Beijing 2008
One World, One Web

An Introduction to Semantic Web (Tutorial)

17th International World Wide Web Conference
Beijing, China, 21st April, 2008

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> Towards a Semantic Web

- The current Web represents information using
  - natural language (English, Hungarian, Chinese,…)
  - graphics, multimedia, page layout
- Humans can process this easily
  - can deduce facts from partial information
  - can create mental associations
  - are used to various sensory information
    - (well, sort of… people with disabilities may have serious problems on the Web with rich media!)

> Towards a Semantic Web

- Tasks often require to combine data on the Web:
  - hotel and travel information may come from different sites
  - searches in different digital libraries
  - etc.
- Again, humans combine these information easily
  - even if different terminologies are used!

> However…

- However: machines are ignorant!
  - partial information is unusable
  - difficult to make sense from, e.g., an image
  - drawing analogies automatically is difficult
  - difficult to combine information automatically
    - is `<foo:creator>` same as `<bar:author>`?
  - …

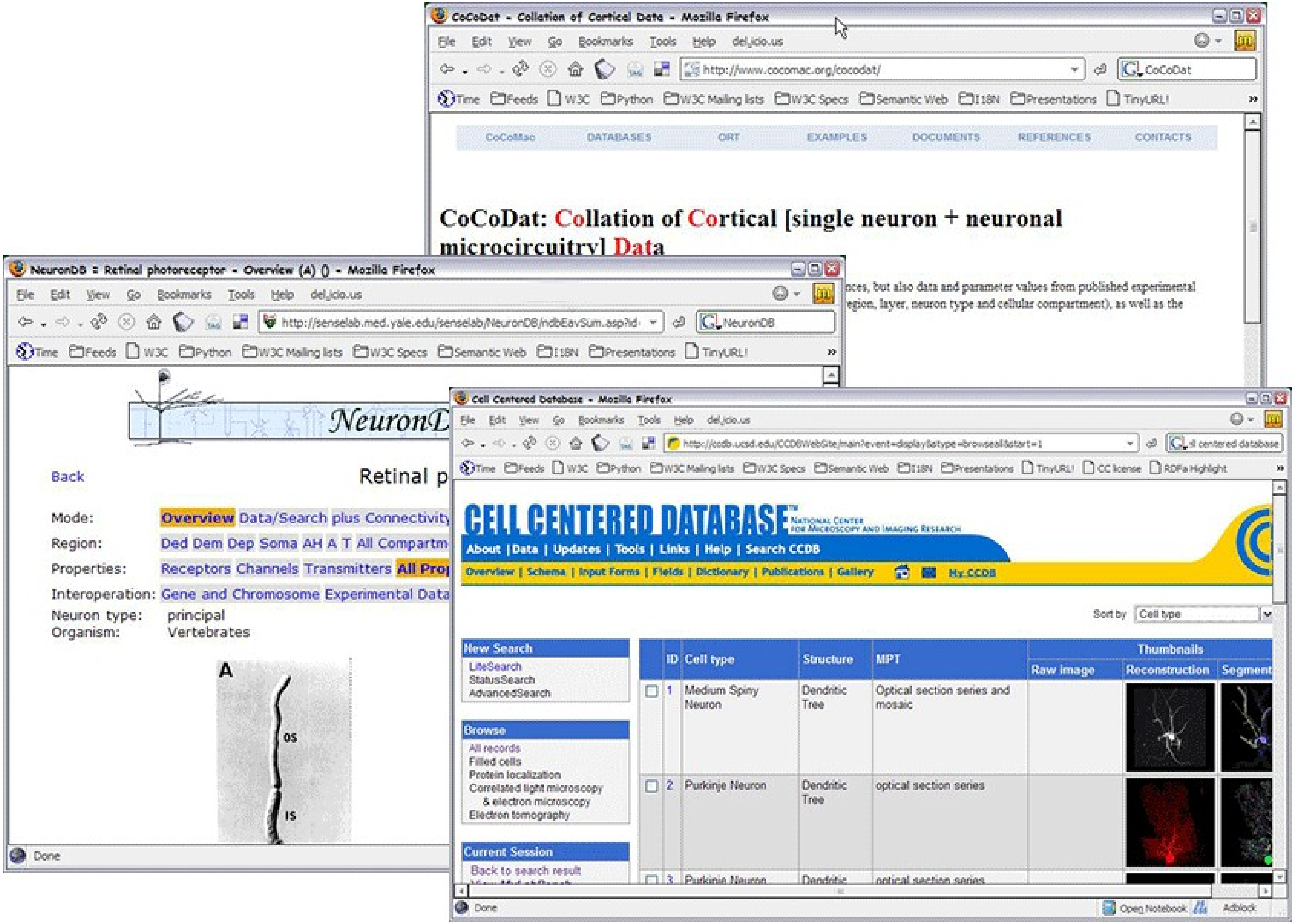
> Example: automatic airline reservation

- Your automatic airline reservation
  - knows about your preferences
  - builds up knowledge base using your past
  - can combine the local knowledge with remote services:
    - airline preferences
    - dietary requirements
    - calendaring
    - etc
- It communicates with remote information (i.e., on the Web!)
  - (M. Dertouzos: The Unfinished Revolution)

> Example: data(base) integration

- Databases are very different in structure, in content
- Lots of applications require managing several databases
  - after company mergers
  - combination of administrative data for e-Government
  - biochemical, genetic, pharmaceutical research
  - etc.
- Most of these data are accessible from the Web (though not necessarily public yet)

> And the problem *is* real…



> Example: Social Networks

- Social sites are everywhere these days (LinkedIn, Facebook, Dopplr, Digg, Plexo, Zyb, …)
- Data is not interchangeable: how many times did you have to add your contacts?
- Applications should be able to get to those data via standard means
  - there are, of course, privacy issues…

> What is needed?

- (Some) data should be available for machines for further processing
- Data should be possibly combined, merged on a Web scale
- Sometimes, data may describe other data (like the library example, using metadata)…
- … but sometimes the data is to be exchanged by itself, like my calendar or my travel preferences
- Machines may also need to *reason* about that data

> In what follows…

- We will use a simplistic example to introduce the main Semantic Web concepts
- We take, as an example area, data integration

> The rough structure of data integration

1. Map the various data onto an abstract data representation
   - make the data independent of its internal representation…
2. Merge the resulting representations
3. Start making queries on the whole!
   - queries that could not have been done on the individual data sets

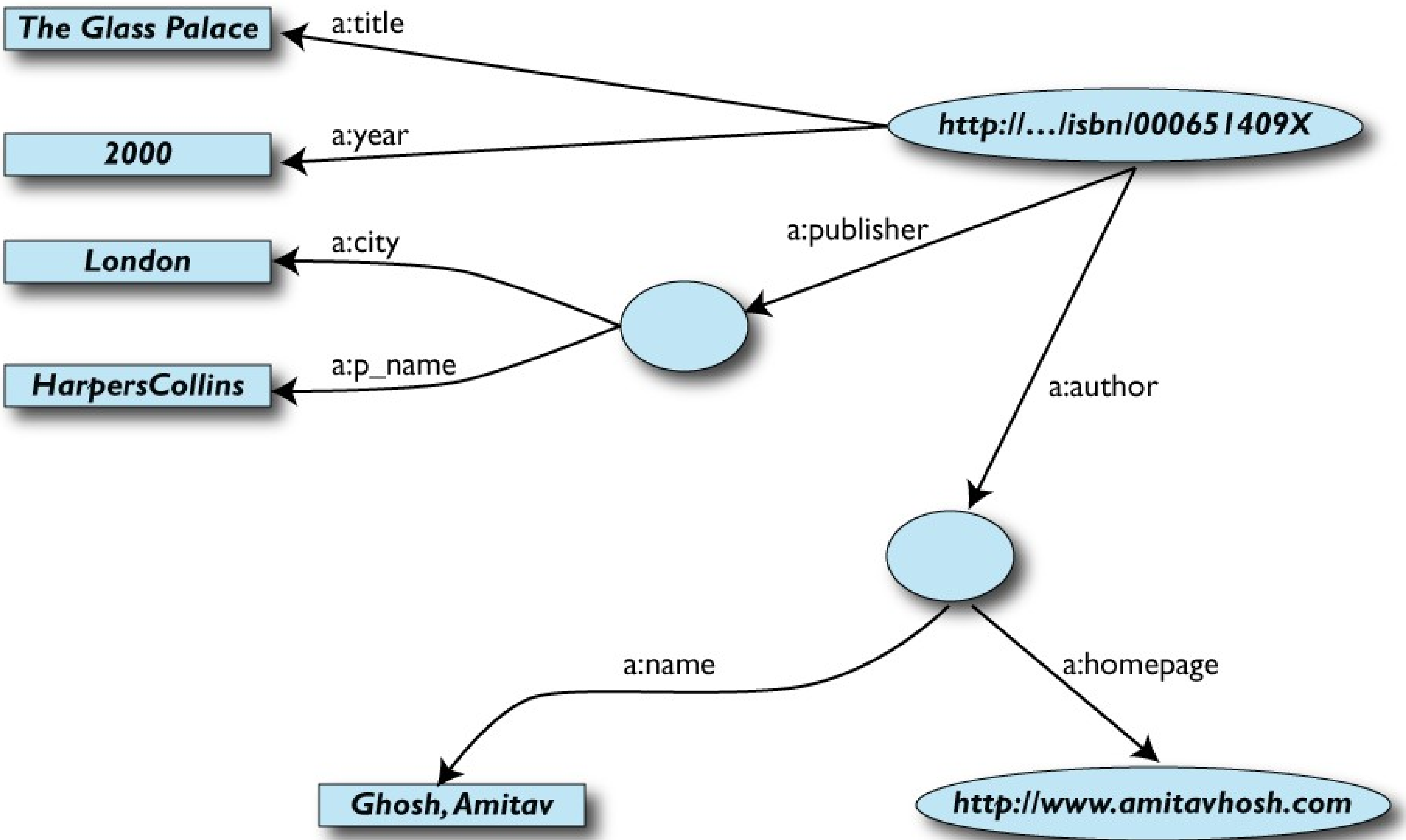
> A *simplified* bookstore data (dataset "A")

ID	Author	Title	Publisher	Year
ISBN0-00-651409-X	id_xyz	The Glass Palace	id_qpr	2000

