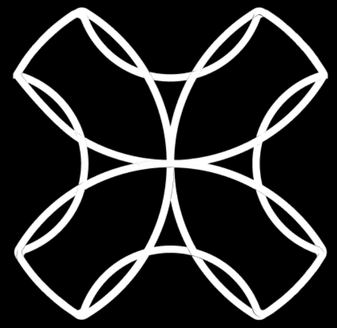


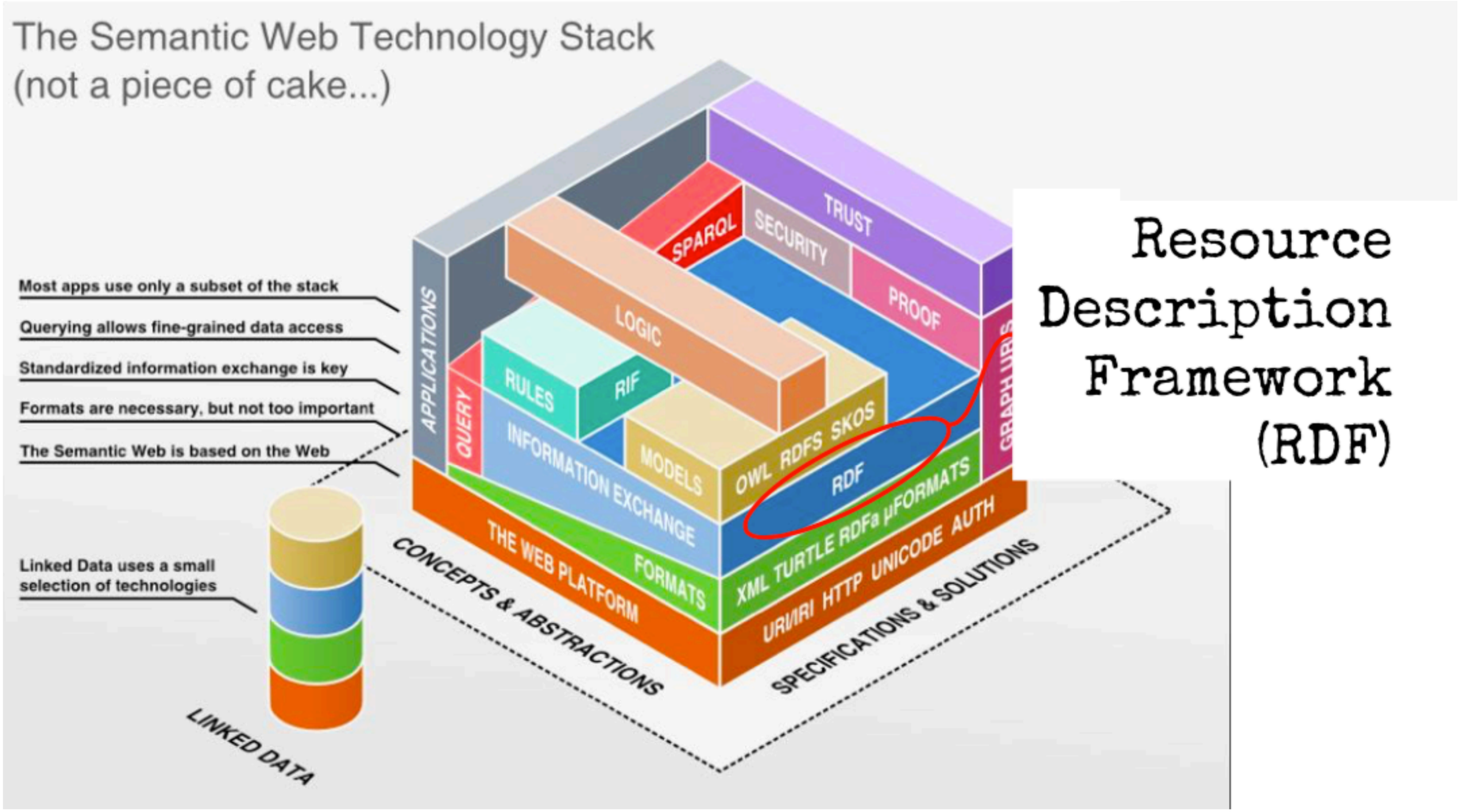
IKNEX

Knowledge Engineering and Linked Data

Fall 2023

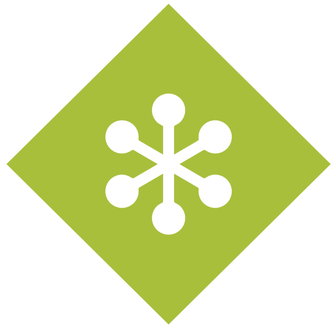
Dr. Amna Basharat | Ms. Amna binte Kamran

RDF


The Semantic Web Technology Stack
(not a piece of cake...)
Most apps use only a subset of the stack
Querying allows fine-grained data access
Standardized information exchange is key
Formats are necessary, but not too important
The Semantic Web is based on the Web
Linked Data uses a small selection of technologies
LINKED DATA
CONCEPTS & ABSTRACTIONS
SPECIFICATIONS & SOLUTIONS
APPLICATIONS
QUERY
SPARQL
TRUST
SECURITY
PROOF
LOGIC
RULES
RIF
INFORMATION EXCHANGE
MODELS
OWL RDFS SKOS
RDF
THE WEB PLATFORM
FORMATS
XML TURTLE RDFa µFORMATS
URI/IRI HTTP UNICODE AUTH
Resource Description Framework (RDF)

Resource Description Framework

Basic concepts of RDF
Formats for serializing RDF data
Advanced features of RDF
What is Linked Data?



Resource Description Framework

- **Resource**
  - can be everything
  - must be uniquely identified and referencable via URI
- **Description**
  - = description of resources
  - ia representing properties and relationships among resources as graphs
- **Framework**
  - = combination of web based protocols (URI, HTTP, XML, Turtle, JSON, ...)
  - based on formal model (semantics)

- Knowledge in RDF is expressed as a list of **statements**
- All RDF statements follow the same simple schema **(= RDF Triple)**

Resource Description Framework

URIs

Uniform Resource Identifier

- A Uniform Resource Identifier (URI) defines a simple and extensible schema for worldwide unique identification of abstract or physical resources (RFC 3986).

- A **Resource** can be every object with a clear identity (according to the context of the application)
  - as e.g., web pages, books, locations, persons, relations among objects, abstract concepts, etc.

- URI concept is already established in various domains, as e.g.,
  - the Web (URL),
  - Books and publications (ISBN, ISSN),
  - Digital Object Identifier (DOI)

What if a URI Does Not Exist (Yet)?

- Define a URI by yourself:
  - avoid overlaps → use your own website
  - enable documentation at the same place → Content Negotiation

- Use separate URIs for the resource (Designatum) and its documentation (Designator) via
  - Content Negotiation and/or
  - URI references (e.g. via "#" fragment identifier)

Resource Description Framework

- **RDF Statements (RDF-Triple):**

Subject	+	Property	+	Object / Value
URI		**URI**		**URI / Literal**

RDF Building Blocks

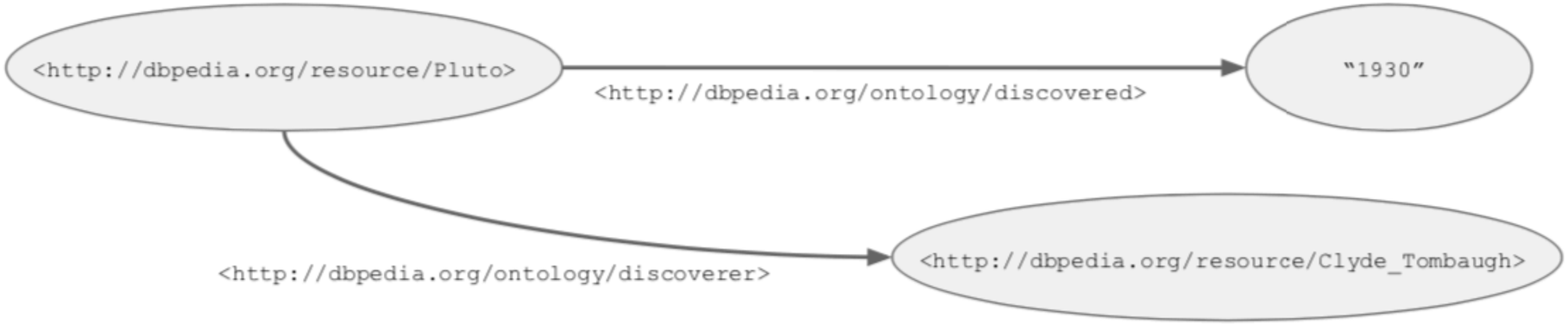
N-Triples Serialization

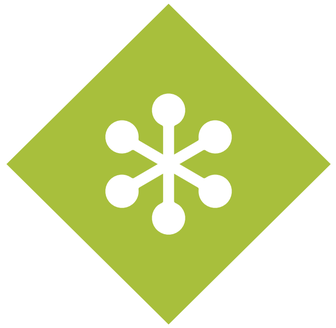
```
<http://dbpedia.org/resource/Pluto>    <http://dbpedia.org/ontology/discovered>    "1930" .
```

graph representation

Resource Description Framework

- **URIs and Literals**
  - URIs reference resources uniquely
  - Literals describe data values that don’t have a separate existence.





Literals and Data Types

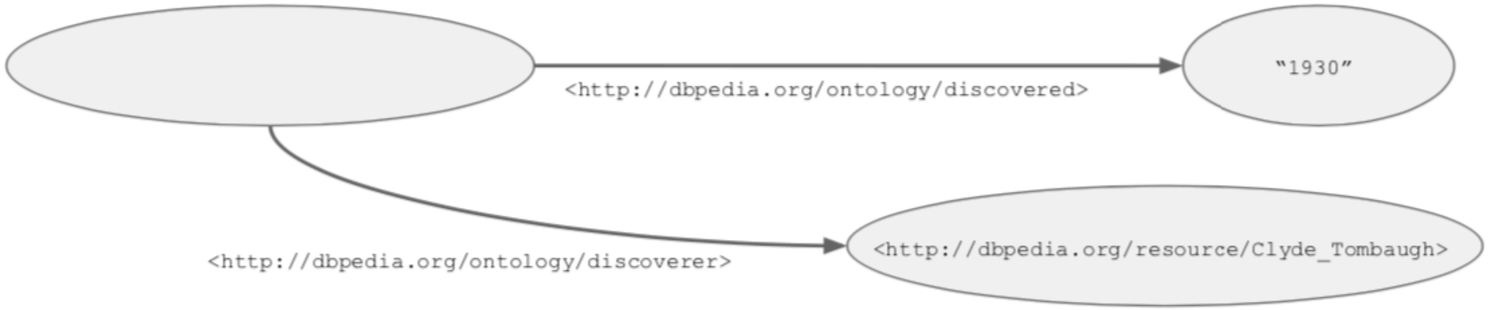
- typed literals can be expressed via **XML Schema datatypes**
- Namespace for typed literals:
  `http://www.w3.org/2001/XMLSchema#`
- Examples:

```
"Semantics"^^<http://www.w3.org/2001/XMLSchema#string>
"1161.00"^^<http://www.w3.org/2001/XMLSchema#float>
"2015-08-02"^^<http://www.w3.org/2001/XMLSchema#date>
```

