Foundations of Semantic Knowledge Graphs

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Modelling Data with RDF Schema

Outline

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  - Properties
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- RDF/S Language Features
  - Predefined Classes and Properties
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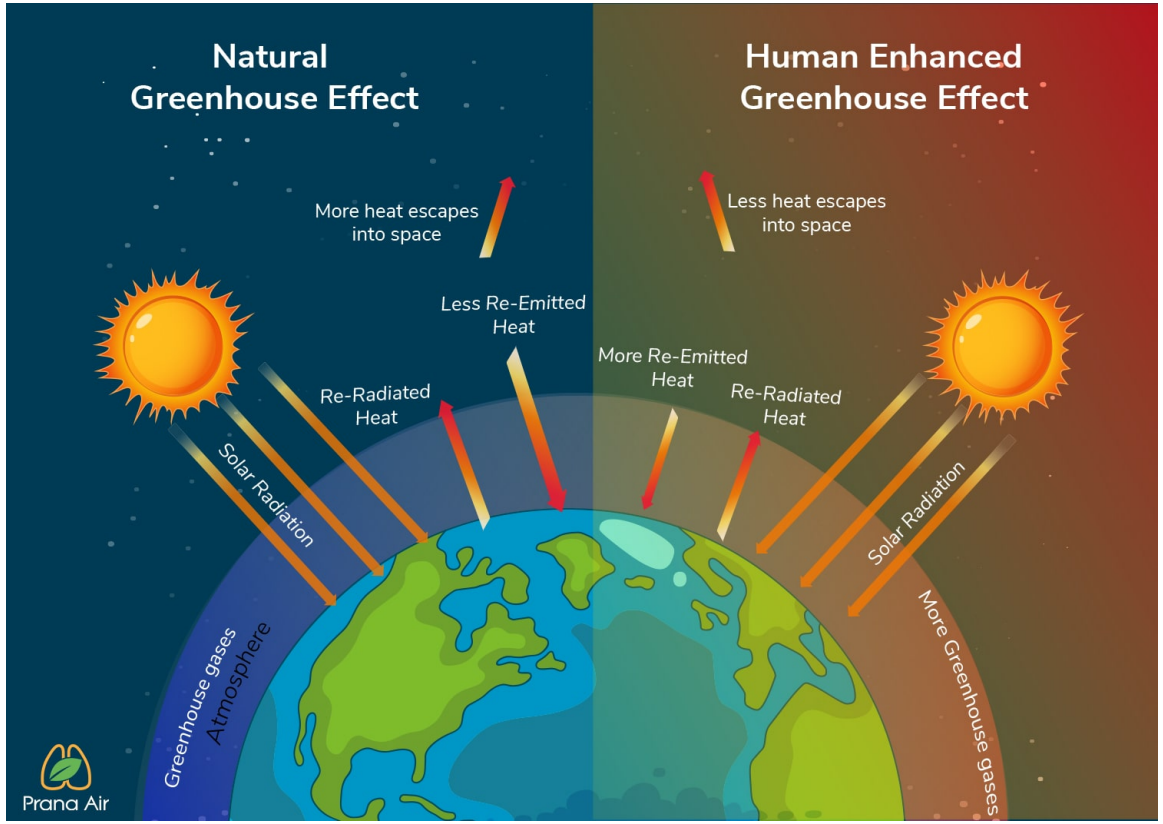
- A holistic RDF Schema Example



Review: RDF Graphs

The **W3C Resource Description Framework** considers three types of RDF terms:

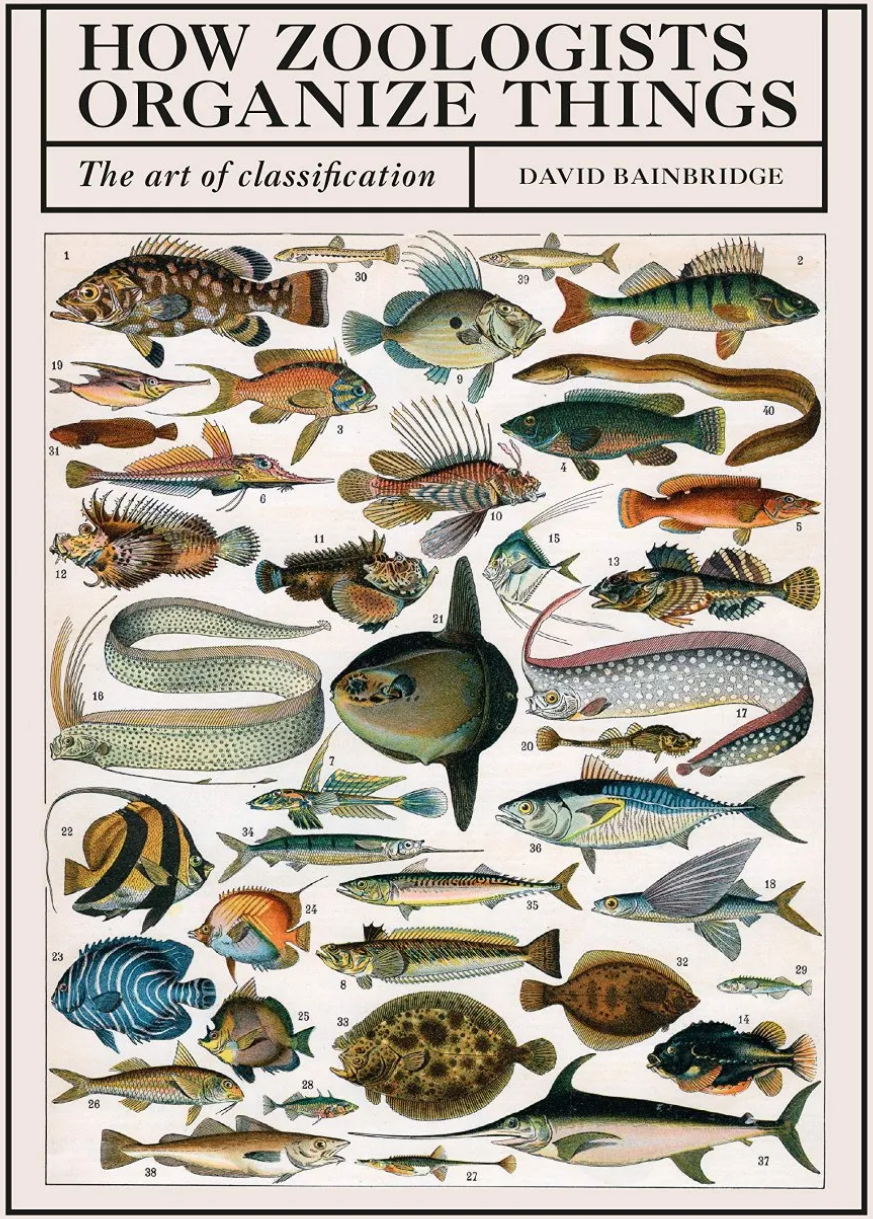
- IRIs, representing a resource using a global identifier
- Blank nodes, representing an unspecified resource without giving any identifier
- Literals that represent values of some datatype
  - either typed literals, such as `"2020-11-10"^^<http://www.w3.org/2001/XMLSchema#date>`
  - or language-tagged strings, such as `"Knowledge Graphs"@en`

RDF graphs are sets of triples consisting of

- a subject, which can be an IRI or bnode,
- a predicate, which can be an IRI,
- an object, which might be an IRI, bnode, or literal
  ⇝ naturally viewed as hypergraphs with ternary edges

Motivation

- RDF allows for making arbitrary assertions about individual resources and their relationships on the Web
- Preferable:
  - To make assertions about **generic sets** of **individuals** (ie. classes)
    e.g. the class of all authors, organizations, books etc.
  - To explicitly specify the **logical relations** between individuals, classes, and their relationships to accurately describe the universe of discourse
    e.g. publisher are organizations / authors are persons / etc.
- **RDFS** allows for the **explicit specification** of **schematic** and **terminological knowledge** (also factual knowledge) about resources