ID	Name	Home Page
id_xyz	Ghosh, Amitav	http://www.amitavghosh.com

ID	Publ. Name	City
id_qpr	Harpers Collins	London

> 1st: export your data as a set of *relations*



> Some notes on the exporting the data

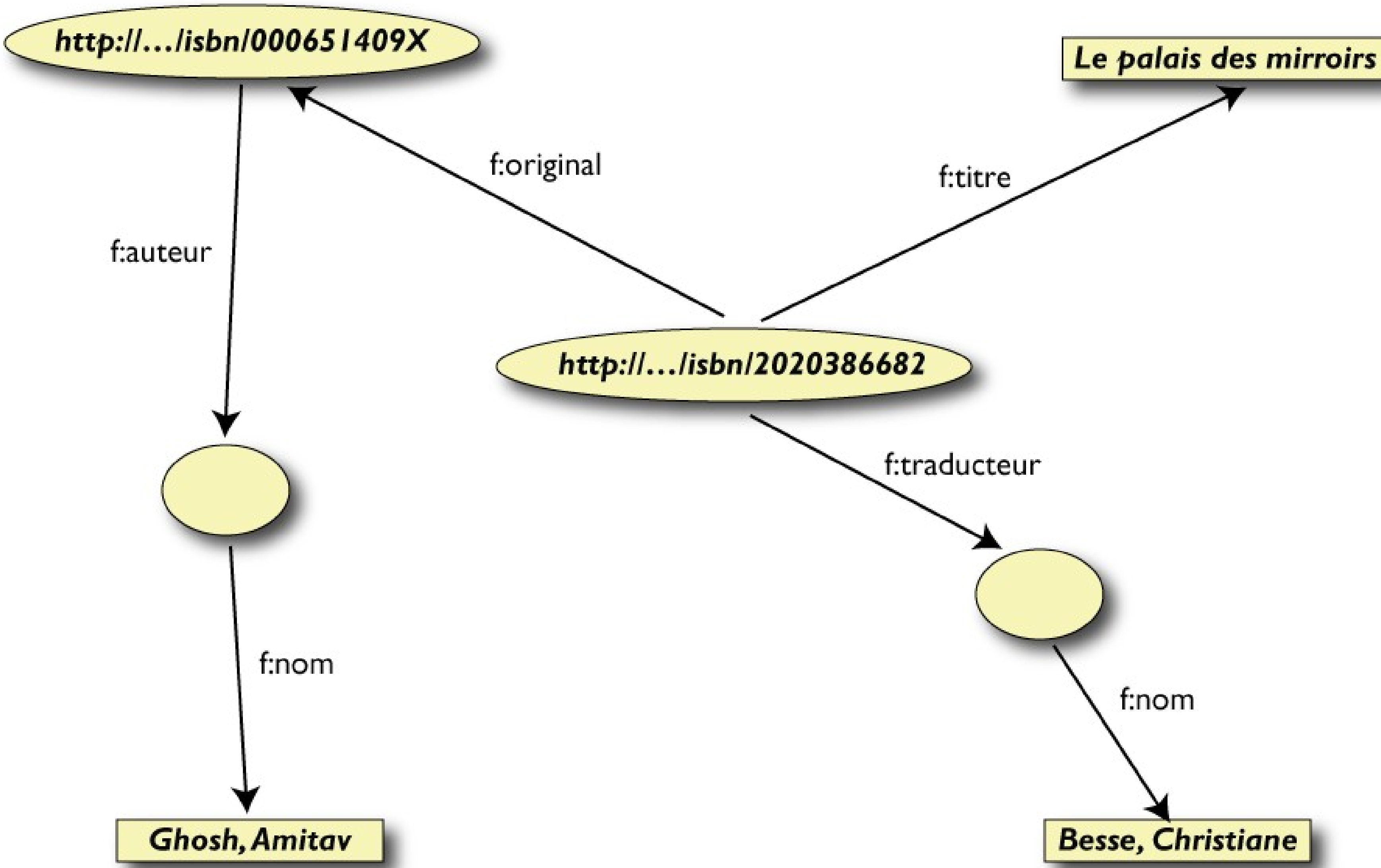
- Relations form a graph
  - the nodes refer to the “real” data or contain some literal
  - how the graph is represented in machine is immaterial for now
- Data export does *not* necessarily mean physical conversion of the data
  - relations can be generated on-the-fly at query time
    - via SQL “bridges”
    - scraping HTML pages
    - extracting data from Excel sheets
    - etc.
- One can export *part* of the data

> Another bookstore data (dataset “F”)

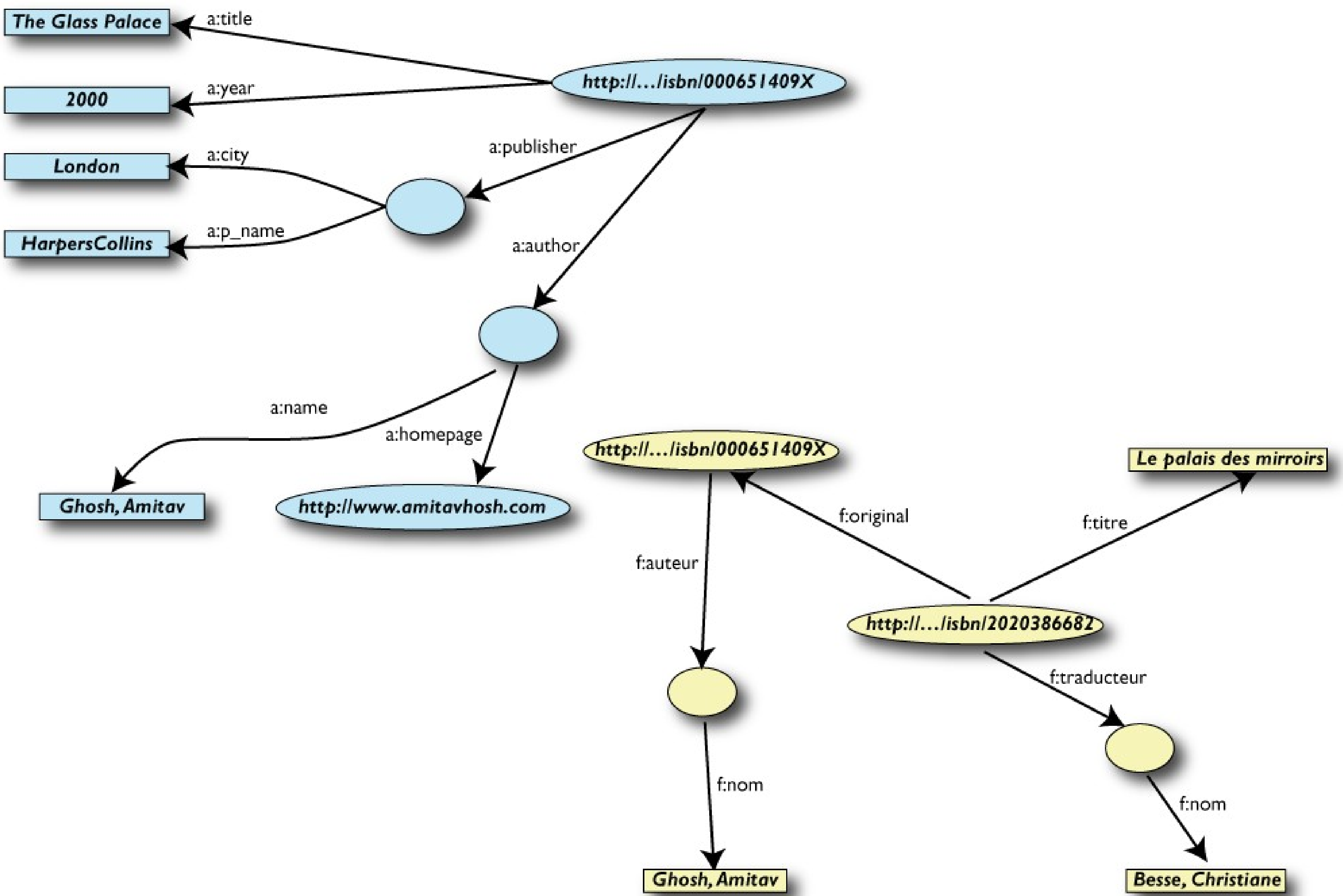
ID	Titre	Auteur	Traducteur	Original
ISBN0 2020386682	Le Palais des miroirs	i_abc	id_qrs	ISBN-0-00-651409-X

