Semantic Web

MPRI 2.26.2: Web Data Management

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Motivation

- Information on the Web is not structured

List of joint winners of the **Hugo and Nebula** awards - Wikipedia, the **...**
en.wikipedia.org/.../List_of_joint_winners_of_the_**Hugo_and_Nebul**...
This is a list of the works that have won both the **Hugo Award** and the **Nebula Award**, **awarded** annually to works of science fiction literature. The **Hugo** Awards **...**

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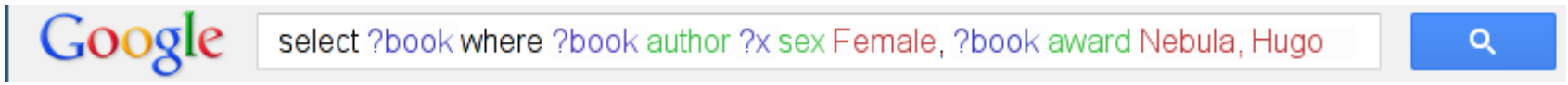
- This makes it difficult to:
  - Combine information from multiple sources
  - Integrate different services
  - Reason with Web data

Goal

What if we could write:



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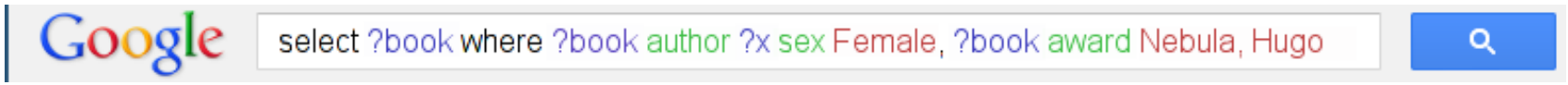



```
SELECT DISTINCT ?book ?bookLabel WHERE {
  ?book wdt:P166/(wdt:P361*|wdt:P31)
      wd:Q194285, wd:Q188914 .
  ?book wdt:P50/wdt:P21 wd:Q6581072 .
  SERVICE wikibase:label { bd:serviceParam
      wikibase:language "[AUTO_LANGUAGE],en". }
}
```

Applications

- Most visible application today: rich search results
  - Bing `https://www.bing.com/webmaster/help/marking-up-your-site-with-structured-data-3a93e731`
  - Google Search `https://developers.google.com/search/docs/guides/search-gallery`
  - Yandex Search `https://yandex.ru/support/webmaster/site-content/data-transmit.html?ncrnd=4299&lang=en`
- Also: SPARQL endpoints, e.g., `https://query.wikidata.org/`
- Indirectly: Graph databases

Key concepts

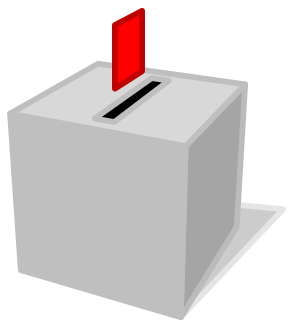
- **Semantic Web:** put **structured data** on the Web
- **Entities:** the things about which we want to express data
- **Ontology:** a **vocabulary** to talk about entities, specifying **relations**, **classes**, etc.
- **Knowledge base:** a set of assertions about entities expressed following an ontology
- **Linked data:** use URIs to create **links** between datasets
- **Information extraction:** creating structured information out of existing Web Data (later)

Resources (or entities)

- A resource is anything that can be referred to by a **URI**
  - a **web page**, identified by a URL
  - a **fragment of an XML document**, identified by an element node of the document,
  - a **web service**,
  - an **identifier**, e.g., an ISBN,
  - a thing, an object, a concept, a property, etc.
- The URI does not need to be **dereferenceable**
- A **cool URI** is one that can be dereferenced to obtain information about the entity
  - `https://www.wikidata.org/wiki/Q42`
  - `https://wiki.openstreetmap.org/wiki/Key:opening_hours`

Examples of entities

Give examples of **entities**? (be creative ;))