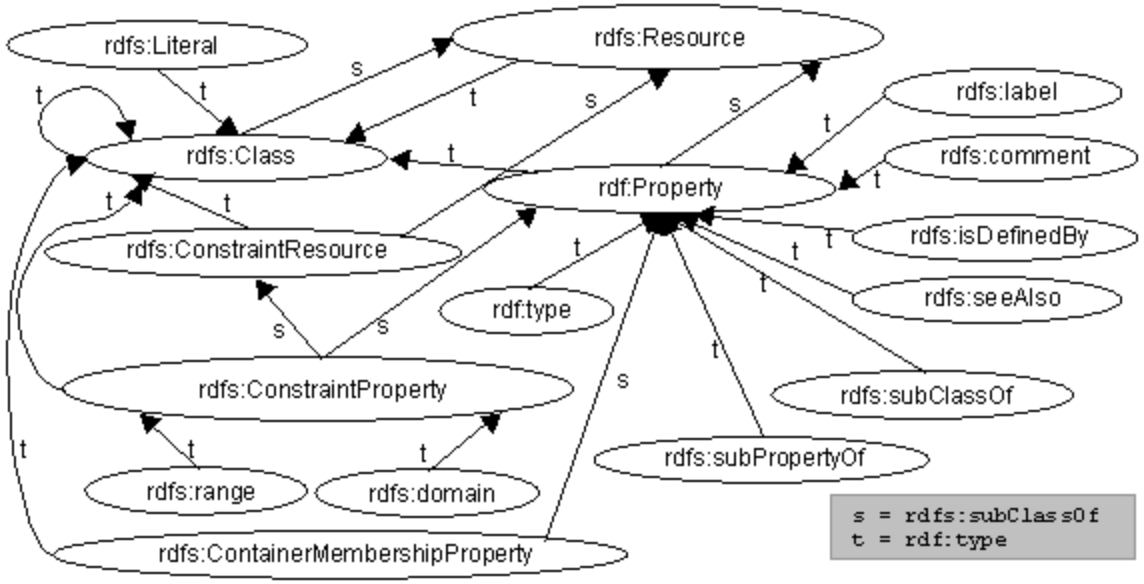
Picture Source: https://www.nhbs.com/how-zoologists-organize-things-book

RDF Schema

- **RDFS** simply defines a data model and a vocabulary for the creation of RDF statements
- Official name: "RDF Vocabulary Description Language"
- RDF Schema provides a data-modelling vocabulary for RDF data

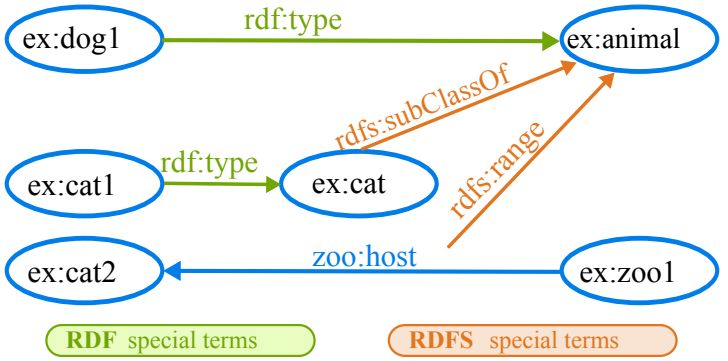
RDF Schema allows

- Definition of **classes**
- Definition of **properties** and **restrictions**
- Definition of hierarchies
  - **Subclasses** and **superclasses**
  - **Subproperties** and **superproperties**



RDF Schema (2/2)

- Part of the W3C RDF Recommendation (https://www.w3.org/TR/rdf-schema/)
- Namespace: `http://www.w3.org/2000/01/rdf-schema#`
- RDFS is a specific RDF vocabulary
  ⇝ ie., every RDFS document is also a valid RDF document
- RDFS is also **meta vocabulary** ⇝ allows for the specification of the **semantics** of arbitrary **RDF vocabularies** (or parts of it)
- Every software with RDFS capabilities is able to comprehend the incorporated RDFS semantics correctly
- RDFS allows for defining **lightweight ontologies**



Modelling with RDF/S

Modelling with RDF/S: Classes and Instances

- Resources can be marked as **instances** of a class using the `rdf:type` property

```
ex:semanticWeb      rdf:type      ex:Lehrbuch .
```

  💬 *assigns the object's URI to the subject as its (new) type, i.e., the resource `ex:semanticWeb` is a (new) instance of the class `ex:Lehrbuch`*

- Class association or class assignment is not exclusive, i.e., a resource can be instance of many classes:

```
ex:semanticWeb      rdf:type       ex:Lecture .
```

- **Problem ☹**
  Syntactically **no inherent differentiation** between **designators** for classes and individuals
  ⇝ i.e., there is no syntactic way in RDFS to distinguish URIs representing individuals from URIs representing class names