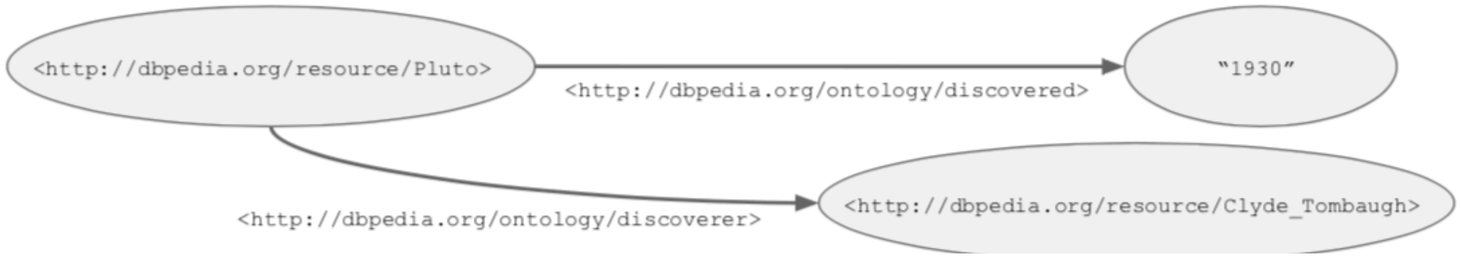
- **Language Tags** denote the (natural) language of the text:
  - Example:
    `"Semantik"@de , "Semantics"@en`

Blank Nodes

- **Blank Nodes**
  - denote existence of an individual with specific attributes, but without
  - providing an identification or reference



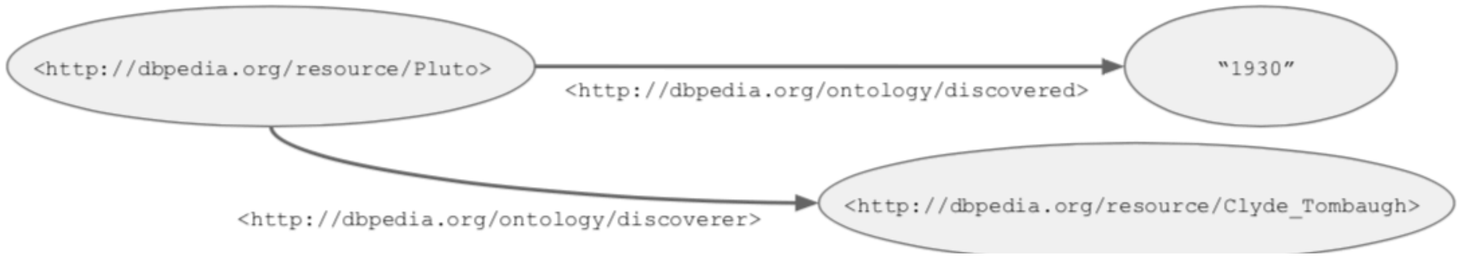
RDF Serialization



- **N-Triples Notation**
  - URIs/IRIs in angle brackets
  - Literals in quotation marks
  - Triple ends with a period

```
<http://dbpedia.org/resource/Pluto> <http://dbpedia.org/ontology/discovered> "1930" .

<http://dbpedia.org/resource/Pluto> <http://dbpedia.org/ontology/discoverer>
<http://dbpedia.org/resource/Clyde_Tombaugh> .
```

RDF Serialization

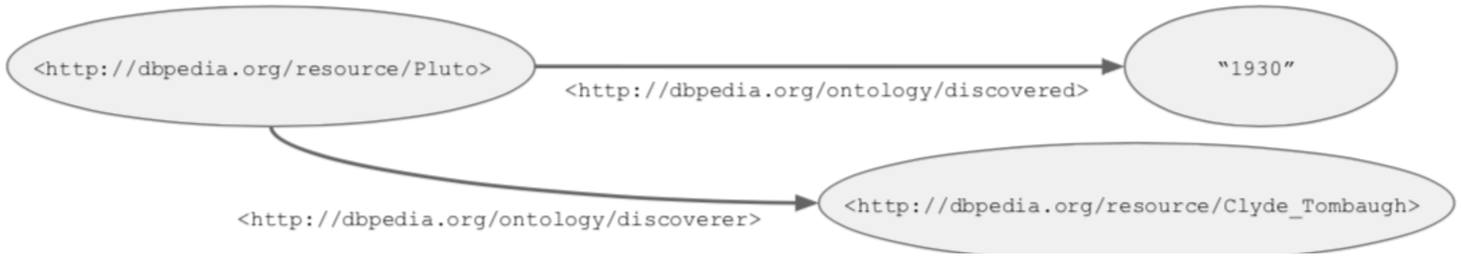


- **RDF/XML Notation**

S P O

```
<?xml version="1.0" encoding="utf-8" ?>
<rdf:RDF xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
         xmlns:ns0="http://dbpedia.org/ontology/">
  <rdf:Description rdf:about="http://dbpedia.org/resource/Pluto">
    <ns0:discovered>1930</ns0:discovered>
    <ns0:discoverer rdf:resource="http://dbpedia.org/resource/Clyde_Tombaugh"/>
  </rdf:Description>
</rdf:RDF>
```

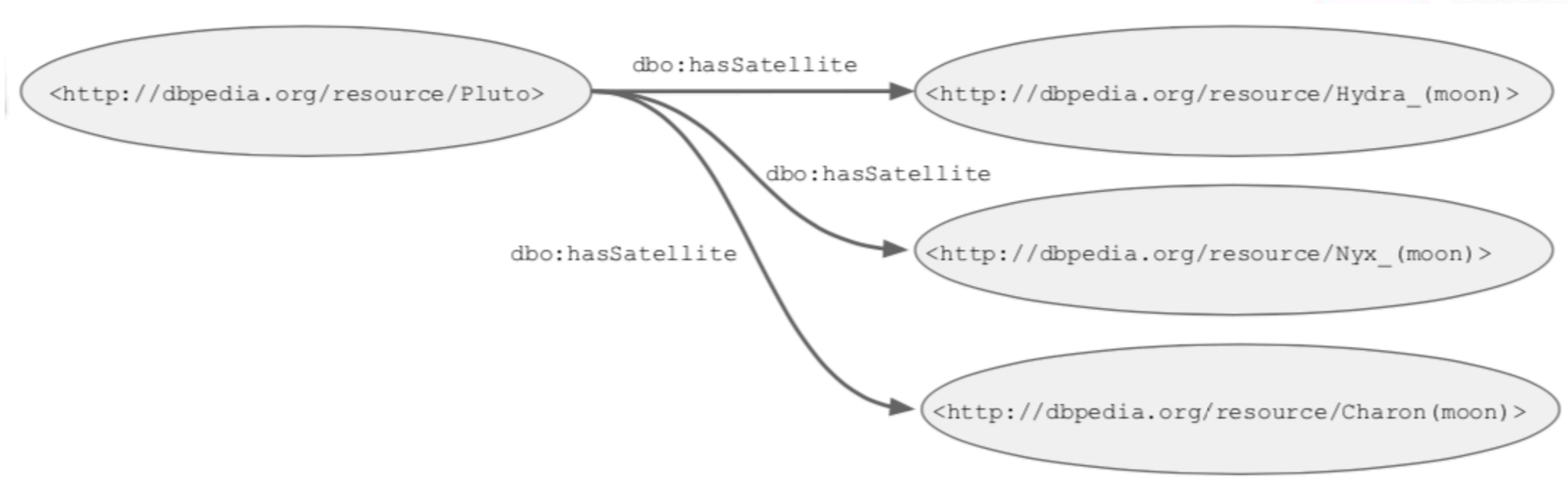
RDF Serialization



- **Turtle (Terse RDF Triple Language) Notation**
  - extension of N_Triples

```
@prefix dbo: <http://dbpedia.org/ontology/> .
@base  <http://dbpedia.org/resource/> .

<Pluto> dbo:discovered "1930" .

<Pluto> dbo:discoverer <Clyde_Tombaugh> .
```

RDF Serialization

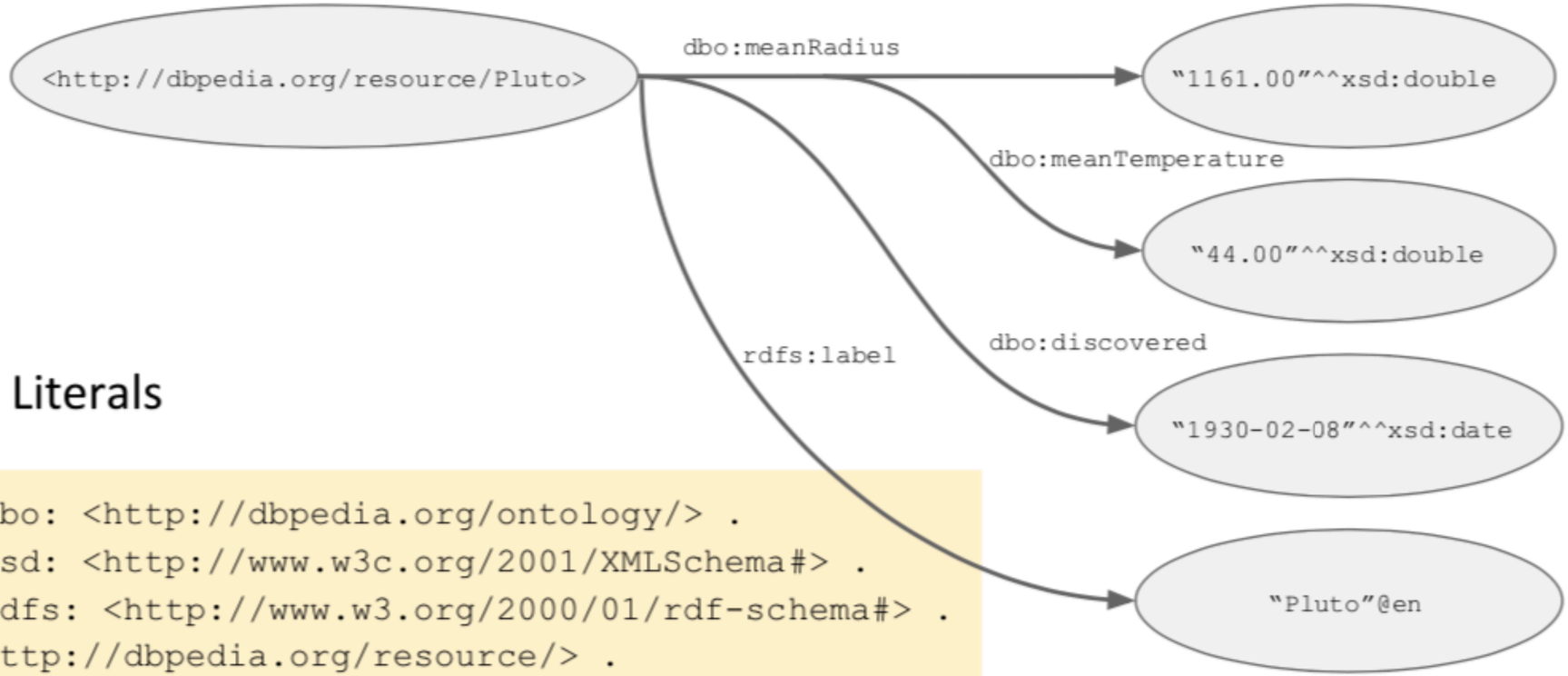


- **Abbreviating in Turtle**

```
@prefix dbo: <http://dbpedia.org/ontology/> .
@base  <http://dbpedia.org/resource/> .

<Pluto> dbo:hasSatellite <Hydra_(moon)> ,
                         <Nyx_(moon)> ,
                       <Charon_(moon)> .
```

comma indicates that subsequent triples have same subject and property **(object list)**

