Lecture 3

Knowledge Graphs: Vocabularies & Ontologies

COMP 474/6741, Winter 2024

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Outline

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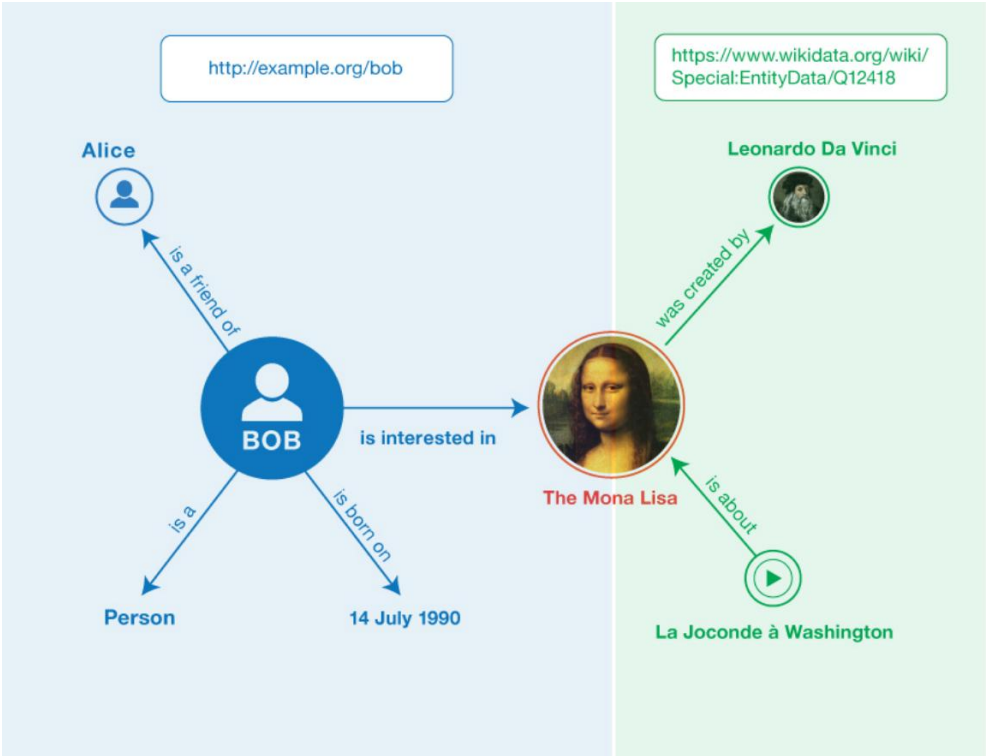
Slides Credit

- Includes slides from Jay Pujara & Sameer Singh, *Mining Knowledge Graphs from Text*, https://kgtutorial.github.io/
- Includes slides by Ivan Herman, W3C [Her]

Outline



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Why knowledge graphs?

- Humans:
  - Combat information overload
  - Explore via intuitive structure
  - Tool for supporting knowledge-driven tasks
- AIs:
  - Key ingredient for many AI tasks
  - Bridge from data to human semantics
  - Use decades of work on graph analysis

RDF triples (cont.)

- An RDF Triple (s,p,o) is such that:
  - "s", "p" are URI-s, ie, resources on the Web; "o" is a URI or a literal
    - "s", "p", and "o" stand for "subject", "property", and "object"
  - here is the complete triple:

```
(<http://…isbn…6682>, <http://…/original>, <http://…isbn…409X>)
```

- *RDF* is a general model for such triples (with machine readable formats like RDF/XML, Turtle, N3, RDFa, Json, …)

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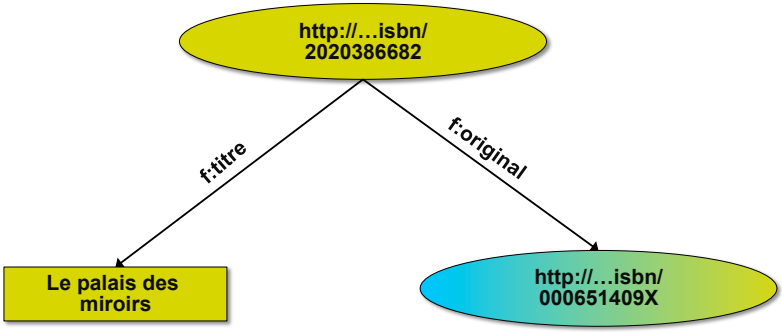
A simple RDF example (in Turtle)




```
<http://…/isbn/2020386682>
    f:titre "Le palais des mirroirs"@fr ;
    f:original <http://…/isbn/000651409X> .
```

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Anatomy of a URI

- A URI *(Uniform Resource Identifier)* uniquely identifies a resource (e.g., person, book, class of things) on the Web.
- A URI is not always a URL *(Uniform Resource Locator)*
  - URNs *(Uniform Resource Names)* are URIs that name resources without specifying how to retrieve them, e.g., `urn:isbn:0451450523`.
  - It's possible URLs are not available, e.g.,
    `http://www.concordia.ca/comp474/lecture03/slide5`
    is a valid URL, but nothing can be (currently?) retrieved from this address
- URIs have a generic syntax:

- Queries are also possible, following the format:
  scheme:[//authority]path[?query][#fragment]
- Namespaces are used to shorten URIs and prevent name clashes, e.g., `ex:me`
- IRIs *(Internationalized Resource Identifiers)* are URIs with Unicode characters