ID	Nom
id_abc	Ghosh, Amitav
id_qrs	Besse, Christiane

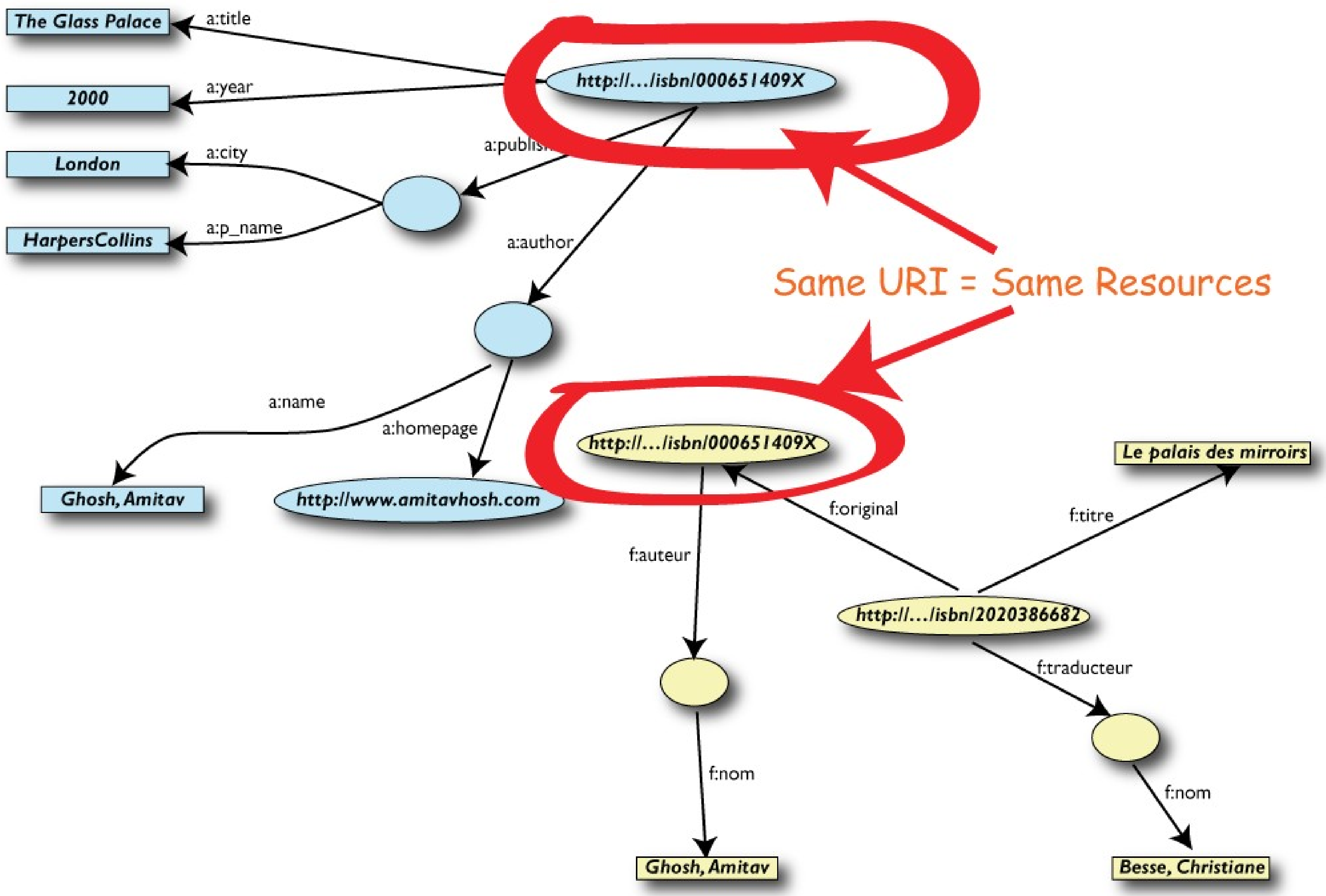
> 2nd: export your second set of data



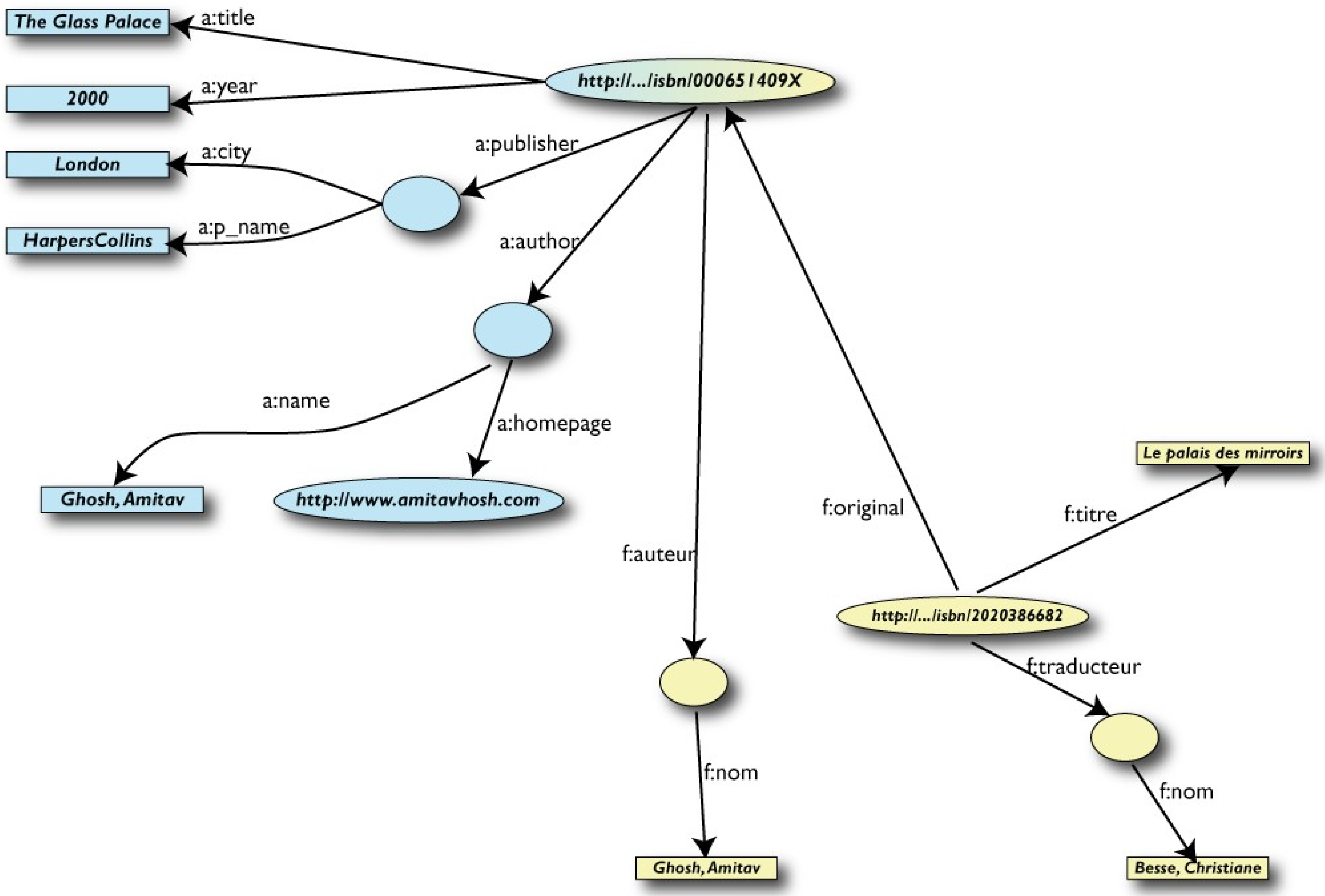
> 3rd: start merging your data



> 3rd: start merging your data (cont.)

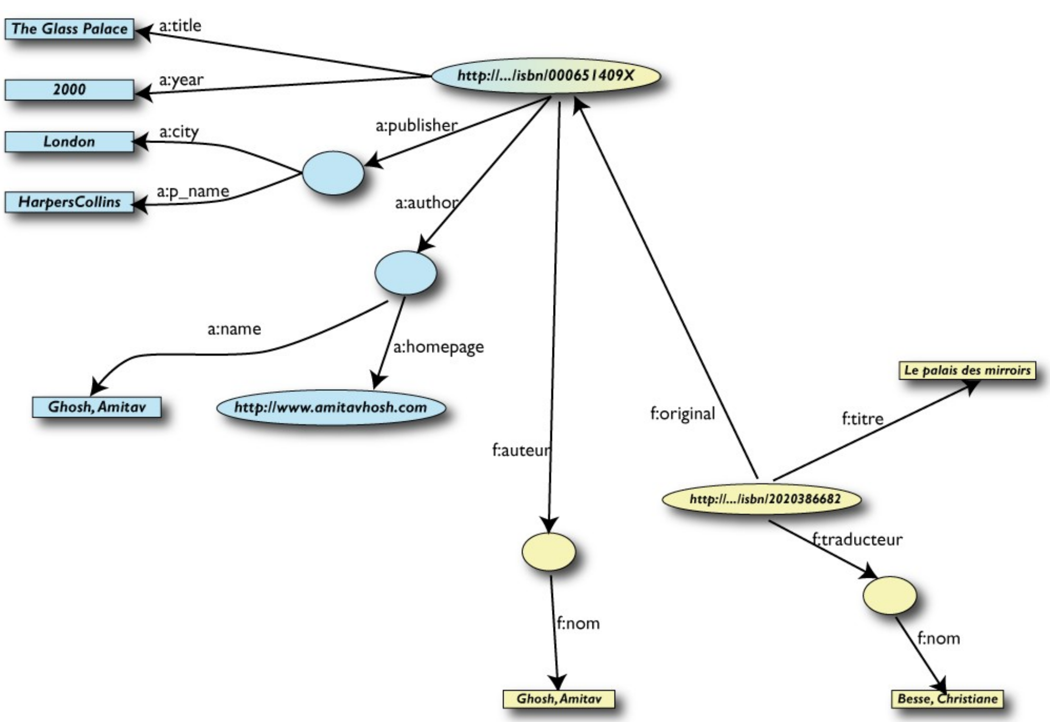


3rd: merge identical resources



> Start making queries…

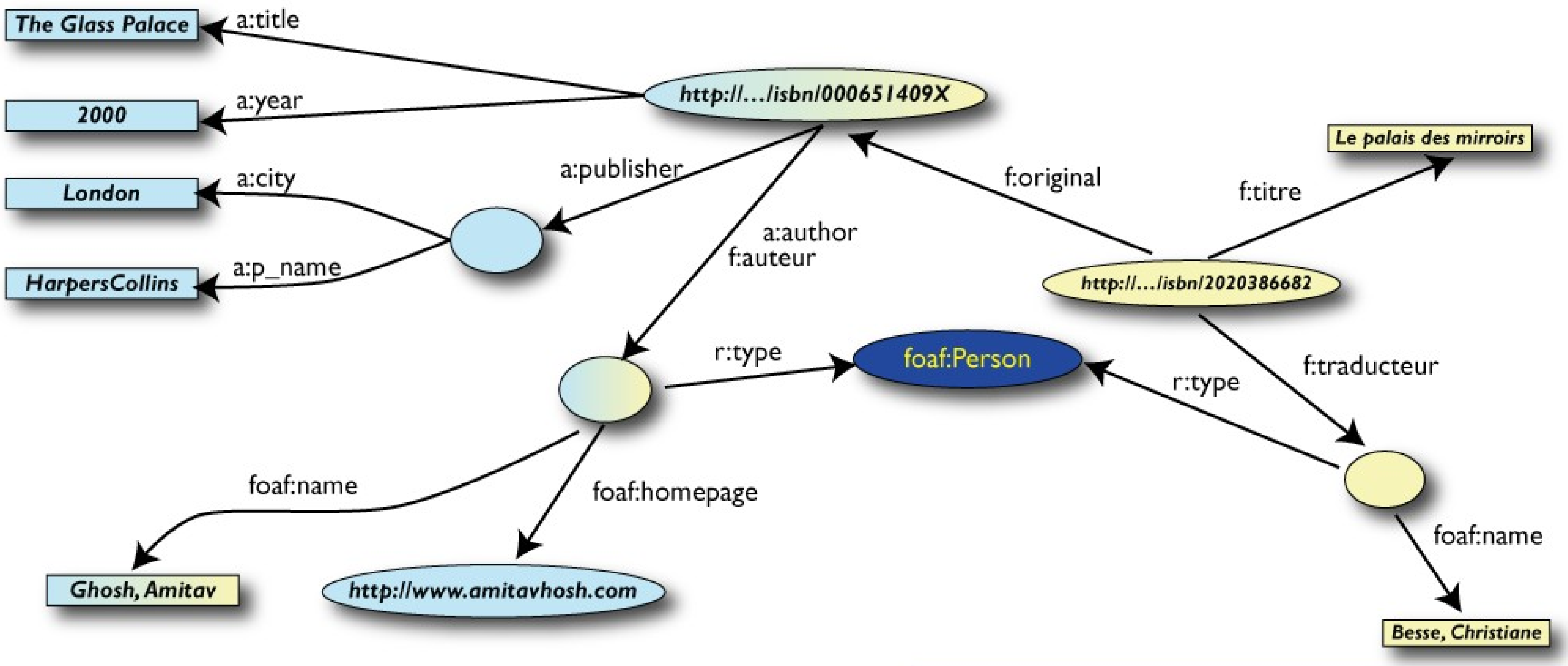
- User of data "F" can now ask queries like:
  - « donnes-moi le titre de l'original »
  - (ie: "give me the title of the original")
- This information is not in the dataset "F"…
- …but can be retrieved by merging with dataset "A"!