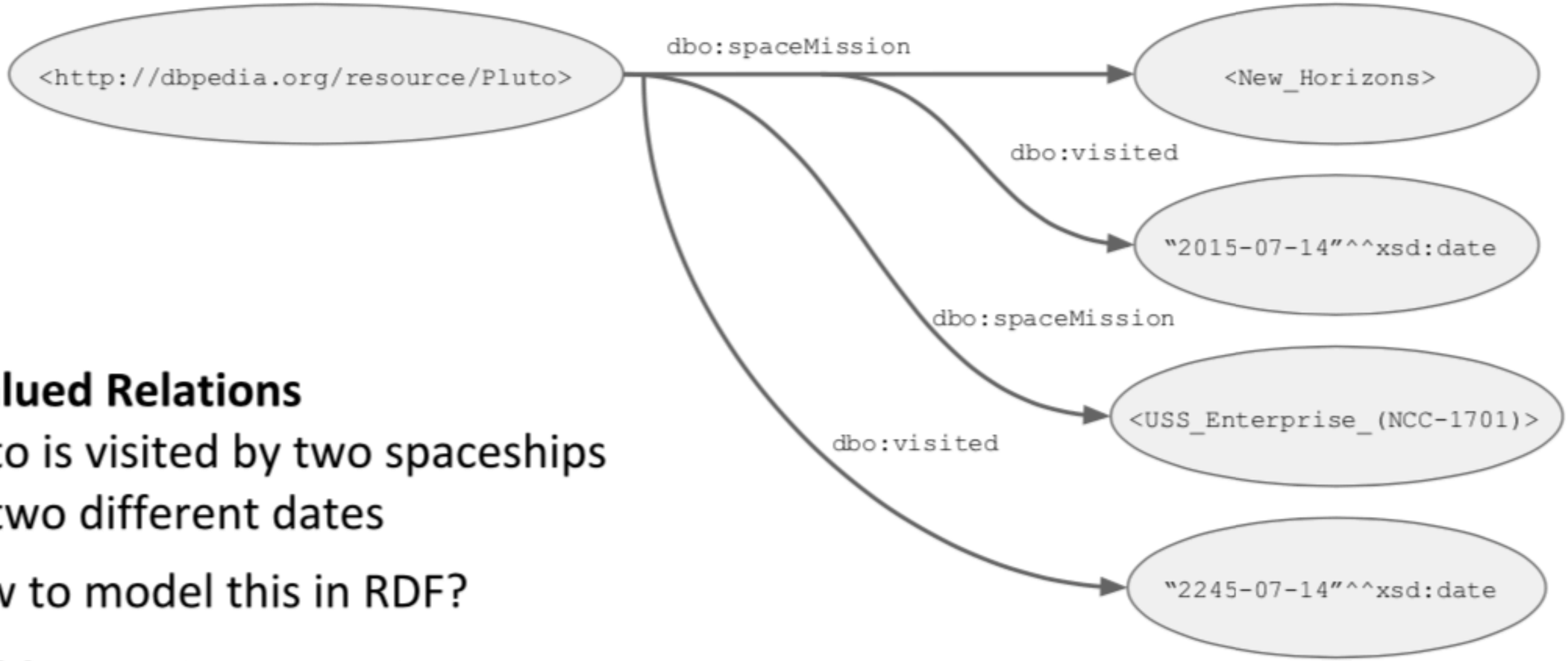
Turtle - Terse RDF



- Typed Literals

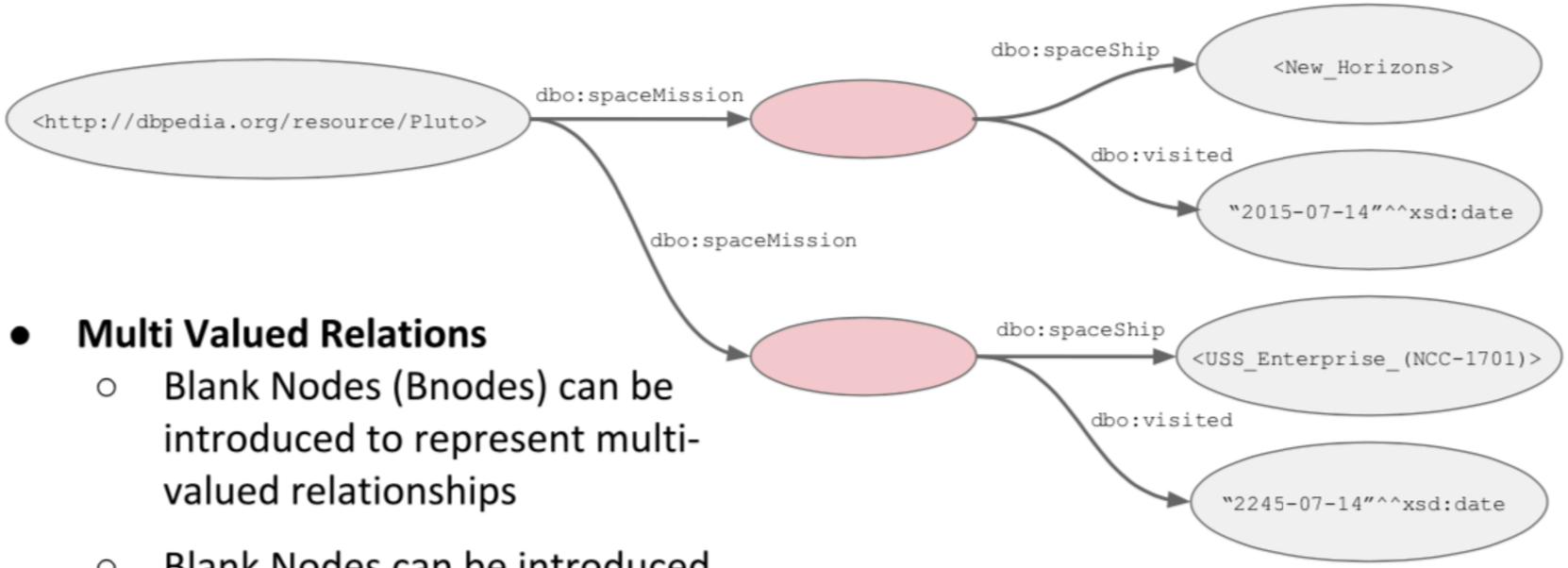
```
@prefix dbo: <http://dbpedia.org/ontology/> .
@prefix xsd: <http://www.w3c.org/2001/XMLSchema#> .
@prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#> .
@base  <http://dbpedia.org/resource/> .

<Pluto> dbo:meanRadius "1161.00"^^xsd:double ;
        dbo:meanTemperature "44.00"^^xsd:double ;
        dbo:discovered "1930-02-18"^^xsd:date ;
        rdfs:label "Pluto"@en .
```

Multi-Valued Relations



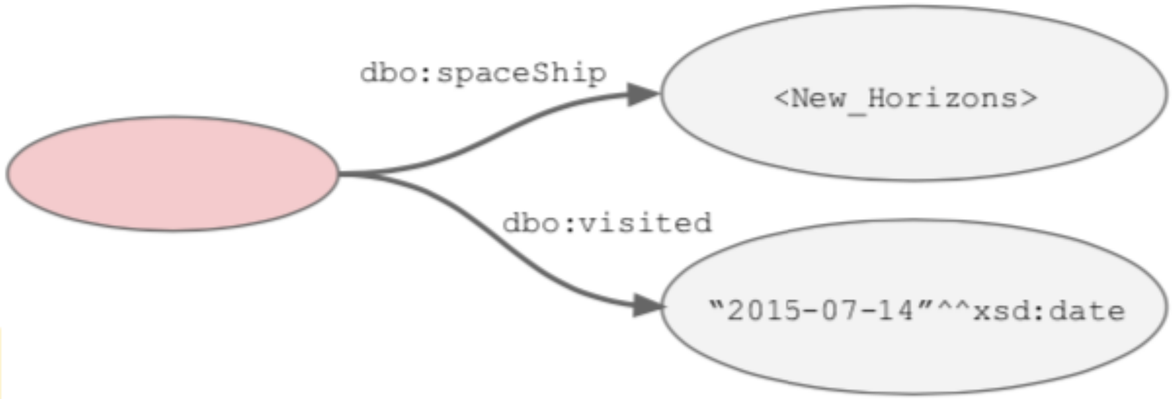
- **Multi Valued Relations**
  - Pluto is visited by two spaceships on two different dates
  - How to model this in RDF?
  - **Problem:** unique association

Blank Nodes



- **Multi Valued Relations**
  - Blank Nodes (Bnodes) can be introduced to represent multi-valued relationships
  - Blank Nodes can be introduced for resources that don‘t need a name (auxiliary nodes)

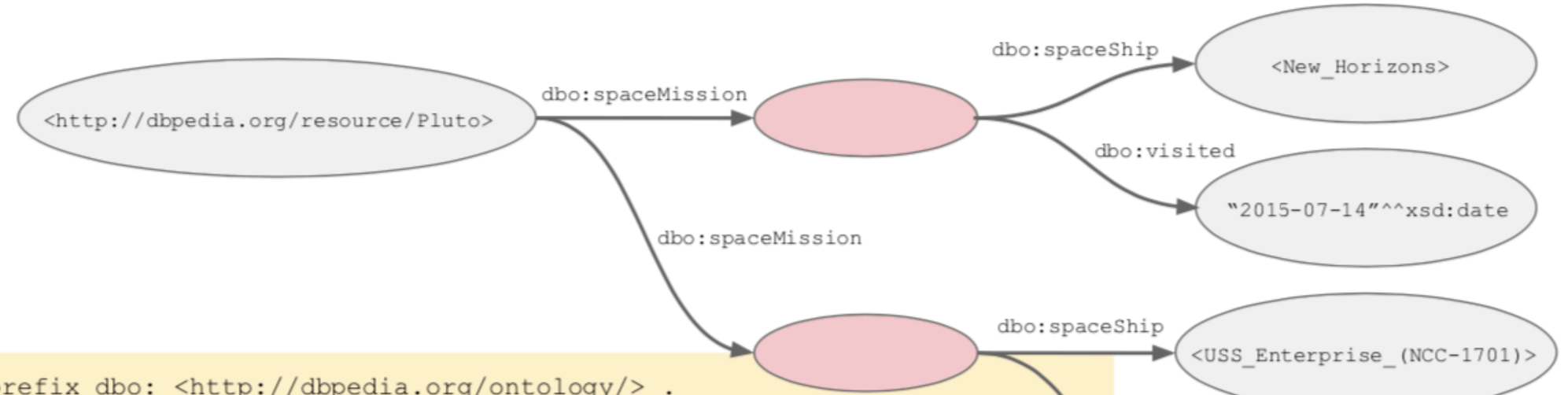
Turtle - Terse RDF




```
@prefix dbo: <http://dbpedia.org/ontology/> .
@prefix xsd: <http://www.w3c.org/2001/XMLSchema#> .
@base  <http://dbpedia.org/resource/> .

[] dbo:spaceShip <New_Horizons> ;
   dbo:visited "2015-07-14"^^xsd:date .
```