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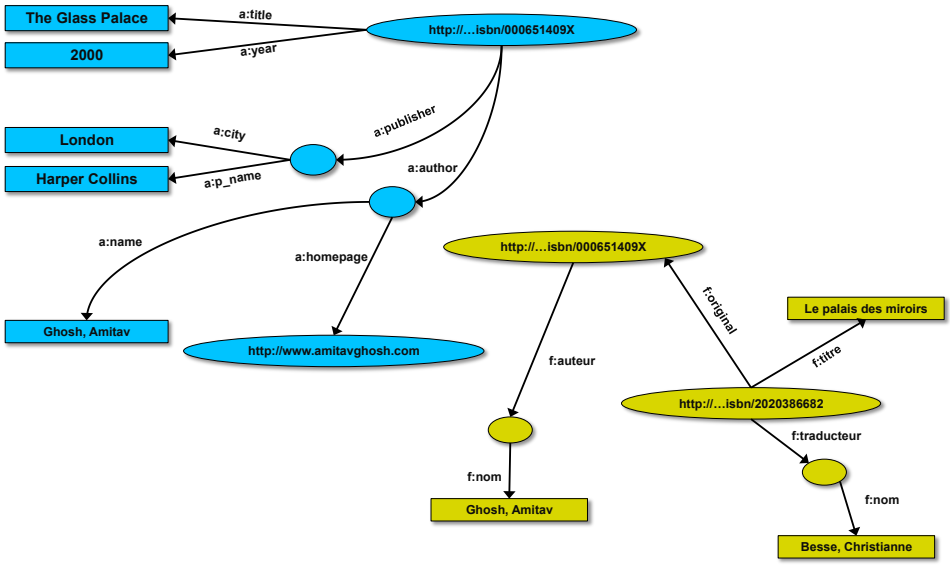
3rd: start merging your data



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From the first week's lecture. . .

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Common Issue

- Data in Information Silos
  Documents, databases, spreadsheets, emails, . . .
- Disconnected, missing knowledge

Knowledge Integration

- Connect silo-ed knowledge
- Leverage existing, external Knowledge Bases
- Freely available, many domains
- Continuously updated

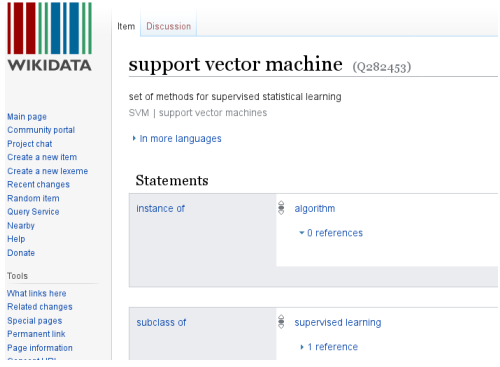

Photo credit "nepatterson", Flickr

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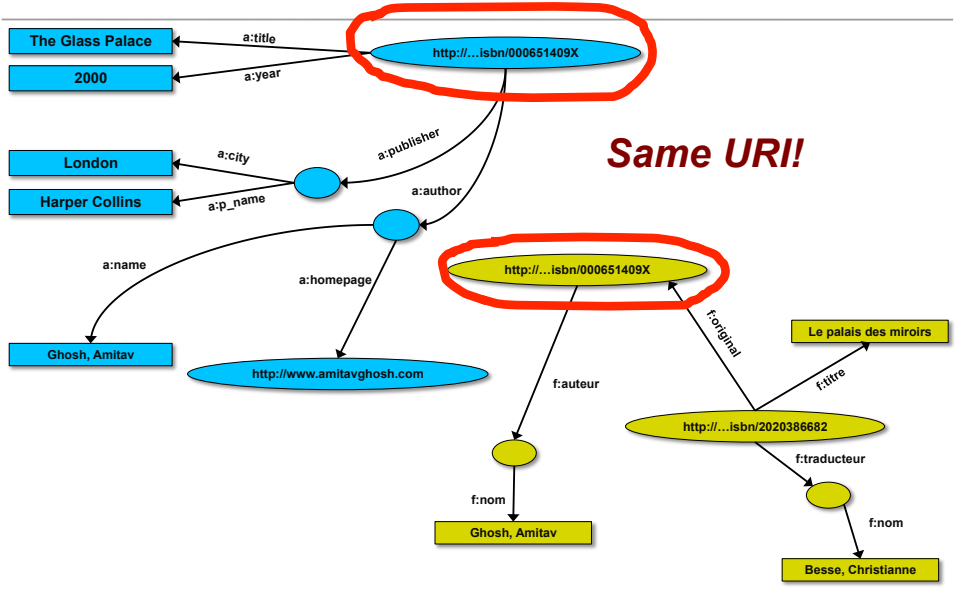
3rd: start merging your data (cont)



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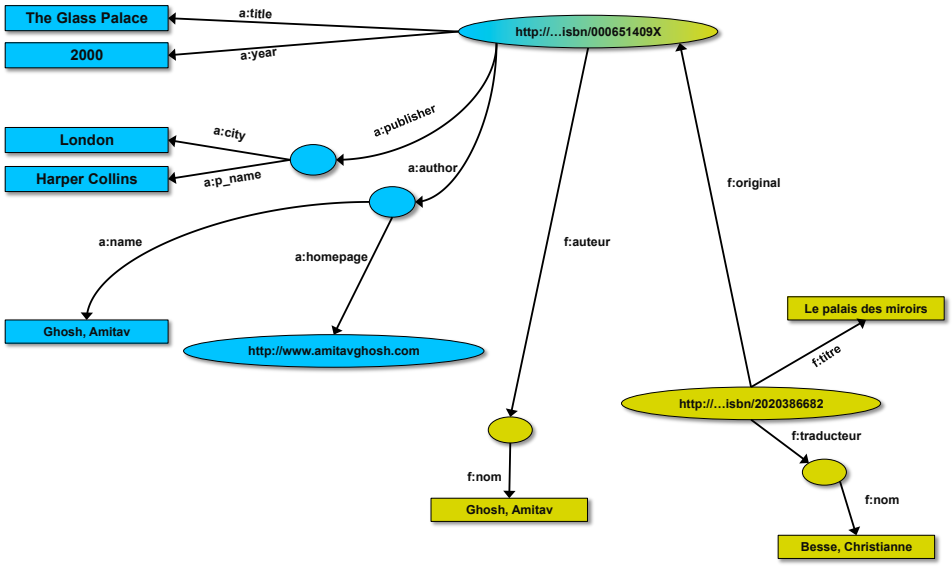
3rd: start merging your data



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Semantics

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What's an "author"?