- **Solution 🤩**
  Explicit designation of an URI/IRI as belonging to the class of all classes using `rdfs:Class`

Modelling with RDF/S: Defining Classes

- Preferable: unique designation of an URI as class
- Designating (typifying) an URI as a class with `rdfs:Class`

```
ex:Lehrbuch          rdf:type        rdfs:Class .
ex:semanticWeb       rdf:type        ex:Lehrbuch .
```

- `rdfs:Class` is the class of all classes and hence also contains itself ⇝ i.e., the following statement is valid:

```
rdfs:Class           rdf:type        rdfs:Class .
```

Notational conventions for classes, properties, and individuals:

- URIs representing classes are Capitalized
- Instance names and properties are written in lower case

Modelling with RDF/S: Classes and Subclasses

Problem ☹

- Search for `ex:Book` only returns such publications that are of this type ⇝ i.e., no instances of class `ex:Textbook` are retrieved
- Asserting `ex:semanticWeb rdf:type ex:Book` allows only for adding one specific resource

```
ex:Textbook         rdf:type        rdfs:Class .
ex:semanticWeb      rdf:type        ex:Textbook .
```

- This explicit inclusion of all instances of a class is cumbersome and leads to large RDF documents

Solution 🤩

- Asserting that every `ex:Textbook` is also an `ex:Book` ⇝ i.e., every instance of `ex:Textbook` is also an instance of `ex:Book`

```
ex:Textbook       rdfs:subClassOf       ex:Book .
```

Modelling with RDF/S: Subclass Semantics

- `rdfs:subClassOf` is **reflexive** ⇝ i.e., every class is subclass of its own

```
ex:Lehrbuch        rdfs:subClassOf      ex:Lehrbuch
```

  is a valid statement

- **Equality** of two classes can be expressed via mutual subclass relationships

```
ex:Hospital        rdfs:subClassOf      ex:Krankenhaus .
ex:Krankenhaus     rdfs:subClassOf      ex:Hospital .
```

  Every instance of `ex:Hospital` is also an instance of `ex:Krankenhaus` and vice versa

Modelling with RDF/S: Class Hierarchies

- `rdfs:subClassOf` allows for defining complex **class hierarchies** (so-called Taxonomies)

```
ex:Textbook   rdfs:subClassOf     ex:Book .
ex:Book       rdfs:subClassOf     ex:Printmedium .
ex:Journal    rdfs:subClassOf     ex:Printmedium .
```

- `rdfs:subClassOf` is transitive, $\rightsquigarrow$ i.e., it allows for the propagation of subclass relationships

  From the assertions above, the following statement can be deduced:

```
ex:Textbook   rdfs:subClassOf     ex:Printmedium .
```

- Relation to **set theory**
  `rdf:type` refers to $\in$
  `rdfs:subClassOf` refers to $\subseteq$

Modelling with RDF/S: Properties

- **Properties** in RDF(S) are treated as first-class citizens
- Properties characterize the relationship between two resources
- Properties are defined independently from concrete or specific classes (as opposed to OOP)
- **Syntactical rule**: properties start with a lower-case letter, e.g., `rdf:type`, `ex:authorOf`, `rdfs:subClassOf` etc.

Modelling with RDF/S: Property Hierarchies

- Properties may be **structured hierarchically** (cf. classes)
- `rdfs:subPropertyOf` is an instance of `rdf:Property` and states that all resources related by one property are also related by another
- `rdfs:subPropertyOf` is transitive

```
ex:happilyMarriedTo      rdf:subPropertyOf       rdf:marriedTo .
ex:markus                ex:happilyMarriedTo     ex:anja .
```

A reasoner can deduce the following

```
ex:markus                ex:marriedTo              ex:anja .
```

Modelling with RDF/S: Restrictions on Properties

Restrictions allow us to state that a certain property can only be between things of a certain type

- *E.g., when individual A is married to individual B, then both A and B are instances of class Person*
- `rdfs:domain`
  - Any resource that has a given property is an instance of one or more classes
- `rdfs:range`
  - Values of a property are instances of one or more classes.
- `P rdfs:domain C`
  - States that `P` is an instance of the class `rdf:Property`, that `C` is a instance of the class `rdfs:Class` and that the resources denoted by the **subjects** of triples whose predicate is `P` are instances of the class `C`.
- `P rdfs:range C`
  - States that `P` is an instance of the class `rdf:Property`, that `C` is an instance of the class `rdfs:Class` and that the resources denoted by the **objects** of triples whose predicate is `P` are instances of the class `C`.