Ontologies

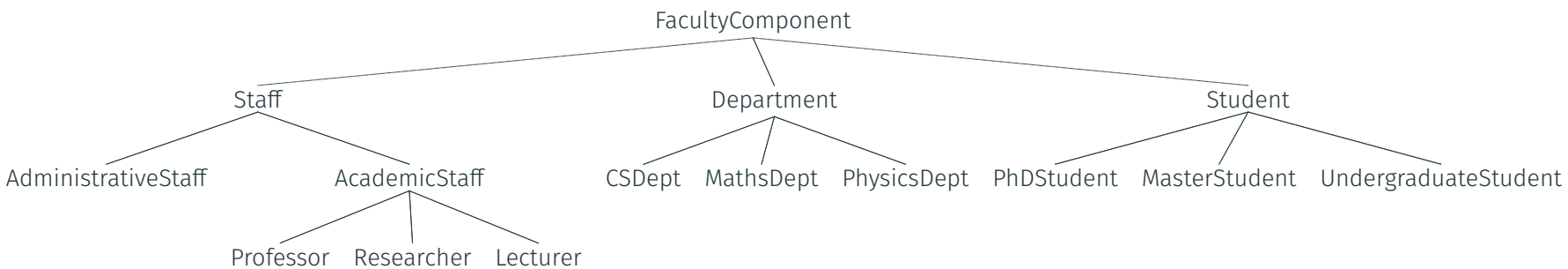
- Formal descriptions providing human users a shared understanding of a given domain
  - A controlled vocabulary
- Formally defined so that it can also be processed by machines
- Logical semantics that can be useful for reasoning
  - to answer queries (over possibly distributed data)
  - to relate objects in different data sources and integrate them
  - to detect inconsistencies or redundancies
  - to refine queries with too many answers
  - to relax queries with no answer

Where do ontologies come from?

- **Manually crafted** to represent the knowledge of a specific domain (e.g., life sciences)
- Exported from **classical Web databases**
- Automatically **extracted** from unstructured content
- Created **collaboratively** (e.g., Wikidata)
- **Private** to a company or **public**
- Value of the Semantic Web: bits of ontologies can be **re-used** in another, and ontologies can be mapped with `owl:sameAs`, `owl:equivalentClass`, `owl:equivalentProperty`, etc.

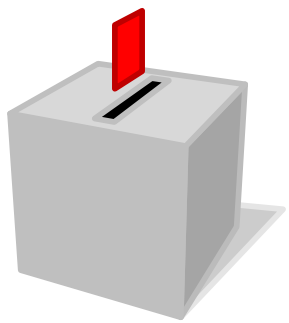
Classes and class hierarchy

- A class denotes a set of entities; e.g., Professor, Country, Person
- An entity can be an instance of one or several classes
- Ex: MPRI instanceOf MasterProgram
- Ex: AcademicStaff subClassOf Staff (interpreted as set inclusion)



Examples of classes

Give examples of classes? (be creative, again ;))

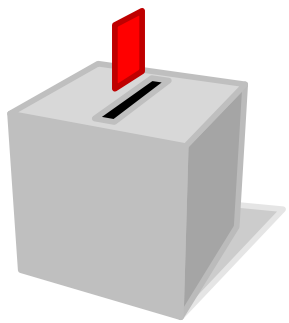


Relations

- A relation denotes a binary relation between objects; e.g., locatedIn, father
- Often convenient to express with a signature (classes for the subject and object)
- `TeachesIn`(AcademicStaff, Course)
  - if one states that "*X* `TeachesIn` *Y*", then *X* belongs to AcademicStaff and *Y* to Course
- `TeachesTo`(AcademicStaff, Student)
- `Leads`(Staff, Department)

Examples of relations

Give examples of relations?