- author
- auteur
- Autor
- book author
- writer
- editor
- ghostwriter
- co-author
- blogger
- ...

How can we define their meaning? And relations?

Everything Search

The Library of Congress > Linked Data Service > **LC Subject Headings (LCSH)**

Authors and publishers

Here are entered works on the relations between author and publisher.

URI(s)
- http://id.loc.gov/authorities/subjects/sh85010023
- info:lc/authorities/sh85010023
- http://id.loc.gov/authorities/sh85010023#concept

Instance Of
- MADS/RDF Topic
- MADS/RDF Authority
- SKOS Concept

Scheme Membership(s)
- Library of Congress Subject Headings

Collection Membership(s)
- LCSH Collection - Authorized Headings
- LCSH Collection - General Collection
- LCSH Collection - May Subdivide Geographically

Variants
- Author and publisher
- Authors and publishers--Law and legislation
- Publishers and authors
- Publishing contracts

Broader Terms
- Authorship
- Contracts

Narrower Terms
- Queries (Authorship)

Related Terms
- Book proposals

Subject Of Works
243 resources filter Page 1 of 5

Alden, Chevy. How to get published, guaranteed
Alden, Chevy. How to get published-guaranteed
Allen, Marilyn. complete idiot's guide to book proposals & query letters
Allfeld, Philipp, 1852- gesetze betreffend das urheberrecht an werken der literatur und der tonkunst und über das verlagsrecht
Allfeld, Philipp, 1852- verlagsrecht
Allison, Alida. Grad student's guide to getting published
Amir, Nina, How to blog a book
Amir, Nina, author training manual
Amir, Nina. How to blog a book
Anderson, Rick, 1965- Scholarly communication
Anderson, Rick, 1965- Scholarly communication
Appelbaum, Judith. How to get happily published

Suggest Alternative Terminology

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Library of Congress

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RDF Triples (SKOS vocabulary, introduced later)

```
<http://id.loc.gov/authorities/subjects/sh85010023>
    <http://www.w3.org/1999/02/22-rdf-syntax-ns#type>
    <http://www.w3.org/2004/02/skos/core#Concept> .

<http://id.loc.gov/authorities/subjects/sh85010023>
    <http://www.w3.org/2004/02/skos/core#prefLabel>
    "Authors and publishers"@en .

<http://id.loc.gov/authorities/subjects/sh85010023>
    <http://www.w3.org/2004/02/skos/core#broader>
    <http://id.loc.gov/authorities/subjects/sh85031620> .

<http://id.loc.gov/authorities/subjects/sh85010023>
    <http://www.w3.org/2004/02/skos/core#narrower>
    <http://id.loc.gov/authorities/subjects/sh85109817> .
...
```

http://id.loc.gov/authorities/subjects/sh85010023.html

Photo credit "kxlly", Flickr

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TBL at TED on “The year open data went worldwide” (2010)

Tim Berners-Lee: The year open data went worldwide

https://www.youtube.com/watch?v=3YcZ3Zqk0a8

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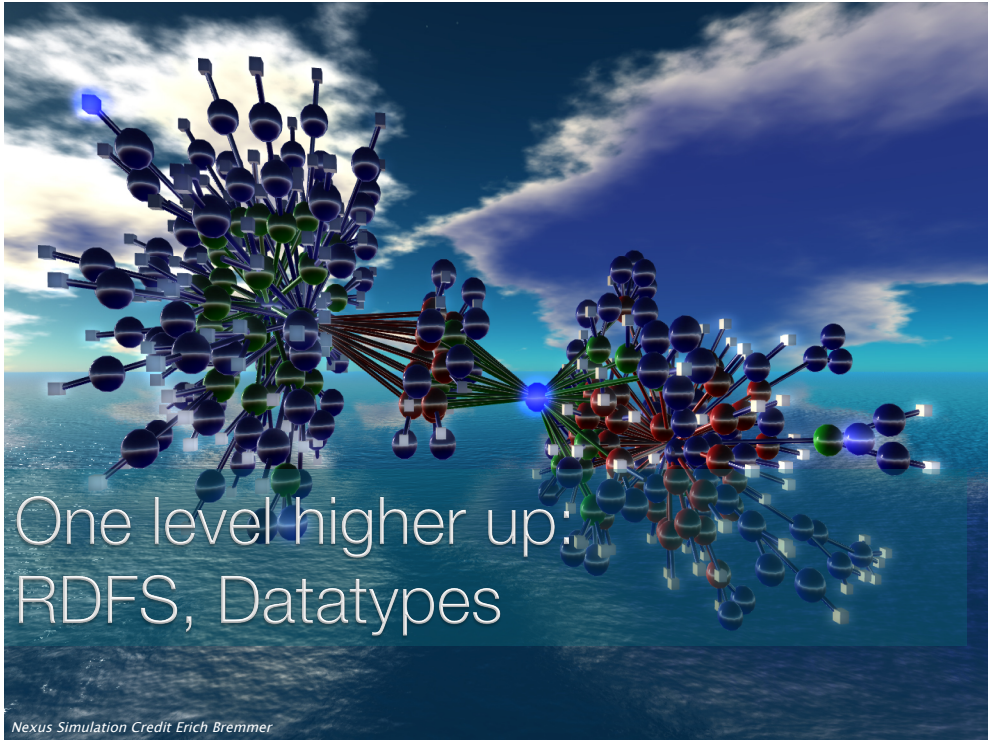
Outline



