Foundations of Semantic Knowledge Graphs

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Creating Ontologies and the Ontology Language OWL

Preamble: What makes a data graph a knowledge graph ?

We have learned about the different types of data graphs and the elements that constitute a data graph.

In order to transform a data graph into a knowledge graph, we need additional features:

- Knowledge Representation Framework ✓
- Identity ✓
- Schema knowledge ✓
- Contextual knowledge ✓
- Semantics 🔍

⇝ We therefore discuss **RDF** and the **RDF Schema data-modelling vocabulary** that allow for the creation of knowledge graphs

What will we learn in this section 🎓

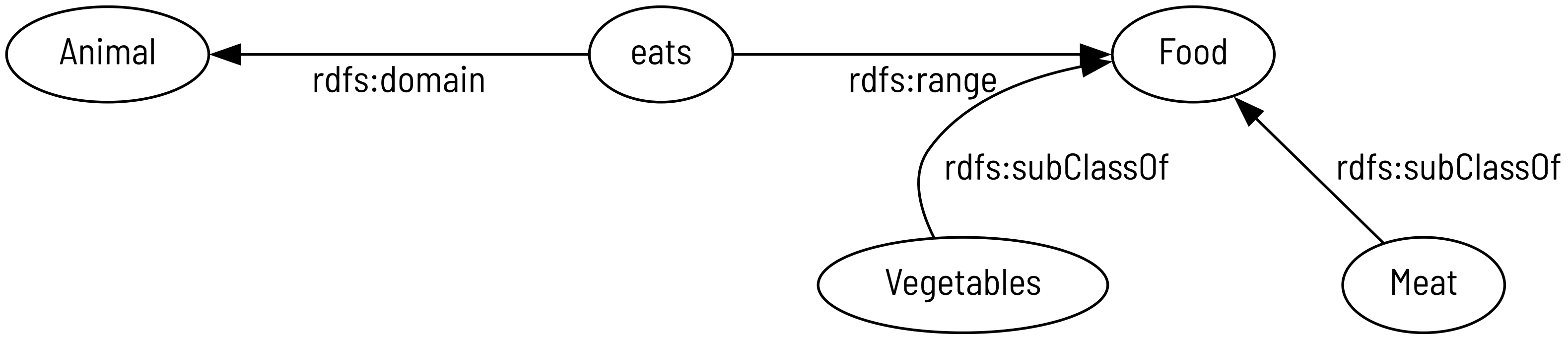
- How to define more complex expressions, the semantics of which exceeds those of RDF/S
- We will learn how to design ontologies for the use in KGs
- We will learn about formal concepts and how they can be used for modelling aspects of a domain

Why RDFS is not sufficient...

Disclaimer: This section was motivated by Prof. Dr. Harald Sack. All examples were originally published in this OWL lecture slides.

Locality of global properties

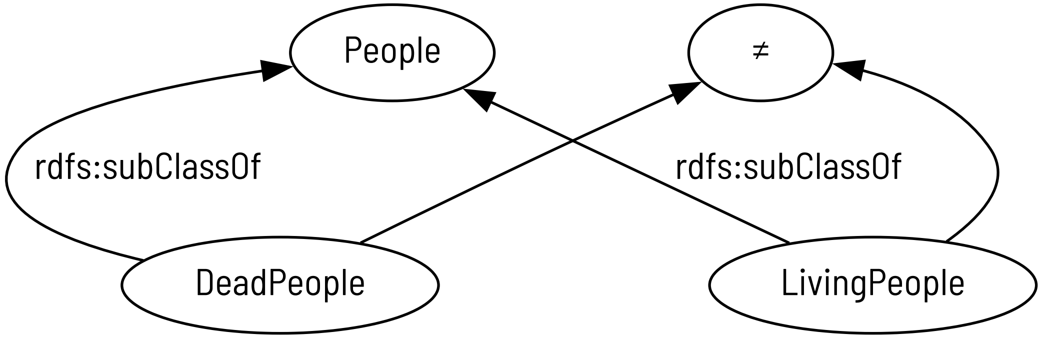
Example



- A cow only eats vegetables
- Other animals only eat meat

Disjunctive Classes

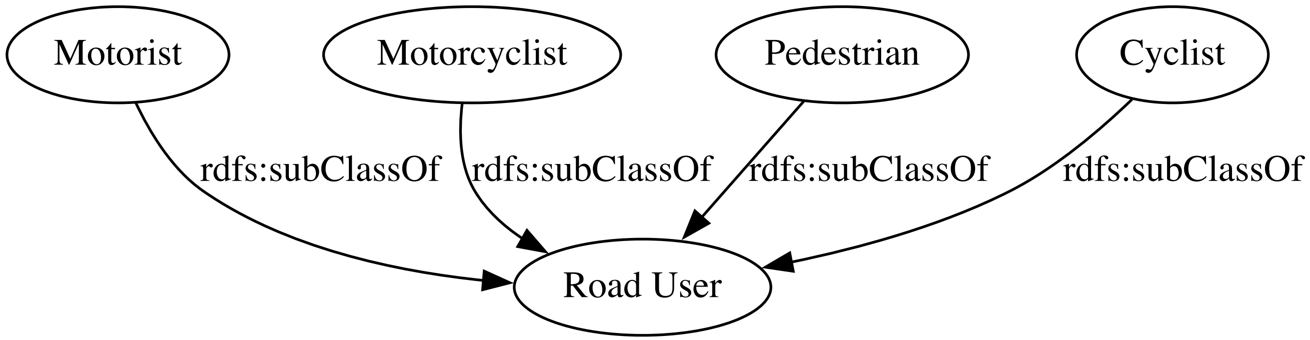
Example



- RDFS subclass relations can not express disjunctive class or subclass membership

Class combinations

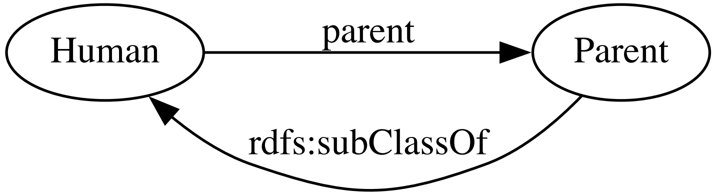
Example



- Combination of classes define a new class
- New class contains only members from given class combinations

