

# Lecture 9

## Artificial Intelligence: Knowledge Graphs

Part II: Vocabularies & Ontologies, RDFS, Linked Open Data

COMP 6721, Fall 2023

# Outline

- ① RDF Schema
- ② Vocabularies
- ③ Example: schema.org
- ④ Knowledge Bases & Linked Open Data
- ⑤ Notes and Further Reading

## Slides Credit

- Includes slides from Jay Pujara & Sameer Singh, *Mining Knowledge Graphs from Text*, <https://kgtutorial.github.io/>
- Includes slides by Ivan Herman, W3C [Her]
- Includes slides from Hoifung Poon, Chris Quirk & Scott Wen-Tau Yih, *Machine Reading for Precision Medicine*,  
[https://www.microsoft.com/en-us/research/uploads/prod/2018/01/1802\\_aaai-tutorial\\_precision-med.pdf](https://www.microsoft.com/en-us/research/uploads/prod/2018/01/1802_aaai-tutorial_precision-med.pdf)

# Outline

## ① RDF Schema

- Introduction
- Class and Instance
- Label & Comment
- Subclass
- Property
- RDFS Utility Vocabulary
- RDFS Summary

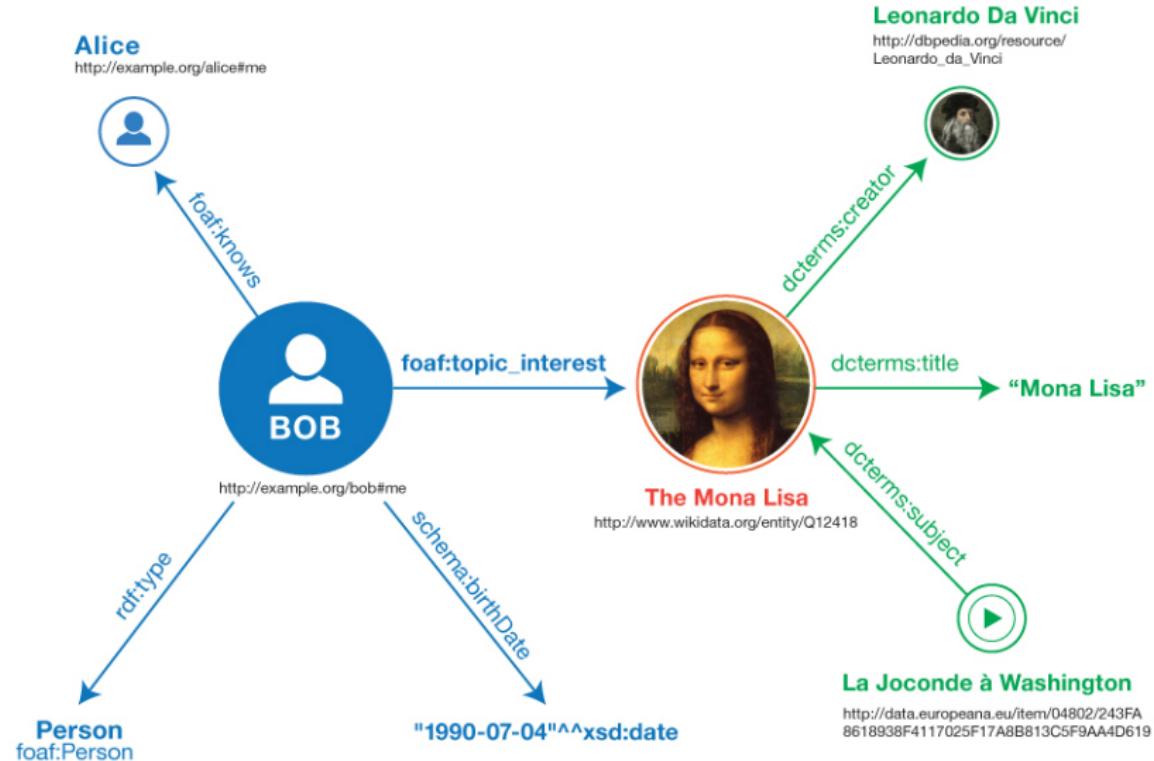
## ② Vocabularies

## ③ Example: schema.org

## ④ Knowledge Bases & Linked Open Data

## ⑤ Notes and Further Reading

# Knowledge Graphs



<https://www.w3.org/TR/rdf11-primer/>

# RDF Triples

## Format of triples

In RDF,

- Subject and predicate must be URIs (IRIs)
- Object can be IRI or **literal**

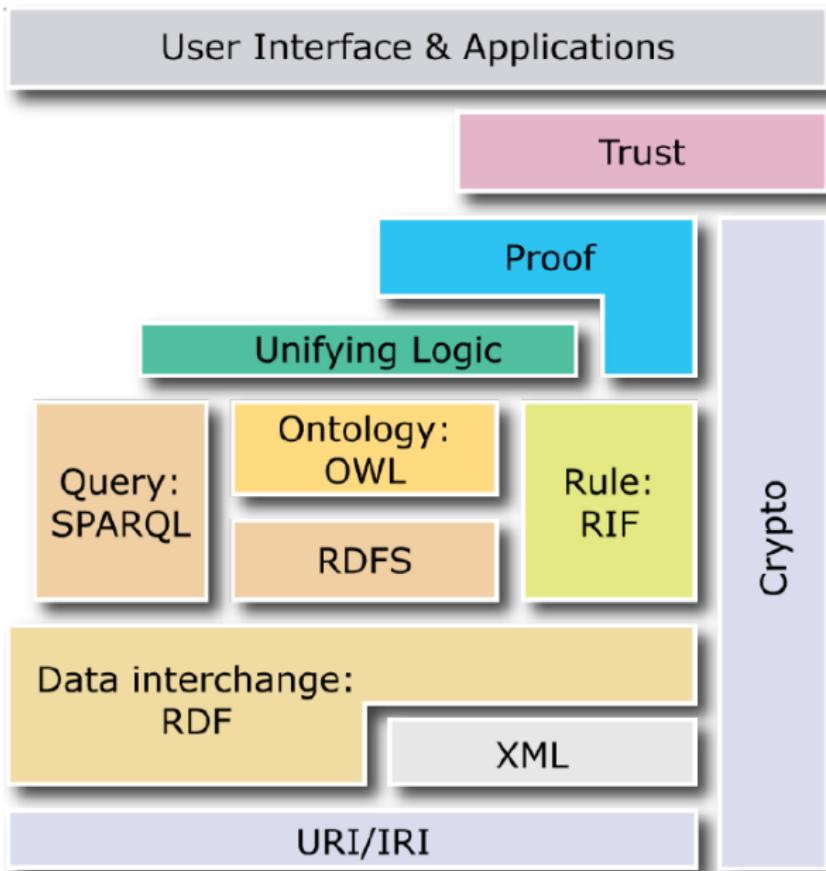
## Examples

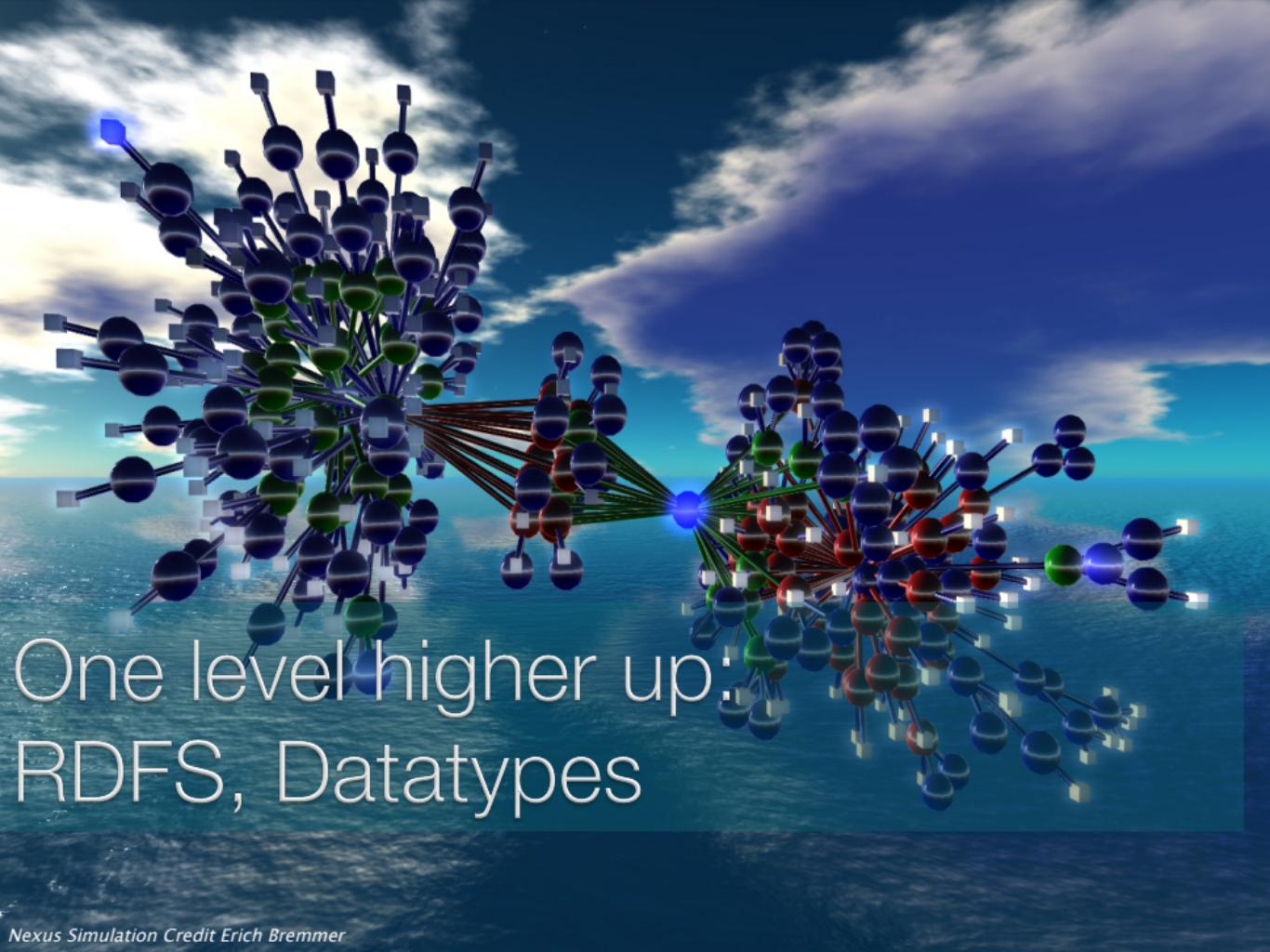
```
<http://www.wikidata.org/entity/Q12418>
  <http://purl.org/dc/terms/title>
  "Mona Lisa" .
```

```
<http://www.wikidata.org/entity/Q12418>
  <http://purl.org/dc/terms/creator>
  <http://dbpedia.org/resource/Leonardo_da_Vinci> .
```

→ Worksheet #8: “N-Triples”

# The W3C “Layer Cake”





One level higher up  
RDFS, Datatypes

# RDF Schema (RDFS)

## W3C Recommendation

- “RDF Vocabulary Description Language 1.0: RDF Schema” (RDFS 1.0)
- Current version (2014): “RDF Schema 1.1”

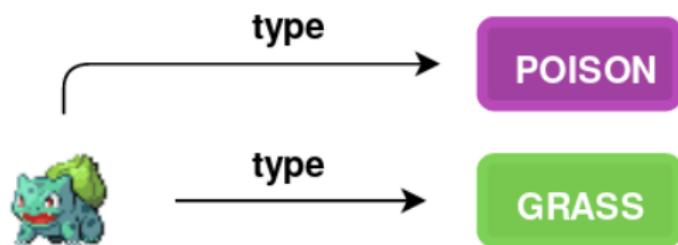
## Used together with RDF

- RDF provides “a way to make statements about resources” (IRIs)
- RDFS provides *semantics* about what the IRIs stand for (Schemas aka Vocabularies aka Ontologies aka...)