Nexus Simulation Credit Erich Bremmer

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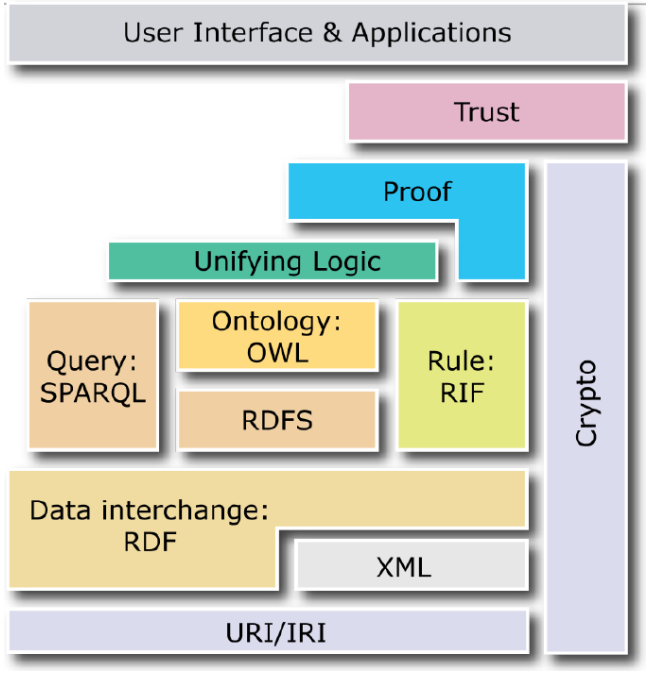
The W3C “Layer Cake”



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RDF Schema (RDFS)

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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

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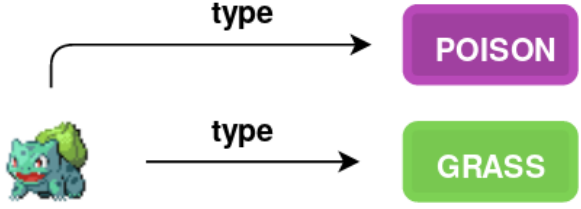
Classes

- 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 URI 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.)

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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 #2: Task 2**

Classes and Instances (contd.)

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Instances

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

I `rdf:type` ***C***

(or `a` instead of `rdf:type` in Turtle.)

Example

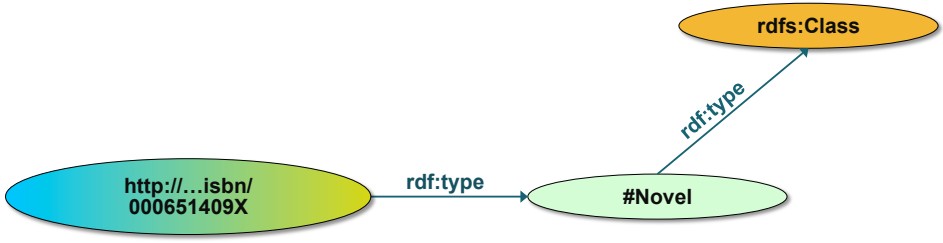
```
<http://...isbn/000651409X> rdf:type ex:Novel
```

Note

This is just another triple, so we can read both *data* and *schema* at run-time!

→ **Worksheet #2: Task 3**

Classes, resources in RDF(S)



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

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Label & Comment

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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 ;
```

→ **Worksheet #2: Task 4**

Subclasses

Defining a subclass

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

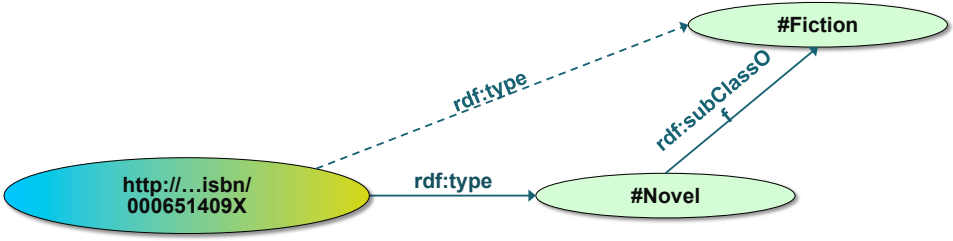
C1 `rdfs:subClassOf` ***C2***

Semantics

This states that all the instances of C1 are also instances of C2.
The `rdfs:subClassOf` property is transitive.

→ **Worksheet #2: Task 5**

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

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Inference: let us be formal…

- 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 .
```

→ **Worksheet #2: Task 6**

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Properties

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Example

`<studies at> <type> <Property>`

Defining a Property

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

P `rdf:type rdf:Property`

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

→ **Worksheet #2: Task 7**

Domain and Range

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Domain

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

P `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 `rdfs:range` ***C***

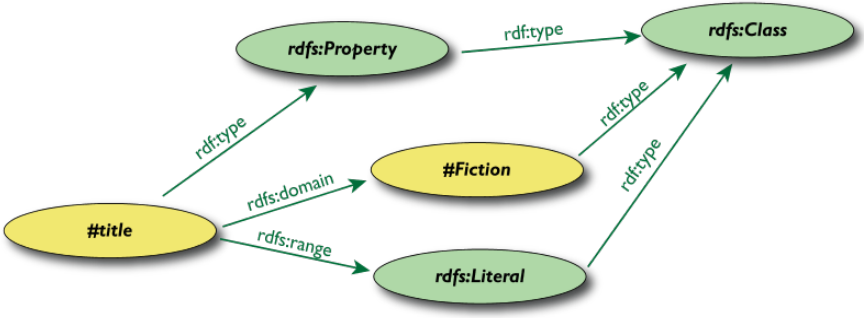
This states that the resources denoted by the objects of triples whose predicate is **P** are instances of the class **C**.