Modelling with RDF/S: Example about Property Restrictions

Example: All individuals that are married are persons

```
ex:isMarriedTo      rdfs:domain          ex:Person .
ex:isMarriedTo      rdfs:range           ex:Person .
```

By stating that...

```
ex:Tom              ex:isMarriedTo       ex:Jane .
```

...we can infer the following:

```
ex:Tom              rdf:type             ex:Person .
ex:Jane             rdf:type             ex:Person .
```

Property restrictions also apply for **data types**:

```
ex:hasAge           rdfs:range           xsd:nonNegativeInteger .
```

Modelling with RDF/S: Property Restrictions Pitfalls 💥

- **Example 1**:

```
ex:authorOf          rdfs:range          ex:Textbook .
ex:authorOf          rdfs:range          ex:Storybook .
```

State that everything in the `rdfs:range` of `ex:author` is both a `ex:Textbook` and a `ex:Storybook`

- **Example 2**:

```
ex:isMarriedTo       rdfs:domain         ex:Person .
ex:isMarriedTo       rdfs:range          ex:Person .
ex:instituteAIFB     rdf:type            ex:Institution .

ex:pascal            ex:isMarriedTo      ex:instituteAIFB .
```

A logical consequence of this is: ⛈️

```
ex:instituteAIFB     rdf:type            ex:Person .
```

RDF/S Language Features

RDFS Language Features

Everything in the RDF model is a resource

```
rdfs:Class          rdf:type       rdfs:Resource .
rdf:Property        rdf:type       rdfs:Resource .
rdfs:Literal        rdf:type       rdfs:Resource .
rdfs:XMLLiteral     rdf:type       rdfs:Resource .
rdfs:Datatype       rdf:type       rdfs:Resource .
```

Predefined Classes by RDF/S

- `rdfs:Class`
  - defines an abstract object and is applied (with rdf:type) to create instances
- `rdfs:Resource`
  - Class of all resources (every entity of an RDF model is instance of this class)
- `rdf:Property`
  - Class of all relationships between resources
- `rdfs:Literal` / `rdf:XMLLiteral`
  - Class for literals / Class of all values pertaining to the predefined data type `XMLLiteral`
- `rdfs:Datatype`
  - Class of all data types, i.e., just as `rdfs:Class`, it is a class for classes
- Other classes
  - `rdf:List`, `rdf:Seq`, `rdf:Bag`, `rdf:Alt`, `rdfs:Container`, `rdfs:ContainerMembershipProperty`, `rdf:Statement`

A good summary of all RDF/S language elements is given in the W3C RDFS specification document: https://www.w3.org/TR/rdf-schema/#ch_summary

Properties defined by RDF/S

- `rdfs:subClassOf`
  - transitive property to define inheritance hierarchies for classes
- `rdfs:subPropertyOf`
  - transitive property to define inheritance hierarchies for properties
- `rdfs:domain`
  - defines the domain of a property concerning a class
- `rdfs:range`
  - defines range of a property concerning a class
- `rdfs:seeAlso`
  - defines a relation of a resource to another, which explains it
- `rdfs:isDefinedBy`
  - subproperty of `rdf:seeAlso`, defines the relation of a resource to its definition
- `rdfs:comment`
  - comment, usually in the form of a text
- `rdfs:label`
  - Human-readable name of a resource; contrary to ID