Cardinality constraints

Example



- Every human usually has two parents

Additional limitations

Special Property Constraints

- Transitivity (e.g. „is greater than“)
- Uniqueness (e.g. „is mother of“)
- Inversiveness (e.g. „is parent of“ and „is child of“)

General Problem of RDF(S)

- RDF(S) does not have the possibility of negation

  `:harald rdf:type :Vegetarian .`

  `:harald rdf:type :NonVegetarian .`

  ...does not automatically generate a contradiction

How to design Ontologies using OWL(2)

Components of OWL Ontologies

Individuals

- Individuals represent objects in the domain of interest
- Individuals are also known as instances of classes
- OWL does not use the Unique Name Assumption ⇝ two different names could refer to the same individual
- In OWL, we must clearly specify for individuals whether they are the same or different from each other

Properties

- Properties represent binary relations on individuals ⇝ properties link two individuals together
- Properties can have different characteristics (being inverse, functional, inverse functional, symetric etc)
- Properties are called roles in description logics or slots in Protégé

Classes

- OWL interprets classes as sets that contain individuals
- Classes are described using formal descriptions that precisely state the requirements for membership
- Classes can be organized in a super-subclass-hierarchies called a taxonomy
- Classes are sometimes denoted as concepts – but classes are concrete representations of concepts

OWL Naming Recommendations

Although there is no strict naming convention for classes, properties and individuals, it is recommended to use the following rules

Naming Convention for Properties

Property naming should use lower camel case notation:

- start with a **lower case letter**,
- have **no spaces**,
- and have the **remaining words capitalised**.
- are **prefixed** with the word '**has**', or the word '**is**'

Example: `hasPart`, `isPartOf`, `hasManufacturer`, `isProducerOf`

Not only does this convention help make the intent of the property clearer to humans, it is also taken advantage of by the 'English Prose Tooltip Generator', which uses this naming convention where possible to generate more human readable expressions for class descriptions.

Naming Convention for Classes

Classes should be named using a upper camel case notation:

- start with a **capital letter**
- should **not contain spaces**.

Examples: `Pizza`, `PizzaTopping`, `MargheritaPizza`.

Alternatively, underscores ('`_`') can be used to join words; for example `Pizza_Topping`.

Which ever convention is used, it is important to be **consistent**.

Source: OWL Pizza Tutorial der University of Manchester

Ontology Features

–Classes

Classes in OWL

❗ Classes are interpreted as sets that contain individuals.

Classes are described using formal, ie. mathematical descriptions that precisely state the requirements from class membership.

Example: `SafetyLaserScanner ⊑ ∃hasCapability.SafeMonitoringOf2DFields`

In OWL, classes are built up of descriptions that specify the conditions that must be satisfied by an individual for it to be a member of the class.

OWL distinguishes between

- primitive classes – classes that only have necessary conditions
- defined classes – classes that have at least one set of necessary and sufficient conditions; any individual that satisfies these conditions (ie., the definition) becomes member of that class; class membership is expressed by necessary and sufficient conditions

Important ⚠
Automatic classification only works with defined classes ⇝ a reasoner can only automatically classify classes under defined classes.

Disjoint Classes

❗ OWL Classes are assumed to 'overlap'

- ⇝ We cannot assume that an individual is not a member of a particular class simply because it has not been asserted to be a member of that class.

In order to 'separate' a group of classes they must made disjoint from one another.

- This ensures that an individual which has been asserted to be a member of one of the classes in the group cannot be a member of any other classes in that group.

As example `Pizza`, `PizzaTopping` and `PizzaBase` must be made disjoint from one another.

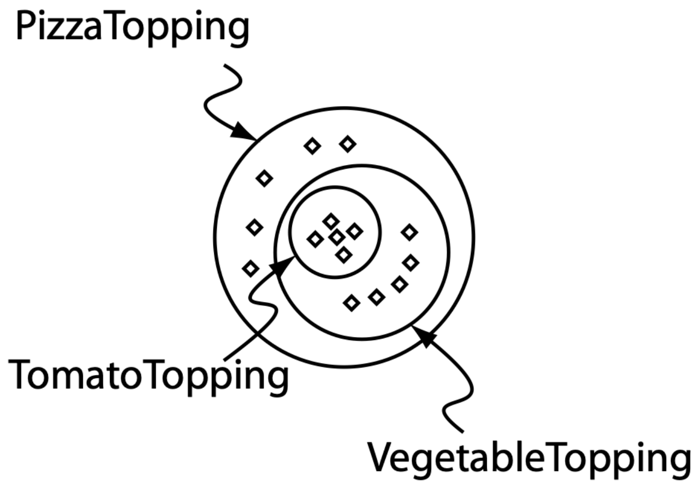
- This means that it is not possible for an individual to be a member of a combination of these classes – it would not make sense for an individual to be a `Pizza` and a `PizzaBase`!

What does it actually mean to be a subclass of something in OWL ?

Example

What does it mean for `VegetableTopping` to be a subclass of `PizzaTopping`, or for `TomatoTopping` to be a subclass of `VegetableTopping`?

⇒ In OWL subclass means necessary implication.



⚠ Meaning

If `VegetableTopping` is a subclass of `PizzaTopping` then **ALL** instances of `VegetableTopping` are instances of `PizzaTopping`, without exception – if something is a `VegetableTopping` then this implies that it is also a `PizzaTopping`.

All individuals that are members of the class `TomatoTopping` are members of the class `VegetableTopping` and members of the class `PizzaTopping` as we have stated that `TomatoTopping` is a subclass of `VegetableTopping` which is a subclass of `PizzaTopping`.