Note

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

→ Worksheet #2: Task 8

Property specification example



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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.
```

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Subproperties

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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

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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
Class (a class)	**C** `rdf:type rdfs:Class`	**C** (a resource) is an RDF class
Property (a class)	**P** `rdf:type rdf:Property`	**P** (a resource) is an RDF property
type (a property)	**I** `rdf:type` **C**	**I** (a resource) is an instance of **C** (a class)
subClassOf (a property)	**C1** `rdfs:subClassOf` **C2**	**C1** (a class) is a subclass of **C2** (a class)
subPropertyOf (a property)	**P1** `rdfs:subPropertyOf` **P2**	**P1** (a property) is a sub-property of **P2** (a property)
domain (a property)	**P** `rdfs:domain` **C**	domain of **P** (a property) is **C** (a class)
range (a property)	**P** `rdfs:range` **C**	range of **P** (a property) is **C** (a class)

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Outline

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Vocabularies

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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.

Self-Describing Datasets

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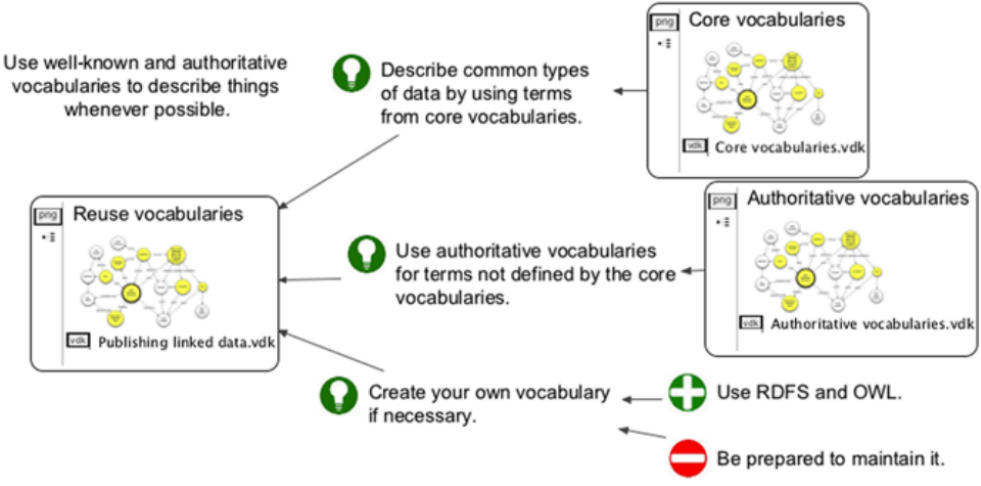
Provide useful information about new terms

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    rdf: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> .
```

Reuse vocabularies whenever possible



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Core Vocabularies

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FOAF (Friend-of-a-Friend) Vocabulary

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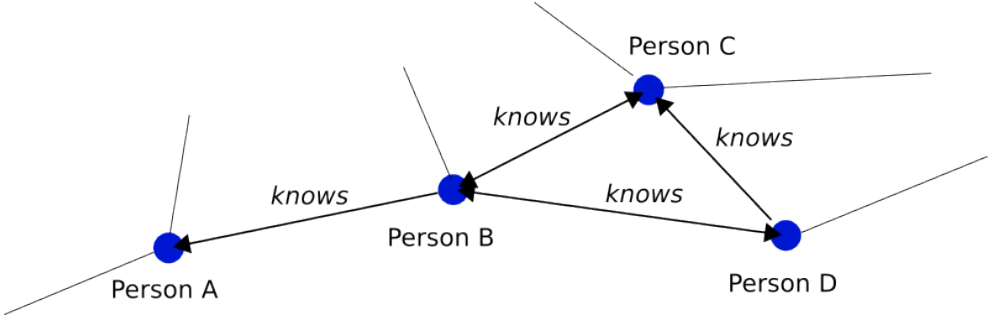
FOAF

Model people and their connections in a social network.