Namespaces

- Using full URLs for URIs is often cumbersome
  - `https://www.wikidata.org/entity/Q42`
- Idea: declare a namespace like `wd` to stand for `https://www.wikidata.org/entity/`
- Then you can write a Compact URI (aka CURIE) `wd:Q42` to mean `https://www.wikidata.org/entity/Q42`
- This is like a simplification of XML namespaces
- Also a default namespace, to write `:Q42`
- In the slides I will just write entities like “MPRI” and ignore the issue

Ontologies and knowledge bases

To summarize:

- Ontology puts the focus on the schema, or TBox
  - The set of class and relation names (= the vocabulary)
  - The signatures of relations and also constraints
  - The constraints can be used to:
    - check data consistency (like dependencies in databases)
    - infer new facts
- Knowledge base puts the focus on the instance, or ABox
  - Entities (instances of a class), and facts about them (see next)
- Many knowledge bases provide their own ontology (but may also use terms from other ontologies)

Ontology Languages for the Web

3 ontology languages for the Web

- **RDF:** not really an ontology language (only ABox facts)
- **RDFS:** schema for RDF, but very basic
- **OWL:** a much richer ontology language

RDF: Resource Description Framework

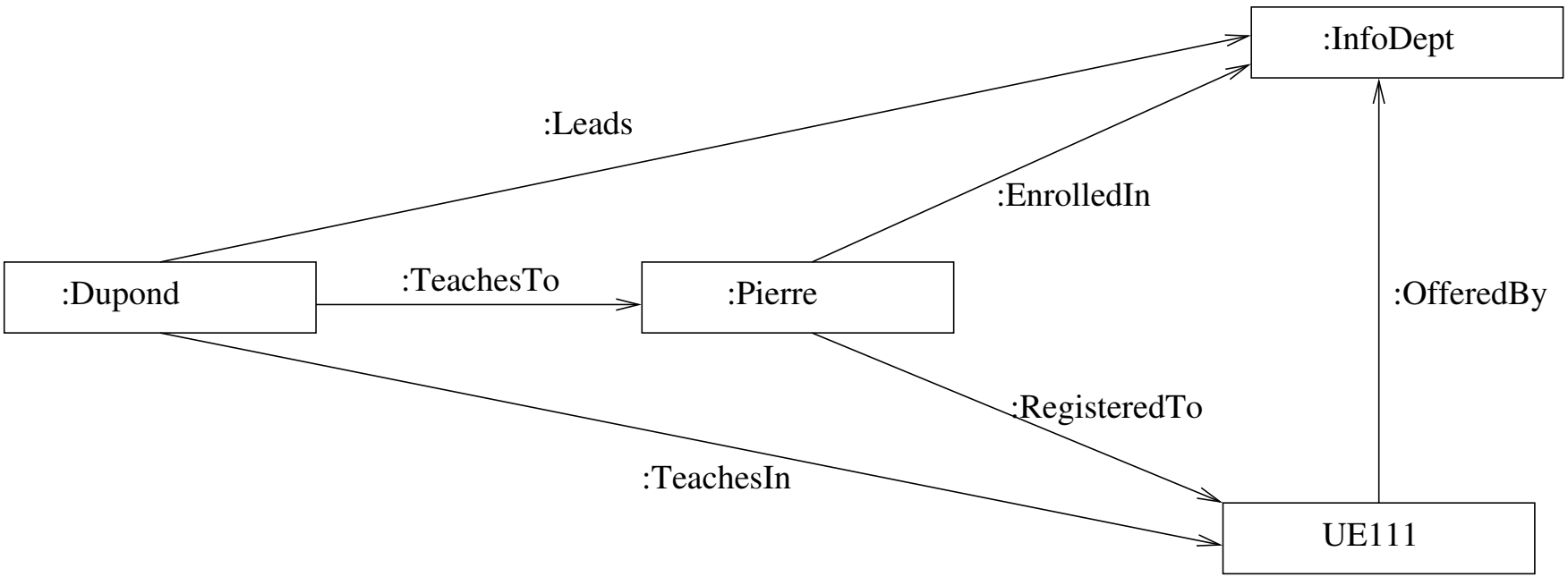
- RDF facts are **triplets**
- Each triplet is of the form: ⟨ **Subject Predicate Object** ⟩
- The subject is a URI, referencing an **entity**
  (from the same KB or a different one)
- The predicate is a URI, referencing a **relation**
  (from some ontology)
- The object is either a URI, referencing an **entity**, or a **literal**