Ontology Features

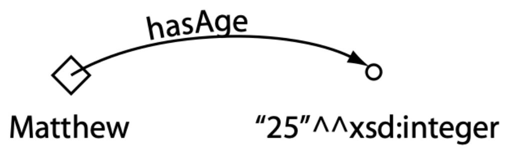
⇝ Properties

OWL Property Types

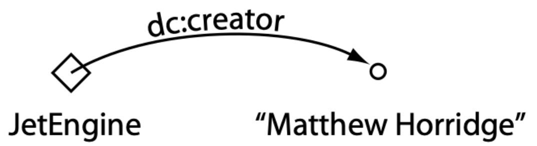
OWL distinguishes between **3 types** of **properties**

- Object Properties
  - represent relationships between individuals, i.e., they link one individual to another
- Datatype Properties
  - the range of those properties is a simple datatype, most commonly defined as XML Schema datatype (`xsd`-prefixed)
- Annotation Properties
  - allow to add additional information to classes, individuals, and object/datatype properties

An object property linking the individual Matthew to the individual Gemma



A datatype property linking the individual Matthew to the data literal '25', which has a type of an xsd:integer.

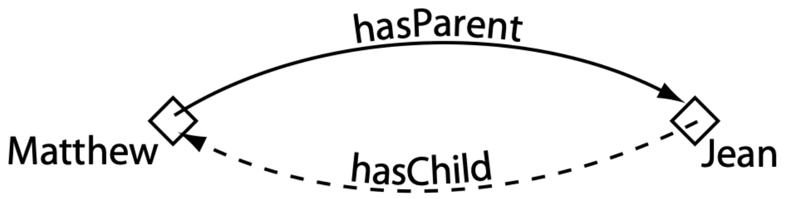


An annotation property, linking the class 'JetEngine' to the data literal (string) "Matthew Horridge".

OWL Object Property Characteristics

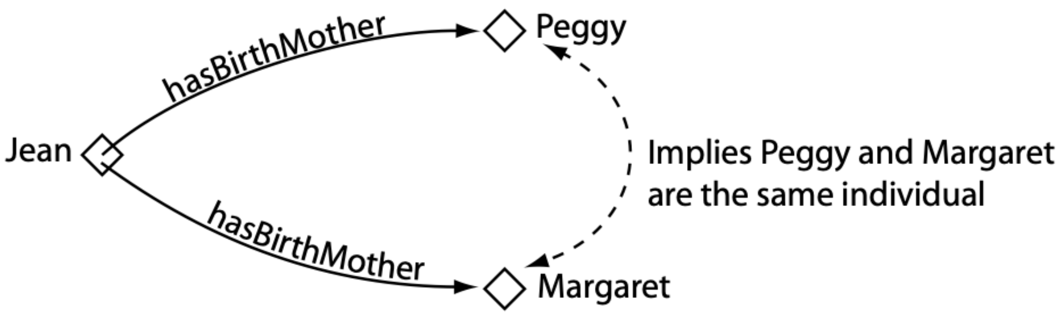
Inverse Properties

- Each object property may have a corresponding inverse property.
- If some property links individual `a` to individual `b` then its inverse property will link individual `b` to individual `a`.



Functional Properties

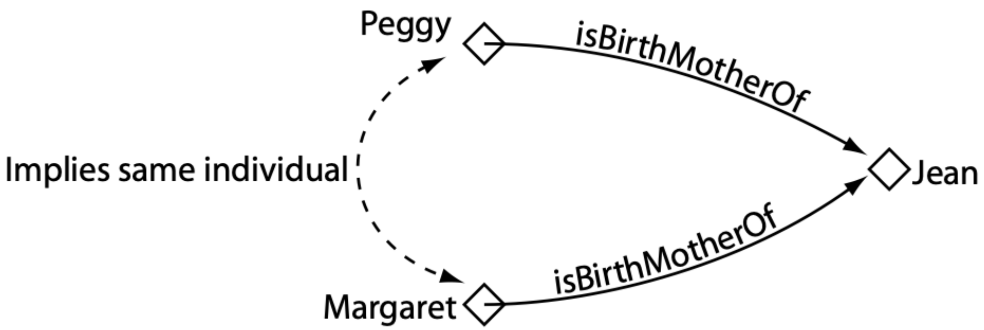
- For a given individual, there can be at most one individual that is related to the individual via the property.
- Functional properties are also known as single valued properties and also features.



OWL Object Property Characteristics

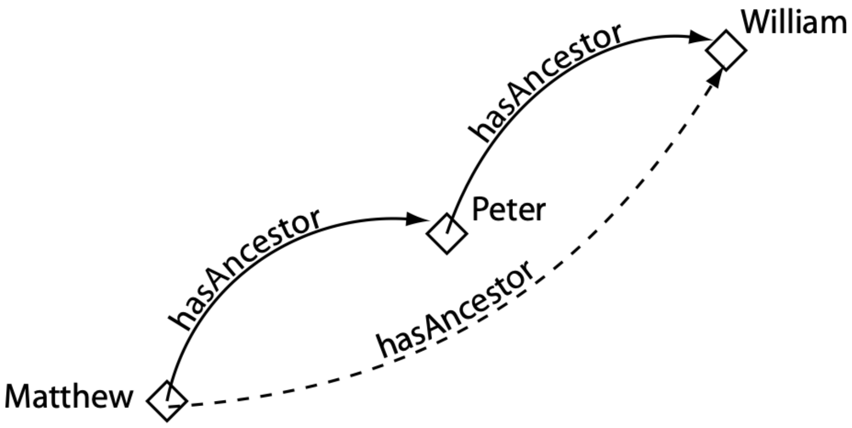
Inverse Functional Properties

- If a property is inverse functional then it means that the inverse property is functional.
- For a given individual, there can be at most one individual related to that individual via the property.