anonymous blank node as subject

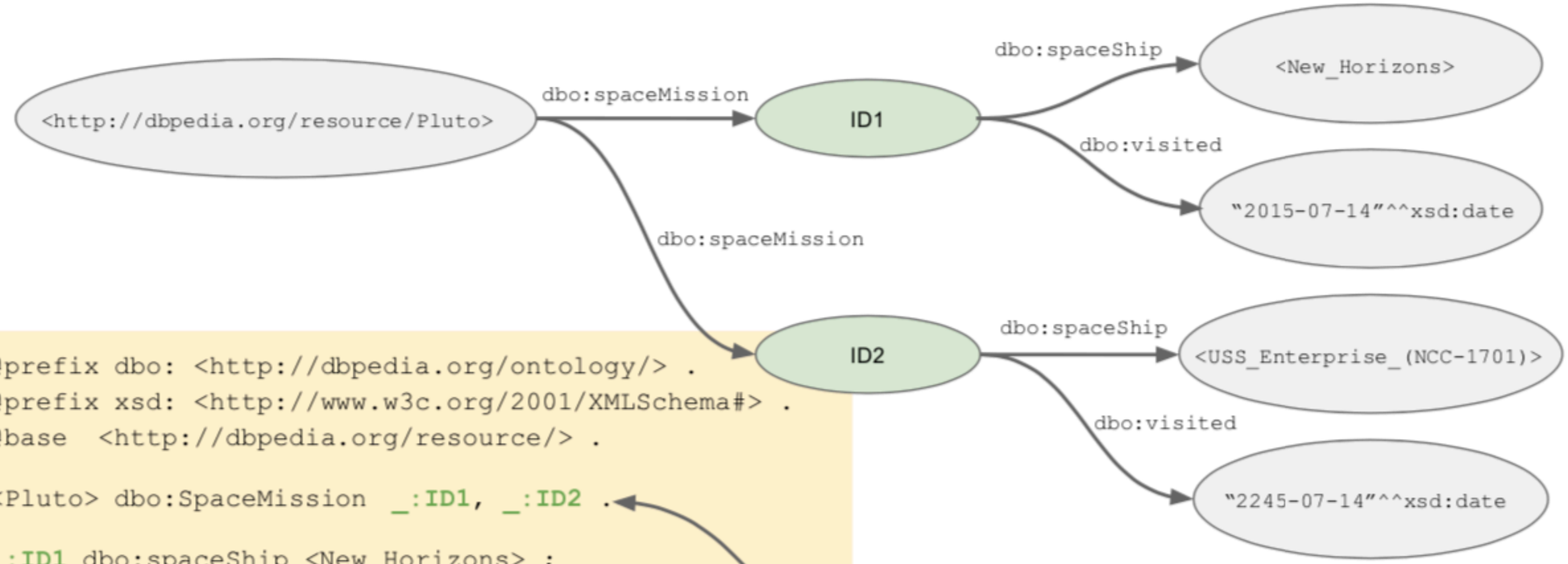
Turtle - Terse RDF




```
@prefix dbo: <http://dbpedia.org/ontology/> .
@prefix xsd: <http://www.w3c.org/2001/XMLSchema#> .
@base  <http://dbpedia.org/resource/> .

<Pluto> dbo:SpaceMission [ dbo:spaceShip <New_Horizons> ;
                           dbo:visited "2015-07-14"^^xsd:date .
                         ],
                         [ dbo:spaceShip <USS_Enterprise_(NCC-1701)> ;
                           dbo:visited "2245-07-14"^^xsd:date .
                         ].
```

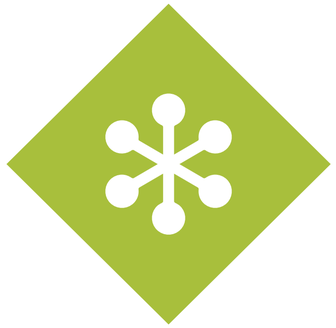
nested anonymous blank nodes

Turtle - Terse RDF




```
@prefix dbo: <http://dbpedia.org/ontology/> .
@prefix xsd: <http://www.w3c.org/2001/XMLSchema#> .
@base  <http://dbpedia.org/resource/> .

<Pluto> dbo:SpaceMission  _:ID1, _:ID2 .

_:ID1 dbo:spaceShip <New_Horizons> ;
      dbo:visited "2015-07-14"^^xsd:date .

_:ID2 dbo:spaceShip <USS_Enterprise_(NCC-1701)> ;
      dbo:visited "2245-07-14"^^xsd:date .
```

dereferencable blank nodes
can only be referenced from
inside a document / graph

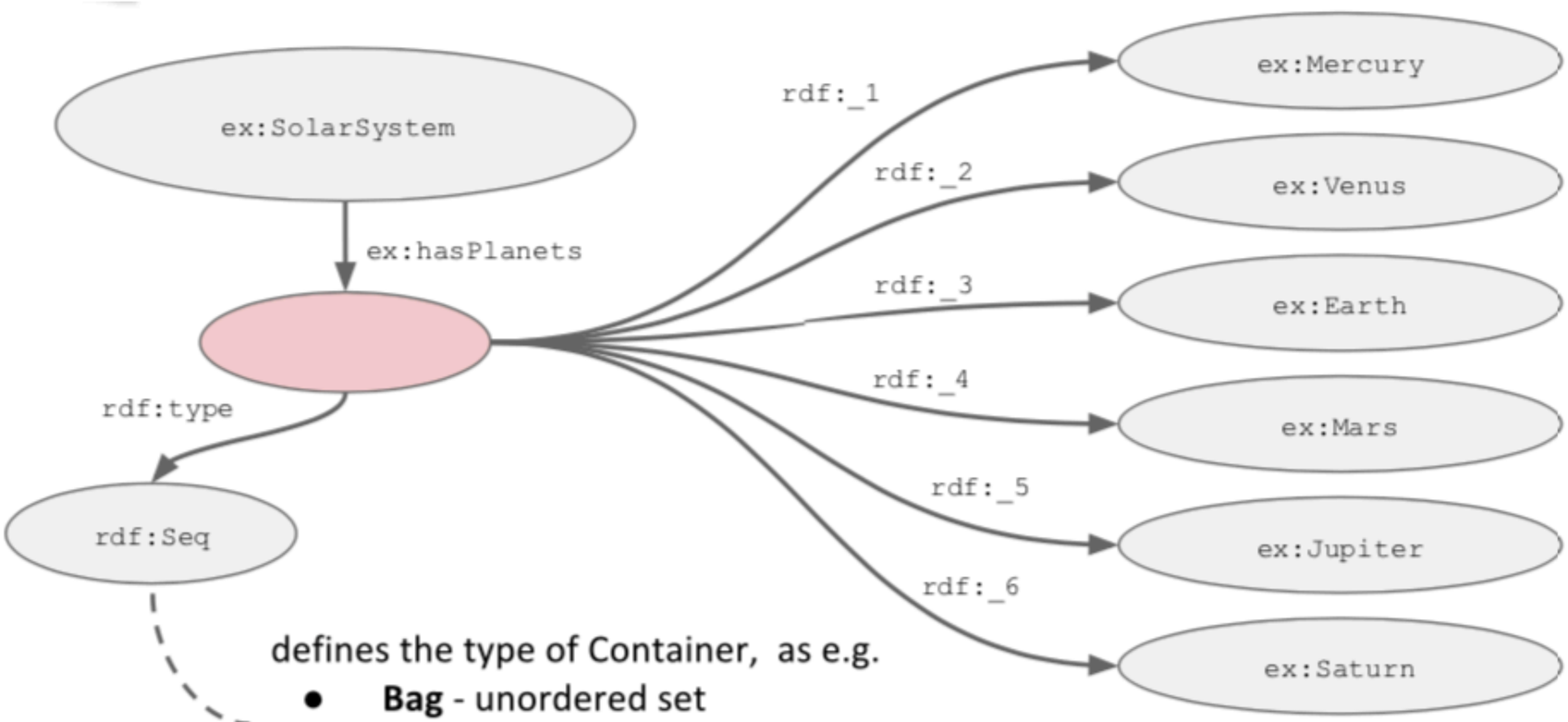


RDF Lists

- General Data structure to enumerate any resources or literals
- Only shortcuts without additional semantic expressivity

- Distinguish between
  - **Container**: open list, i.e. extension (new entries) possible
  - **Collection**: closed list, i.e. no extension possible

RDF Container

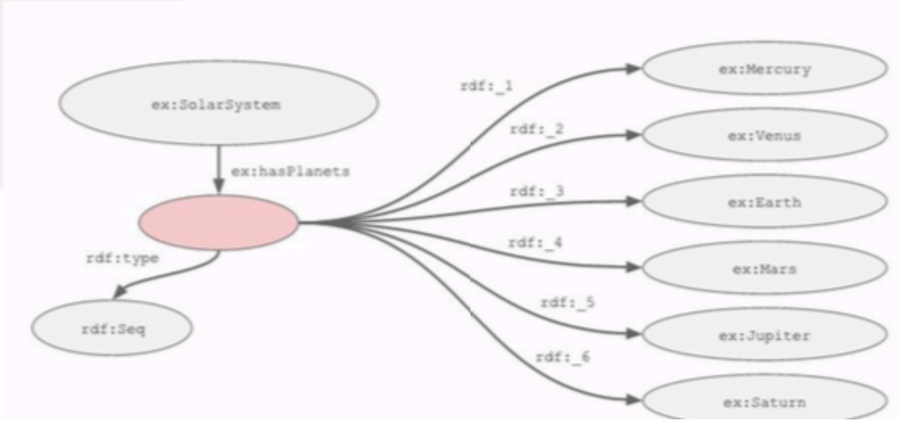


defines the type of Container, as e.g.

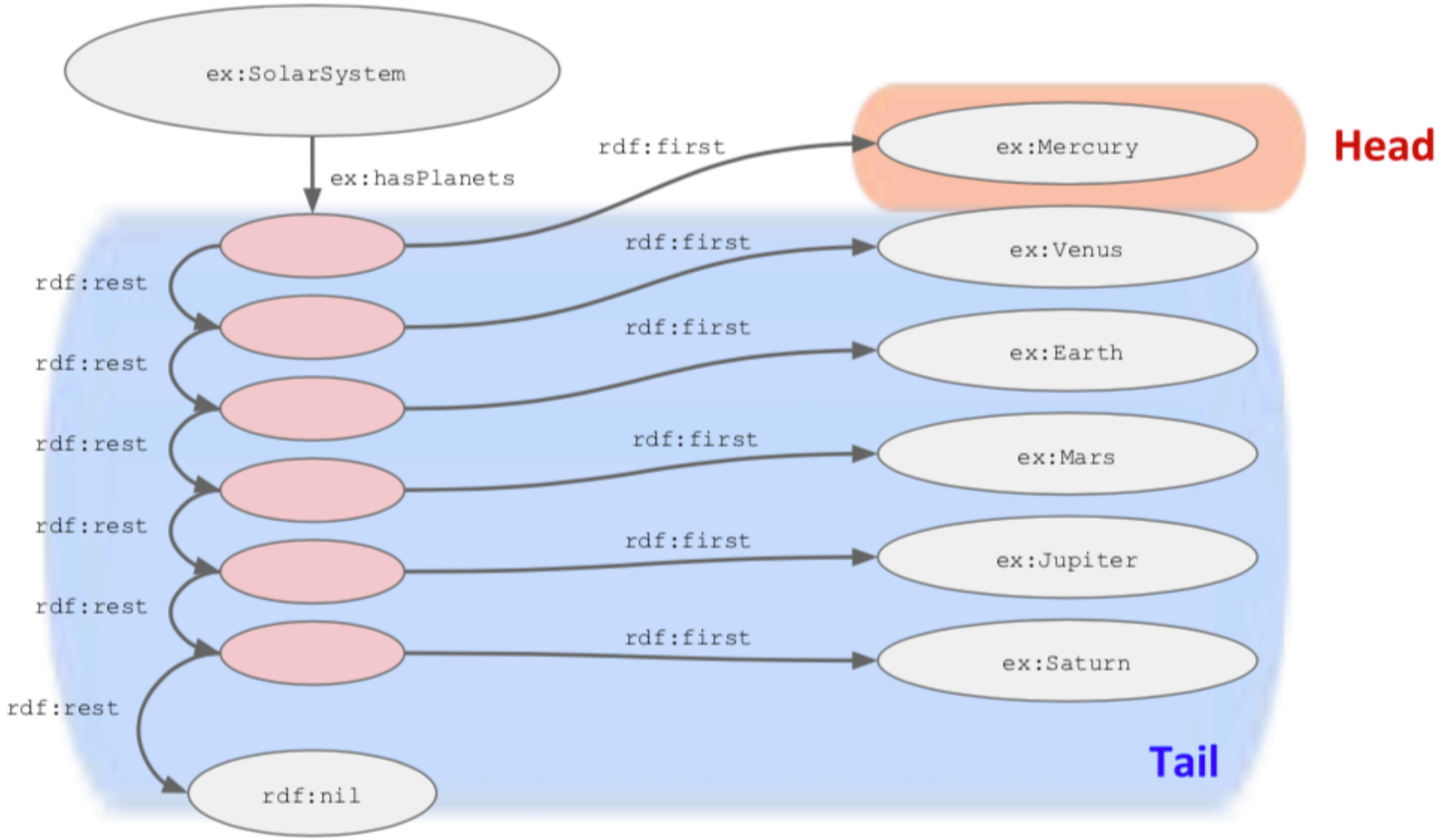
- **Bag** - unordered set
- **Seq** - ordered set
- **Alt** - alternatives