# Classes and Instances

## Classes

- Resources may be divided into groups called **classes**
- The members of a class are known as **instances** of the class
- An instance can be member of **more than one class**



What is a knowledge graph – Pokémon edition: <https://pieterheyvaert.com/blog/2019/12/27/kg-pkmn/>

## Defining Classes

We define that an IRI in a triple is a class using ... a triple!  
(sounds weird the first time you hear it, but you get used to it)

# Classes and Instances (contd.)

## Defining Classes

To define that **C** (a resource) is an RDFS **class**, write:

**C rdf:type rdfs:Class**

with **rdfs** defined as <http://www.w3.org/2000/01/rdf-schema#>

## Example

**ex:Novel rdf:type rdfs:Class**

## Turtle

In Turtle, **rdf:type** can be abbreviated as **a**

→ Worksheet #8: "Your first Vocabulary"

# Classes and Instances (contd.)

## Instances

To define that **I** (a resource) is an instance of **C** (a class), write:

*I rdf:type C*

(or **i** instead of **rdf:type** in Turtle.)

## Example

<http://...isbn/000651409X> **rdf:type** ex:Novel

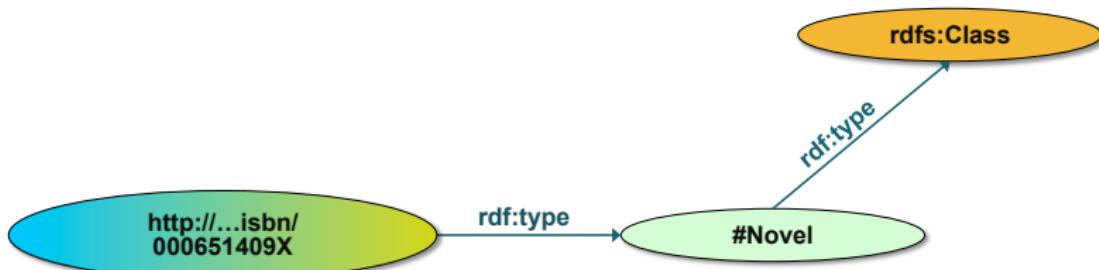
## Note

This is just another triple...

→ Worksheet #8: "Creating Instances"

# Classes, resources in RDF(S)

---



- ▶ RDFS defines the meaning of these terms
  - (these are all special URI-s, we just use the namespace abbreviation)

# Label & Comment

## Human-Readable Content

By convention, always provide:

`rdfs:label` a human-readable label

`rdfs:comment` a short (one paragraph) description  
using language tags for multiple languages.

## Examples (`dbpedia:The_Glass_Palace`)

```
<http://dbpedia.org/resource/The_Glass_Palace>
  rdfs:label    "The Glass Palace"@en ,
                 "Le Palais des miroirs"@fr ;
```

```
  rdfs:comment  "The Glass Palace is a 2000 historical novel..."@en ,
                 "Le Palais des miroirs est un roman..."@fr ;
```

# Subclasses

## Defining a subclass

To define that **C1** (a class) is a **subclass** of **C2** (a class), write:

***C1 rdfs:subClassOf C2***

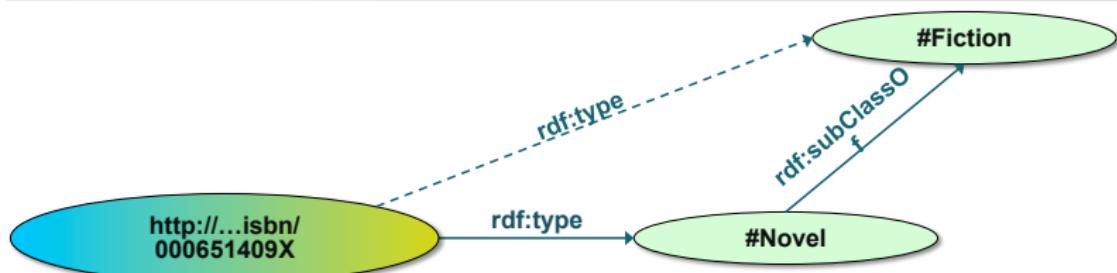
## Semantics

This states that all the instances of C1 are also instances of C2.

The **rdfs:subClassOf** property is **transitive**.

→ Worksheet #8: "Subclasses"

# Inferred properties



```
(<http://...isbn/000651409X> rdf:type #Fiction)
```

- ▶ is not in the original RDF data...
- ▶ ...but can be inferred from the RDFS rules
- ▶ RDFS environments return that triple, too

# Inference: let us be formal...

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- ▶ The RDF Semantics document has a list of (33) entailment rules:
  - “if such and such triples are in the graph, add this and this”
  - do that recursively until the graph does not change
- ▶ The relevant rule for our example:

```
If:  
  uuu rdfs:subClassOf xxx .  
  vvv rdf:type uuu .  
Then add:  
  vvv rdf:type xxx .
```

# Properties

## Example

<studies at> <type> <Property>

## Defining a Property

To define that  $P$  (a resource) is a *property*, write:

$P \text{ rdf:type } \text{rdf:Property}$

Properties are used to define *relations* between subject resources and object resources.

→ Worksheet #8: "Properties" & "Are we there yet?"

# Domain and Range

## Domain

To define a class **C** as the **domain** of a property **P**, write:

$P \text{ rdfs:domain } C$

This states that resources denoted by the subjects of triples whose predicate is **P** are instances of the class **C**.

## Range

To define a class **C** as the **range** of a property **P**, write:

$P \text{ rdfs:range } C$

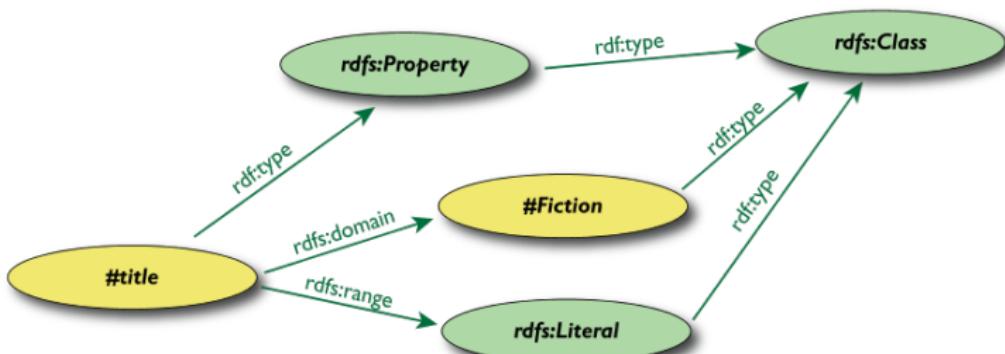
This states that the resources denoted by the objects of triples whose predicate is **P** are instances of the class **C**.

## Note

- Properties are also resources (named with URIs)
- So we define properties of properties using... RDF properties!
- Again, you'll get used to it...

# Property specification example

---



# Property specification serialized

---

- ▶ In RDF/XML:

```
<rdf:Property rdf:ID="title">
  <rdfs:domain rdf:resource="#Fiction"/>
  <rdfs:range rdf:resource="http://...#Literal"/>
</rdf:Property>
```

- ▶ In Turtle:

```
:title
  rdf:type    rdf:Property;
  rdfs:domain :Fiction;
  rdfs:range  rdfs:Literal.
```

# Subproperties

## Defining a Subproperty

To define that **P1** (a property) is a **subproperty** of **P2** (a property), write:

**P1 rdfs:subPropertyOf P2**

With a subproperty, we can state that all resources related by one property are also related by another.

## Example

Like inheritance for classes, we can have inheritance for properties:

**<is father of> <subPropertyOf> <is parent of>**

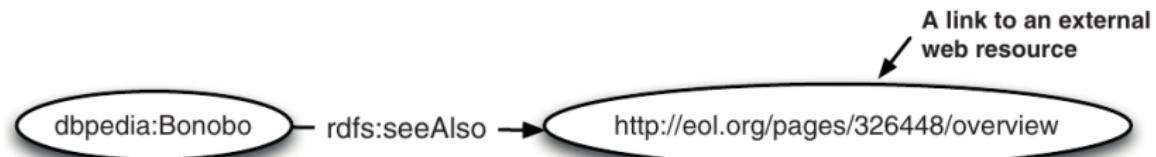
# RDFS Utility Vocabulary

## Some “helper” constructs

`rdfs:seeAlso` a property that links a resource to another for more information (can be in any format)

`rdfs:isDefinedBy` a property typically used to refer to a vocabulary (RDF Schema) defining the subject IRI

There are also some datastructures (bag, list etc.) – read more before using!



# RDF Schema Constructs: Summary

Construct	Syntactic form	Description
<u>Class</u> (a class)	<b>C</b> <code>rdf:type rdfs:Class</code>	<b>C</b> (a resource) is an RDF class
<u>Property</u> (a class)	<b>P</b> <code>rdf:type rdf:Property</code>	<b>P</b> (a resource) is an RDF property
<u>type</u> (a property)	<b>I</b> <code>rdf:type C</code>	<b>I</b> (a resource) is an instance of <b>C</b> (a class)
<u>subClassOf</u> (a property)	<b>C1</b> <code>rdfs:subClassOf C2</code>	<b>C1</b> (a class) is a subclass of <b>C2</b> (a class)
<u>subPropertyOf</u> (a property)	<b>P1</b> <code>rdfs:subPropertyOf P2</code>	<b>P1</b> (a property) is a sub-property of <b>P2</b> (a property)
<u>domain</u> (a property)	<b>P</b> <code>rdfs:domain C</code>	domain of <b>P</b> (a property) is <b>C</b> (a class)
<u>range</u> (a property)	<b>P</b> <code>rdfs:range C</code>	range of <b>P</b> (a property) is <b>C</b> (a class)

# Outline

## ① RDF Schema

## ② Vocabularies

Introduction

FOAF

Dublin Core

Summary

## ③ Example: schema.org

## ④ Knowledge Bases & Linked Open Data

## ⑤ Notes and Further Reading

# Vocabularies

## Goal: Knowledge Integration

Two major principles:

① Reuse of vocabularies

E.g., always use FOAF to describe names, emails, etc., instead of making up your own schema

② Make your data self-describing

Embed metadata using RDF to ensure data can be understood and processed independently.

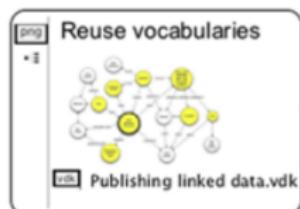
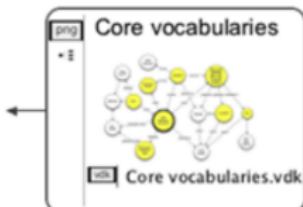
Adhering to these principles supports interoperability and semantic understanding across different systems.

# Reuse vocabularies whenever possible

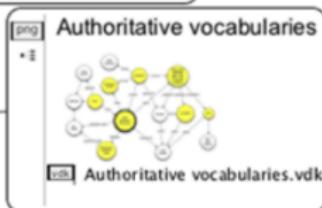
Use well-known and authoritative vocabularies to describe things whenever possible.



Describe common types of data by using terms from core vocabularies.



Use authoritative vocabularies for terms not defined by the core vocabularies.



Create your own vocabulary if necessary.



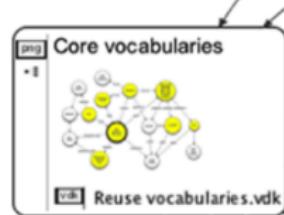
Use RDFS and OWL.



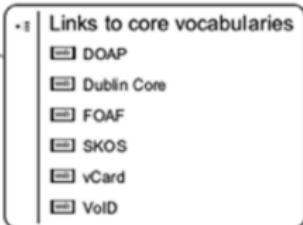
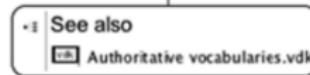
Be prepared to maintain it.

# Core Vocabularies

Use terms from these core vocabularies to describe commonly understood data.