Transitive Properties

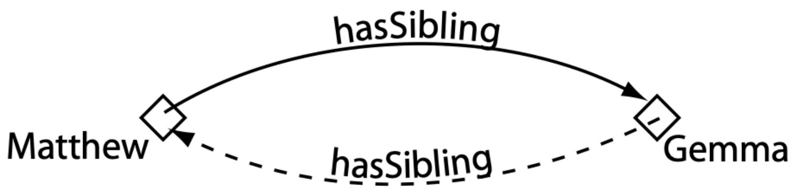
- If a property is transitive, and the property `P` relates individual `a` to individual `b`, and also individual `b` to individual `c`, then we can infer that individual `a` is related to individual `c` via property `P`.
- The inverse of a transitive property should also be transitive.
- If a property is transitive then it cannot be functional



OWL Object Property Characteristics

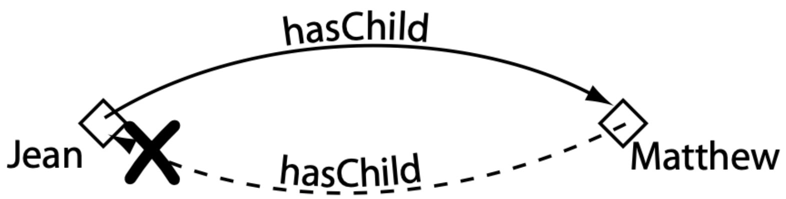
Symmetric Properties

- If a property `P` is symmetric, and the property relates individual `a` to individual `b` then individual `b` is also related to individual `a` via property `P`
- In other words – the property is its own inverse property.



Asymmetric Properties

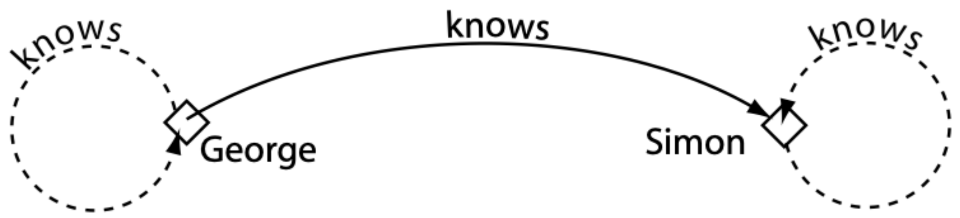
- If a property `P` is asymmetric, and the property relates individual `a` to individual `b` then individual `b` cannot be related to individual `a` via property `P`.



OWL Object Property Characteristics (4/4)

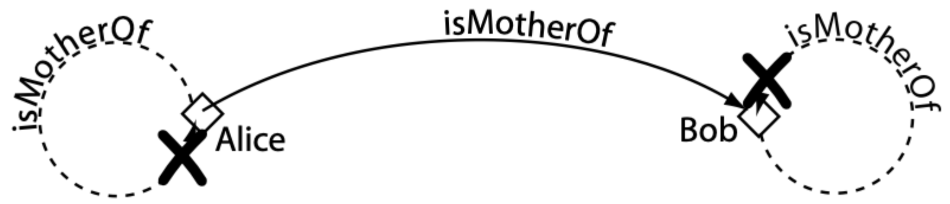
Reflexive Properties

- A property `P` is said to be reflexive when the property must relate individual `a` to itself.
- E.g. `knows` is such a property that could be defined as being reflexive



Irreflexive Properties

- If a property `P` is irreflexive, it can be described as a property that relates an individual `a` to individual `b`, where individual `a` and individual `b` are not the same.
- E.g., an individual `Alice` can be related to individual `Bob` along the property `motherOf`, but `Alice` cannot be `motherOf` herself.



Describing and Defining Classes

Property Restrictions

Key idea

A **restriction** describes a **class of individuals** based on the **relationships** that members of the class participate in. The key idea is that a **class of individuals** is described or defined by the **relationships** that these individuals **participate in**. The annonymous class contains all individuals that satisfy the restriction.

OWL distinguishes between the following **types** of restrictions

- Quantifier Restrictions
  - Existential Restrictions – denoted by the existential quantifier $\exists$ and formulated as `someValuesFrom` in OWL.
  - Universal Restrictions – denoted by the universal quantifier $\forall$ and read as 'only'. The formulation in OWL is `allValuesFrom`.
- (Qualified) Cardinality Restrictions
- hasValue Restrictions

Quantifier Restrictions

Quantifier restrictions consist of three parts:

1. A quantifier, which is either the existential quantifier (some), or the universal quantifier (only).
2. A property, along which the restriction acts.
3. A filler that is a class description.

⚠ For a given individual, the quantifier effectively puts **constraints** on the **relationships** that the individual participates in.

It does this by either

- specifying that **at least one** kind of relationship must exist,
- or by specifying the **only** kinds of relationships that can exist (if they exist).

Existential Restrictions (∃)

Existential restrictions are by far the most common type of restrictions in OWL ontologies.

An existential restriction describes a **class of individuals** that have **at least one** (some) **relationship** along a **specified property** to an **individual** that is a member of a **specified class**.

Example

- `hasTopping some MozarellaTopping` describes an annonymous class of individuals that have at least one (some) `hasTopping` relationship to an individual that is members of `MozzarellaTopping`
- The restriction acts along the `hasTopping` property, and has a filler `MozzarellaTopping`.
- Protégé uses the keyword `some` and the class expression editor

Remember
A restriction describes an anonymous class (an unnamed class). The anonymous class contains all of the individuals that satisfy the restriction – i.e. all of the individuals that have the relationships required to be a member of the class.

Existential Restrictions (∃)

