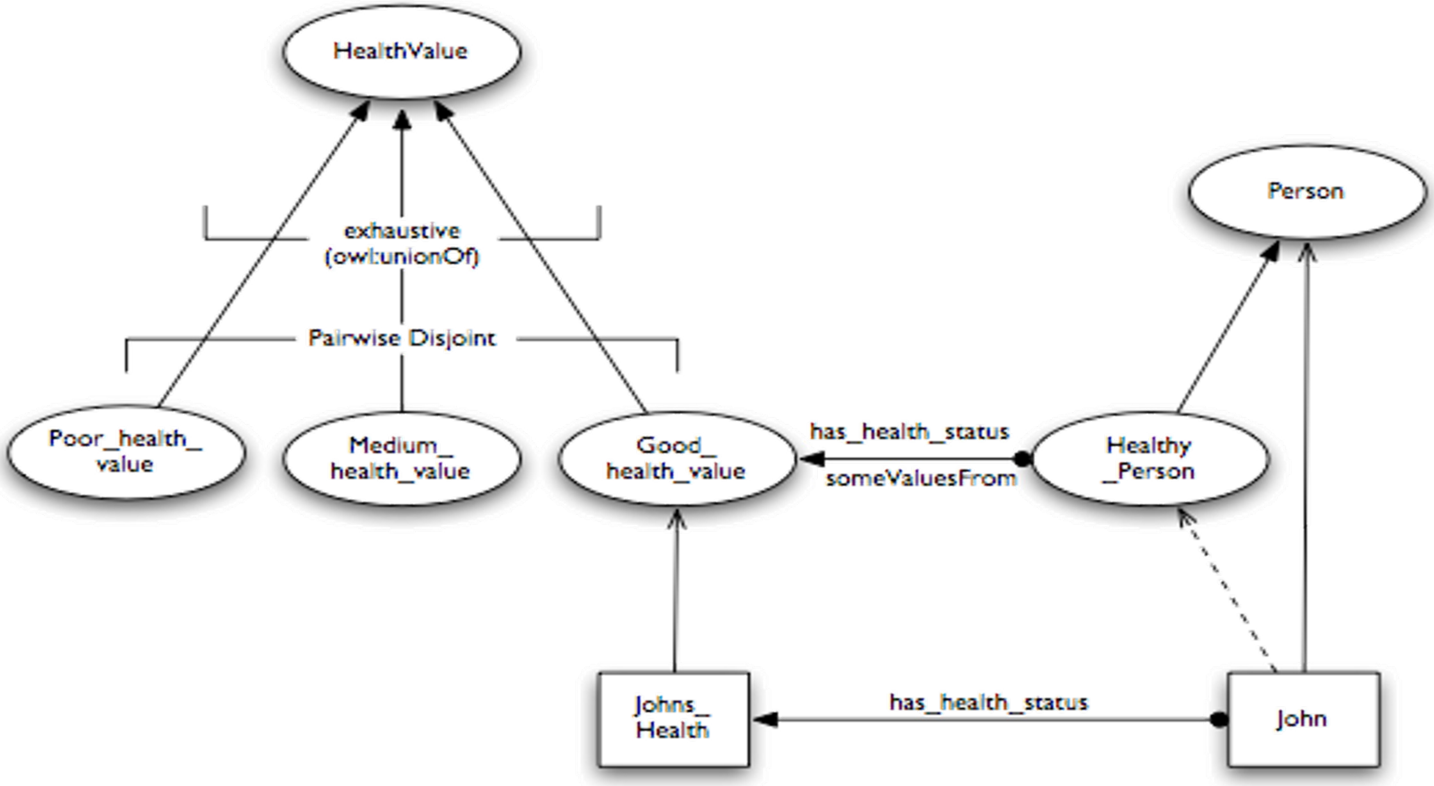
- e.g. cannot have fairly_good_health as a subtype of good_health

Only one set of values is allowed for a feature

- The class HealthValue cannot be equivalent to more than one set of distinct values
- Doing so will cause inconsistencies

Value Partitions

Values of descriptive features are disjoint subclasses:



Value Partitions

Poor, medium and good are types of health value:

$$\text{PoorHealth} \sqsubseteq \text{HealthValue}$$
$$\text{MediumHealth} \sqsubseteq \text{HealthValue}$$
$$\text{GoodHealth} \sqsubseteq \text{HealthValue}$$

Covering axiom (the only types of health value are poor, medium and good):

$$\text{HealthValue} \equiv \text{PoorHealth} \sqcup \text{MediumHealth} \sqcup \text{GoodHealth}$$

Poor, medium and good are pairwise disjoint:

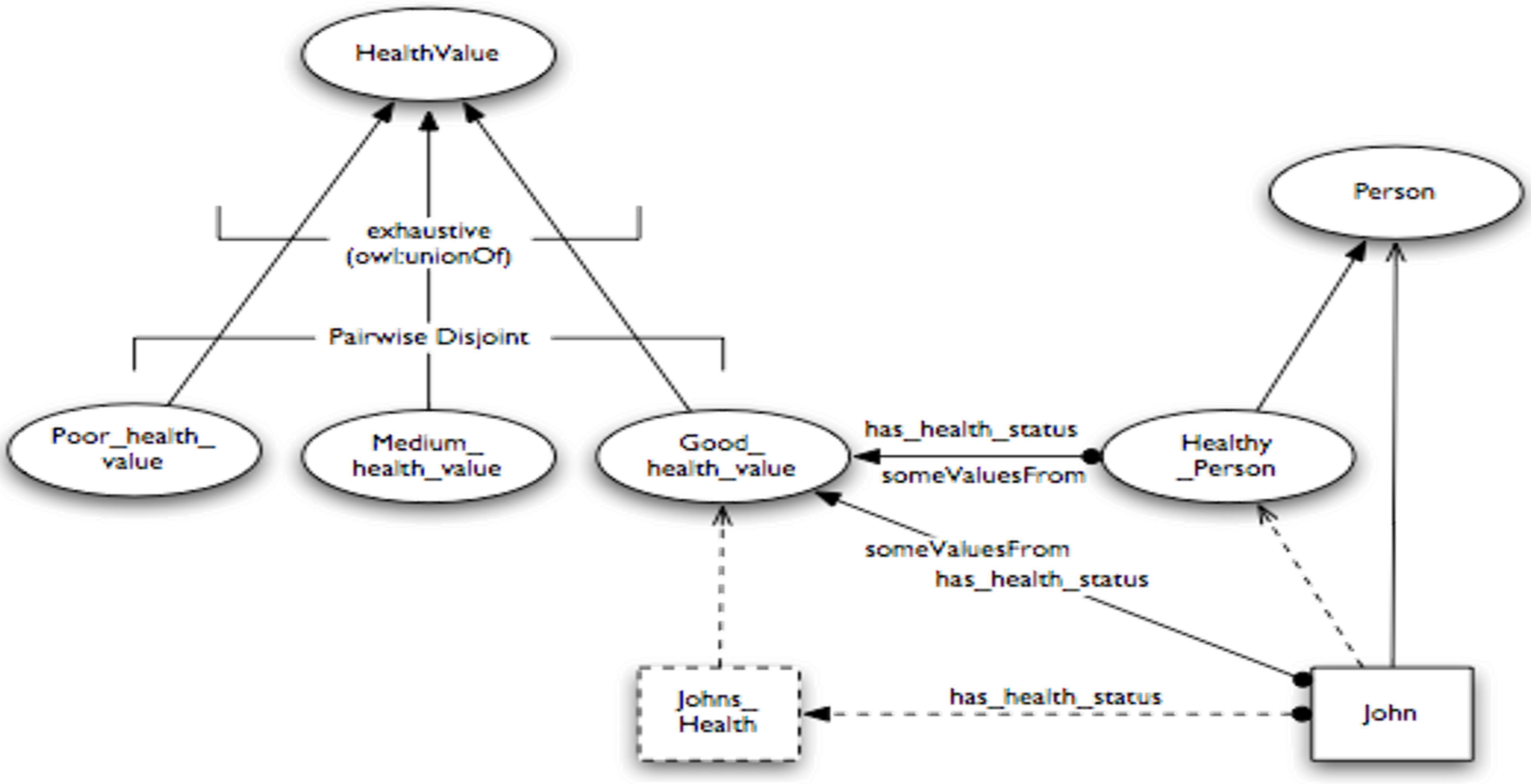
$$\text{PoorHealth} \sqcap \text{MediumHealth} \equiv \bot$$
$$\text{PoorHealth} \sqcap \text{GoodHealth} \equiv \bot$$
$$\text{MediumHealth} \sqcap \text{GoodHealth} \equiv \bot$$

A healthy person is a person who has some health status which is an instance of good

$$\text{HealthyPerson} \equiv \text{Person} \sqcap \exists \text{hasHealthStatus}.\text{GoodHealth}$$

Value Partitions

The instance JohnsHealth can be made anonymous



Notes on Value Partitions

Values can be further partitioned

- Simply add subclasses to the value classes

Can have alternative partitions of the same feature

OWL 2 contains specific support for defining disjoint unions

$$C \equiv C_1 \sqcup C_2 \sqcup \cdots \sqcup C_n$$
$$C_1 \sqcap C_2 \equiv \bot$$
$$C_1 \sqcap C_3 \equiv \bot$$
$$\dots$$
$$C_{n-1} \sqcap C_n \equiv \bot$$