RDF Container

```
@prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .
@prefix ex: <http://example.org/test#> .

ex:SolarSystem ex:hasPlanets [
  a rdf:Seq ;
  rdf:_1 ex:Mercury ;
  rdf:_2 ex:Venus ;
  rdf:_3 ex:Earth ;
  rdf:_4 ex:Mars ;
  rdf:_5 ex:Jupiter ;
  rdf:_6 ex:Saturn
] .
```



RDF Collection

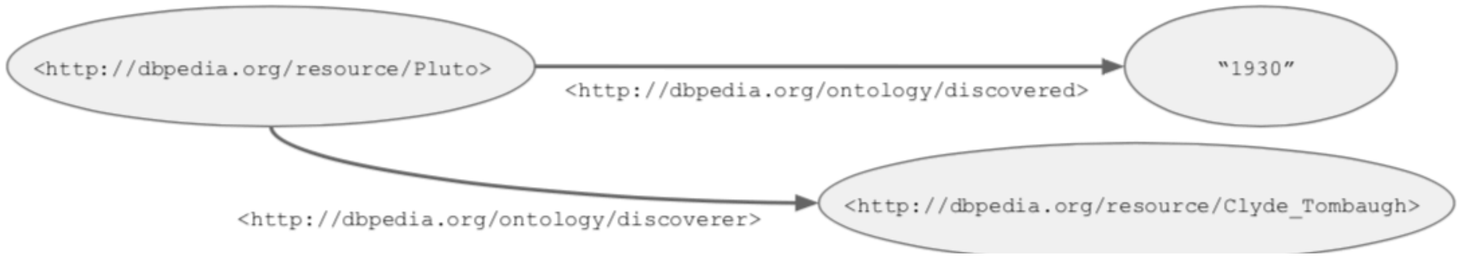


RDF Collection

```
@prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .
@prefix ex: <http://example.org/test#> .

ex:SolarSystem ex:hasPlanets [
  rdf:first ex:Mercury ; rdf:rest [
   rdf:first ex:Venus ; rdf:rest [
    rdf:first ex:Earth ; rdf:rest [
     rdf:first ex:Mars ; rdf:rest [
      rdf:first ex:Jupiter ; rdf:rest [
       rdf:first ex:Saturn ;
       rdf:rest rdf:nil
     ]
    ]
   ]
  ]
 ]
] .
```


```
@prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .
@prefix ex: <http://example.org/test#> .

ex:SolarSystem ex:hasPlanets (
  ex:Mercury ex:Venus ex:Earth ex:Mars ex:Jupiter ex:Saturn
) .
```

RDF Serialization



- **JSON-LD Notation (RDF 1.1)**

```
{
 "http://dbpedia.org/resource/Pluto" : {
     "http://dbpedia.org/ontology/discovered" : [ { "value" : "1930",
                                                    "type" : "literal" } ]
  } {
     "http://dbpedia.org/ontology/discoverer" : [ { "value" : "http://dbpedia.org/resource/Clyde_Tombaugh",
                                                    "type" : "uri" } ]
  }
}
```

How Would You Say?

"My dear Watson, ...I suppose that it was the gardener who has killed the butler!"

RDF Reification

Making Statements about Statements

RDF Reification

- RDF also permits interleaving of statements, i.e. to make statements about statements
- Example:
  - Sherlock Holmes supposes that the gardener has killed the butler
-
  - **Part 1**: the gardener has killed the butler

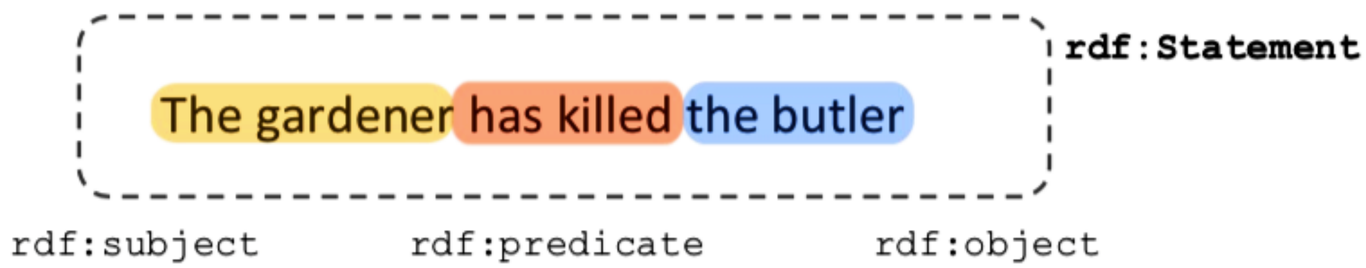
    ```
    ex:Gardener ex:hasKilled  ex:butler .
    ```

  - **Part 2**: Sherlock Holmes supposes...

    ```
    dbpedia:Sherlock_Holmes ex:supposes ????
    ```

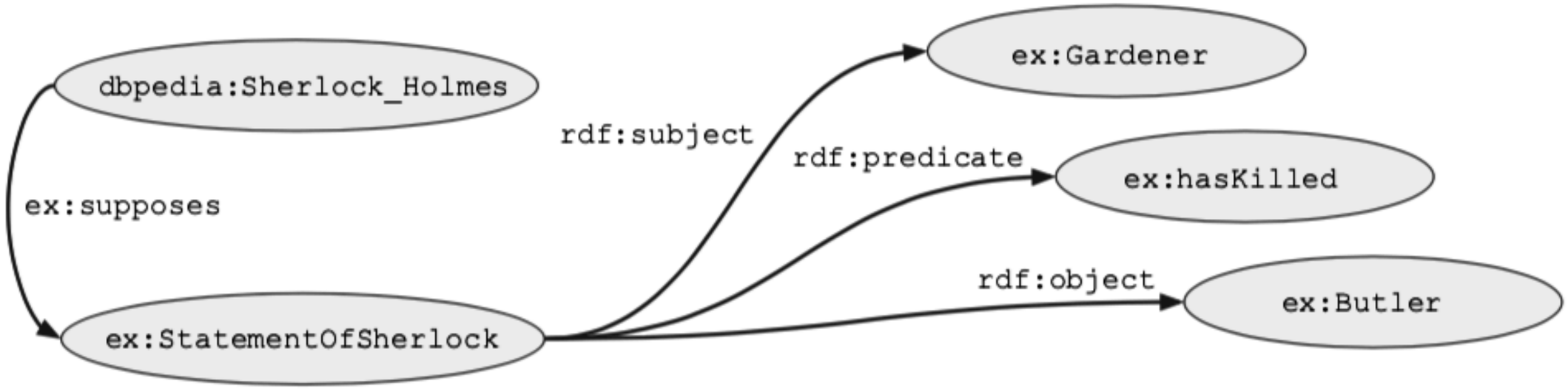
RDF Reification

- **rdf:Statement**
  defines an RDF statement consisting of subject, predicate, object
-
  - `rdf:subject` - the described resource
  - `rdf:predicate` - the original property
  - `rdf:object` - the value of the property



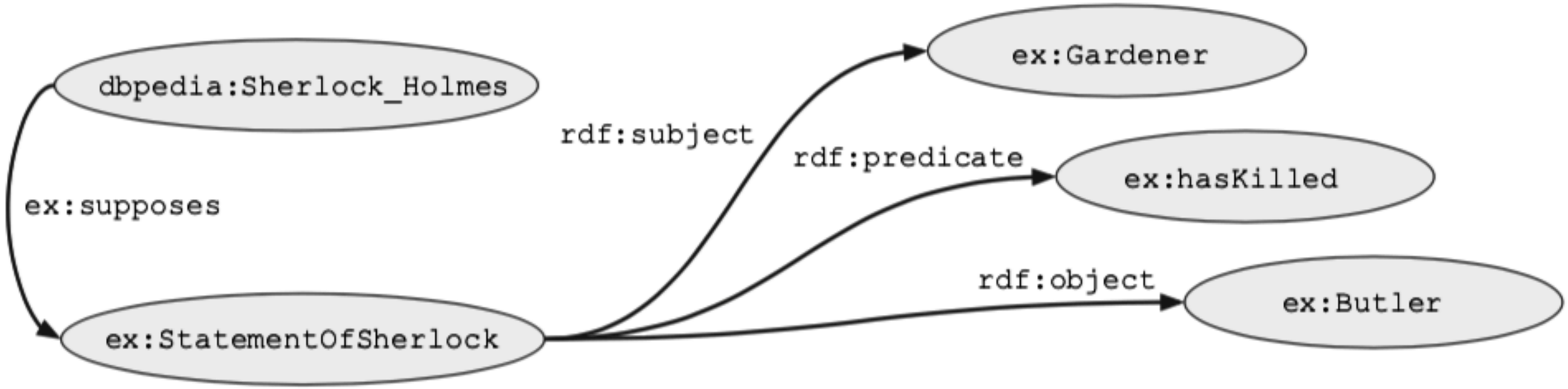
RDF Reification

- Sherlock Holmes supposes that the gardener has killed the butler



@prefix	**rdf: <http://www.w3.org/1999/02/22-rdf-syntax-** **.**
@prefix	dbpedia <http://dbpedia.org/resource/> .
@prefix	ex: <http://example.org/Crimestories#> .