- ? Naming things? ← Use rdfs:label, foaf:name, skos:prefLabel.
- ? Describing people? ← Use FOAF, vCard.
- ? Describing addresses? ← Use vCard.
- ? Describing projects? ← Use Description of a Project (DOAP).
- ? Describing web pages and other publications? ← Use dc:creator and dc:description.
- ? Describing an RDF vocabulary? ← Use a VoID description.
- ? Describing existing taxonomies? ← Use SKOS.



# Self-Describing Datasets

Provide useful information about new terms

For example, if we create our own proprietary term, like **SmallMediumEnterprise**, we could describe it as [HB11]:

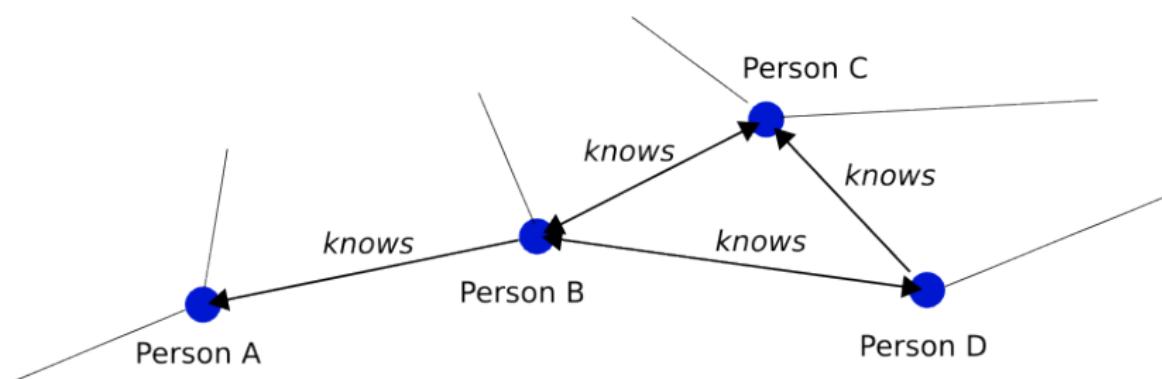
```
1 @prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .  
2 @prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#> .  
3 @prefix owl: <http://www.w3.org/2002/07/owl#> .  
4 @prefix co: <http://biglynx.co.uk/vocab/sme#> .  
5  
6 <http://biglynx.co.uk/vocab/sme#SmallMediumEnterprise>  
7   rdfs:type rdfs:Class ;  
8     rdfs:label "Small or Medium-sized Enterprise" ;  
9     rdfs:subClassOf <http://dbpedia.org/ontology/Company> .  
10    rdfs:subClassOf <http://umbel.org/umbel/sc/Business> ;  
11    rdfs:subClassOf <http://sw.opencyc.org/concept/Mx4rvVjQNpwpEbGdrcN5Y29ycA> ;  
12    rdfs:subClassOf <http://rdf.freebase.com/ns/m/0qb7t> .
```

# FOAF (Friend-of-a-Friend) Vocabulary

## FOAF

Model people and their connections in a social network.

```
<#RW>
  a foaf:Person ;
  foaf:name "Rene Witte" ;
  foaf:mbox_sha1sum "5d5705ff1b2142d62a38061f804f766ffaf806ef" .
```



→ Worksheet #8: "FOAF"

# Dublin Core



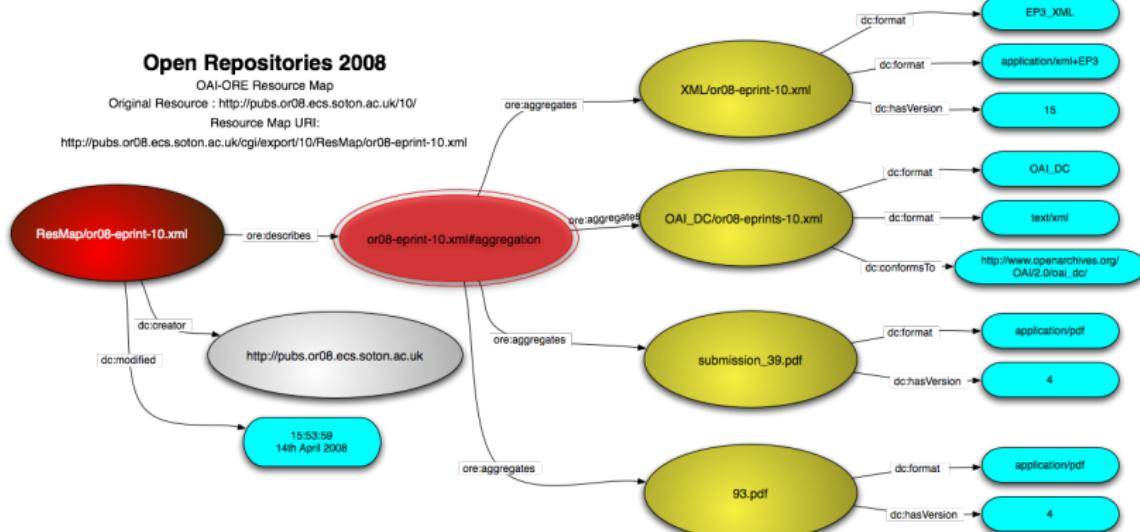
## Open Repositories 2008

OAI-ORE Resource Map

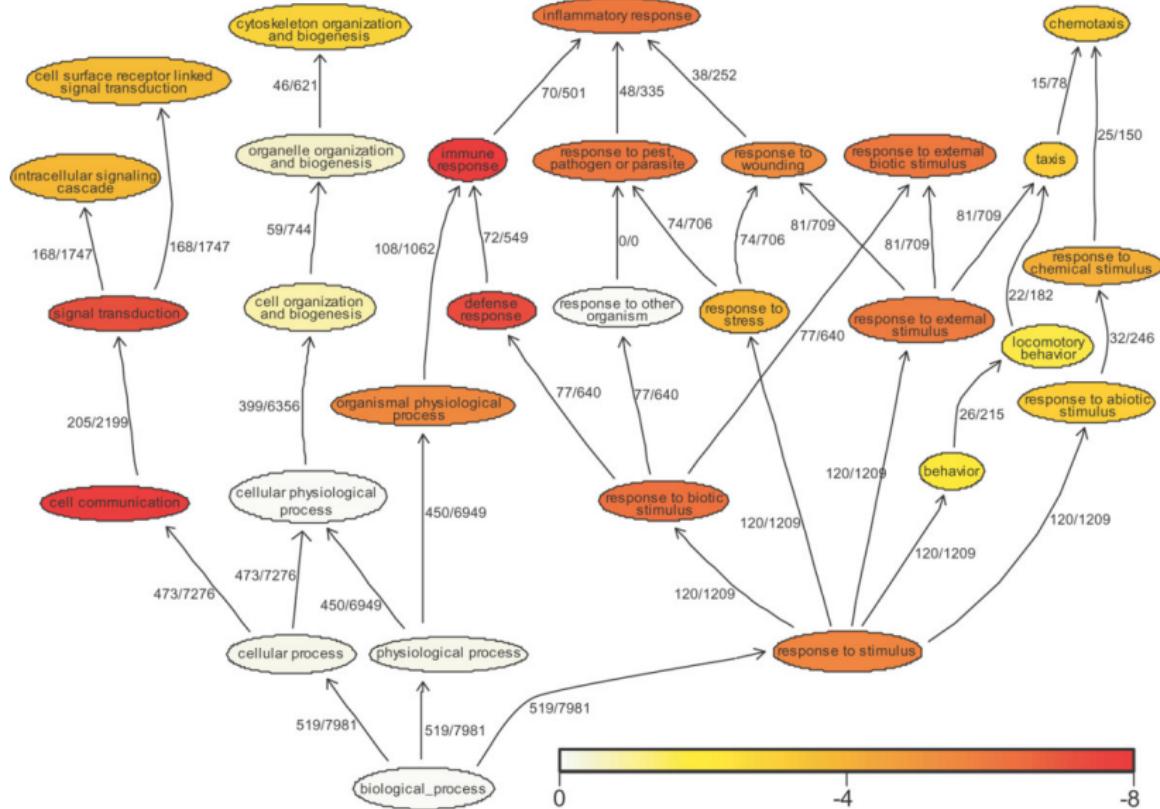
Original Resource : <http://pubs.or08.ecs.soton.ac.uk/10/>

Resource Map URI:

<http://pubs.or08.ecs.soton.ac.uk/cgi/export/10/ResMap/or08-eprint-10.xml>

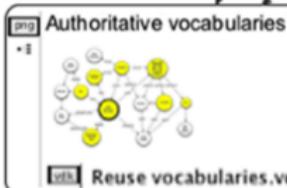


## Gene Ontology (GO)



# More authoritative vocabularies

Use these authoritative vocabularies to describe data you couldn't describe with the core vocabularies.



See also

Core vocabularies.vdk

## Links to authoritative vocabularies

- BIBO
- Creative Commons Rights Expression Language
- Geo
- GeoNames
- Good Relations
- Object Reuse and Exchange
- SIOC

# Outline

- 1 RDF Schema
- 2 Vocabularies
- 3 Example: schema.org
- 4 Knowledge Bases & Linked Open Data
- 5 Notes and Further Reading

# Typical usage of structured data

the artist movie - Google Search

[https://www.google.nl/#hl=en&sugexp=frgbld&gs\\_nf=1&cp=11&gs\\_id=5p&xhr=t&q=the+artist+movie+database](https://www.google.nl/#hl=en&sugexp=frgbld&gs_nf=1&cp=11&gs_id=5p&xhr=t&q=the+artist+movie+database)

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**Everything**

**Images**

**Maps**

**Videos**

**News**

**Shopping**

**More**

**Amsterdam**

Change location

**Any time**

Past hour

Past 24 hours

Past week

Past month

Past year

Custom range...

More search tools

**The Artist showtimes for Amsterdam**

Pathé Tuschinski - Reguliersbreestraat 26-34, Amsterdam - [Map](#)  
11:50 - 14:05 - 19:10

Filmtheater "De Uithof" - Prinsengracht 452, Amsterdam - [Map](#)  
12:15 - 19:00 - 21:15

Filmtheater Rialto - Ceintuurbaan 338, Amsterdam - [Map](#)  
12:45

+ Show more theaters

**The Artist (2011) - IMDb**  
[www.imdb.com/title/tt1655442/](http://www.imdb.com/title/tt1655442/)  
Silent movie star George Valentin bemoans the coming era of talking ... Still of Jean Dujardin and Miss Pyle in **The Artist** Still of Bérénice Bejo in **The Artist** Reem ...  
↳ Full cast and crew - **The Artist** Trailer (Official ... - Bérénice Bejo - Jean Dujardin

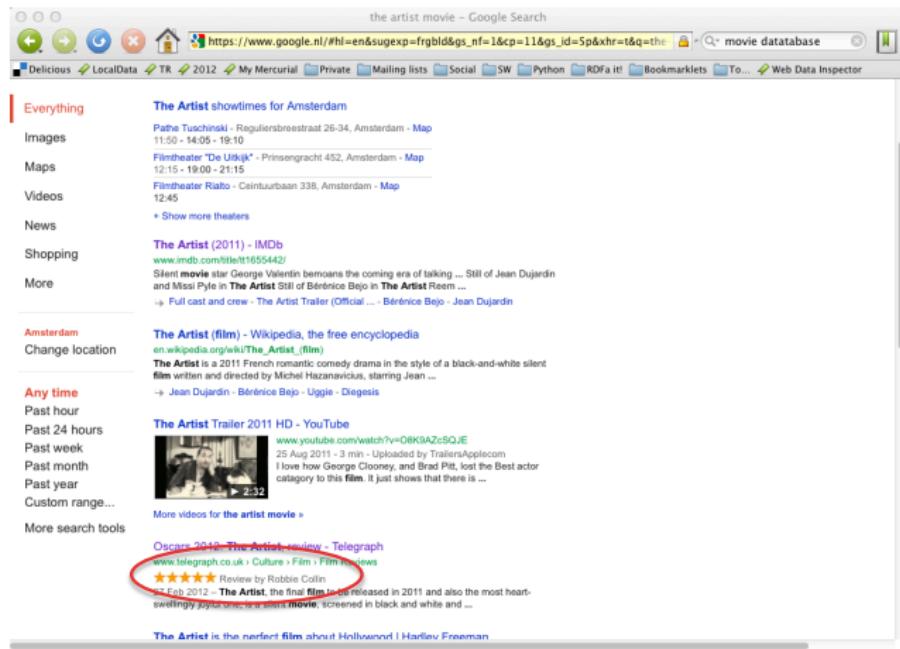
**The Artist (film) - Wikipedia, the free encyclopedia**  
[en.wikipedia.org/wiki/The\\_Artist\\_\(film\)](http://en.wikipedia.org/wiki/The_Artist_(film))  
**The Artist** is a 2011 French romantic comedy drama in the style of a black-and-white silent film written and directed by Michel Hazanavicius, starring Jean ...  
↳ Jean Dujardin - Bérénice Bejo - Uggie - [Digestis](#)

**The Artist Trailer 2011 HD - YouTube**  
[www.youtube.com/watch?v=O8K3AZcSQJE](http://www.youtube.com/watch?v=O8K3AZcSQJE)  
25 Aug 2011 - 3 min - Uploaded by TrailersApplecom  
I love how George Clooney, and Brad Pitt, lost the Best actor category to this **film**. It just shows that there is ...  
↳ More videos for **the artist movie**

**Oscars 2012: The Artist review - Telegraph**  
[www.telegraph.co.uk/Culture/Film/Film\\_Reviews](http://www.telegraph.co.uk/Culture/Film/Film_Reviews)

★★★★★ Review by Robbie Collin  
17 Feb 2012 - **The Artist**, the final **film** to be released in 2011 and also the most heart-wrenchingly joyous since **It's a Wonderful Life**, screened in black and white and ...