⟨ :Dupond :Leads :CSDept ⟩
⟨ :Dupond :HasName "Paul Dupond" ⟩
⟨ :Dupond :TeachesIn :UE111 ⟩
⟨ :Dupond :TeachesTo :Pierre ⟩
⟨ :Pierre :EnrolledIn :CSDept ⟩
⟨ :Pierre :RegisteredTo :UE111 ⟩
⟨ :UE111 :OfferedBy :CSDept ⟩

- The linked data cloud contains **dozens of billions** of RDF triples

RDF graph

- A set of RDF facts defines
  - a set of relations between objects
  - an RDF graph where the nodes are objects:



RDF semantics

- A triplet $\langle s \ P \ o \rangle$ is interpreted in first-order logic (FOL) as a fact $P(s, o)$
- Example:

  $\texttt{Leads}(\texttt{Dupond}, \texttt{CSDept})$

  $\texttt{TeachesIn}(\texttt{Dupond}, \texttt{UE111})$

  $\texttt{TeachesTo}(\texttt{Dupond},\texttt{Pierre})$

  $\texttt{EnrolledIn}(\texttt{Pierre}, \texttt{CSDept})$

  $\texttt{RegisteredTo}(\texttt{Pierre}, \texttt{UE111})$

  $\texttt{OfferedBy}(\texttt{UE111}, \texttt{CSDept})$

Literals

- Sometimes the object of a statement is a literal value, e.g., a name, number, date
- Literals can come with a language, i.e., an ISO language name

  `"France"@en`
- They can have a data type, which is just a URI

  `"28753"^^<http://www.w3.org/2001/XMLSchema#nonNegativeInteger>`
  `"6.96E10"^^<http://dbpedia.org/datatype/euro>`
- The data type also indicates how the value is interpreted, how comparisons work, etc.

RDF Serialization

Several serialization formats for RDF data, see alternate formats of `http://live.dbpedia.org/page/%C3%89lectricit%C3%A9_de_France`:

- RDF/XML, structured XML representation, allowing for nesting
- N-Triples, Turtle, N3, text-based formats
- RDFa and JSON-LD to integrate RDF annotations into HTML

N-Triples

Simplest text-based format

- Each fact is a triple of a subject, predicate, object, followed by a full stop.

```
<http://live.dbpedia.org/resource/\u00C9lectricit\u00E9_de_France>
  <http://live.dbpedia.org/property/netIncome>
  "3.2E9"^^<http://dbpedia.org/datatype/euro> .
```

- Possibility of comments
- Support for literals with language and datatype
- All usual questions of quoting, escaping, character encodings...

Turtle

Turtle is a superset of N-Triples

- Adds prefixes (for CURIEs) and default prefix

```
@prefix foaf:   <http://xmlns.com/foaf/0.1/> .
```

- Adds factoring of common subjects, common predicates

```
:s1 :p1 :o1, :o2, :o3 ;
    :p2 :o4 .
:s2 :p3 :o5 .
```

- Adds `a` alias for the type relation

Turtle (cont'd) and N3

- Adds square brackets for blank nodes (see later)

```
ex:coursenotes ex:author [
  foaf:name "Amarilli" ; foaf:givenname "Antoine"
] .
# stands for
ex:coursenotes ex:author _:b1 .
_:b1 foaf:name "Amarilli" ;
     foaf:givenname "Antoine" .
```

- Adds brackets for linked lists

Notation3 (N3) is a superset of Turtle with additional features for semantic assertions (not just RDF data).