RDF Reification




```
@prefix dbpedia: <http://dbpedia.org/resource/> .
@prefix rdf:     <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .
@prefix ex:      <http://example.org/Crimestories#> .

dbpedia:SherlockHolmes ex:supposes ex:StatementOfSherlock .
ex:StatementOfSherlock a rdf:Statement ;
rdf:subject ex:Gardener ;
rdf:predicate ex:hasKilled ;
rdf:object ex:Butler .
```

RDF Reification

- What is the use of reification?
  - modeling data provenance
  - formalizing statements about reliability and trust
  - define metadata about statements

- But… you should be careful….
  - with reification relations can be transformed into classes/instances (type conflicts)
  - definition of infinite recursions and cycles

RDFS

Enhancing the expressivity of RDF

What does it really mean?

http://dbpedia.org/resource/Pluto

http://dbpedia.org/property/satelliteOf

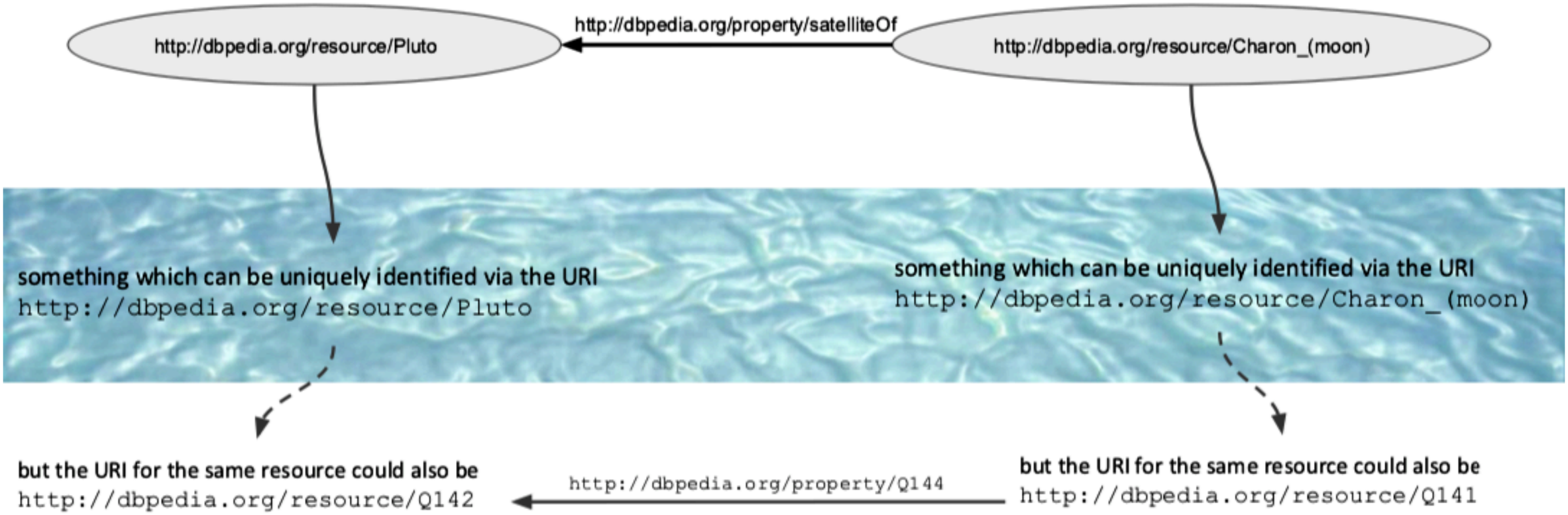
http://dbpedia.org/resource/Charon_(moon)

http://dbpedia.org/ontology/discoverer

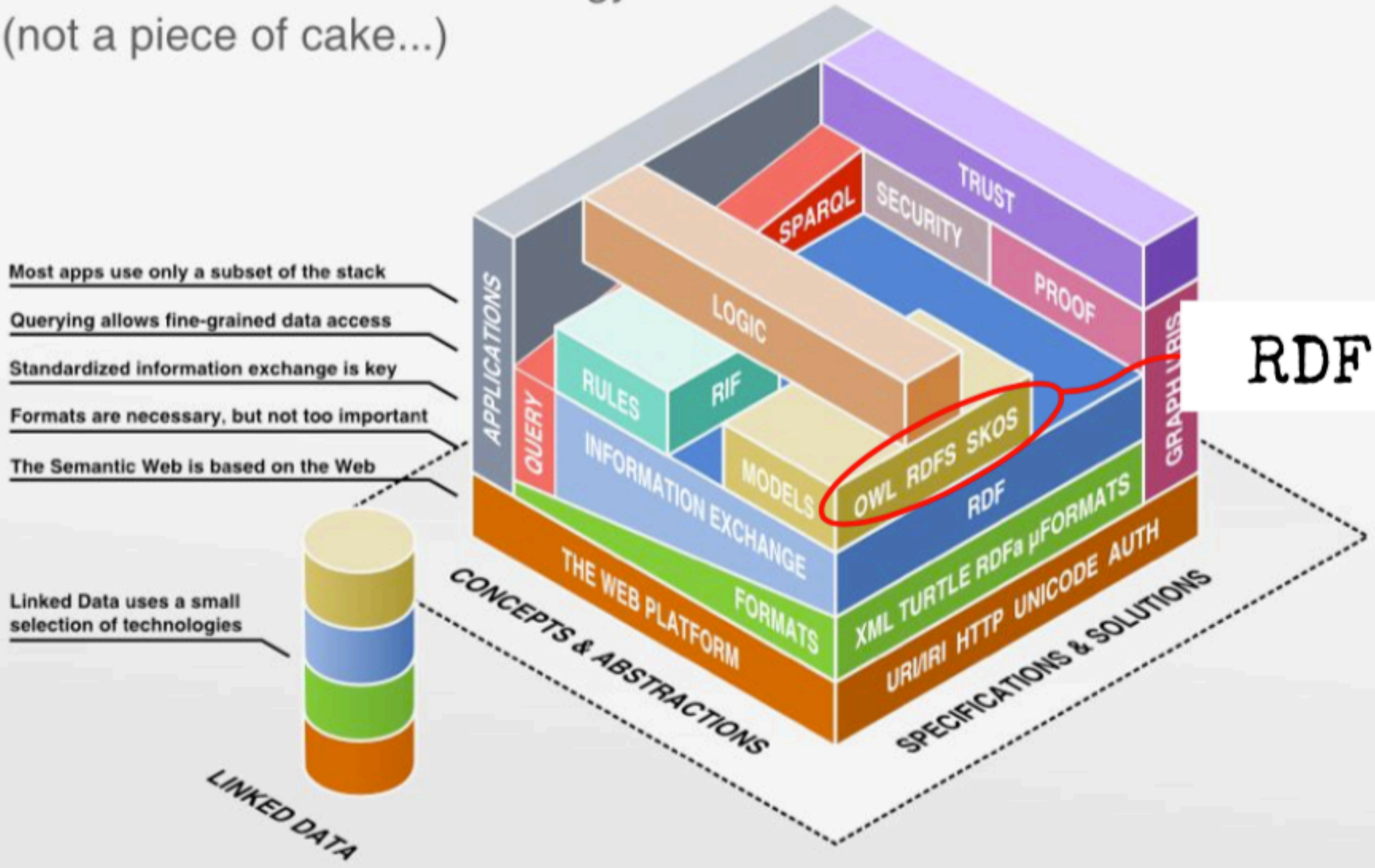
http://dbpedia.org/resource/Clyde_Tombaugh

Where does the intended meaning really come from?

What Does It Really Mean?



The Semantic Web Technology Stack
(not a piece of cake...)



RDF Schema

RDF Schema

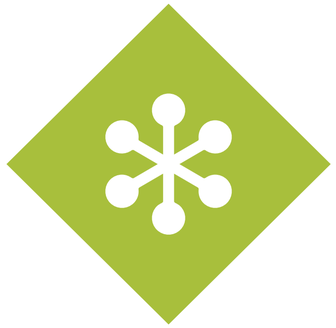
- RDF Schema, officially called “RDF Vocabulary Description Language”

- RDF Schema allows:
  - Definition of classes via rdfs:Class
  - Class instantiation in RDF via rdf:type

- Example:
  - :Planet rdf:type rdfs:Class .
  - :Earth rdf:type :Planet .

RDF Schema

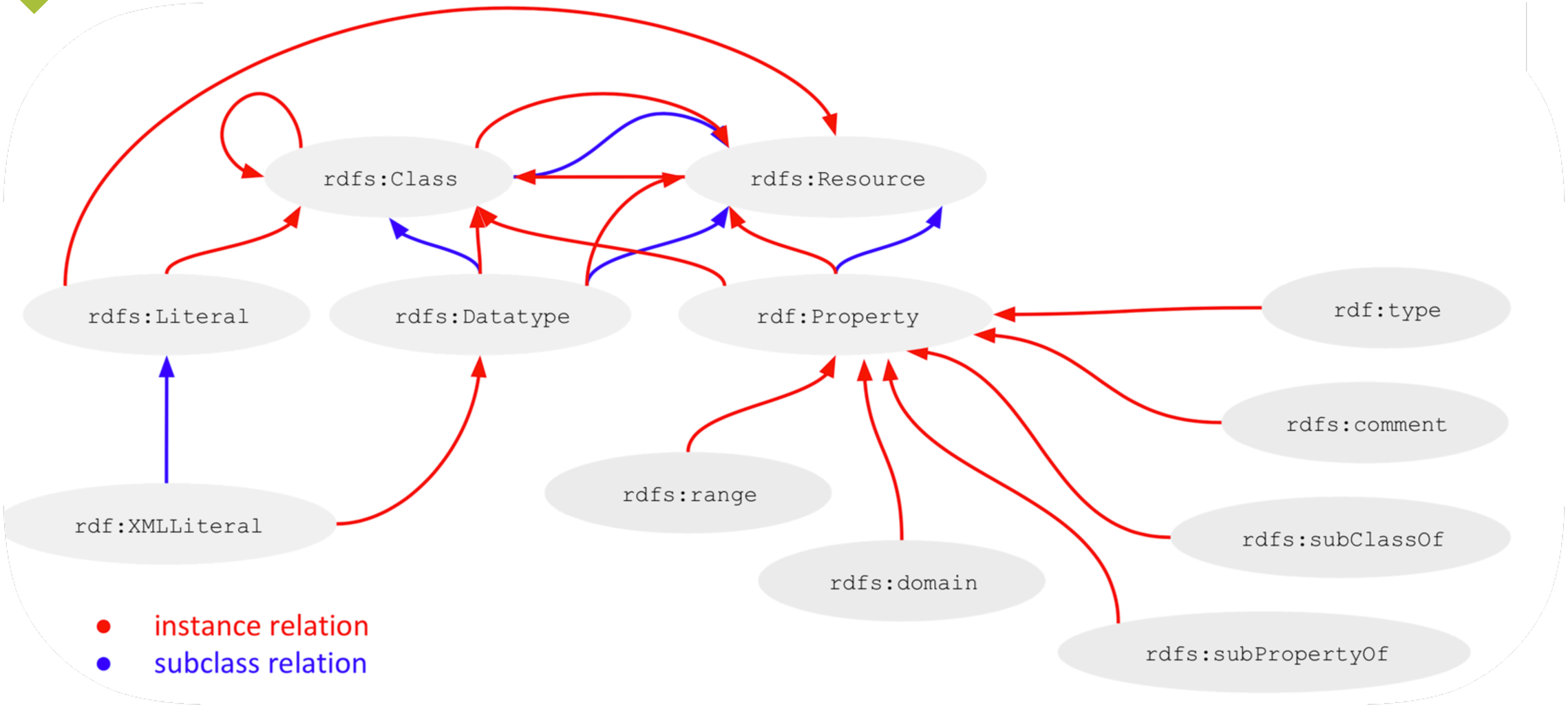
- Definition of properties via rdf:Property
- Definition of property restrictions on domain and range via rdfs:domain and rdfs:range
- Example
  - :CelestialBody rdf:type rdfs:Class .
  - :satelliteOf rdf:type rdf:Property .
  - :satelliteOf rdfs:domain :CelestialBody .
  - :satelliteOf rdfs:range :CelestialBody .