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

<http://example.org/joe> a foaf:Person ;
    foaf:name "Joe Doe" ;
    foaf:mbox <mailto:joe.doe@example.com> .
```



→ Worksheet #2: Task 9

Dublin Core

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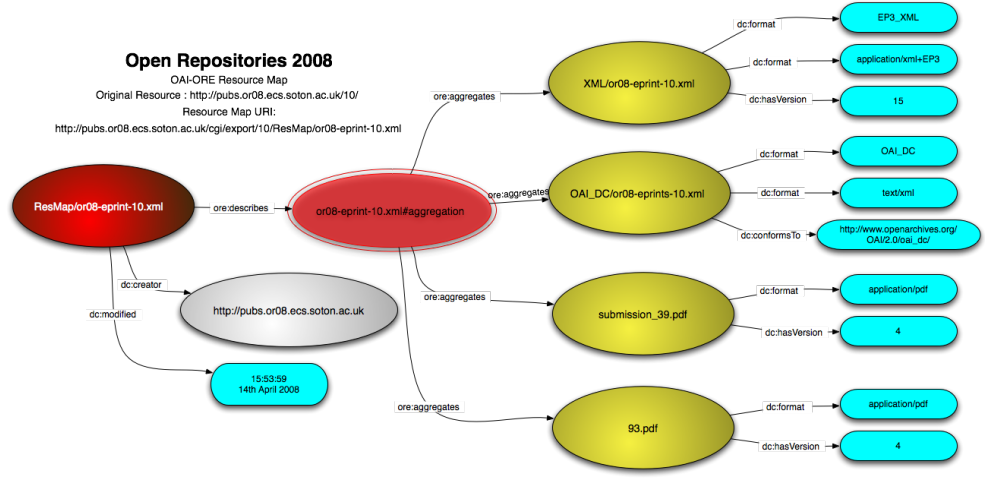
Dublin Core® Metadata Initiative

Making it easier to find information.



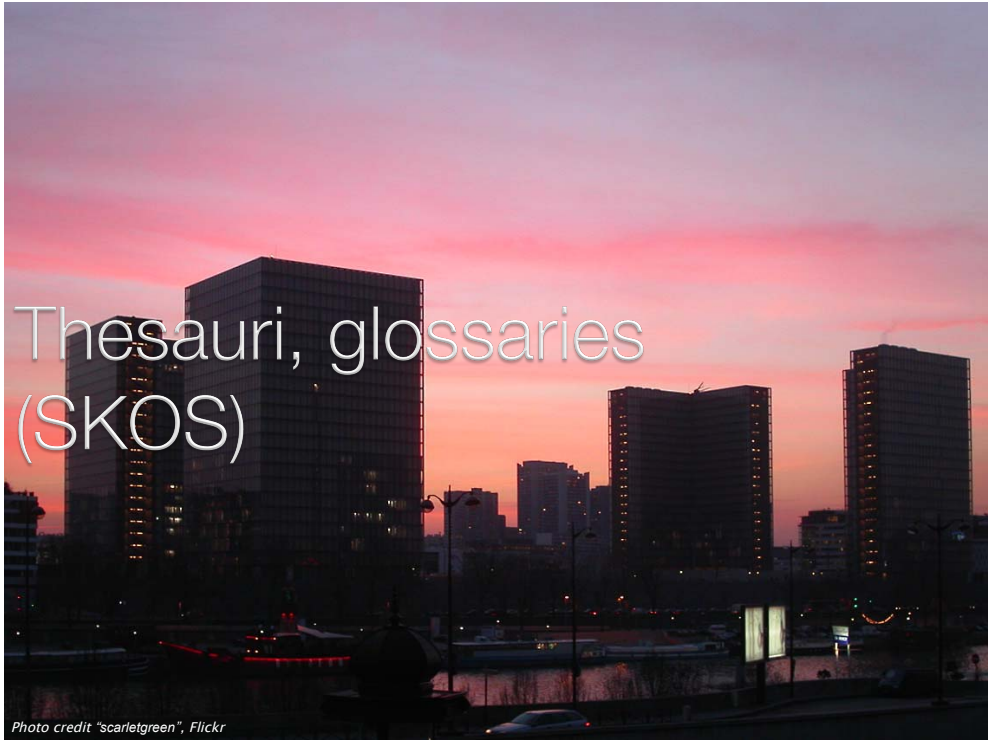


Photo credit "scarletgreen", Flickr

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SKOS

- Represent and share classifications, glossaries, thesauri, etc
  - for example:
    - Dewey Decimal Classification, Art and Architecture Thesaurus, ACM classification of keywords and terms…
    - classification/formalization of Web 2.0 type tags
- Define classes and properties to add those structures to an RDF universe
  - allow for a quick port of this traditional data, combine it with other data