Blank nodes

- Some entities may be **blank nodes**, i.e., nodes with no URI.
- They are written `_:xyz` with `xyz` being a **local identifier**
- Common usage: n-ary relations

```
ex:speaker ex:gaveSeminar _:seminar .
_:seminar ex:date "2022-01-15"^^xsd:date .
_:seminar ex:room ex:Room101 .
_:seminar ex:title "Example seminar title"@en .
```

Reification

Another common usage of blank nodes is **reification**:

```
dbp:Earth dbprop:creationDate "-4003-10-23"^^xsd:date .
# can be written as
_:stmt rdf:type rdf:Statement ;
       rdf:subject dbp:Earth ;
       rdf:predicate dbprop:creationDate ;
       rdf:object "-4003-10-23"^^xsd:date .
# allowing us to say, e.g.,
_:stmt dbp:author dbp:James_Ussher .
```

RDF built-ins

- Some classes, i.e., literals, properties, statements, etc.
- Some datatypes, i.e., unordered lists, ordered lists, bags
- `rdf:type` to say that something is an instance of a class

→ To say more about the schema, we need RDF Schema

RDF Schema (RDFS)

- RDF Schema is a language to describe the schema of RDF documents
- Do not get confused: RDFS can use RDF as syntax, i.e., RDFS statements are themselves expressed as RDF triplets with some specific properties and objects

- Declaration of classes and subclass relationships
  - ⟨ Staff `rdf:type` rdfs:Class ⟩
  - ⟨ `JavaCourse` `rdfs:subClassOf` CSCourse ⟩
- Declaration of instances
  - ⟨ `Dupond` `rdf:type` `AcademicStaff` ⟩

RDF Schema - continued

- Declaration of relations (properties in RDFS terminology)
  - ⟨ RegisteredTo `rdf:type` rdfs:Property ⟩
- Declaration of subproperty relationships
  - ⟨ `LateRegisteredTo` `rdfs:subPropertyOf` `RegisteredTo` ⟩
- Declaration of domain and range for predicates (used for inference)
  - ⟨ `TeachesIn` `rdfs:domain` AcademicStaff ⟩
  - ⟨ `TeachesIn` `rdfs:range` Course ⟩
  - `TeachesIn`(AcademicStaff, Course)

RDFS logical semantics

RDF and RDFS statements	FOL translation	DL notation
$\langle$ i `rdf:type` C $\rangle$	$C(i)$	$i : C$ or $C(i)$
$\langle$ i P j $\rangle$	$P(i, j)$	$i\,P\,j$ or $P(i, j)$
$\langle$ C `rdfs:subClassOf` D $\rangle$	$\forall X\,(C(X) \Rightarrow D(X))$	$C \sqsubseteq D$
$\langle$ P `rdfs:subPropertyOf` R $\rangle$	$\forall X\,\forall Y\,(P(X, Y) \Rightarrow R(X, Y))$	$P \sqsubseteq R$
$\langle$ P `rdfs:domain` C $\rangle$	$\forall X\,\forall Y\,(P(X, Y) \Rightarrow C(X))$	$\exists P \sqsubseteq C$
$\langle$ P `rdfs:range` D $\rangle$	$\forall X\,\forall Y\,(P(X, Y) \Rightarrow D(Y))$	$\exists P^{-} \sqsubseteq D$

DL: Description logics, a specialized logical formalism

OWL: Web Ontology Language

- OWL extends RDFS to express richer constraints
- Main OWL constructs
  - Disjointness between classes
  - Constraints of functionality and symmetry on predicates
  - Class union and intersection
- Inspired by description logics
- Several profiles: OWL Full, OWL DL, OWL Lite, OWL 2 EL, OWL 2 QL, OWL 2 RL.
- Different profiles include different features, and have different (in)tractability

Slide acknowledgements

- Material reused from Pierre Senellart's class `http://pierre.senellart.com/talks/romatre-20130923.pdf` itself adapted from Web data management, S. Abiteboul, I. Manolescu, P. Rigaux, M.-C. Rousset, P. Senellart, Cambridge University Press, 2012. Also available at `http://webdam.inria.fr/Jorge/`