**The Artist is the nerfiest film about Hollywood | Harvey Freeman**



Oscars 2012: The Artist, review – Telegraph

<http://www.telegraph.co.uk/culture/film/filmreviews/8982558/Oscars-2012-The-Artist-review.html>

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# The Telegraph

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## Oscars 2012: The Artist, review

The Artist, an utterly beguiling silent, black-and-white celebration of early Hollywood won Best Picture at the Oscars 2012.

★★★★★



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Oscars 2012: The Artist, review – Telegraph

<http://www.telegraph.co.uk/culture/film/filmreviews/8982558/Oscars-2012-The-Artist-review.html>

the artist

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Source of http://www.telegraph.co.uk/culture/film/filmreviews/8982558/Oscars-2012-The-Artist-review.html

Oscars 2012: The Artist, review - Telegraph

The Telegraph

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TELEGRAPH TICKETS

```
<li class="c1"><a href="#">
```

```
<div class="c1"></div>
```

```
<!-- googleon: all -->
```

```
<div id="tmglBody" >
```

```
<div class="access"><a name="a1" href="#">
```

```
<div class="twoThirdsThird2 gutter" >
```

```
<div class="twoThirds gutt" >
```

```
<div class="story" >
```

```
<h1 itemprop="name">Oscars 2012: The Artist, review
```

```
<h2 itemprop="description">
```

```
The Artist, an utterly beguiling silent, black-and-white celebration of early Hollywood won Best Picture at the Oscars 2012
```

```
</h2>
```

```
<div class="rating" itemprop="reviewRating" >
```

```
<meta itemprop="worstRating" />
```

```
<meta itemprop="bestRating" />
```

```
<span itemprop="ratingValue" >
```

```

```

```
</div>
```

```
<div class="artIntro" >
```

```
<div id="storyEm" >
```

```
<div class="slideshow ssIntro" >
```

```
<div class="nextPrevLayer" >
```

```
<div class="oneHalf gutter" >
```

```
<div class="story" >
```

```
<div class="c1" > </div>
```

```
<!-- remove the whitespace added by escenic before end of file -->
```

```
Source of http://www.telegraph.co.uk/culture/film/filmreviews/8982558/Oscars-2012-The-Artist-review.html
    <li class="first"><a href="/">Home</a><span>&raquo;</span></li>
    <li><a href="http://www.telegraph.co.uk/culture/">Culture</a><span>&raquo;</span></li>
        <li><a href="http://www.telegraph.co.uk/culture/film/">Film</a><span>&raquo;</span></li>
        <li class="styleSix"><a href="http://www.telegraph.co.uk/culture/film/filmreviews/">Film reviews</a></li>
    </div>
</div>

<!-- googleon: all -->
<div id="tmq1Body" >
    <div class="access"><a name="article"></a></div>

    <div class="twoThirdsThird2 gutterUnder" >
        <div class="twoThirds gutter" itemscope itemtype="http://schema.org/Review">
            <div class="storyHead" >
                <h1 itemprop="name">Oscars 2012: The Artist, review</h1>
                <h2 itemprop="description">
                    The Artist, an utterly beguiling silent, black-and-white celebration of early Hollywood won Best Picture at the Oscars 2012.
                </h2>
                <div class="rating" itemprop="reviewRating" itemscope itemtype="http://schema.org/Rating">
                    <meta itemprop="worstRating" content = "0.5">
                    <meta itemprop="bestRating" content = "5">
                    <span itemprop="ratingValue" class="hidden">5</span>
                    
                </div>
                <div class="artIntro" >
                    <div id="storyEmbSlide" >
                        <div class="slideshow ssIntro" >
                            <div class="nextPrevLayer" >
                                <div class="ssImg" >
                                    
                                    <div class="artImageExtras" >
                                        <div class="ingCaptionCredit" >
                                            <span class="caption" >Bérénice Bejo as Rita</span>
                                        </div>
                                    </div>
                                </div>
                            </div>
                        </div>
                    </div>
                </div>
            </div>
            <div class="oneHalf gutter" >
                <div class="story" >
                    <div class="cl" > </div>
                </div>
            </div>
        </div>
    </div>
</div>

<!-- remove the whitespace added by escenic before end of </a> tag -->
```

# In a slightly more readable format...

---

```
<div itemscope itemtype="http://schema.org/Review">
  ...
  <h1 itemprop="name">Oscars 2012: The Artist, review</h1>
  <h2 itemprop="description">The Artist, an utterly beguiling..</h2>
  ...
  <span itemprop="ratingValue" class="hidden">5</span>
  ...
```

# Yielding...

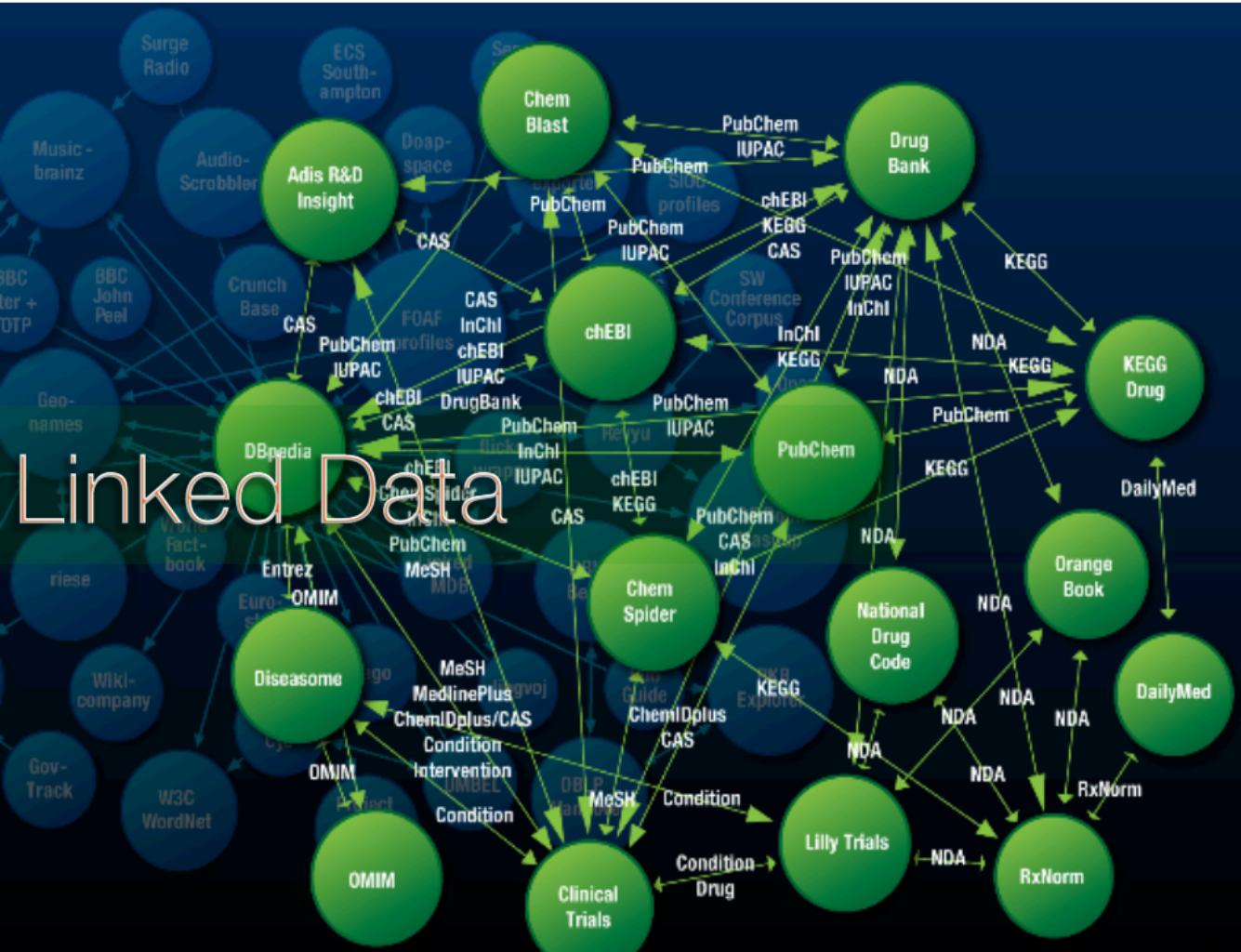
---

```
[ rdf:type schema:Review ,  
  schema:name "Oscars 2012: The Artist, review" ;  
  schema:description "The Artist, an utterly beguiling..." ;  
  schema:ratingValue "5" ;  
  ...  
 ]
```

# Outline

- 1 RDF Schema
- 2 Vocabularies
- 3 Example: schema.org
- 4 Knowledge Bases & Linked Open Data
  - Introduction
  - DBpedia
  - Google's Knowledge Graph
  - SPARQL Queries
  - Application Architecture
- 5 Notes and Further Reading

# Linked Data



# Linked Data “Project”

---

- ▶ Goal: “expose” datasets on the Web
  - remember the importance of data!
- ▶ Set links among the data items from different datasets
  - we want to avoid the silo effects

# Is your data 5 Star?

---



- ★ Available on the web (whatever format), but with an open license
- ★★ Available as machine-readable structured data (e.g., excel instead of an image scan)
- ★★★ As before, but using a non-proprietary format (e.g., CSV instead of excel)
- ★★★★ All the above, plus use open standards (RDF & Co.) to identify things, so that people could point at your stuff
- ★★★★★ All the above, plus link your data to other people's data to provide context

# Example data source: DBpedia

---

- ▶ DBpedia is a community effort to
  - extract structured (“infobox”) information from Wikipedia
  - provide a query endpoint to the dataset
  - interlink the DBpedia dataset with other datasets on the Web