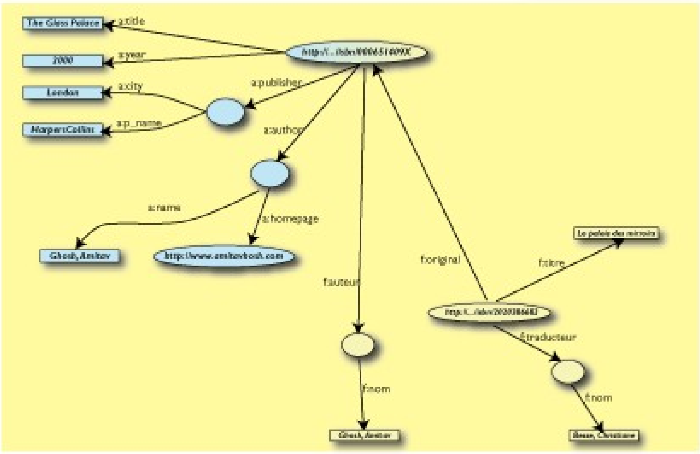


> However, more can be achieved…

- We “feel” that **`a:author`** and **`f:auteur`** should be the same
- But an automatic merge does not know that!
- Let us add some extra information to the merged data:
  - **`a:author`** same as **`f:auteur`**
  - both identify a “Person”
  - a term that a community may have already defined:
    - a “Person” is uniquely identified by his/her name and, say, homepage
    - it can be used as a “category” for certain type of resources

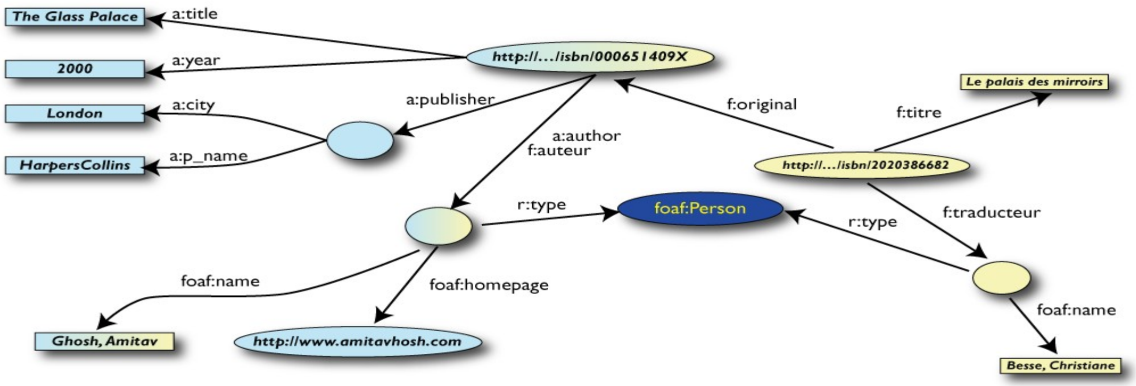
> 3rd revisited: use the extra knowledge





> Start making richer queries!

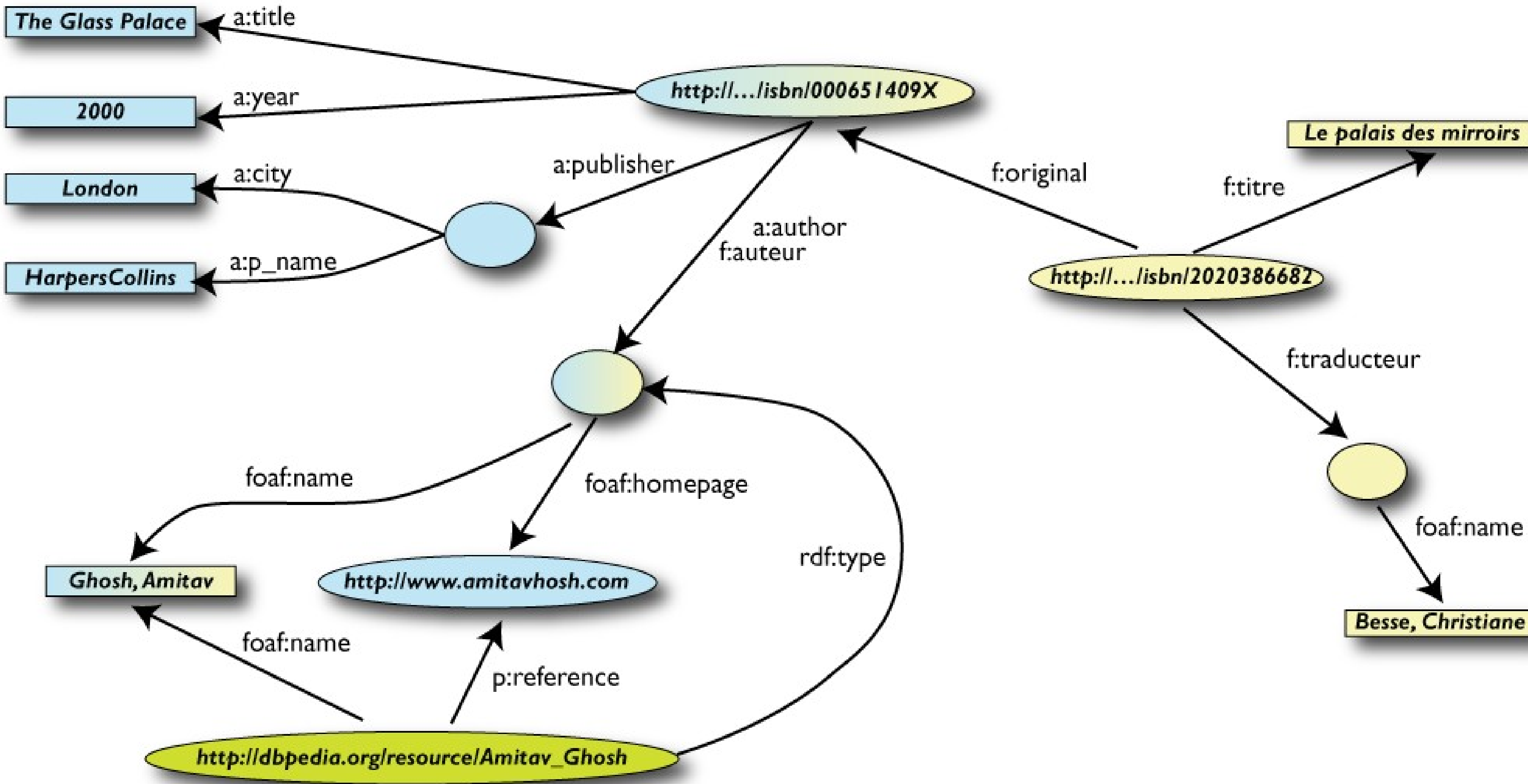
- User of dataset “F” can now query:
  - « donnes-moi la page d’accueil de l’auteur de l’original »
  - (ie, “give me the home page of the original’s author”)
- The information is not in datasets “F” or “A”…
- …but was made available by:
  - merging datasets “A” and datasets “F”
  - adding three simple extra statements as an extra “glue”



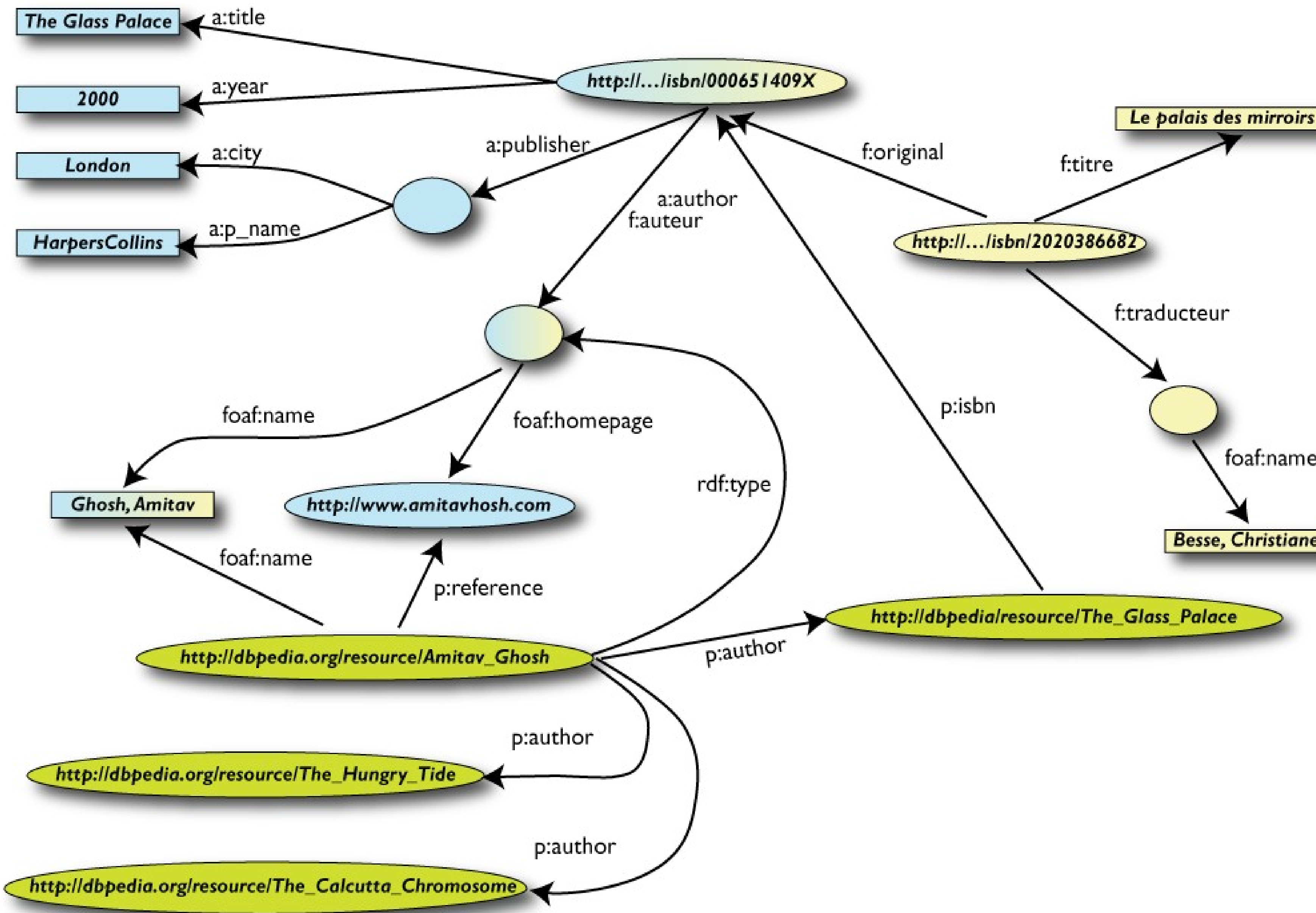
Combine with different datasets

- Using, e.g., the “Person”, the dataset can be combined with other sources
- For example, data in Wikipedia can be extracted using dedicated tools
  - there is an active development to add some simple semantic “tag” to wikipedia entries (so called “Semantic Wiki”-s)
  - the “DBpedia” project can extract the “infobox” information from Wikipedia already… (see later)