Part-Whole Hierarchies

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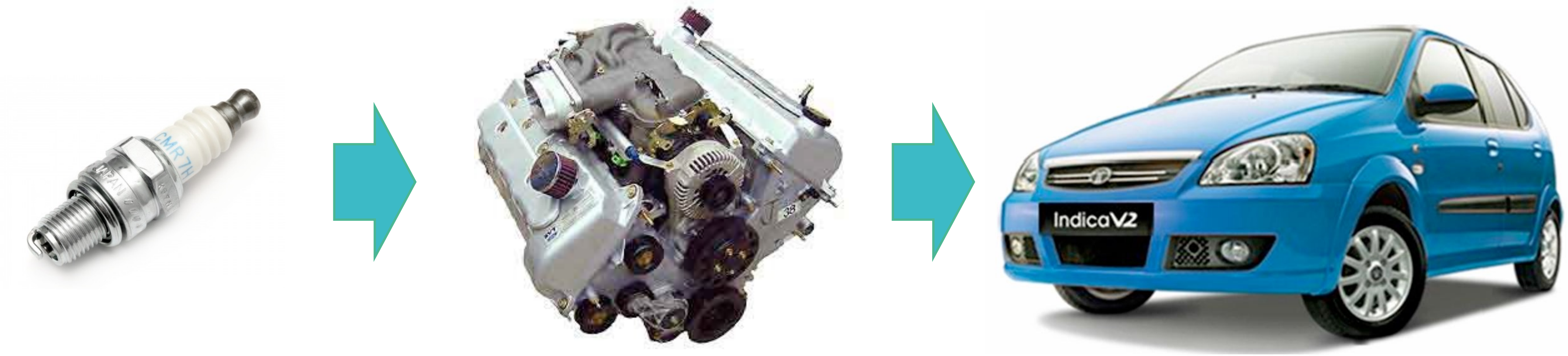
Meronymies (part-whole relations)

Taxonomies are not the only hierarchical relation that we wish to model



- A spark plug isn’t a kind of engine (class-instance)
- A spark plug is a **part of** an engine

Simple Part-Whole Representation

We need two properties:

- partOf (a transitive property)
- directPartOf (a subproperty of partOf)

$$\text{part of} \circ \text{partOf} \sqsubseteq \text{partOf}$$
$$\text{directPartOf} \sqsubseteq \text{partOf}$$

Part-Whole Hierarchies

Represent part-whole relationships between classes using existential restrictions:

Every spark plug is a direct part of some engine:	$\text{SparkPlug} \sqsubseteq \exists \text{directPartOf}.\text{Engine}$
Every engine is a direct part of some car:	$\text{Engine} \sqsubseteq \exists \text{directPartOf}.\text{Car}$
Every wheel is a direct part of some car:	$\text{Wheel} \sqsubseteq \exists \text{directPartOf}.\text{Car}$

Defining Classes of Parts

Extend the ontology with classes of parts for each level, so that the reasoner can automatically derive a class hierarchy:

A car part is a part of some car: $\mathrm{CarPart} \equiv \exists \mathrm{partOf}.\mathrm{Car}$

A direct car part is a direct part of some car: $\mathrm{DirectCarPart} \equiv \exists \mathrm{directPartOf}.\mathrm{Car}$

An engine part is a part of some engine: $\mathrm{EnginePart} \equiv \exists \mathrm{partOf}.\mathrm{Engine}$

A reasoner will infer that $\mathrm{EnginePart} \sqsubseteq \mathrm{CarPart}$ (but not $\mathrm{EnginePart} \sqsubseteq \mathrm{DirectCarPart}$)

Fault Location

Once we have a meronymy, we can use it to inherit features within that hierarchy

For example, a reasoner could infer that a fault in a part is a fault in a whole

- Need a new property for the location of a fault: $\mathrm{hasLocus}$
- Need a new class for faults: Fault

We can then define general types of located faults:

$$\mathrm{FaultInCar} \equiv \mathrm{Fault} \sqcap \exists \mathrm{hasLocus}.\mathrm{CarPart}$$
$$\mathrm{FaultInEngine} \equiv \mathrm{Fault} \sqcap \exists \mathrm{hasLocus}.\mathrm{EnginePart}$$

Fault Location

Now we can define specific types of located fault:

$$\text{DirtySparkPlug} \sqsubseteq \text{Fault} \sqcap \exists \text{hasLocus}.\text{SparkPlug}$$
$$\text{FlatTyre} \sqsubseteq \text{Fault} \sqcap \exists \text{hasLocus}.\text{Wheel}$$

The definition of the hierarchy allows a reasoner to infer that:

$$\text{DirtySparkPlug} \sqsubseteq \text{FaultInCar}$$
$$\text{DirtySparkPlug} \sqsubseteq \text{FaultInEngine}$$
$$\text{FlatTyre} \sqsubseteq \text{FaultInCar}$$

But not:

$$\text{FlatTyre} \sqsubseteq \text{FaultInEngine}$$

Further Reading

SWBP Notes

Defining N-ary Relations on the Semantic Web
http://www.w3.org/TR/swbp-n-aryRelations

Representing Specified Values in OWL
http://www.w3.org/TR/swbp-specified-values

Simple part-whole relations in OWL Ontologies
http://www.w3.org/2001/sw/BestPractices/OEP/SimplePartWhole/