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# Extracting structured data from Wikipedia

```
@prefix dbpedia <http://dbpedia.org/resource/>.  
@prefix dbterm <http://dbpedia.org/property/>.
```

dbpedia:**Amsterdam**

```
dbterm:officialName "Amsterdam" ;  
dbterm:longd "4" ;  
dbterm:longm "53" ;  
dbterm:longs "32" ;  
dbterm:website <http://www.amsterdam.nl> ;  
dbterm:populationUrban "1364422" ;  
dbterm:areaTotalKm "219" ;  
...
```

dbpedia:**ABN\_AMRO**

```
dbterm:location dbpedia:Amsterdam ;  
...
```

Amsterdam	
— Municipality / City —	
	Coordinates: 52°22'23"N 4°53'32"E
Country	Netherlands
Province	North Holland
COROP	Amsterdam
Boroughs	Boroughs
Government	
- Mayor	Eberhard van der Laan (PvdA)
- Aldermen	Carolin Gijssels Hans Gerven Maarten Poelgeest Freek Ooster Marjke Vos Henk de Jong
Area[1][2]	
- Municipality / City	219 km <sup>2</sup> (84.6 sq mi)
- Land	166 km <sup>2</sup> (64.1 sq mi)
- Water	53 km <sup>2</sup> (20.5 sq mi)
- Urban	1,003 km <sup>2</sup> (387.3 sq mi)
- Metro	1,815 km <sup>2</sup> (700.8 sq mi)
Elevation[3]	2 m (7 ft)
Population (June 2009)[4][5]	
- Municipality / City	762,057
- Density	4,459/km <sup>2</sup> (11,548.8/sq mi)
- Urban	1,364,422
- Metro	2,158,372
- Demonym	Amsterdammer
Time zone	CET (UTC+01)
- Summer (DST)	CEST (UTC+02) (UTC)
Postal codes	1011-1109
Area code(s)	020
Website	<a href="http://www.amsterdam.nl">www.amsterdam.nl</a>

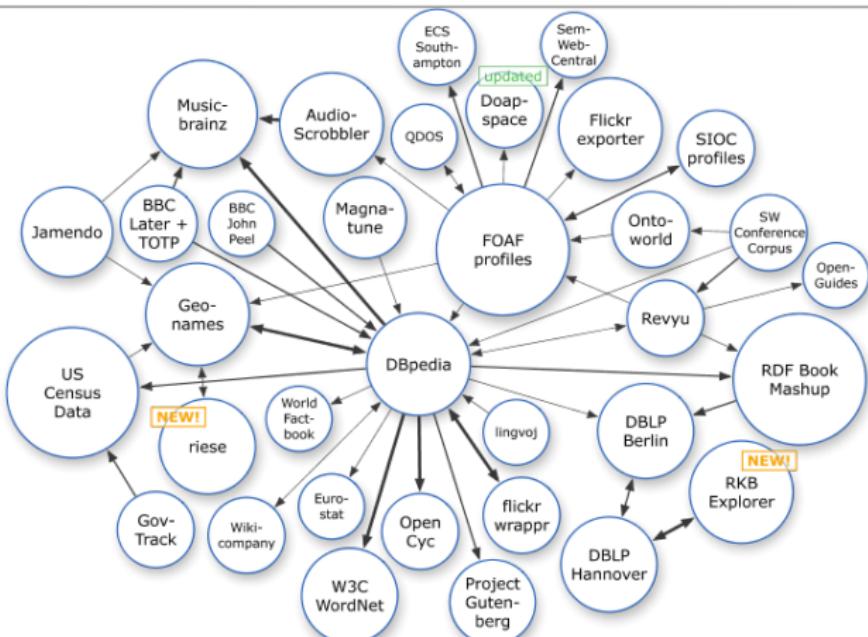
# Automatic links among open datasets

```
<http://dbpedia.org/resource/Amsterdam> ←  
owl:sameAs <http://rdf.freebase.com/ns/...> ;  
owl:sameAs <http://sws.geonames.org/2759793> ;  
...
```

```
<http://sws.geonames.org/2759793>  
owl:sameAs <http://dbpedia.org/resource/Amsterdam>  
wgs84_pos:lat "52.3666667" ;  
wgs84_pos:long "4.8833333" ;  
geo:inCountry <http://www.geonames.org/countries/#NL> ;  
...
```

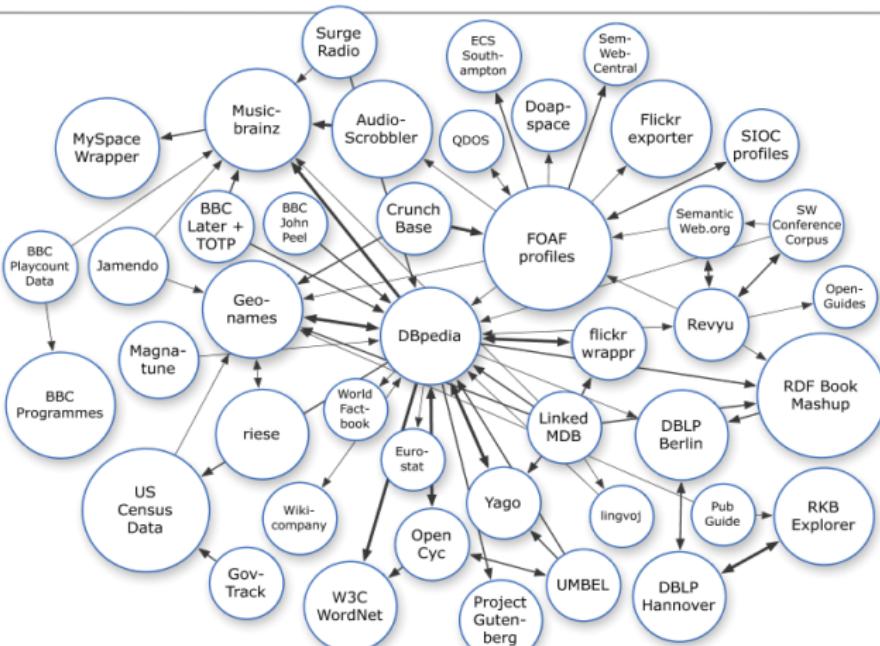
Processors can switch automatically from one to the other...