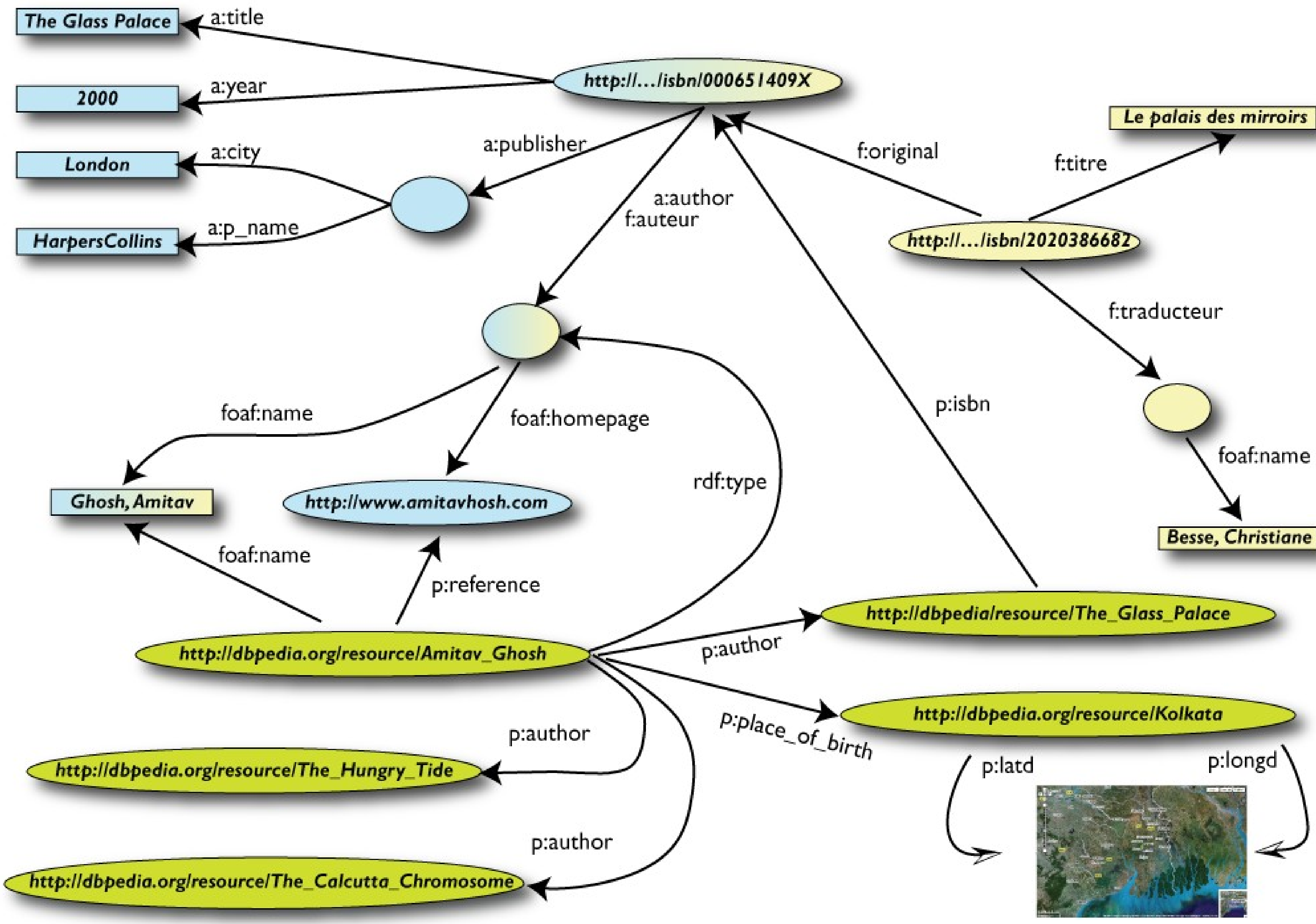
> Merge with Wikipedia data



> Merge with Wikipedia data



> Merge with Wikipedia data



> Is that surprising?

- Maybe but, in fact, no…
- What happened via automatic means is done all the time, every day by the users of the Web!
- The difference: a bit of extra rigor (e.g., naming the relationships) is necessary so that machines could do this, too

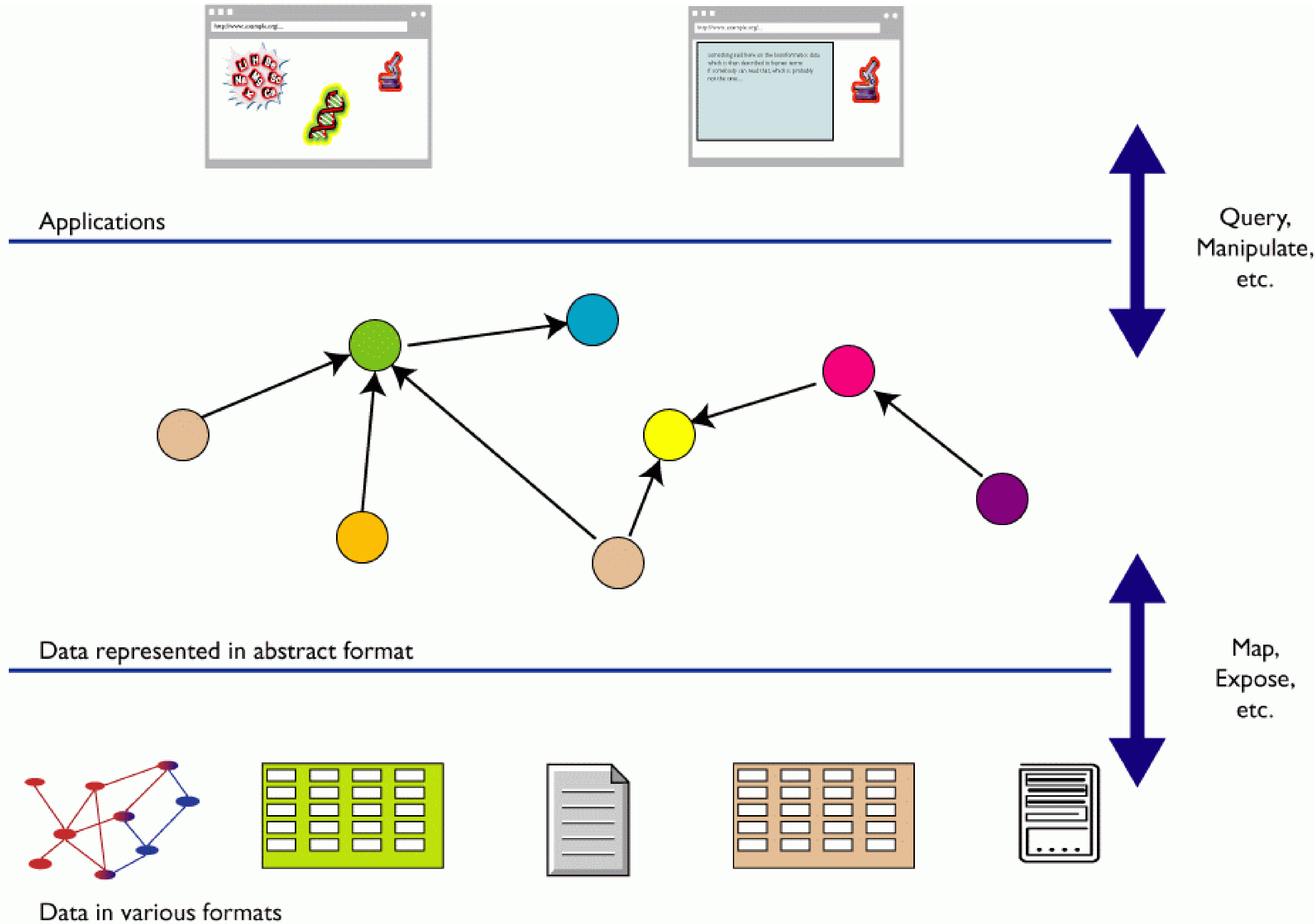
> What did we do?

- We combined different datasets
  - all may be of different origin somewhere on the web
  - all may have different formats (mysql, excel sheet, XHTML, etc)
  - all may have different names for relations (e.g., multilingual)
- We could combine the data because some URI-s were identical (the ISBN-s in this case)
- We could add some simple additional information (the “glue”), also using common terminologies that a community has produced
- As a result, new relations could be found and retrieved

> It could become even more powerful

- We could add extra knowledge to the merged datasets
  - e.g., a full classification of various type of library data
  - geographical information
  - etc.
- This is where *ontologies*, *thesauri*, extra *rules*, etc, come in
  - ontologies/rule sets can be relatively simple and small, or…
  - huge …
  - or anything in between…
- Even more powerful queries can be asked as a result
  - e.g., in case of large ontologies the emphasis of queries may be drawn with the help of specialized engines

> What did we do? (cont)



> The abstraction pays off because…

- … the graph representation is independent on the exact structures in, say, a relational database
- … a change in local database schema’s, XHTML structures, etc, do not affect the whole, only the “export” step
  - “schema independence”
- … new data, new connections can be added seamlessly, regardless of the structure of other data sources

> So where is the Semantic Web?