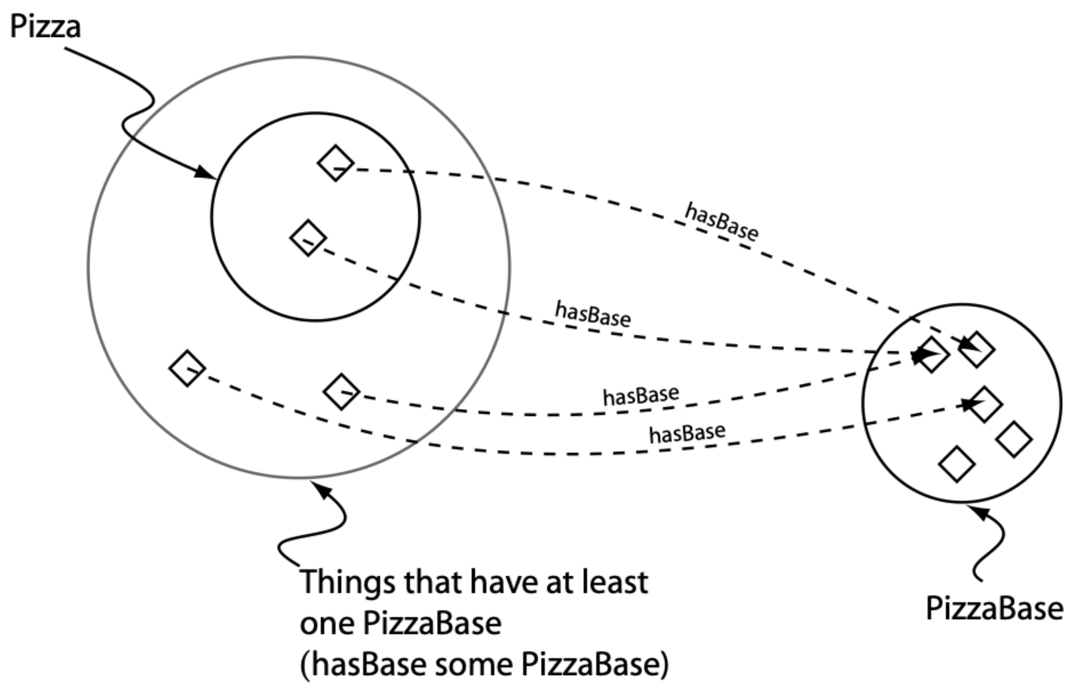
The class `Pizza` is described to be a subclass of `Thing` and a subclass of the things that have a base which is some kind of `PizzaBase`.

Notice that these are **necessary conditions** — if something is a `Pizza`...

- ...it is necessary for it to be a member of the class `Thing` and
- ...necessary for it to have a kind of `PizzaBase`.

More formally, for something to be a `Pizza` it is necessary for it to be in a relationship with an individual that is a member of the class `PizzaBase` via the property `hasBase`.

When restrictions are used to describe classes, they actually specify anonymous superclasses of the class being described. For example, we could say that `MargheritaPizza` is a subclass of, amongst other things, `Pizza` and also a subclass of the things that have at least one topping that is `MozzarellaTopping`.



A Schematic Description of a Pizza — In order for something to be a Pizza it is necessary for it to have a (at least one) PizzaBase — A Pizza is a subclass of the things that have at least one PizzaBase

In OWL, everything is a member of the class `Thing`.

Existential Restrictions (∃) – Example

We can add restrictions to `MargeritaPizza` to say that a `MargheritaPizza` is a `NamedPizza` that has at least one kind of `MozzarellaTopping` and at least one kind of `TomatoTopping`.

More formally (reading the class description view line by line)

If something is a member of the class `MargheritaPizza`...

- ...it is necessary for it to be a member of the class `NamedPizza`
- ...and it is necessary for it to be a member of the anonymous class of things that are linked to at least one member of the class `MozzarellaTopping` via the property `hasTopping`,
- ...and it is necessary for it to be a member of the anonymous class of things that are linked to at least one member of the class `TomatoTopping` via the property `hasTopping`.

The Class Description View Showing A Description Of a `MargheritaPizza`

Universal Restrictions (∀)

❗ With existential restrictions, we could not say, that **all** relationships of individuals must be to members of a specific class.

Universal restrictions (represented by the symbol ∀) describe the set of individuals that, for a given property, **only have relationships** to other individuals that are members of a specific class.

- Universal restrictions constrain the relationships along a given property to individuals that are members of a specific class.
  - **Example**: The universal restriction ∀ `hasTopping MozzarellaTopping` describes the individuals all of whose `hasTopping` relationships are to members of the class `MozzarellaTopping` — the individuals do not have a `hasTopping` relationships to individuals that aren't members of the class `MozzarellaTopping`.
- Universal restrictions are also known as `allValuesFrom` restrictions, or `only` restrictions since they constrain the filler for a given property to a specific class.

> ⚠ **Warning**
> A feature of universal restrictions is, that for the given property, the set of individuals that the restriction describes will also contain the individuals that do not have any relationship along this property to any other individuals.

Universal Restrictions (∀)

Remember

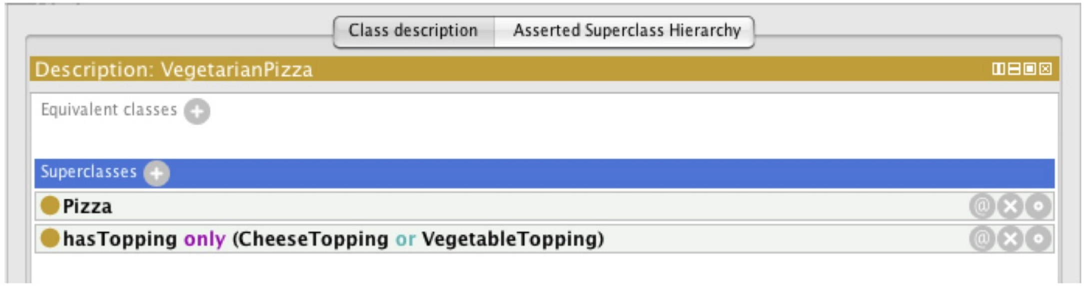
An important point to note is that universal restrictions do not ‘guarentee’ the **existence** of a relationship for a given property.
⇝ They merely state that if such a relationship for the given property exists, then it must be with an individual that is a member of a specified class.

Example

- The restriction, ∀ `hasTopping TomatoTopping` describes the anonymous class of individuals that **only** have `hasTopping` relationships to individuals that are members of the class `TomatoTopping`, **OR**, individuals that definitely do not participate in any `hasTopping` relationships at all.