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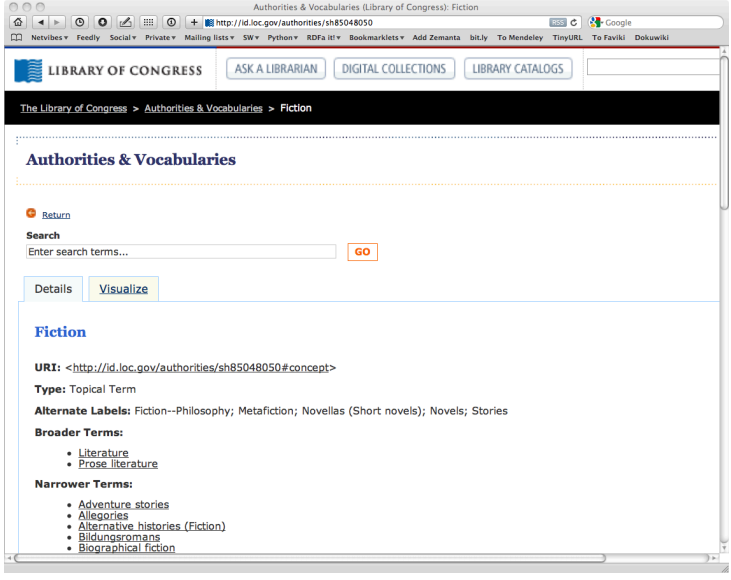
Example: the term “Fiction”, as defined by the Library of Congress



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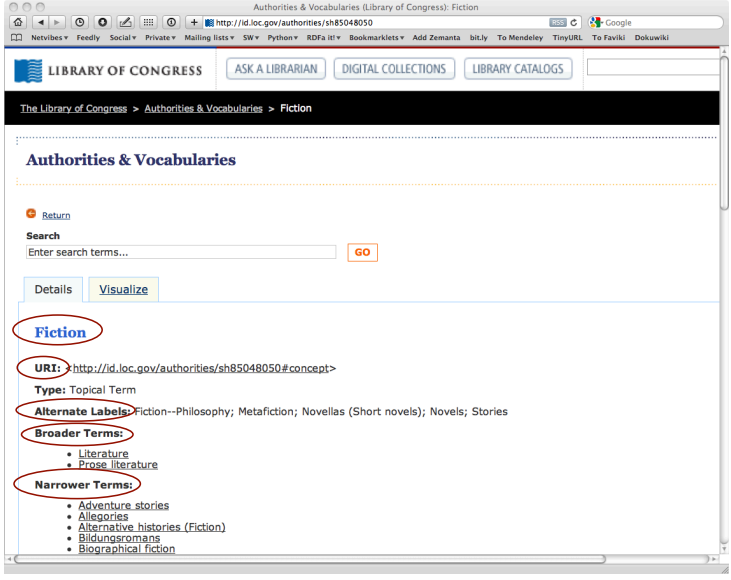

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Thesauri have identical structures…

- The structure of the LOC page is fairly typical
  - label, alternate label, narrower, broader, …
  - there is even an ISO standard for these
- SKOS provides a basic structure to create an RDF representation of these

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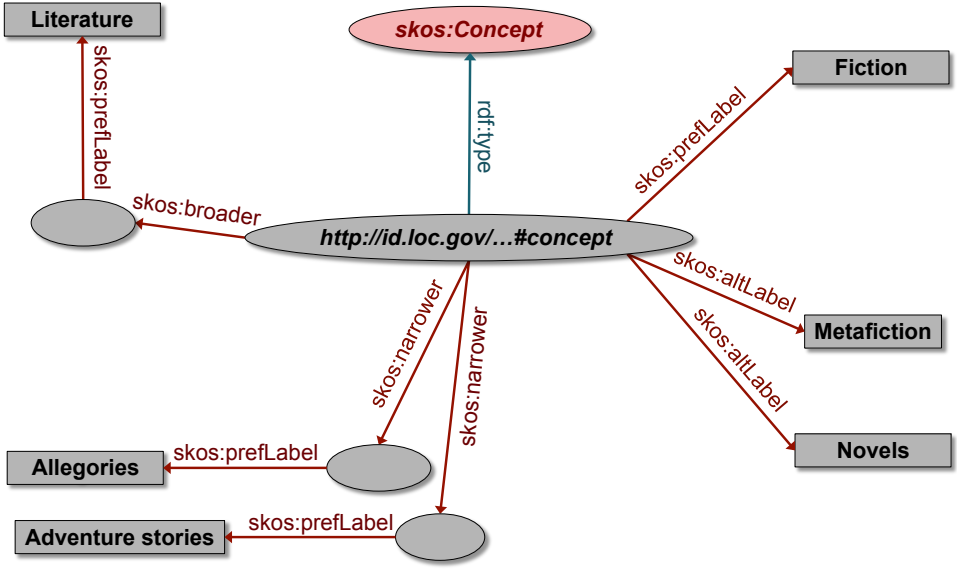
LOC's "Fiction" in SKOS/RDF



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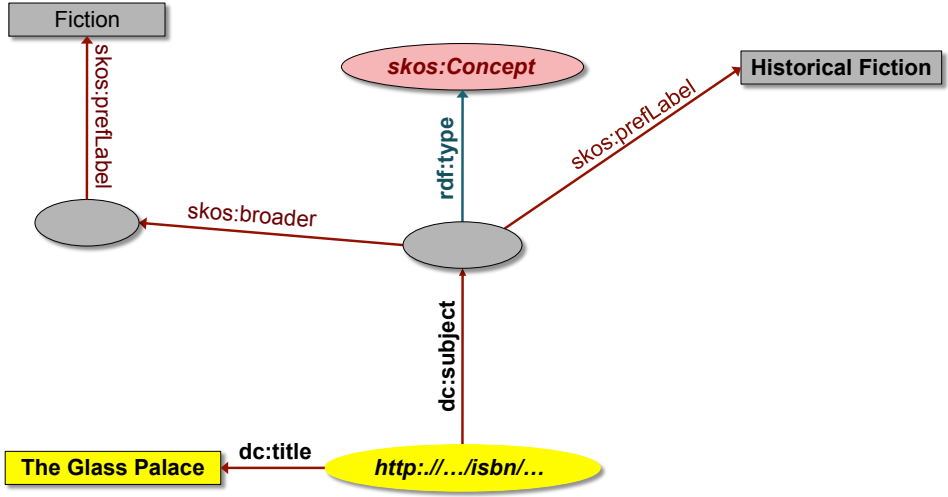
Usage of the LOC graph



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Same serialized