# The LOD “cloud”, March 2008



Courtesy of Richard Cyganiak and Anja Jentzsch

# The LOD “cloud”, September 2008

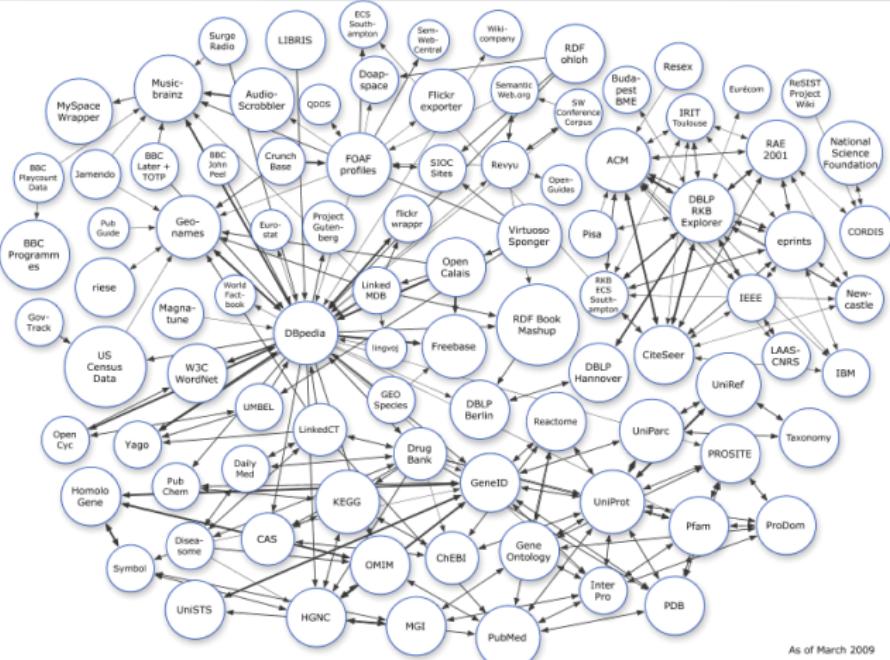


As of September 2008

Courtesy of Richard Cyganiak and Anja Jentzsch

W3C Semantic Web

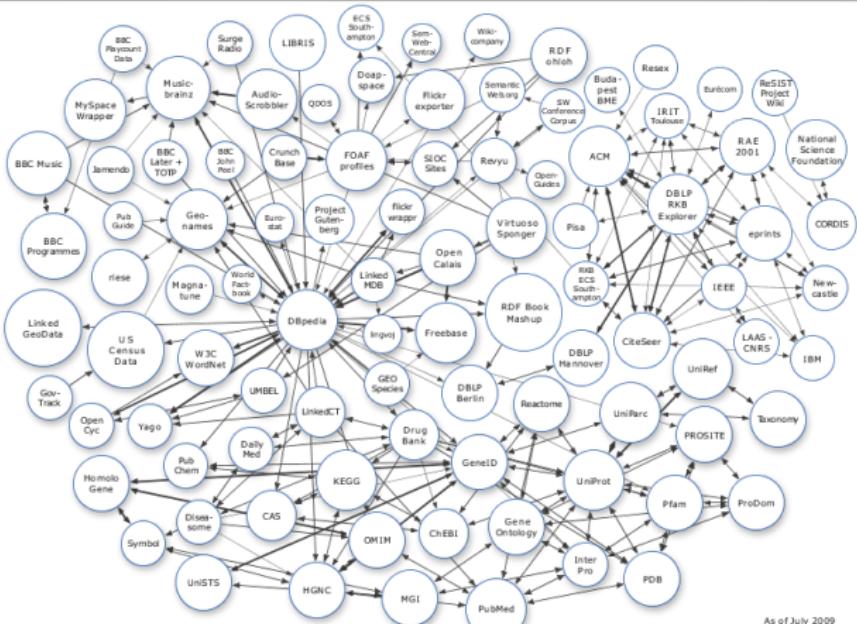
The LOD “cloud”, March 2009



As of March 2009

*Courtesy of Richard Cyganiak and Anja Jentzsch*

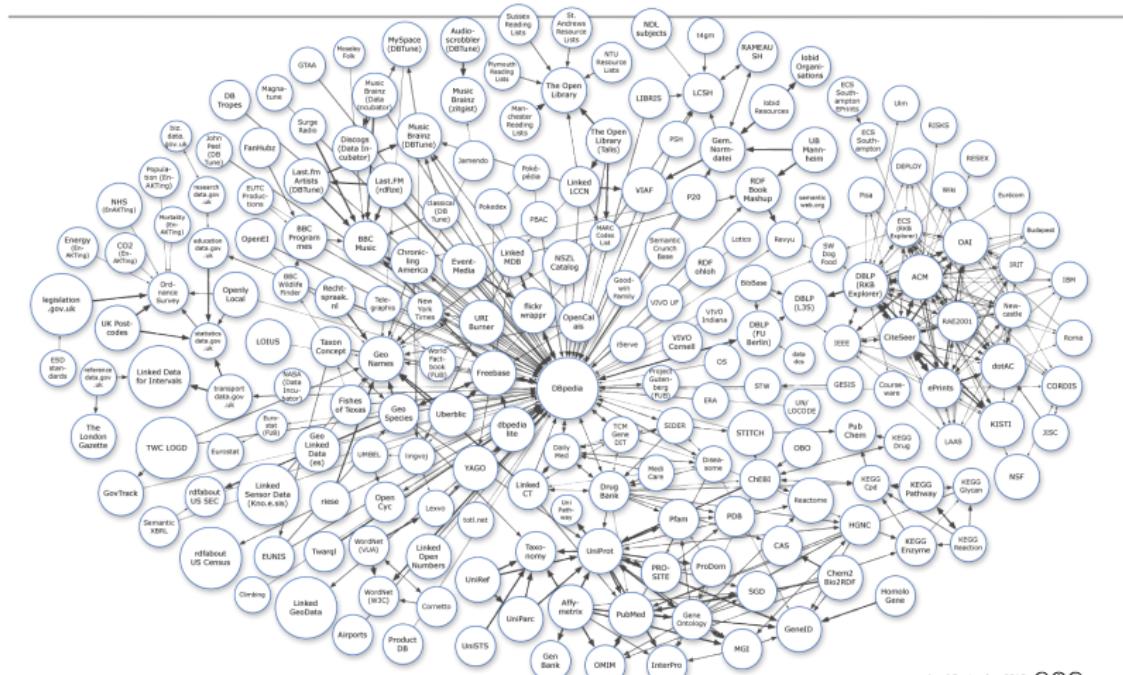
The LOD “cloud”, June 2009



As of July 2009

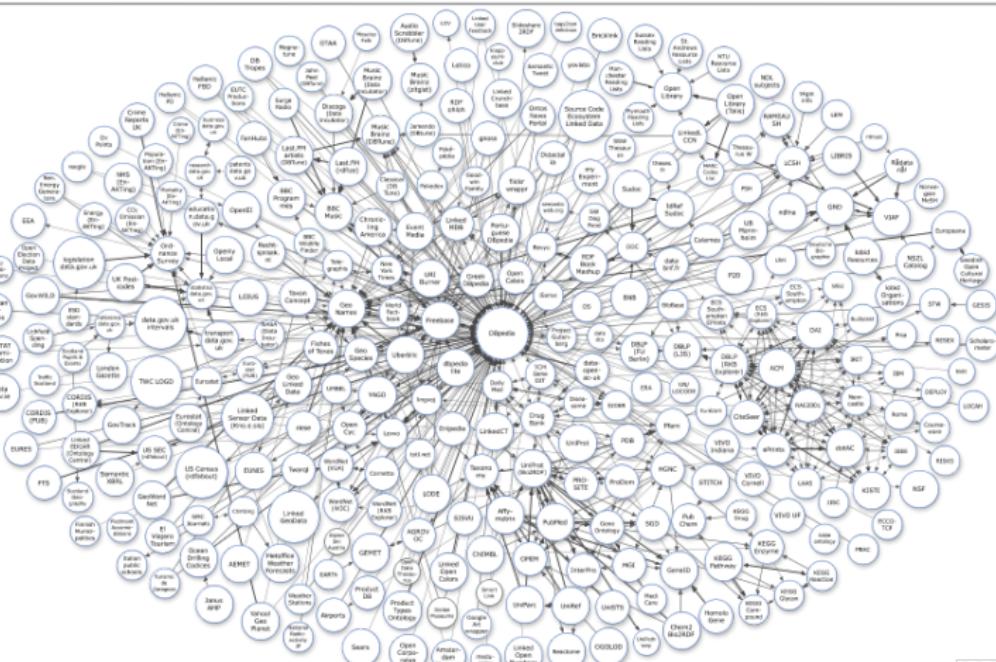
*Courtesy of Richard Cyganiak and Anja Jentzsch*

# The LOD “cloud”, September 2010



As of September 2010

# The LOD “cloud”, September 2011



*Courtesy of Richard Cyganiak and Anja Jentzsch*

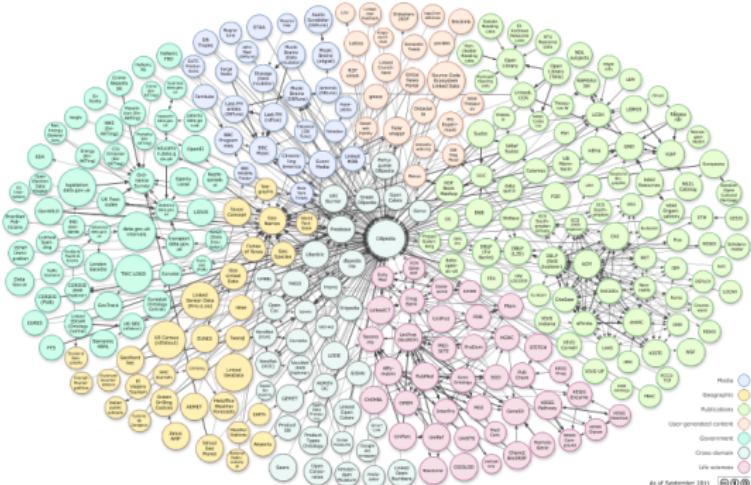
As of September 2011



# Application specific portions of the cloud

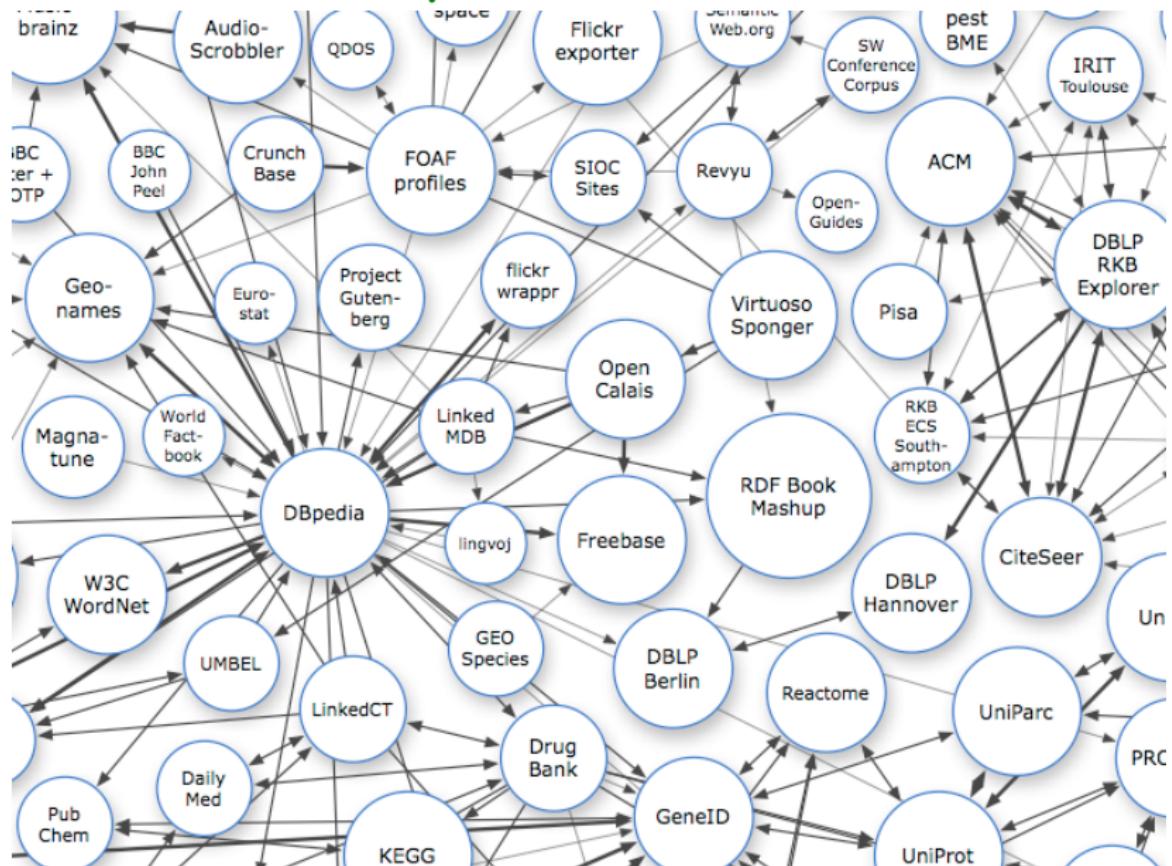
- ▶ Eg, “bio” related datasets

- done, partially, by the “Linking Open Drug Data” task force of the HCLS IG at W3C



Courtesy of Richard Cyganiak and Anja Jentzsch

# LOD Datasets: <https://lod-cloud.net/>



# Google's Knowledge Graph (2012)



## Introducing the Knowledge Graph

<https://www.youtube.com/watch?v=mmQI6VGvX-c>

All Images Videos News Shopping Books Maps

About 125,000,000 results

#### Any country

Country: Canada

#### Any time

Past hour

Past 24 hours

Past week

Past month

Past year

#### All results

Verbatim

Entrepreneur,  
Film producer,  
Business magnate,  
Inventor,  
Businessperson,  
Designer  
Steve Jobs, Professions

#### Steve Jobs - Inventor - Biography.com

[www.biography.com/people/steve-jobs-9354805](http://www.biography.com/people/steve-jobs-9354805) - Cached - Similar

24 Sep 2015 ... **Steven Paul Jobs** was born on February 24, 1955, in San Francisco, California, to Joanne Schieble (later Joanne Simpson) and Abdulfattah "John" Jandali, two University of Wisconsin graduate students who gave their unnamed son up for adoption.

#### Steve Jobs - Wikipedia

[https://en.wikipedia.org/wiki/Steve\\_Jobs](https://en.wikipedia.org/wiki/Steve_Jobs) - Cached - Similar

—Steve Jobs, 1995. From the documentary, **Steve Jobs**: The Lost Interview. Schieble became pregnant in 1954 when she and Jandali spent the summer with his family in Homs, Syria.

#### Biography | all about Steve Jobs .com

[allaboutstevejobs.com/bio/bio.php](http://allaboutstevejobs.com/bio/bio.php) - Cached - Similar

Timeline, short biography and detailed biography of Apple CEO **Steve Jobs**, complete with key people in his life.

#### all about Steve Jobs .com

[allaboutstevejobs.com/](http://allaboutstevejobs.com/) - Cached - Similar

all about Steve Jobs .com: biography, pictures, movies, life and work of Apple CEO **Steve Jobs**.

## Steve Jobs



Entrepreneur

Steven Paul "Steve" Jobs was an American information technology entrepreneur and inventor. He was the co-founder, chairman, and chief executive officer of Apple Inc., CEO and majority shareholder of ... [Wikipedia](#)

**Born:** February 24, 1955, San Francisco, California, United States

**Died:** October 5, 2011, Palo Alto, California, United States

**Spouse:** Laurene Powell (m. 1991–2011)

**Education:** Reed College (1972–1974), more

**Children:** Lisa Brennan-Jobs, Eve Jobs, Erin Siena Jobs, Reed Jobs

**Siblings:** Mona Simpson, Patricia Ann Jobs

## People also search for



Bill Gates



Laurene Powell  
Spouse



Lisa  
Brennan-Jobs  
Daughter

## About: Steve Jobs

An Entity of Type : [person](#), from Named Graph : <http://dbpedia.org>, within Data Space : dbpedia.org

Steven Paul "Steve" Jobs (/dʒɒpbz/; February 24, 1955 – October 5, 2011) was an American information technology entrepreneur and inventor. He was the co-founder, chairman, and chief executive officer (CEO) of Apple Inc.; CEO and majority shareholder of Pixar Animation Studios; a member of The Walt Disney Company's board of directors following its acquisition of Pixar; and founder, chairman, and CEO of NeXT Inc. Jobs is widely recognized as a pioneer of the microcomputer revolution of the 1970s and 1980s, along with Apple co-founder Steve Wozniak. Shortly after his death, Jobs's official biographer, Walter Isaacson, described him as a "creative entrepreneur whose passion for perfection and ferocious drive revolutionized six industries: personal computers, animated movies, music, phones, tab

Property	Value
<a href="#">dbo:abstract</a>	■ Steven Paul "Steve" Jobs (/dʒɒpbz/; February 24, 1955 – October 5, 2011) was an American information technology entrepreneur and inventor. He was the co-founder, chairman, and chief executive officer (CEO) of Apple Inc.; CEO and majority shareholder of Pixar Animation Studios; a member of The Walt Disney Company's board of directors following its acquisition of Pixar; and founder, chairman, and CEO of NeXT Inc. Jobs is widely recognized as a pioneer of the microcomputer revolution of the 1970s and 1980s, along with Apple co-founder Steve Wozniak. Shortly after his death, Jobs's official biographer, Walter Isaacson, described him as a "creative entrepreneur whose passion for perfection and ferocious drive revolutionized six industries: personal computers, animated movies, music, phones, tab

[http://dbpedia.org/resource/Steve\\_Jobs](http://dbpedia.org/resource/Steve_Jobs)

# Querying RDF graphs

---

- ▶ In practice, more complex queries into the RDF data are necessary
  - something like: “give me the (a,b) pair of resources, for which there is an x such that (x parent a) and (b brother x) holds” (ie, return the uncles)
    - these rules may become quite complex
- ▶ The goal of SPARQL (Query Language for RDF)