RDF Schema

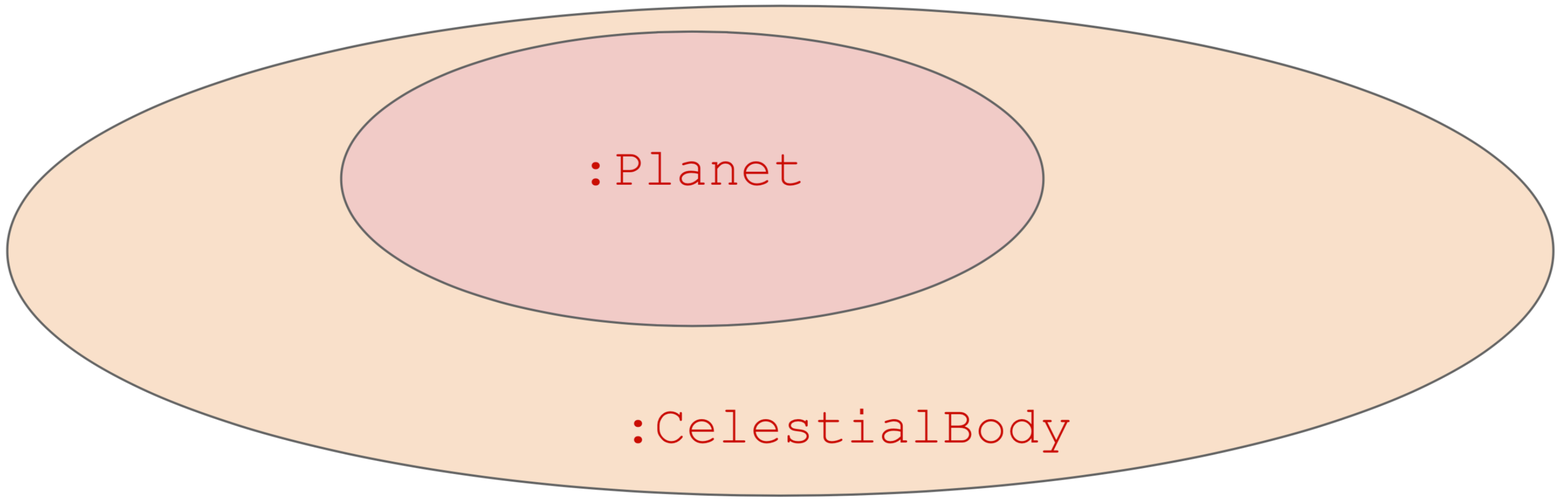
- Everything in the RDF model is a resource
  - rdfs:Class rdf:type rdfs:Resource .
  - rdf:Property rdf:type refs:resource .
  - rdfs:Literal rdf:type rdfs:Resource .
  - rdfs:XMLLiteral rdf:type rdfs:Resource .
  - rdfs:Datatype rdf:type rdfs:Resource .
  - rdfs:Container rdf:type rdfs:Resource .
  - rdfs:ContainerMembershipProperty rdf:type rdfs:Resource .

RDF Schema


rdfs:Class
rdfs:Resource
rdfs:Literal
rdfs:Datatype
rdf:Property
rdf:type
rdfs:comment
rdfs:range
rdf:XMLLiteral
rdfs:subClassOf
rdfs:domain
rdfs:subPropertyOf
instance relation
subclass relation

Definition of Hierarchical Relationships

- Subclasses and superclasses via rdfs:subClassOf
  - Example:
    - *:Planet rdfs:subClassOf :CelestialBody .*



Definition of Hierarchical Relationships

- Definition of hierarchical relationships:
  - Subclasses and superclasses via rdfs:subClassOf
  - Example:
    - *:Planet rdfs:subClassOf :CelestialBody .*
  - Subproperties and superproperties via subPropertyOf
  - Example
    - *:artificialSatelliteOf rdfs:subPropertyOf :satelliteOf .*

RDF Schema

- Some more properties:
  - **rdfs:seeAlso**
    defines a relation of a resource to another, which explains it
  - **rdfs:isDefinedBy**
    subproperty of rdfs:seeAlso, defines the relation of a resource to its definition
  - **rdfs:comment** comment, usually as text
  - **rdfs:label**
    „readable“ name of a resource (contrary to ID)
  - **rdfs:member**
    super-property of all the container membership properties (e.g. rdf:_1, ...)

RDFS Example

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

```
:Planet rdf:type         rdfs:Class ;
        rdfs:subClassOf :CelestialBody .
:Satellite rdf:type         rdfs:Class ;
           rdfs:subClassOf :CelestialBody .
:ArtificialSatellite rdf:type         rdfs:Class ;
                     rdfs:subClassOf :Satellite .
```

Class Definitions

```
:satelliteOf   rdf:type    rdf:Property ;
               rdfs:domain :CelestialBody .
               rdfs:range  :CelestialBody .
```

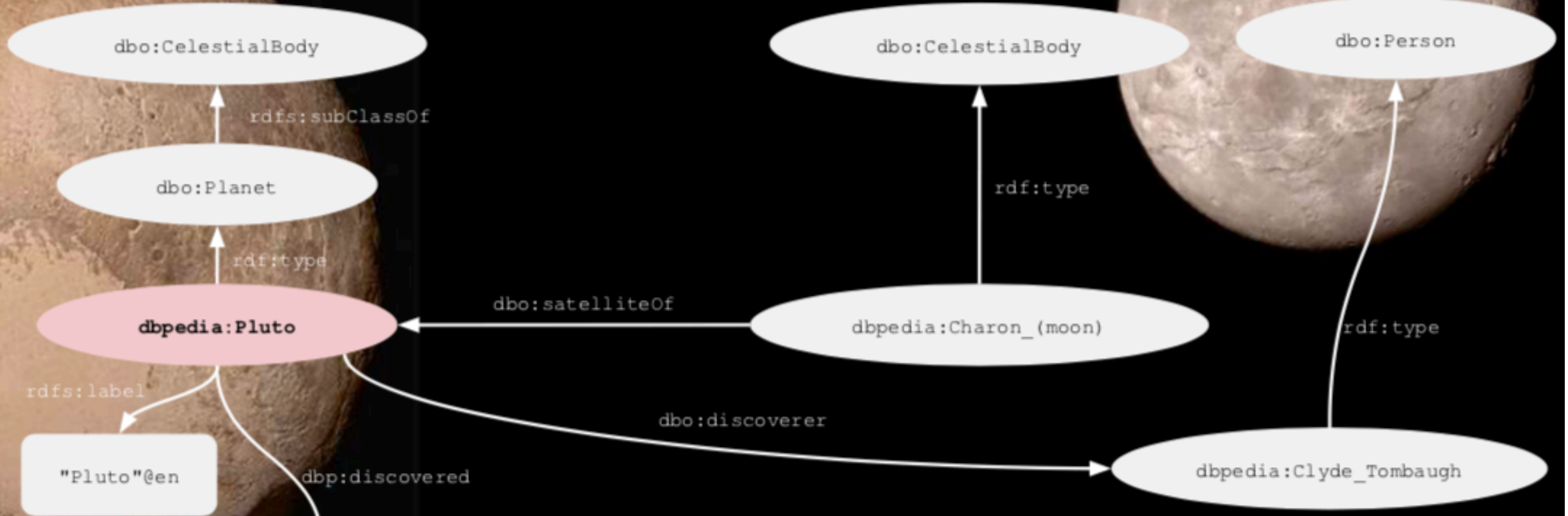
Property Definitions

```
:Earth    rdf:type     :Planet .
:Moon     rdf:type     :Satellite ;
          :satelliteOf :Earth .
:Sputnik1 rdf:type     :ArtificialSatellite ;
          :satelliteOf :Earth ;
          rdfs:label   "Sputnik 1"@en ;
          rdfs:comment "the first artificial Earth satellite in 1957" .
```

Instance Definitions

Logical Inference With RDFS

How much knowledge (semantics) is there?



The semantics of a term from an RDF(S) ontology is given in terms of its properties and its values (instances)

RDF(S) Semantics

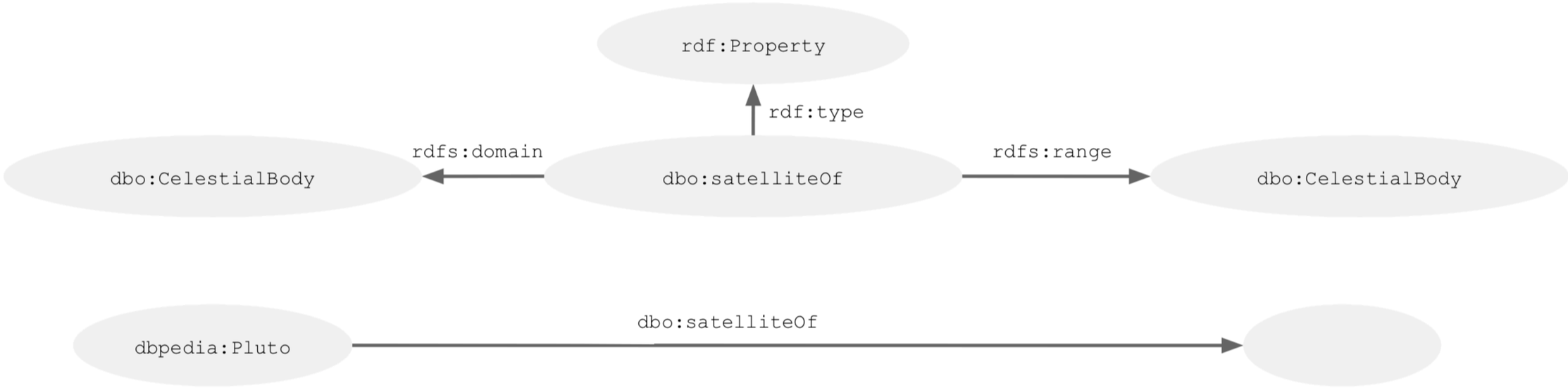
- In difference to other data definition languages, RDF(S) is based on **formal semantics**
- Formal semantics enables RDF(S) to draw **valid** and **sound logical inferences**

- Examples:
  - dbpedia:Pluto rdf:type dbo:Planet
  - dbo:Planet rdfs:subClassOf dbo:CelestialBody
  - dbo:artificialSatelliteOf rdfs:subPropertyOf dbo:satelliteOf

dbpedia:Pluto ∈ dbo:Planet
dbo:Planet ⊆ dbo:CelestialBody
dbo:artificialSatelliteOf ⊆ dbo:satelliteOf

Model-theoretic Semantics

Which Conclusions Can We Deduce With RDF(S)?



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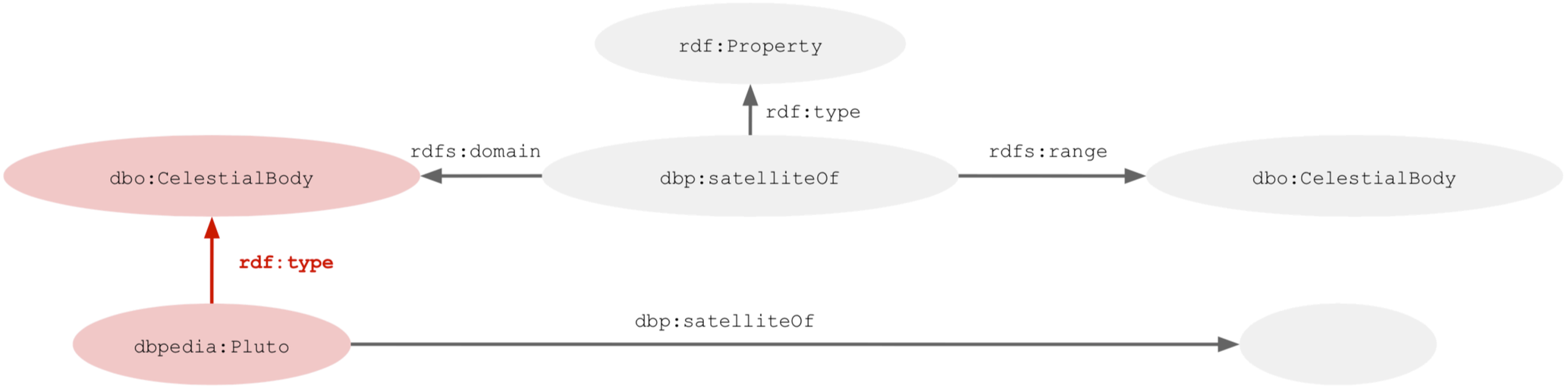
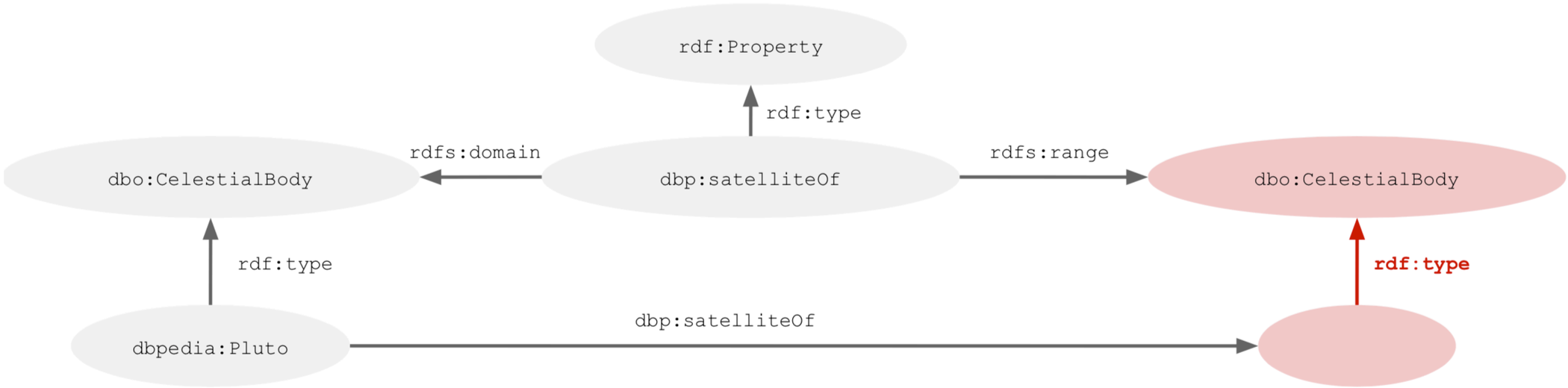