Common pitfalls in universal restrictions

1. **Use an intersection instead of a union ⚠**
   - For example, `CheeseTopping` ⊓ `VegetableTopping`.
     - This reads, `CheeseTopping` and `VegetableTopping`. Although "CheeseTopping and Vegetable" might be a natural thing to say in English, this logically means something that is simultaneously a kind of `CheeseTopping` AND `VegetableTopping`.
     - If the classes `CheeseTopping` and `VegetableTopping` were not disjoint, this would have been a logically legitimate thing to say – it would not be inconsistent and therefore would not be 'spotted' by a reasoner.
2. **Create two universal restrictions ⚠**
   - one for `CheeseTopping` (`∀ hasTopping CheeseTopping`) and
   - one for `VegetableTopping` (`∀ hasTopping VegetableTopping`).
     - When multiple restrictions are used (for any type of restriction) the total description is taken to be the **intersection** of the individual restrictions. This would have therefore been equivalent to one restriction with a filler that is the intersection of `MozzarellaTopping` and `TomatoTopping` — as explained above this would have been logically incorrect.



How to do it right ✔

- If something is a member of the class `VegetarianPizza` it is necessary for it to be a kind of `Pizza` **and** it is necessary for it to **only** (∀ universal quantifier) have toppings that are kinds of `CheeseTopping` **or** kinds of `VegetableTopping`.
- In other words, all `hasTopping` relationships that individuals, which are members of the class `VegetarianPizza` participate in must be to individuals that are either members of the class `CheeseTopping` or `VegetableTopping`.
- The class `VegetarianPizza` also contains individuals that are `Pizza`s and do not participate in any `hasTopping` relationships.

Cardinality Restrictions

Cardinality restrictions are used to talk about the number of relationships that an individual may participate in for a given property.

Minimum Cardinality Restrictions (≥)

- Specify the minimum number of relationships that an individual must participate in for a given property.
- For example `≥ hasTopping 3` describes the individuals that participate in **at least** three `hasTopping` relationships.
- Minimum cardinality restrictions place no maximum limit on the number of relationships that an individual can participate in for a given property.

Maximum Cardinality Restrictions (≤)

- Specify the maximum number of relationships that an individual can participate in for a given property.
- For example `≤ hasTopping 2` describes the class of individuals that participate in **at most** two `hasTopping` relationships.
- Maximum cardinality restrictions place no minimum limit on the number of relationships that an individual must participate in for a specific property.

Cardinality Restrictions (=)

- Specify the exact number of relationships that an individual must participate in for a given property.
- For example `= hasTopping 5` describes the set of individuals that participate in **exactly** five `hasTopping` relationships.
- Cardinality restriction is a syntactic short hand for using a combination of a minimum cardinality restriction and a maximum cardinality restriction.

For example the above cardinality restriction could be represented by using the intersection of the two restrictions: `≤ hasTopping 5`, and, `≥ hasTopping 5`.

hasValue-Restriction

A **hasValue restriction** ('∋') describes the **set of individuals** that have **at least one relationship** along a **specified property** to a **specific individual**, i.e., it defines an anonymous class of individuals that are related to another specific individual along a specified property.

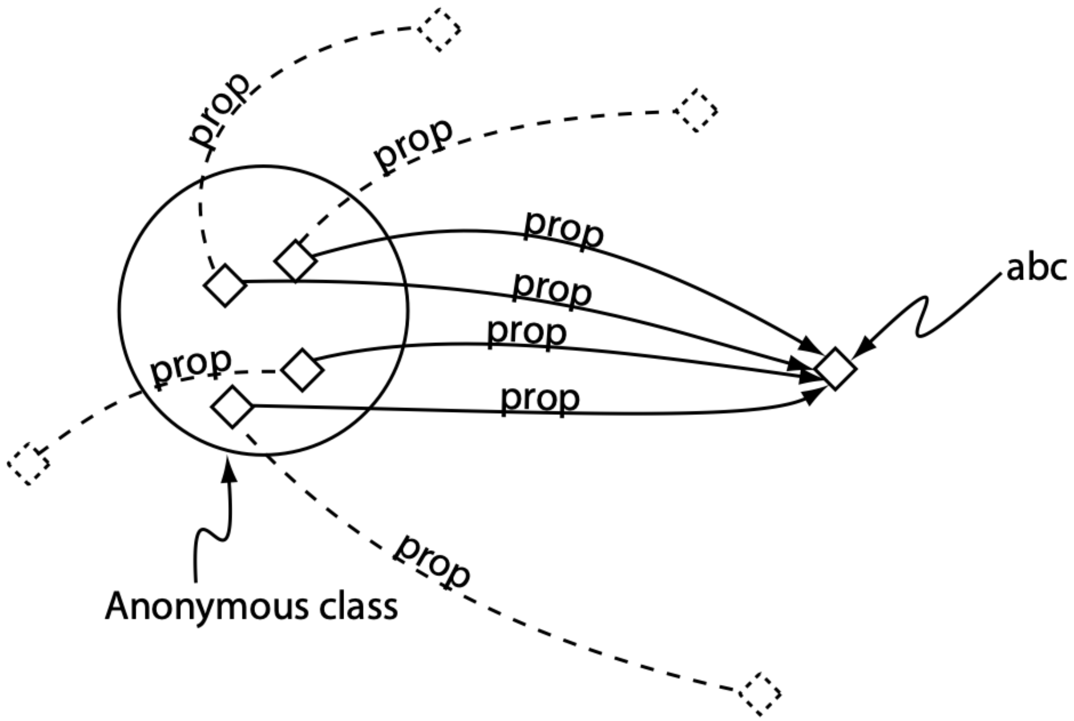
Example

- We can state that an ingredient is from a specific country, e.g., that `MozarellaTopping` is from `Italy`
  `MozarellaTopping` ⊑ `hasCountryOfOrigin value Italy` ('Italy' being an individual)

- ❗ Contrast this with a quantifier restriction where the individuals that are described by the quantifier restriction are related to **any indvidual** from a specified class along a specified property.

Semantic equivalence via enumerated classes
hasValue restrictions are semantically equivalent to an existential restriction along the same property as the hasValue restriction, which has a filler that is an enumerated class that contains the individual (and only the individual) used in the hasValue restriction.

hasValue-Restriction



- The figure shows a schematic view of the hasValue restriction `prop ∋ abc`.
- This restriction describes the anonymous class of individuals that have at least one relationship along the `prop` property to the specific individual `abc`.
- The dashed lines indicate that this type of restriction does not constrain the property used in the hasValue restriction solely to the individual used in the hasValue restriction.