- The Semantic Web provides technologies to make such integration possible!
- Hopefully you get a full picture at the end of the tutorial…

> Basic RDF

> RDF triples

- Let us begin to formalize what we did!
  - we “connected” the data…
  - but a simple connection is not enough… it should be named somehow
  - hence the RDF Triples: *a labeled connection between two resources*

> 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", "predicate", and "object", respectively
    - conceptually: "**`p`**" connects, or relates the "**`s`**" and "**`o`**"
    - note that we use URI-s for naming: i.e., we can use **`http://www.example.org/original`**
  - here is the complete triple:

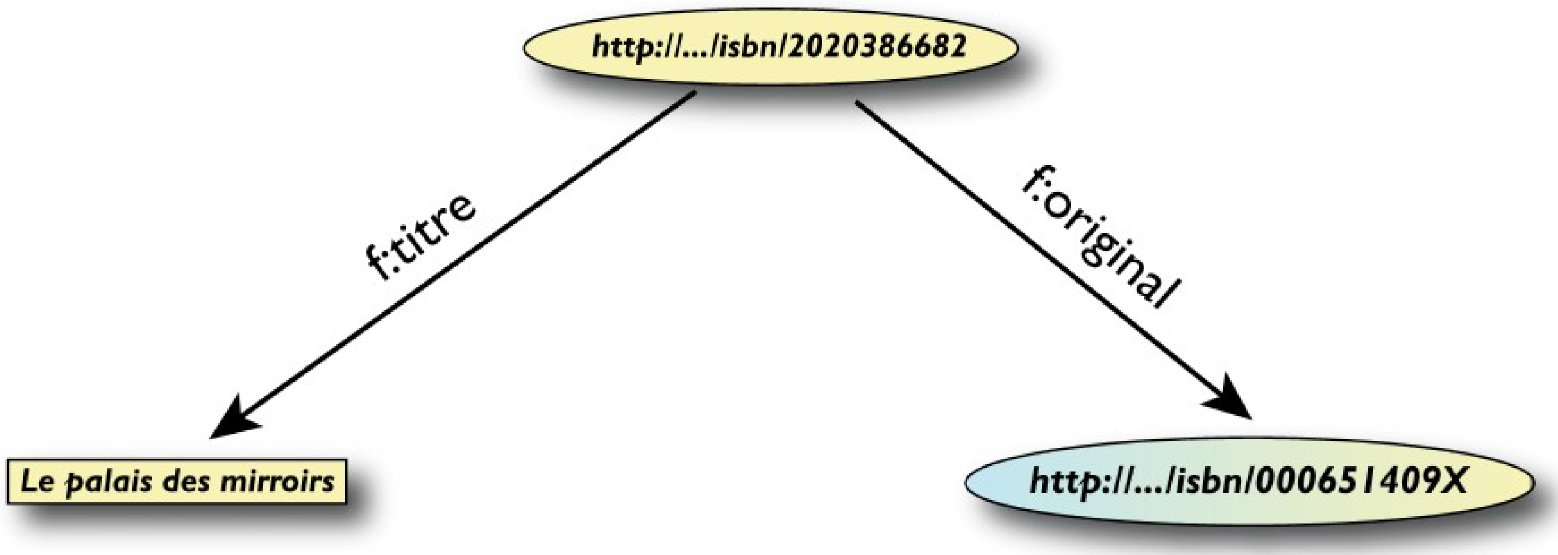
```
(<http://…isbn…6682>, <http://…/original>, <http://…isbn…409X>)
```

- *RDF* is a general model for such triples (with machine readable formats like RDF/XML, Turtle, N3, RXR, …)
- … *and that's it!*

> RDF triples (cont.)

- RDF triples are also referred to as “triplets”, or “statements”
- The “**`p`**” is also referred to as “property” in some cases
- Resources can use any URI; it can denote an element within an XML file on the Web, not only a “full” resource, e.g.:
  - **`http://www.example.org/file.xml#element(home)`**
  - **`http://www.example.org/file.html#home`**
  - **`http://www.example.org/file2.xml#xpath1(//q[@a=b])`**
- RDF triples form a directed, labeled graph (best way to think about them!)

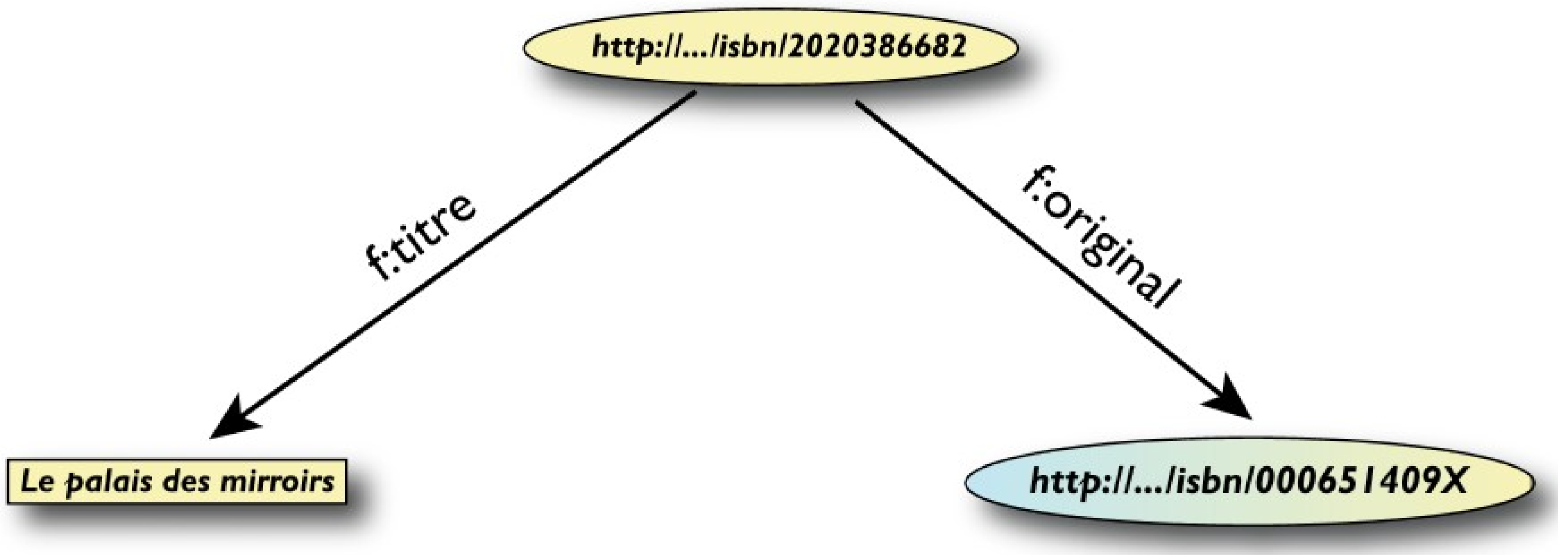
> A simple RDF example (in RDF/XML)




```
<rdf:Description rdf:about="http://…/isbn/2020386682">
    <f:titre xml:lang="fr">Le palais des mirroirs</f:titre>
    <f:original rdf:resource="http://…/isbn/000651409X"/>
</rdf:Description>
```

(Note: namespaces are used to simplify the URI-s)

> A simple RDF example (in Turtle)



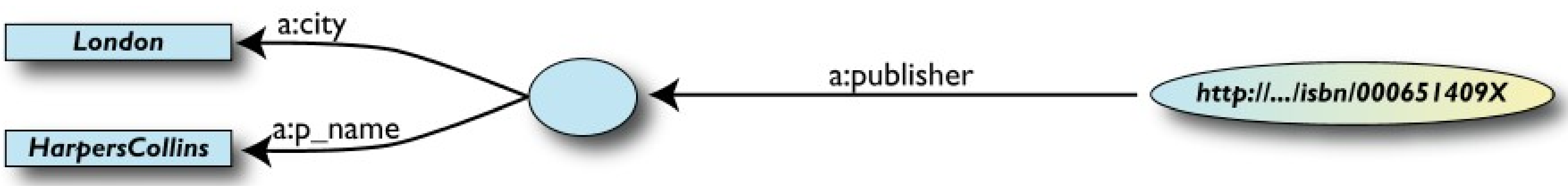

```
<http://…/isbn/2020386682>
    f:titre "Le palais des mirroirs"@fr;
    f:original <http://…/isbn/000651409X>.
```

> URI-s play a fundamental role

- URI-s made the merge possible
- Anybody can create (meta)data on any resource on the Web
  - e.g., the same XHTML file could be annotated through other terms
  - semantics is added to existing Web resources via URI-s
  - URI-s make it possible to link (via properties) data with one another
- *URI-s ground RDF into the Web*
  - information can be retrieved using existing tools
  - this makes the “Semantic Web”, well… “Semantic *Web*”

> “Internal” nodes

- Consider the following statement:
  - “the publisher is a «thing» that has a name and an address”
- Until now, nodes were identified with a URI. But…
- …what is the URI of «thing»?



> One solution: create an extra URI

```
<rdf:Description rdf:about="http://…/isbn/000651409X">
   <a:publisher rdf:resource="urn:uuid:f60ffb40-307d-…"/>
</rdf:Description>
<rdf:Description rdf:about="urn:uuid:f60ffb40-307d-…">
   <a:p_name>HarpersCollins</a:p_name>
   <a:city>HarpersCollins</a:city>
</rdf:Description>
```

- The resource will be “visible” on the Web as all other resources
  - care should be taken to define *unique* URI-s (hence the UUID in the example)
- Serializations may give syntactic help to define local URI-s (much like the id-s in HTML)

> Internal identifier (blank nodes)

```
<rdf:Description rdf:about="http://…/isbn/000651409X">
   <a:publisher rdf:nodeID="A234"/>
</rdf:Description>
<rdf:Description rdf:nodeID="A234">
   <a:p_name>HarpersCollins</a:p_name>
   <a:city>HarpersCollins</a:city>
</rdf:Description>
```

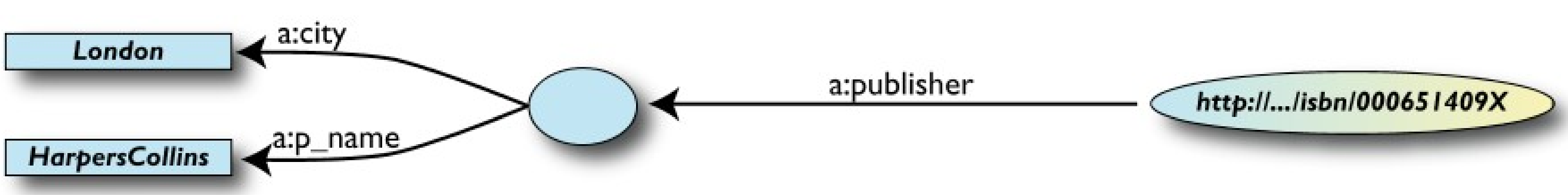
```
<http://…/isbn/2020386682> a:publisher _:A234.
_:A234 a:p_name "HarpersCollins".
```

- The exact syntax depends on the serialization format
- A234 is invisible from outside (it is not a “real” URI!); it is an internal identifier for a resource

Blank nodes: the system can also do it

- Let the system create a “nodeID” internally (you do not really care about the name…)
- The example below is in Turtle (RDF/XML has something similar):

```
<http://…/isbn/000651409X> a:publisher [
    a:p_name "HarpersCollins";
    …
].
```



> Blank nodes: some more remarks

- Blank nodes require attention when merging
  - blanks nodes with identical nodeID-s in *different* graphs are *different*
  - implementations must be careful with their naming schemes when merging
- Many applications prefer not to use blank nodes and define new URI-s “on-the-fly”
  - eg, when triples are in a database
- From a logic point of view, blank nodes represent an “existential” statement (“there is a resource such that…”)

> RDF in programming practice

- For example, using Java+Jena (HP's Bristol Lab):
  - a "Model" object is created
  - the RDF file is parsed and results stored in the Model
  - the Model offers methods to retrieve:
    - triples
    - (property,object) pairs for a specific subject
    - (subject,property) pairs for specific object
    - etc.
  - the rest is conventional programming…
- Similar tools exist in Python, PHP, etc.