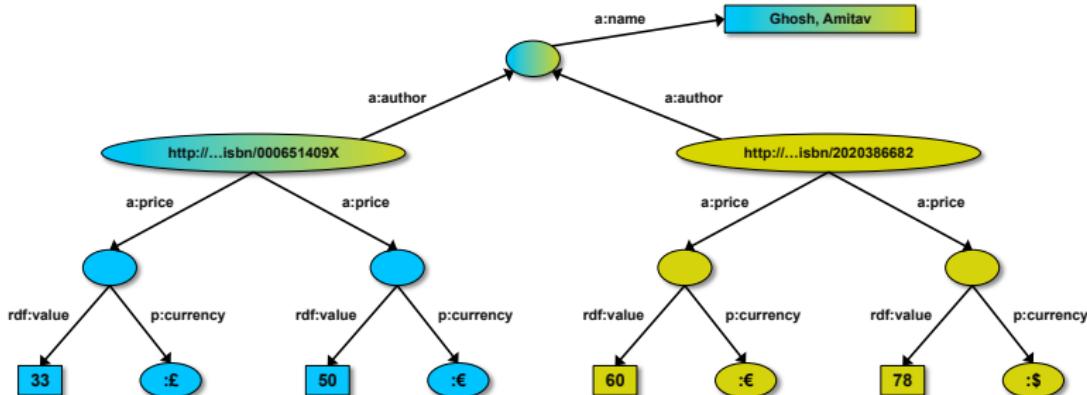
# General: graph patterns

---

- ▶ The fundamental idea: use graph patterns
  - the pattern contains unbound symbols
  - by binding the symbols, subgraphs of the RDF graph are selected
  - if there is such a selection, the query returns the bound resources

# Simple SPARQL example

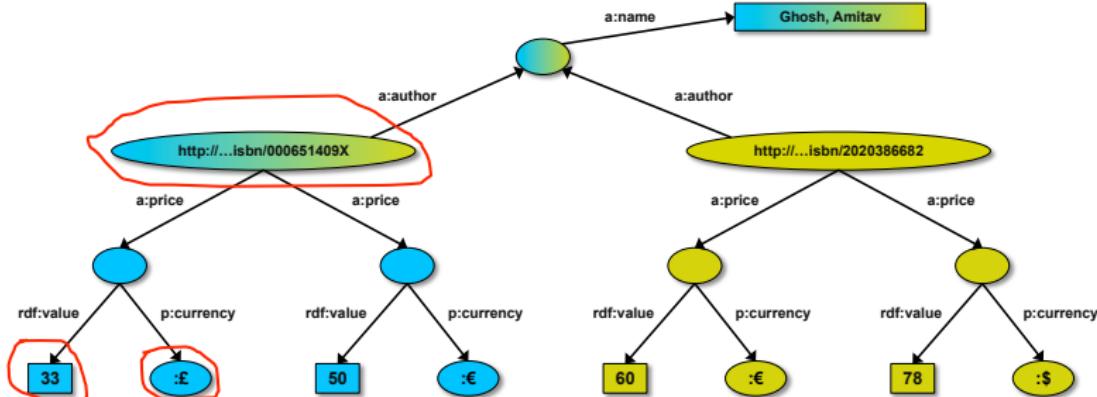
```
SELECT ?isbn ?price ?currency # note: not ?x!
WHERE {?isbn a:price ?x. ?x rdf:value ?price. ?x p:currency ?currency.}
```



# Simple SPARQL example

```
SELECT ?isbn ?price ?currency # note: not ?x!
WHERE {?isbn a:price ?x. ?x rdf:value ?price. ?x p:currency ?currency.}
```

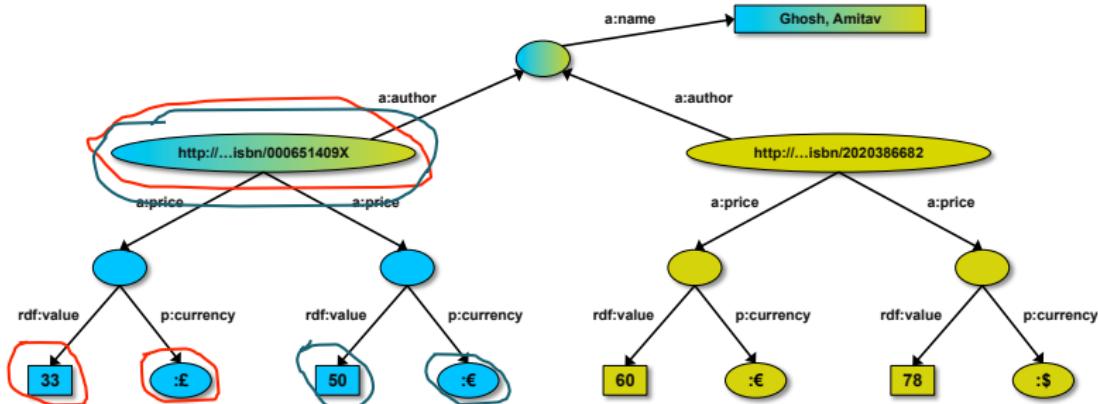
Returns: [<...409X>,33,:£]



# Simple SPARQL example

```
SELECT ?isbn ?price ?currency # note: not ?x!
WHERE {?isbn a:price ?x. ?x rdf:value ?price. ?x p:currency ?currency.}
```

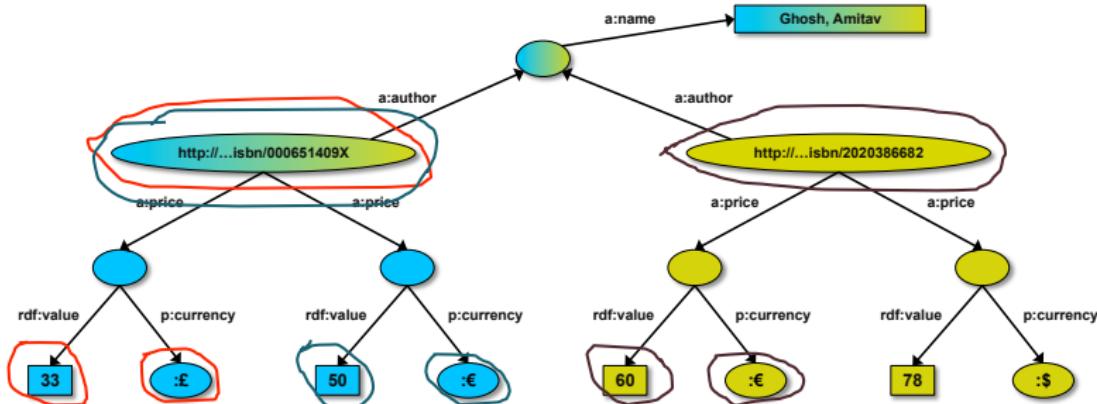
Returns: [<...409X>,33,:£], [<...409X>,50,:€]



# Simple SPARQL example

```
SELECT ?isbn ?price ?currency # note: not ?x!
WHERE {?isbn a:price ?x. ?x rdf:value ?price. ?x p:currency ?currency.}
```

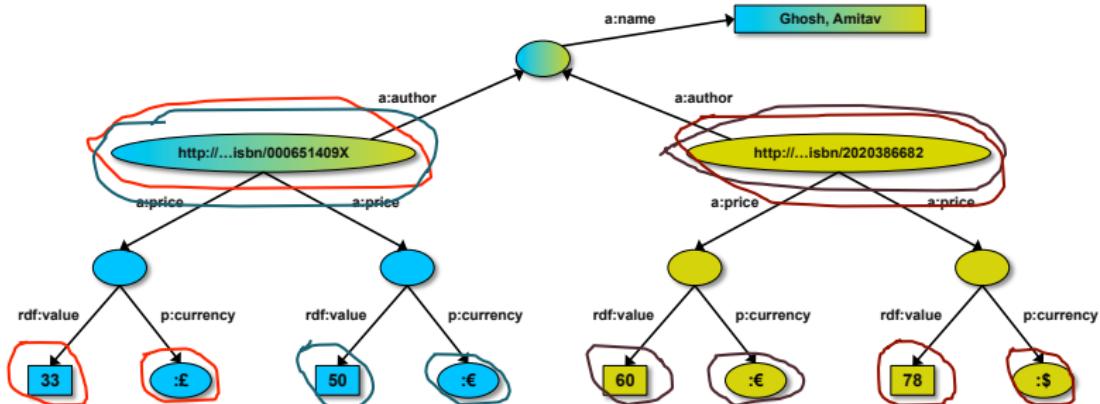
Returns: [<...409X>,33,:£], [<...409X>,50,:€],  
[<...6682>,60,:€]



# Simple SPARQL example

```
SELECT ?isbn ?price ?currency # note: not ?x!
WHERE {?isbn a:price ?x. ?x rdf:value ?price. ?x p:currency ?currency.}
```

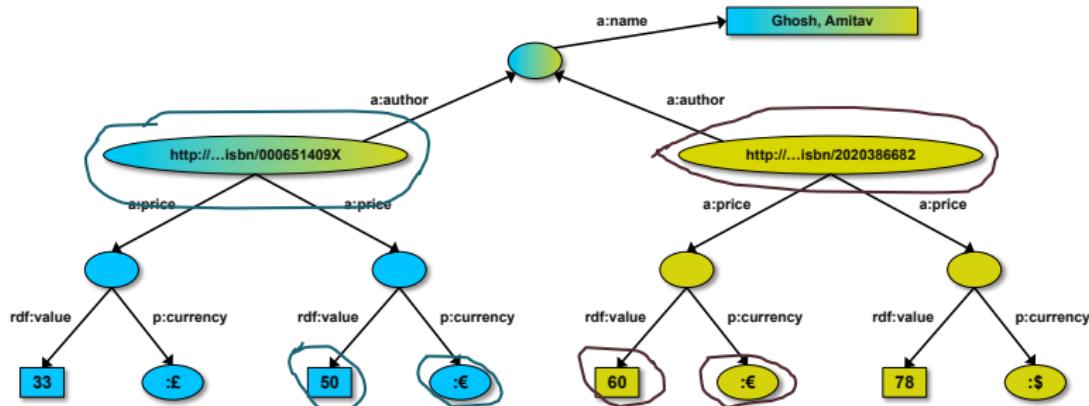
Returns: [⟨...409X>,33,:£], [⟨...409X>,50,:€],  
[⟨...6682>,60,:€], [⟨...6682>,78,:\$]



# Pattern constraints

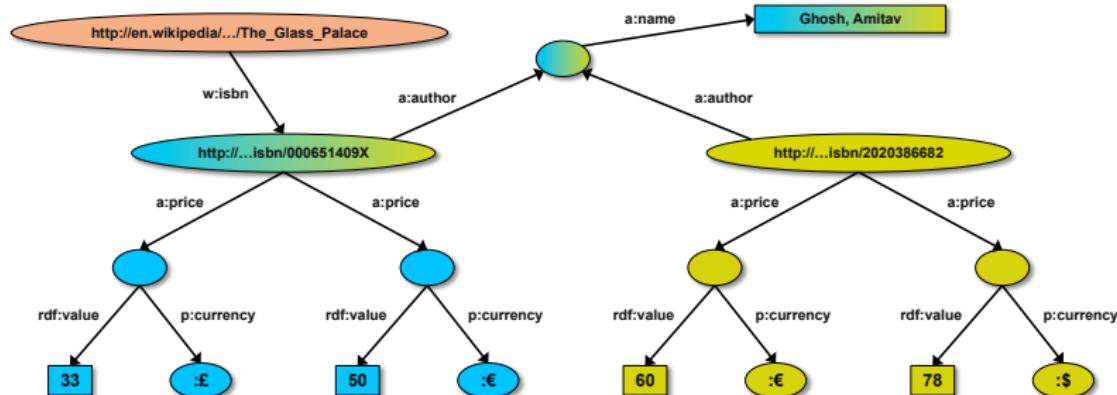
```
SELECT ?isbn ?price ?currency # note: not ?x!
WHERE { ?isbn a:price ?x. ?x rdf:value ?price. ?x p:currency ?currency.
        FILTER(?currency == :€) }
```