How to formulate class descriptions using restrictions

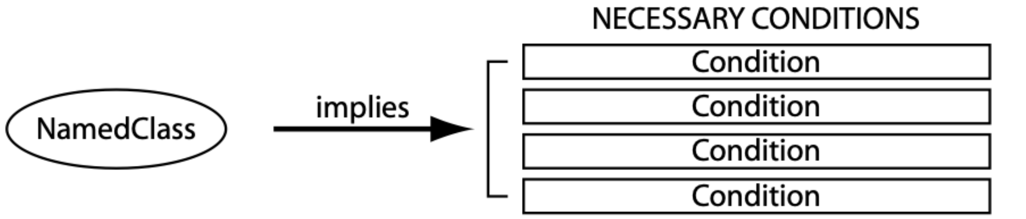
Restrictions in class descriptions can be formulated in two different ways:

- As necessary conditions
  - If something is a member of this class then it is necessary to fulfil these conditions
  - With necessary conditions alone, we cannot say – "If something fulfils these conditions then it must be a member of this class"
  - A class that only has necessary conditions is known as a **Primitive Class**.
- As sufficient AND necessary conditions
  - Not only are the conditions necessary for membership of the class, they are also sufficient to determine that any (random) individual that satisfies them must be a member of the class
  - Necessary conditions are simply called **Superclasses** in Protégé. Necessary and sufficient condition are called **Equivalent classes**.
  - A class that has at least one set of necessary and sufficient conditions is known as a **Defined Class**.

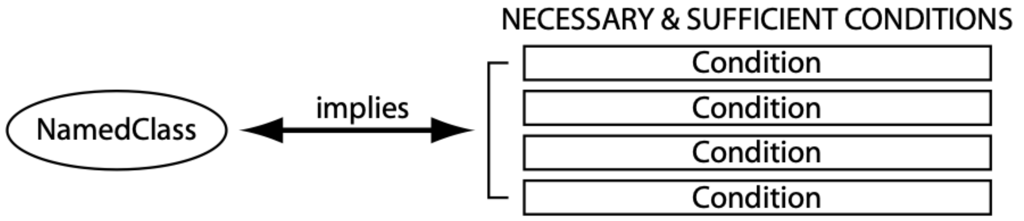
Necessary and Sufficient Conditions

What does it mean to use a specific type of condition:

- If class `A` is described using necessary conditions, then we can say that if an individual is a member of class `A` it must satisfy the conditions.
- We cannot say that any (random) individual satisfying these conditions must be member of class `A`.
- If class `A` is defined using necessary AND sufficient conditions, we can say that if any (random) individual satisfies these conditions then it must be a member of class `A`.
- The conditions are not only necessary for membership of `A` but also sufficient to determine that something satisfying these conditions is a member of `A`.



If an individual is a member of 'NamedClass' then it must satisfy the conditions. However if some individual satisfies these necessary conditions, we cannot say that it is a member of 'Named Class' (the conditions are not 'sufficient' to be able to say this) - this is indicated by the direction of the arrow.



If an individual is a memeber of 'NamedClass' then it must satisfy the conditions. If some individual satisfies the condtions then the individual must be a member of 'NamedClass' - this is indicated by the double arrow.

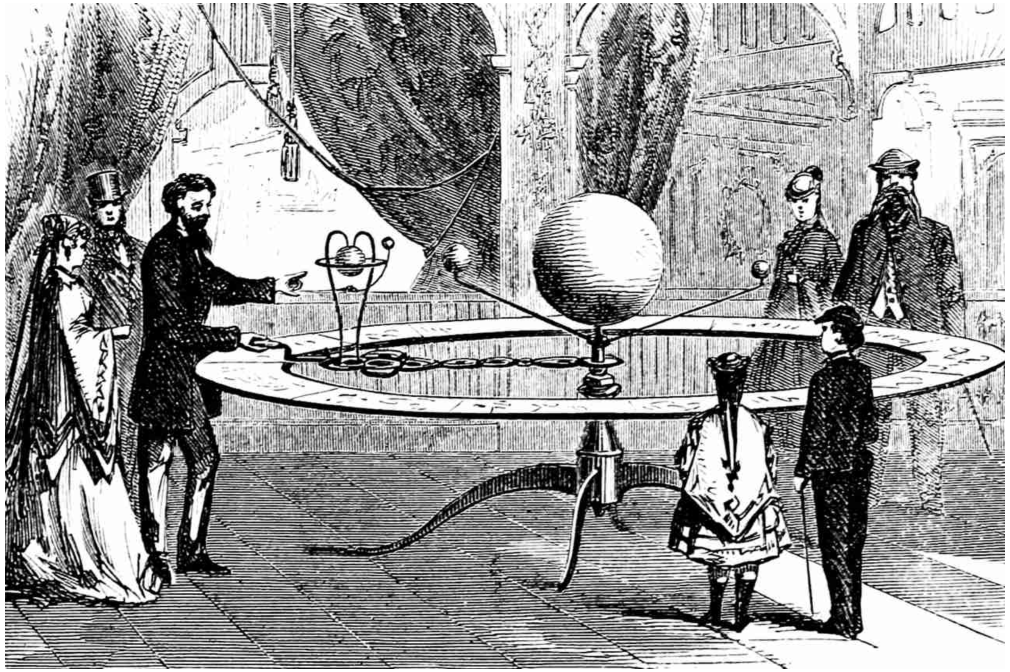
How are necessary and sufficient conditions useful in practice ?

Suppose the following...

- we have another class `B`,
- we know that any individuals being members of class `B` also satisfy the conditions that define class `A`.

We can determine that...

- class `B` is subsumed by class `A`
- $\Rightarrow$ `B` is a **subclass** of `A`.



Checking for class subsumption is a key task of a DL reasoner for automatically computing classification hierarchies.