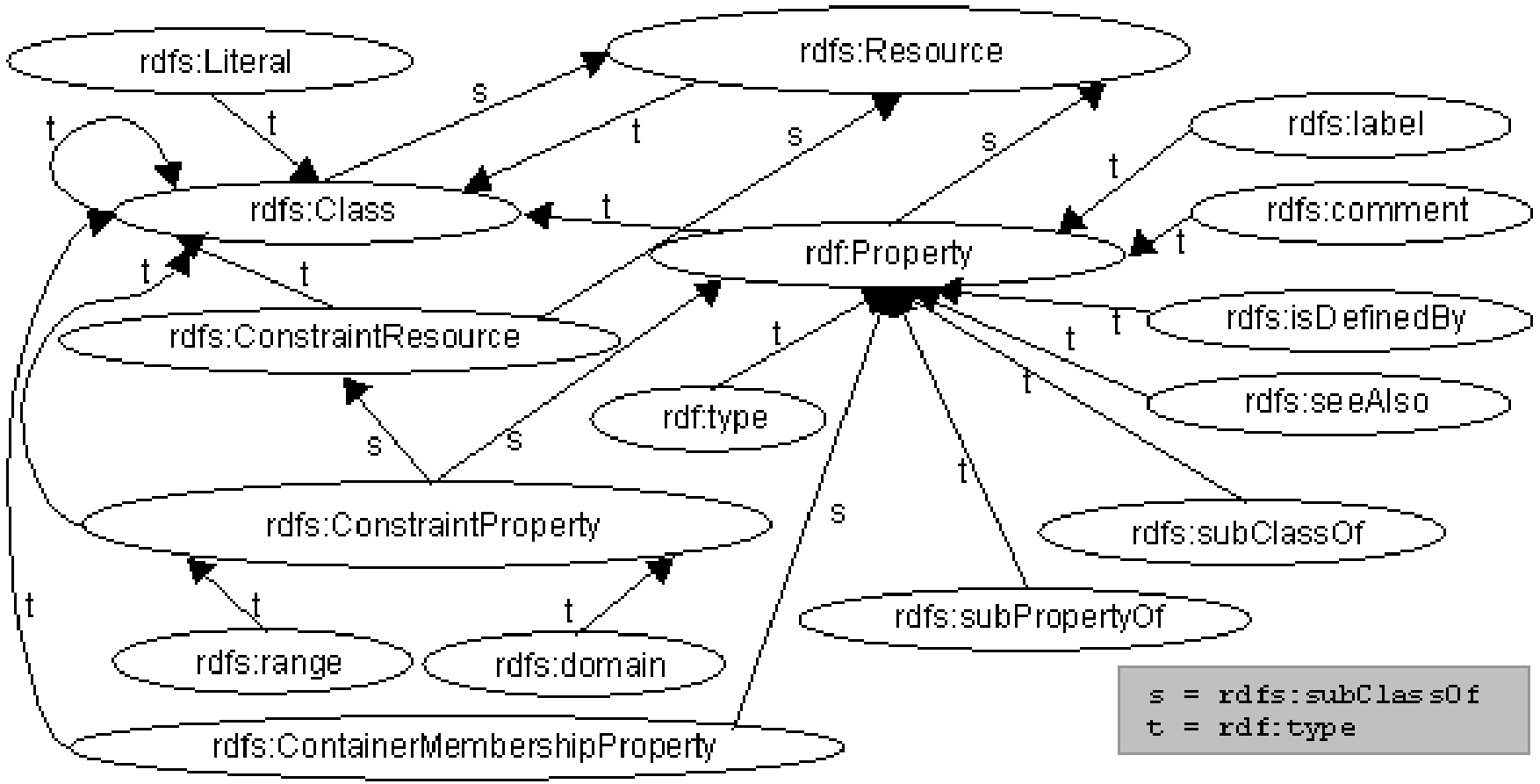
How to describe Schema Information in RDF/S

- Triples about properties can also be used to specify how properties should be used.
- **Example**: RDF provides several properties for describing properties:

```
<PropertyIRI>   rdf:type      rdfs:Property .                        # declare resource as property
<PropertyIRI>   rdfs:label    "some label"@en .                      # assign label
<PropertyIRI>   rdfs:comment  "Some human-readable comment"@en .
<PropertyIRI>   rdfs:range    xsd:decimal .                          # define range datatype
<PropertyIRI>   rdfs:domain   <classIRI> .                           # define domain type (class)
```

- There are many properties beyond those from the RDF standard for such purposes,
  ⇝ e.g., `rdfs:label` can be replaced by `<http://schema.org/name>` or `<http://www.w3.org/2004/02/skos/core#prefLabel>`
- RDF defines how its properties should be interpreted semantically (⇝ see OWL lectures)
- There are more elaborate ways of expressions schematic information in RDF
  - The **OWL Web Ontology Language** extends the semantic features of RDF
  - Constraint languages **SHACL** and **SHEX** can restrict graphs syntactically