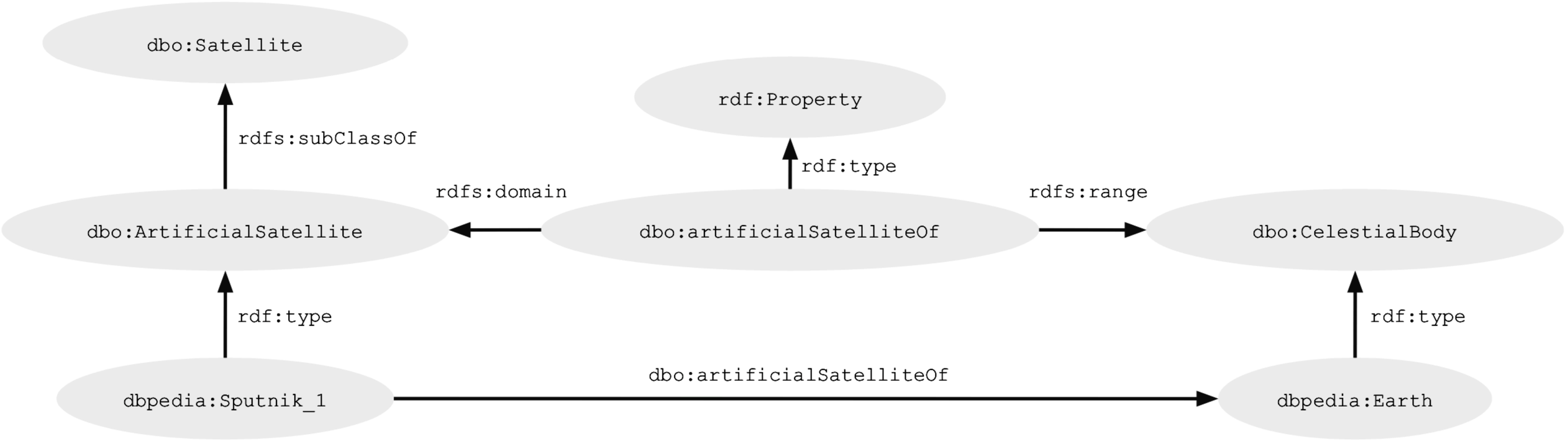
- Deduction of entity **class membership** from **domain** of one of its properties

Which Conclusions Can We Deduce With RDF(S)?

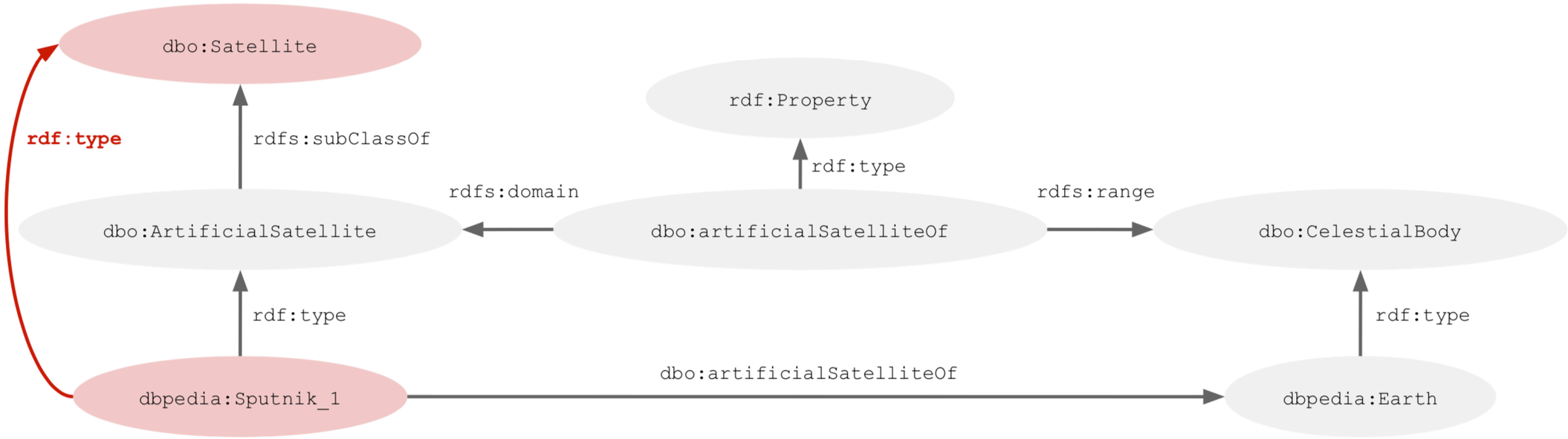


- Deduction of entity **class membership** from the **range** of one of its properties

Which Conclusions Can We Deduce With RDF(S)?

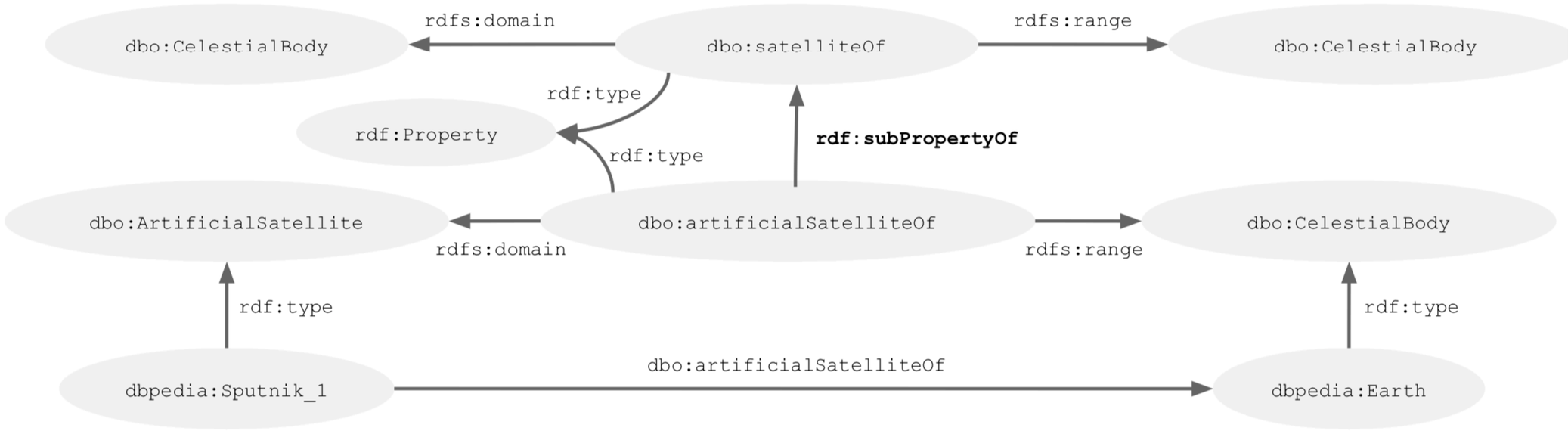


Which Conclusions Can We Deduce With RDF(S)?

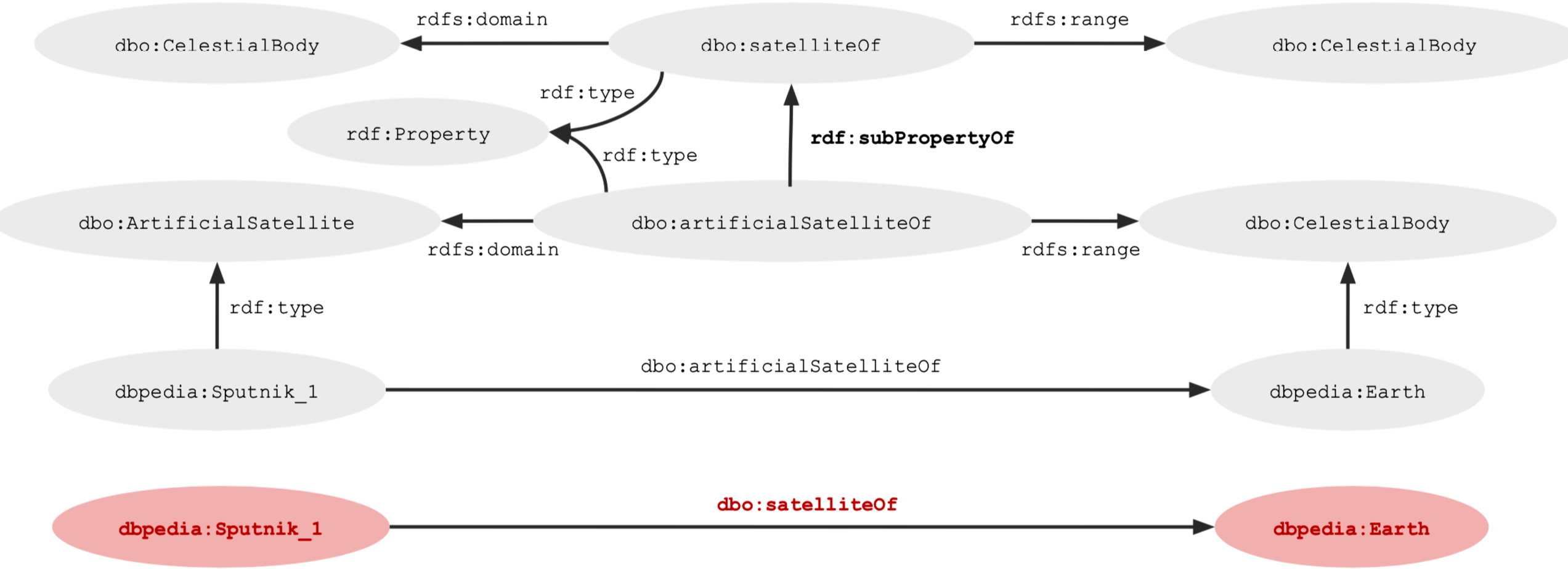


- Deduction of entity **superclass membership** from a **class hierarchy.**

Which Conclusions Can We Deduce With RDF(S)?



Which Conclusions Can We Deduce With RDF(S)?



- Deduction of entity **new facts** from **subproperty** relationships**.**