> Jena example

```
// create a model
Model model=new ModelMem();
Resource subject=model.createResource("URI_of_Subject")
// 'in' refers to the input file
model.read(new InputStreamReader(in));
StmtIterator iter=model.listStatements(subject,null,null);
while(iter.hasNext()) {
   st = iter.next();
   p = st.getProperty();
   o = st.getObject();
   do_something(p,o);
}
```

> Merge in practice

- Environments merge graphs automatically
  - e.g., in Jena, the Model can load several files
  - the load merges the new statements automatically

> RDF schemas

> Need for RDF schemas

- This is the simple form of our “extra knowledge”:
  - define the terms we can use
  - what restrictions apply
  - what extra relationships are there?
- This is where RDF Schemas come in
  - officially: “RDF Vocabulary Description Language”; the term “Schema” is retained for historical reasons…

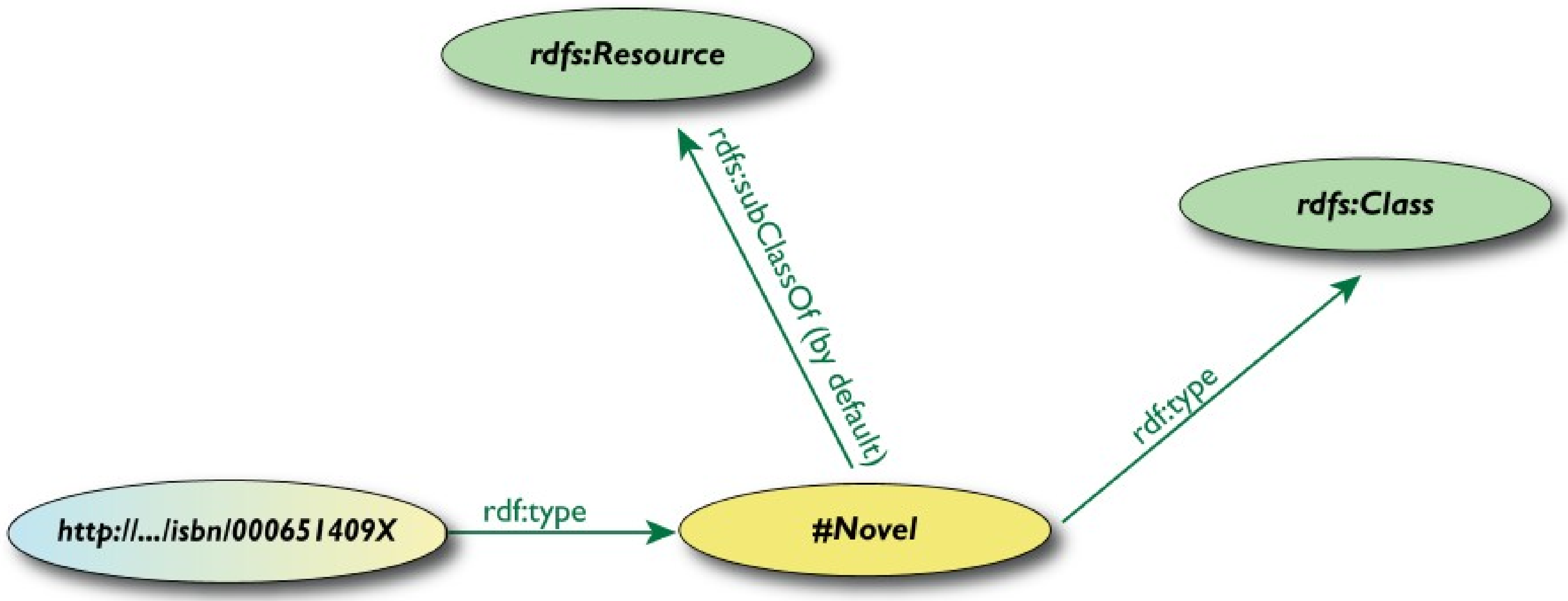
> Classes, resources, …

- Think of well known traditional ontologies or taxonomies:
  - use the term “novel”
  - “every novel is a fiction”
  - “«The Glass Palace» is a novel”
  - etc.
- RDFS defines resources and classes:
  - everything in RDF is a “resource”
  - “classes” are also resources, but…
  - …they are also a collection of possible resources (i.e., “individuals”)
    - “fiction”, “novel”, …

> Classes, resources, … (cont.)

- Relationships are defined among classes/resources:
  - “typing”: an individual belongs to a specific class (“«The Glass Palace» is a novel”)
    - to be more precise: “«http://.../**`000651409X`**» is a novel”
  - “subclassing”: *all* instances of one are also the instances of the other (“every novel is a fiction”)
- *RDFS formalizes these notions in RDF*

> Classes, resources in RDF(S)



- RDFS defines **`rdfs:Resource`**, **`rdfs:Class`** as nodes; **`rdf:type`**, **`rdfs:subClassOf`** as properties
  - (these are all special URI-s, we just use the namespace abbreviation)

> Schema example in RDF/XML

- The schema part ("application's data types"):

```
<rdf:Description rdf:ID="Novel">
  <rdf:type rdf:resource= "http://www.w3.org/2000/01/rdf-schema#Class"/>
</rdf:Description>
```

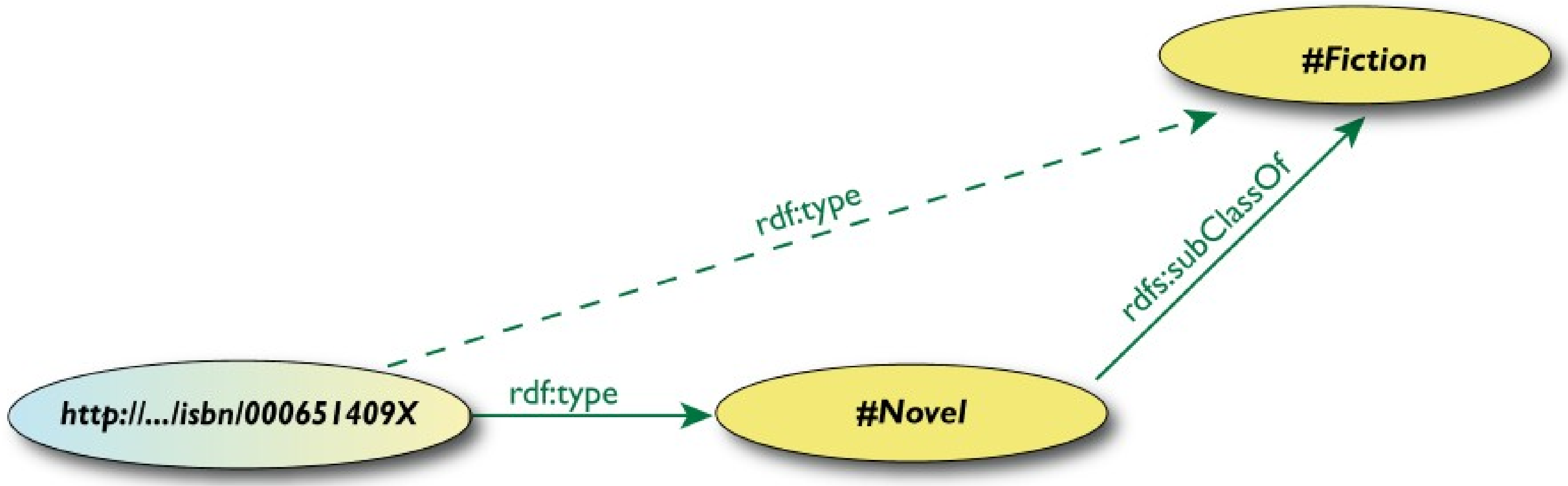
- The RDF data on a specific novel ("using the type"):

```
<rdf:Description rdf:about="http://…/isbn/000651409X">
   <rdf:type rdf:resource="http://…/bookSchema.rdf#Novel"/>
</rdf:Description>
```

> On types

- The **`rdf:type`** information may be very important for applications
  - e.g., it may be used for a categorization of possible nodes
  - probably the most frequently used RDF predicate…
- (remember the “Person” in our example?)

> Inferred properties




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

- is not in the original RDF data…
- …but can be inferred from the RDFS rules
- Better (“RDFS aware”) RDF environments return that triple, too

> Inference: let us be formal…

- The RDF Semantics document has a list of (44) *entailment rules*:
  - “if such and such triples are in the graph, add this and this triple”
  - 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 .
```

- Whether those extra triplets are physically added to the graph or deduced when needed is an implementation issue

> Properties

- Property is a special class (**`rdf:Property`**)
  - properties are also resources identified by URI-s
- Properties’ range and domain can be specified
  - i.e., what type of resources can serve as object and subject
- There is also a possibility for a “sub-property”
  - all resources bound by the “sub” are also bound by the other

> Properties (cont.)

- Properties are also resources (named via URI–s)…
- So properties of properties can be expressed as… RDF properties
  - this twists your mind a bit, but you can get used to it
- For example, **`(P rdfs:range C)`** means:
  - **`P`** is a property
  - **`C`** is a class instance
  - when using **`P`**, the "object" must be an individual in **`C`**
- This is an RDF statement with subject **`P`**, object **`C`**, and property **`rdfs:range`**

> 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.
```

What does this mean?