```
<http://…/isbn/000651409X>
    dc:title "The Glass Palace"@en;
    dc:subject <http://id.loc.gov/authorities/sh85061165#concept>;
    ...

<http://id.loc.gov/authorities/sh85061165#concept>
    a    skos:Concept;
    skos:prefLabel "Historical Fiction"@en;
    skos:broader <http://id.loc.gov/authorities/sh85048050#concept>;
    ...

<http://id.loc.gov/authorities/sh85048050#concept>
    a skos:Concept;
    skos:prefLabel "Fiction"@en;
    skos:narrower <http://id.loc.gov/authorities/sh85061165#concept>;
    ...
```

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SKOS terms overview

- Classes and Properties:
  - Basic description (Concept, ConceptScheme,…)
  - Labeling (prefLabel, altLabel,…)
  - Documentation (definition, historyNote,…)
  - Semantic relations (broader, narrower, related,…)
  - Collections (Collection, OrderedCollection,…)
  - Concept mappings (broadMatch, narrowMatch,…)

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Importance of SKOS

- SKOS provides a simple bridge between the “print world” and the (Semantic) Web
- Thesauri, glossaries, etc, from the library community can be made available
  - LOC is a good example
- SKOS can also be used to organize, eg, tags, annotate other vocabularies, …

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Importance of SKOS

- Anybody in the World can refer to common concepts
  - they mean the same for everybody
- Applications may exploit the relationships among concepts
  - eg, SPARQL queries may be issued on the library data+LOC

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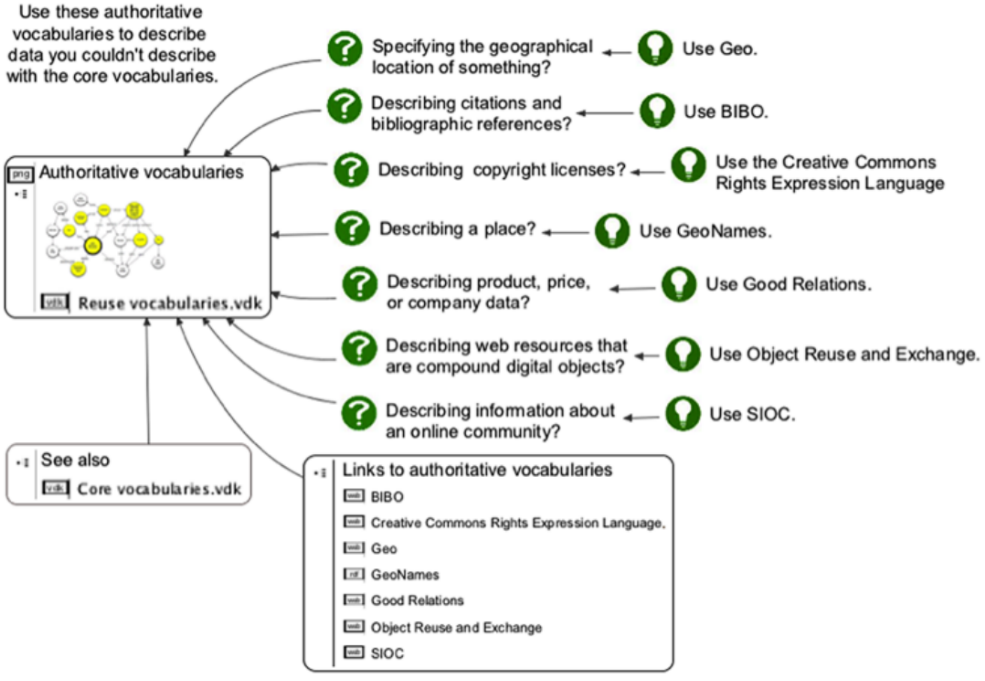
More authoritative vocabularies



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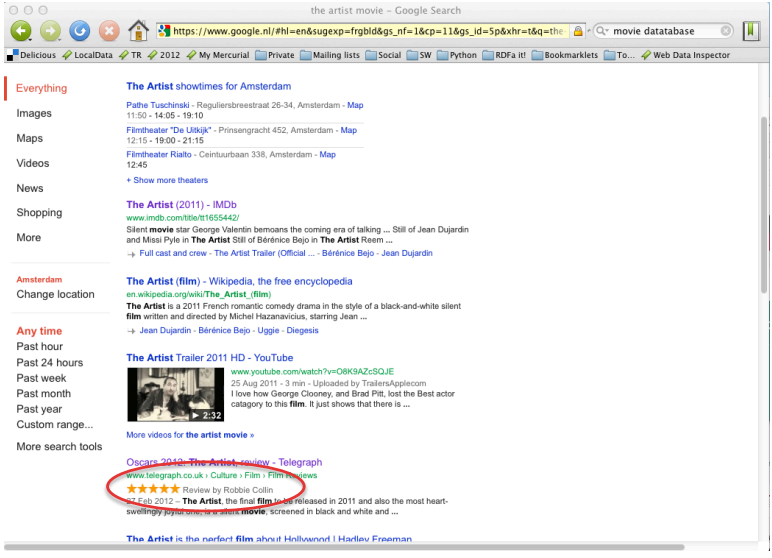
Typical usage of structured data



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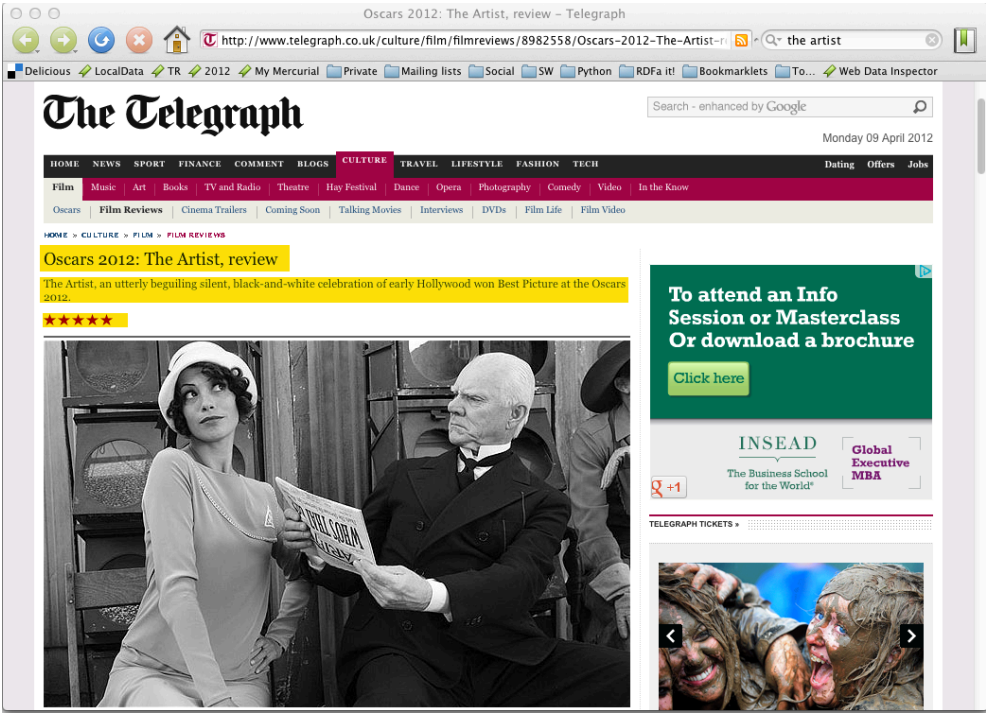

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Source of http://www.telegraph.co.uk/culture/film/filmreviews/8982558/Oscars-2012-The-Artist-review.html

```
                        <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 R
                <div class="cl"></div>
        </div>
</div>

<!-- googleon: all -->
<div id="tmglBody" >
        <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>
                        <img src="/template/ver1-0/i/ratings/star_5_styleSix.png" alt="5 out of 5 stars" width="73" height="14" />
                </div>
        <div class="artIntro">
                                <div id="storyEmbSlide">
                        <div class="slideshow ssIntro">
                                <div class="nextPrevLayer">
                                        <div class="ssImg">
                                                <img src="http://i.telegraph.co.uk/multimedia/archive/0209
                                                <div class="artImageExtras" >

                                                        <div class="imgCaptionCredit">
                                                                <span class="caption">Bérénice Bejo as ris
                                                        </div>
                                                </div>
                                        </div>
                                </div>
                <div class="cl"></div>

        </div>
                        </div>
<div class="oneHalf gutter">
                        <div class="story">
                                <div class="cl"> </div>
                <!-- remove the whitespace added by escenic before end of </a> tag -->
```

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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>
  ...
```

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Yielding…

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

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Reading Material

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Required

- [Yu14, Chapter 4] (RDFS)
- [Yu14, Chapter 7] (FOAF)

Supplemental

- [Wor14] (RDF Primer)
- [Yu14, Chapter 10] (Schema.org)
- [WZRH14, Chapters 2, 4] (RDF, FOAF)

References

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Morgan & Claypool, 2011.
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[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.
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[Yu14] Liyang Yu.
A Developer's Guide to the Semantic Web.
Springer-Verlag Berlin Heidelberg, 2nd edition, 2014.
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