A Simplified RDF Schema Language Model



RDF Schema Example

RDF Schema Example

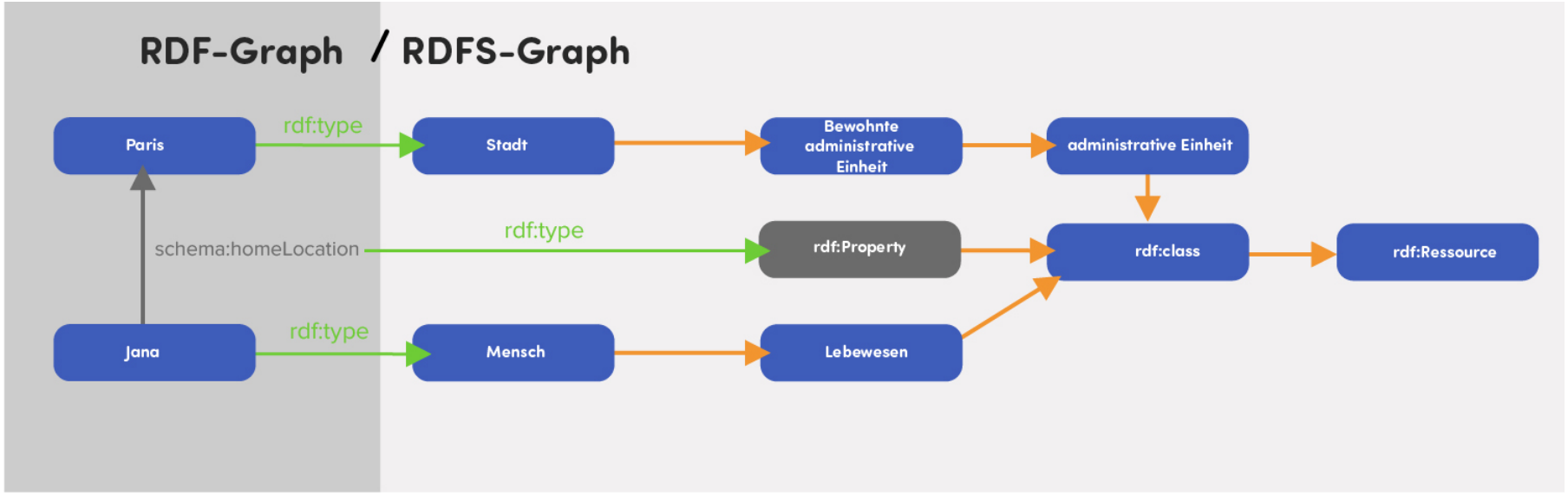
```
@prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#> .
@prefix rdf:  <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .
@prefix owl:  <http://www.w3.org/2002/07/owl#>
@prefix :     <http://example.org/Climate#> .
```

```
:Greenhouse_gas     rdf:type            rdfs:Class ;                  // Class Definitions
                    rdfs:subClassOf     :Air_pollutant .
:Person             rdf:type            rdfs:Class .
:Scientist          rdfs:subClassOf     :Person .
:Physicist          rdfs:subClassOf     :Scientist .
:Chemist            rdfs:subClassOf     :Scientist .
```

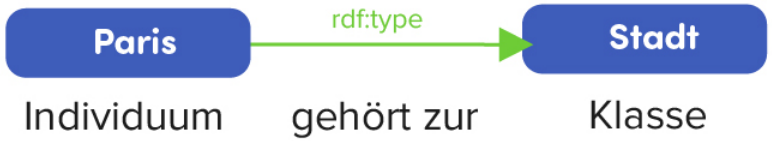
```
:discoverer         rdf:type            rdf:Property ;                // Property Definitions
                    rdfs:domain         owl:Thing ;
                    rdfs:range          :Person .
```

```
:Carbon_dioxide             rdf:type        :Greenhouse_gas ;         // Instance Definitions
                            :discoverer     :Jan_Baptist_van_Helmont ;
                            :discoverer     :Joseph_Black .
:Jan_Baptist_van_Helmont    rdf:type        :Physicist .
:Joseph_Black               rdf:type        :Chemist ;
                            rdfs:label      "Joseph Black"@en ;
                            rdfs:comment    "co-discovered CO2" .
```

RDF Schema Summary by Example



RDF-Triple



Klassenhierarchie