Computing automated classifications using the reasoner

Important:

- It is important to understand that a reasoner can only automatically classify classes under defined classes - i.e. classes with at least one set of necessary and sufficient conditions.
- Without a reasoner it is very difficult to keep large ontologies in a maintainable and logically correct state.
- The use of a reasoner to compute subclass-superclass relationships between classes becomes almost vital.
- In cases where ontologies can have classes that have many superclasses (multiple inheritance) it is almost always a good idea to construct the class hierarchy as a simple tree.
- Classes in the asserted hierarchy (manually constructed hierarchy) therefore have no more than one superclass.
- Computing and maintaining multiple inheritance is the job of the reasoner.
- This helps to keep the ontology in a maintainable and modular state.
- Not only does this promote the reuse of the ontology by other ontologies and applications, it also minimises human errors that are inherent in maintaining a multiple inheritance hierarchy.

See illustrations on page 58 of the OWL pizza tutorial about asserted and inferred hierarchy

Automated classification and open world reasoning

Motivation

- `MargheritaPizza` and `SohoPizza` should by classified by the reasoner as `VegetarianPizza` based on their `hasTopping` relationsships to vegetarian individuals, e.g., being members of the classes `CheeseTopping` or `VegetableTopping` and their subclasses.

Observation

- Despite creating a definition for `VegetarianPizza` using necessary and sufficient conditions, `MargheritaPizza` and `SohoPizza` were not classified as subclasses of it.

Problem

- Reasoning in OWL is based on what is known as the open world assumption (OWA) or as open world reasoning (OWR).
- The open world assumption means that we cannot assume something doesn't exist until it is explicitly stated that it does not exist.
- Because something hasn't been stated to be true, it cannot be assumed to be false — it is assumed that 'the knowledge just hasn't been added to the knowledge base'.

What does it mean for our vegetarian pizzas...?

- In the case of our pizzas, we have stated that `MargheritaPizza` has toppings that are kinds of `MozzarellaTopping` and also kinds of `TomatoTopping`.
- Because of the open world assumption, until we explicitly say that a `MargheritaPizza` only has these kinds of toppings, the reasoner assumes that a `MargheritaPizza` could have other toppings.
- To specify explicitly that a `MargheritaPizza` has toppings that are only kinds of `MozzarellaTopping` or `TomatoTopping`, we must add a closure axiom on the `hasTopping` property.

Closure Axiom

A closure axiom on a property consists of a universal restriction along the property to say that it can only be filled by the specified fillers. The restriction has a filler that is the union of the fillers that occur in the existential restrictions for the property.

Explanation

This now says that...

- ...if an individual is a member of the class `MargeritaPizza`

then

- it must be a member of the class `Pizza`,
- and it must have at least one topping that is a kind of `MozzarellaTopping`
- and it must have at least one topping that is a member of the class `TomatoTopping`
- and the toppings must only be kinds of `MozzarellaTopping` or `TomatoTopping`.

A common error in situations such as above is to **only** use **universal restrictions** in descriptions. For example, describing a `MargheritaPizza` by making it a subclass of `Pizza` and then only using `∀ hasTopping (MozzarellaTopping ⊔ TomatoTopping)` without any existential restrictions. However, because of the semantics of the universal restriction, this actually means either: things that are `Pizza`s and only have toppings that are `MozzarellaTopping` or `TomatoTopping`, OR, things that are `Pizza`s and do not have any toppings at all.

Reasoning

Basic Inference Types

- **Subsumption** – find out whether class C is a subclass of D, i.e., $C \sqsubseteq D$
- **Class Equivalence** – find out whether class C is equivalent to D, i.e., $C \equiv D$
- **Class Disjointness** – find out whether C and D disjoint, i.e., $C \sqcap D \sqsubseteq \bot$
- **Global Consistency** – find out whether a knowledge base is globally consistent, i.e., that it has a model
- **Class Consistency** – e.g., find out whether a given class C is consistent, i.e., show that $C \sqsubseteq \bot$ is not a logical consequence of the given knowledge base
- **Instance Checking** – e.g., find out if an individual a belongs to a class C, i.e., check whether C(a) is a logical consequence of the given knowledge base
- **Instance Retrieval** – find all individuals that are members of a given class or class expression

What a Reasoner can do with ontological semantics

Ontologies described by OWL can be processed by a reasoner

- A reasoner can test whether a class is a subclass of another class
- A reasoner can compute the inferred ontology hierarchy
- A reasoner can perform consistency checking
  - i.e., based on the descriptions (conditions) of a class, a reasoner can check whether or not it is possible for a class to have any instances
  - An inconsistent class can not have any instances

Excursus: How to make URIs function as an unambiguous entity name

Q: Given the URI: https://example.com/people/albert_einstein, what are the implementation mechanics for ensuring that it functions as an unambiguous entity name?

To ensure that a URI, like https://example.com/people/albert_einstein, functions as an unambiguous entity name, you need to follow these implementation mechanics:

- **Unique identifier**: Make sure the URI is unique and doesn't refer to multiple entities. This prevents confusion and ensures that the URI unambiguously identifies a single entity. In this example, "albert_einstein" should only refer to one person, and not be reused for different entities.
- **Persistent and stable**: Ensure that the URI remains stable and persistent over time. Avoid changing the URI structure or removing the resource, as this may lead to broken links and loss of information. Use a domain and hosting service that you can maintain for a long period.
- **Content negotiation**: Implement content negotiation on the server hosting the resource. This allows the server to return different representations of the resource based on the client's preferences (e.g., RDF, JSON-LD, or HTML). This way, both humans and machines can access the information associated with the URI.
- **Structured data**: Provide a machine-readable description of the entity using a structured data format like RDF, JSON-LD, or Microdata. Include the URI as the subject, and use standardized vocabularies, like schema.org or Dublin Core, to describe the entity's properties and relationships.
- **Linking related entities**: Within the entity's description, link to other related entities using their URIs. This helps create a web of interconnected data that improves machine understanding and discoverability.

By following these implementation mechanics, you can ensure that the URI https://example.com/people/albert_einstein functions as an unambiguous entity name, in line with the Linked Data Principles.

Source: Extracted from a post to the linked data mailinglist by Kingsley Idehen from May 5th, 2023.