Returns: [<...409X>,50,:€], [<...6682>,60,:€]



# Optional pattern

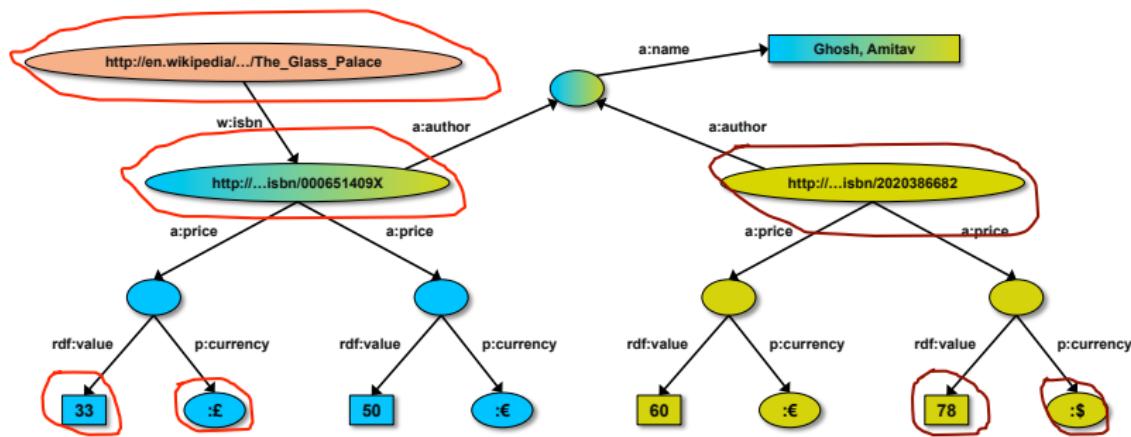
```
SELECT ?isbn ?price ?currency ?wiki
WHERE { ?isbn a:price ?x. ?x rdf:value ?price. ?x p:currency ?currency.
        OPTIONAL ?wiki w:isbn ?isbn. }
```



# Optional pattern

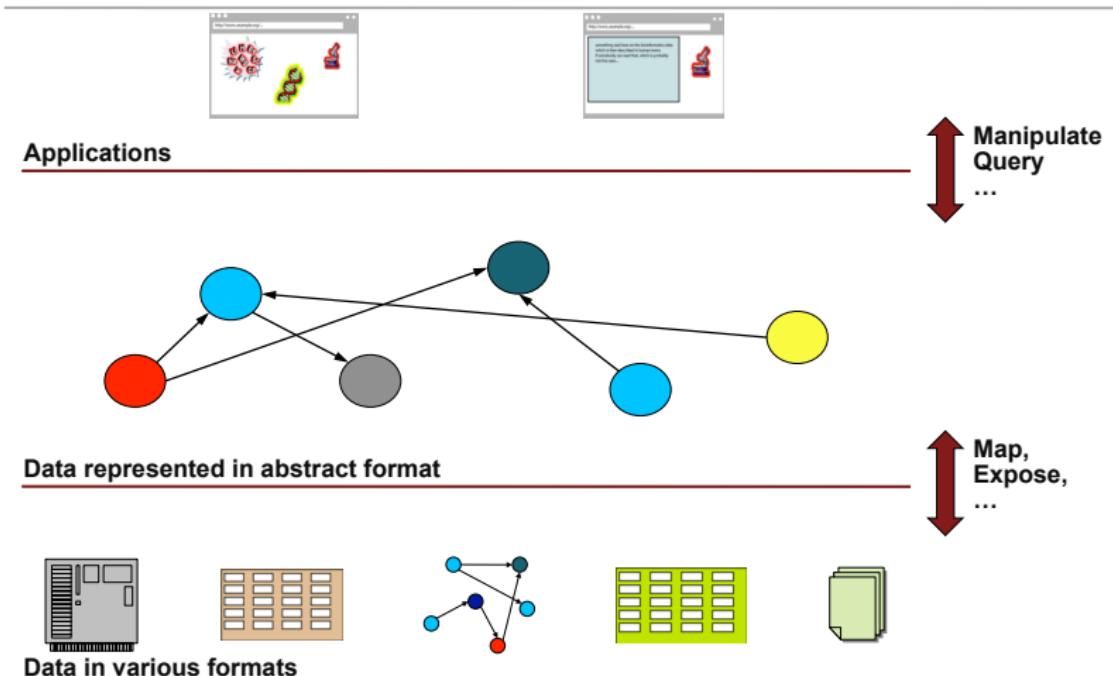
```
SELECT ?isbn ?price ?currency ?wiki
WHERE { ?isbn a:price ?x. ?x rdf:value ?price. ?x p:currency ?currency.
        OPTIONAL ?wiki w:isbn ?isbn. }
```

Returns: [[<..09X>,33,:£,<...Palace>], ... , [<..6682>,78,:\$, ]]

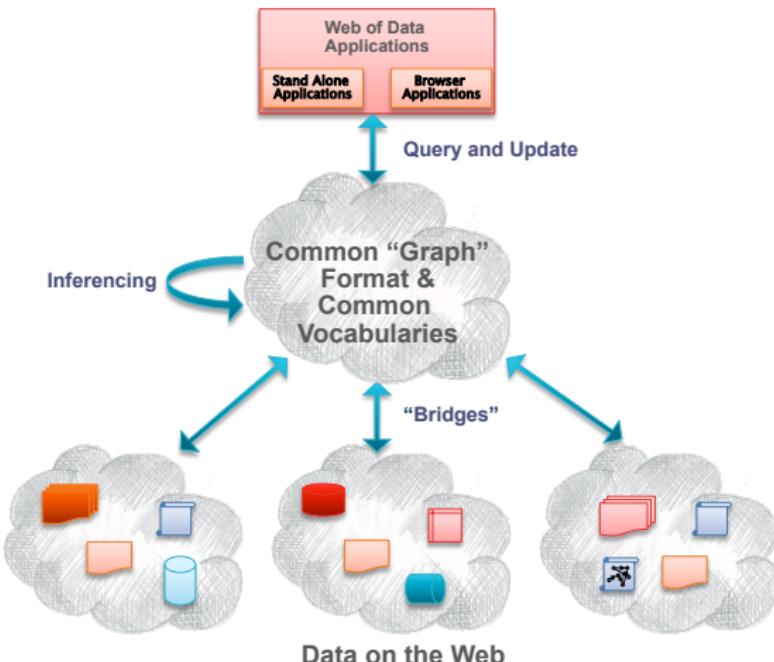


→ Worksheet #8: "SPARQL"

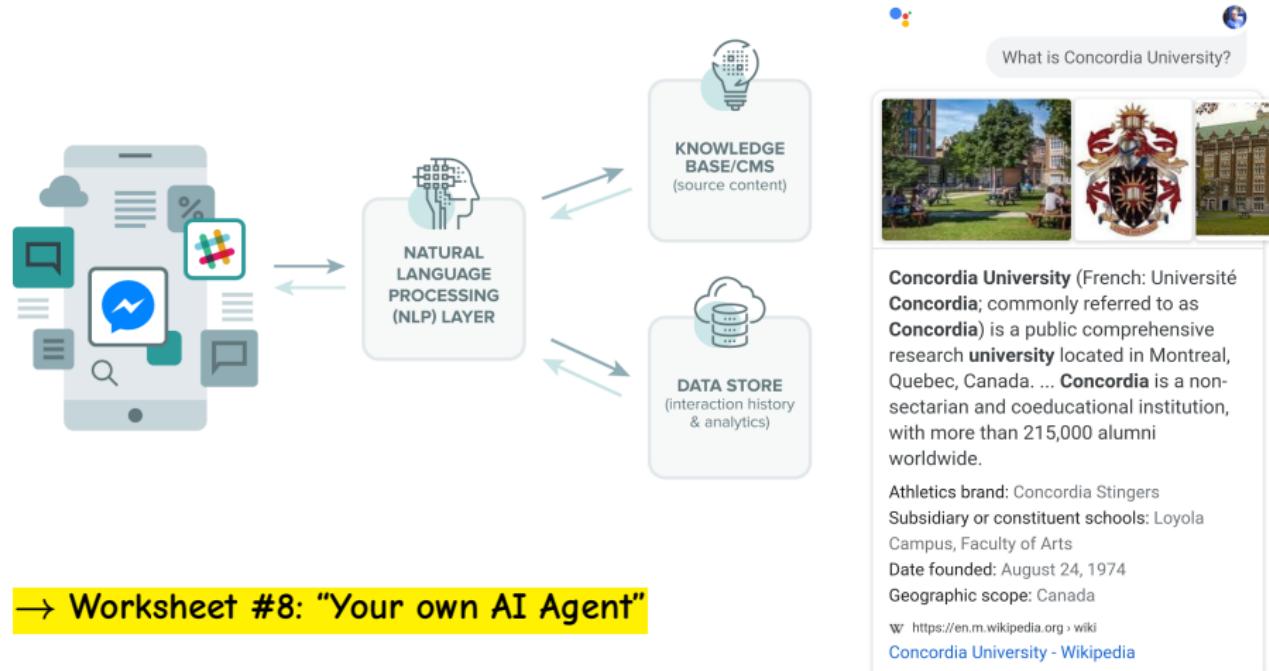
# What did we do?



# What did we do? (alternate view)



# Generic Assistant Architecture Revisited



→ Worksheet #8: "Your own AI Agent"

# Knowledge Graphs in AI: Recap

## Foundations of the Semantic Web

RDF Describing (web) resources with a triple-based structure

RDFS Adding layers of meaning with classes and properties

## Standardization and Interoperability

Vocabularies Emphasizing reuse with vocabularies like FOAF and Schema.org, to standardize terms for interoperability

Linked Data Principles: URIs, information richness, and dataset interlinking

## Queries and Integration

SPARQL Querying and exploring interconnected datasets

AI Apps Semantic search and question-answering systems, leveraging structured knowledge

# Knowledge Graphs in AI: Context and Outlook

## AI's Expanding Horizons with Knowledge Graphs

**Structured Knowledge** Advanced reasoning and AI decision support

**Data Integration** Cross-domain analysis and holistic insights for (business) information silos

**Property Graphs** Utilized in systems like Neo4J; similar to RDF in data representation, yet distinct in structure and query language (Cypher vs. SPARQL), often used in analytics

## Future Directions

**KG Research** Dynamic knowledge graph generation and automated reasoning

**Deep Learning** Merging deep learning with knowledge graphs for richer AI insights and verifiable information

**Top Applications** Personalized recommendations, semantic search, data-driven healthcare, social networks, ...

# Outline

- 1 RDF Schema
- 2 Vocabularies
- 3 Example: schema.org
- 4 Knowledge Bases & Linked Open Data
- 5 Notes and Further Reading

# Reading Material

## Required

- [Wor14, Sections 4–7] (RDF Primer)

## Supplemental

- [Yu14, Chapter 4] (RDFS)
- [WZRH14, Chapters 1, 2] (Linked Data, RDF(S), Vocabularies)

# References I

- [HB11] Tom Heath and Christian Bizer.  
*Linked Data: Evolving the Web into a Global Data Space.*  
Morgan & Claypool, 2011.  
<https://concordiauniversity.on.worldcat.org/oclc/704257552>.
- [Her] Ivan Herman.  
Tutorial on Semantic Web Technologies.  
<http://www.w3.org/People/Ivan/CorePresentations/RDFTutorial/>.
- [Wor14] World Wide Web Consortium (W3C).  
RDF 1.1 Primer.  
<http://www.w3.org/TR/rdf11-primer/>, 24 June 2014.
- [WZRH14] David Wood, Marsha Zaidman, Luke Ruth, and Michael Hausenblas.  
*Linked Data: Structured Data on the Web.*  
Manning, 2014.  
<https://concordiauniversity.on.worldcat.org/oclc/871683907>.

## References II

- [Yu14] Liyang Yu.  
*A Developer's Guide to the Semantic Web.*  
Springer-Verlag Berlin Heidelberg, 2nd edition, 2014.  
<https://concordiauniversity.on.worldcat.org/oclc/897466408>.