- Again, new relations can be deduced. Indeed, if

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

<http://…/isbn/000651409X> :title "The Glass Palace" .
```

- then the system can *infer* that:

```
<http://…/isbn/000651409X> rdf:type :Fiction .
```

> A bit of RDFS can take you far…

- Remember the power of merge?
- We could have used, in our example:
  - `f:auteur` is a subproperty of `a:author` and vice versa (although we will see other ways to do that…)
- Of course, in some cases, more complex knowledge is necessary (see later…)

> Get to RDF(S) data

> Simple approach

- Write RDF/XML or Turtle “manually”
- In some cases that is necessary, but it really does not scale…

> RDF can also be extracted/generated

- Use intelligent “scrapers” or “wrappers” to extract a structure (hence RDF) from a Web pages or XML files…
- … and then generate RDF automatically (e.g., via an XSLT script)

> Formalizing the scraper approach: GRDDL

- GRDDL formalizes the scraper approach. For example:

```
<html xmlns="http://www.w3.org/1999/">
  <head profile="http://www.w3.org/2003/g/data-view">
    <title>Some Document</title>
    <link rel="transformation" href="http:…/dc-extract.xsl"/>
    <meta name="DC.Subject" content="Some subject"/>
    ...
  </head>
  ...
  <span class="date">2006-01-02</span>
  ...
</html>
```

- yields, by running the file through **`dc-extract.xsl`**:

```
<rdf:Description rdf:about="…">
  <dc:subject>Some subject</dc:subject>
  <dc:date>2006-01-02</dc:date>
</rdf:Description>
```

> GRDDL

- The transformation itself has to be provided for each set of conventions (making use of meta-s, class id-s, etc…)
- A “bridge” to “microformats”
- A more general syntax is defined for XML formats in general (e.g., via the namespace document)
  - a method to get data in other formats to RDF (e.g., XBRL)

> Another upcoming solution: RDFa

- For example:

```
<div about="http://uri.to.newsitem">
  <span property="dc:date">March 23, 2004</span>
  <span property="dc:title">Rollers hit casino for £1.3m</span>
  By <span property="dc:creator">Steve Bird</span>. See
  <a href="http://www.a.b.c/d.avi" rel="dcmtype:MovingImage">
  also video footage</a>…
</div>
```

- yields, by running the file through an RDFa processor:

```
<http://uri.to.newsitem>
  dc:date             "March 23, 2004";
  dc:title            "Rollers hit casino for £1.3m;
  dc:creator          "Steve Bird";
  dcmtype:MovingImage <http://www.a.b.c/d.avi>.
```

> RDFa (cont.)

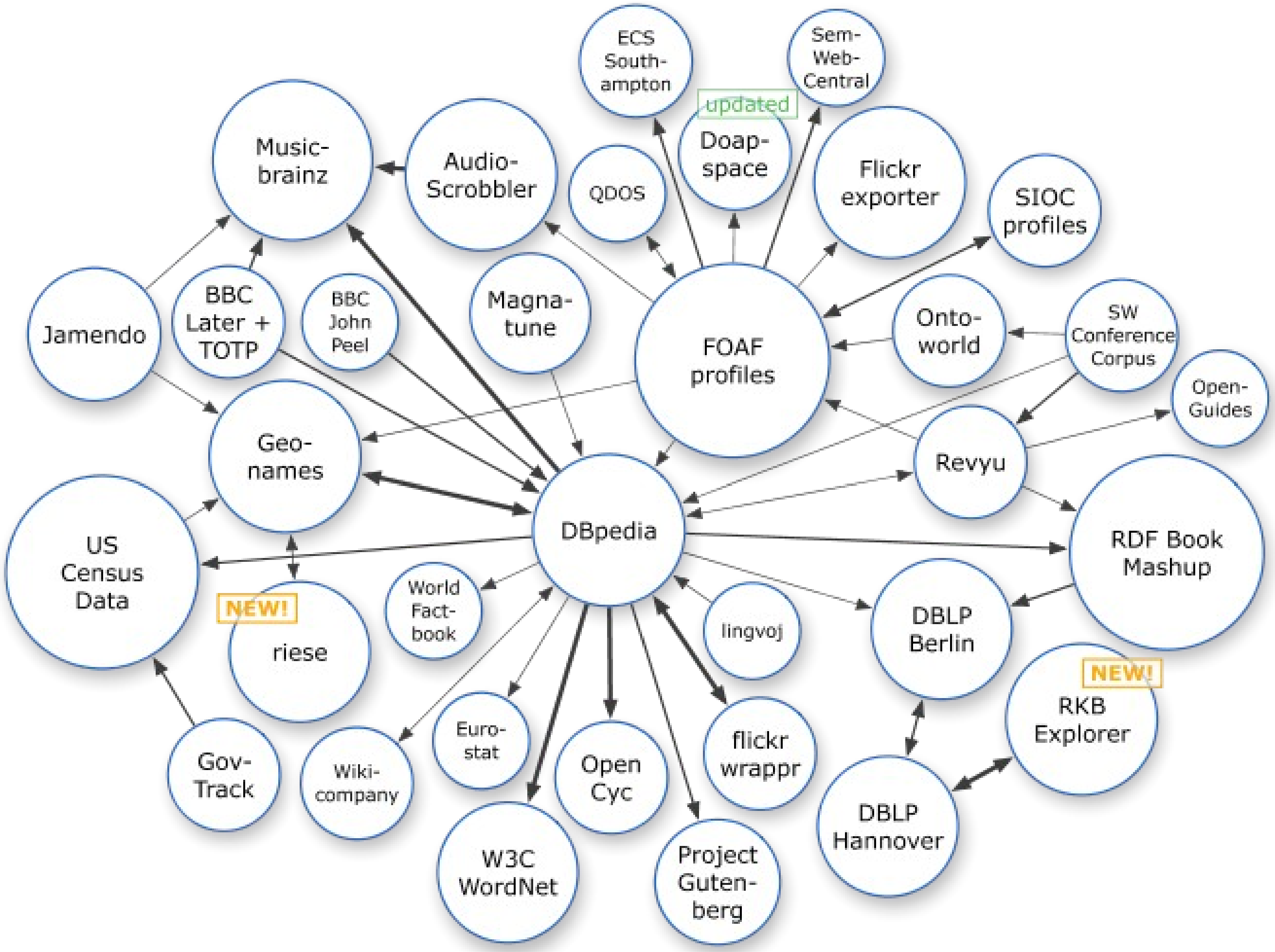
- RDFa extends (X)HTML a bit by:
  - defining general attributes to add metadata to any elements
  - provides an almost complete “serialization” of RDF in XHTML
- It is a bit like the microformats/GRDDL approach but with more rigor and fully generic
- See the separate tutorial this afternoon!

> Bridge to relational databases

- Most of the data on the Web are stored in relational databases
  - “RDFying” them is not possible
  - relational databases are here to stay…
- “Bridges” are being defined:
  - a layer between RDF and the relational data
    - RDB tables are “mapped” to RDF graphs, possibly on the fly
    - different mapping approaches are being used
  - this is what our examples did…
  - a number RDB systems offer this facility already (eg, Oracle, OpenLink, …)
- Work for a survey of mapping techniques has started at W3C

> A good example: Linking Open Data Project

- Goal: "expose" open datasets in RDF
- *Set RDF links among the data items* from different datasets
- Billions triples, millions of "links"



> Example data source: DBpedia

- Extracting structured data ("infobox") from Wikipedia:

```
http://en.wikipedia.org/wiki/Kolkata
```

```
<http://dbpedia.org/resource/Kolkata>
  dbpedia:native_name "Kolkata (Calcutta)"@en;
  dbpedia:altitude "9";
  dbpedia:populationTotal  "4580544";
  dbpedia:population_metro "14681589";
  geo:lat "22.56970024108887";
 ...
```

> Automatic links among open datasets

DBpedia

```
<http://dbpedia.org/resource/Kolkata>
  owl.sameAs <http://sws.geonames.org/1275004/>;
 ...
```

Geonames

```
<http://sws.geonames.org/1275004/>
  owl:sameAs <http://DBpedia.org/resource/Kolkata>
  wgs84_pos:lat “22.5697222”;
  wgs84_pos:long “88.3697222”;
  sws:population “4631392”
 ...
```

Processors can switch automatically from one to the other…

> RDF data access, a.k.a. query (SPARQL)

> RDF data access

- How do I *query* the RDF data?
  - e.g., how do I get to the DBpedia data?

> Querying RDF graphs

- Remember the Jena idiom:

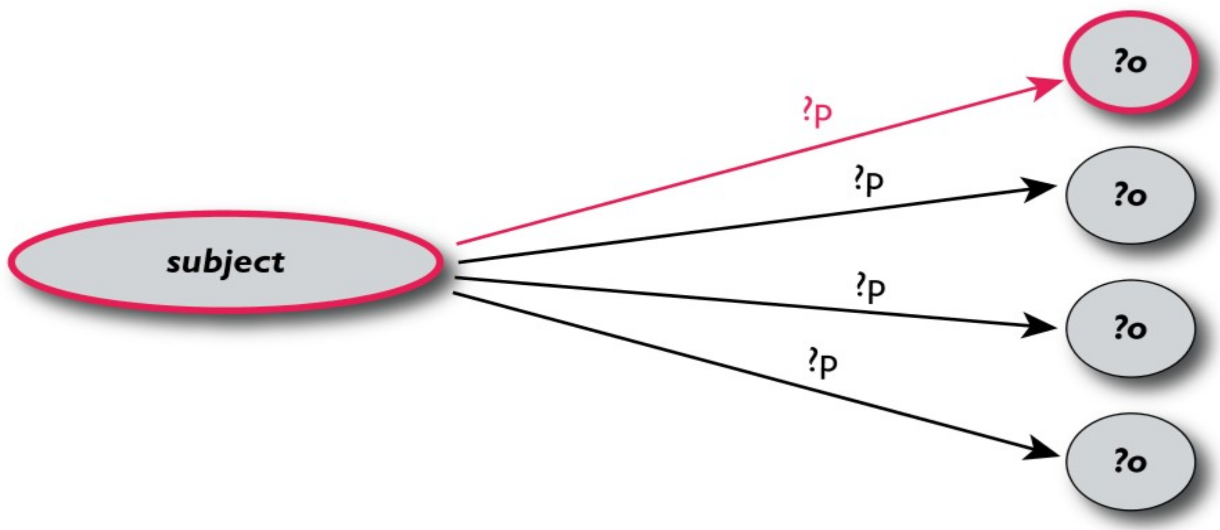
```
StmtIterator iter=model.listStatements(subject,null,null);
while(iter.hasNext()) {
    st = iter.next();
    p = st.getProperty(); o = st.getObject();
    do_something(p,o);
```

- 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
- This is the goal of SPARQL (Query Language for RDF)

> Analyze the Jena example

```
StmtIterator iter=model.listStatements(subject,null,null);
while(iter.hasNext()) {
    st = iter.next();
    p = st.getProperty(); o = st.getObject();
    do_something(p,o);
```

- The **`(subject,?p,?o)`** is a *pattern* for what we are looking for (with **`?p`** and **`?o`** as “unknowns”)



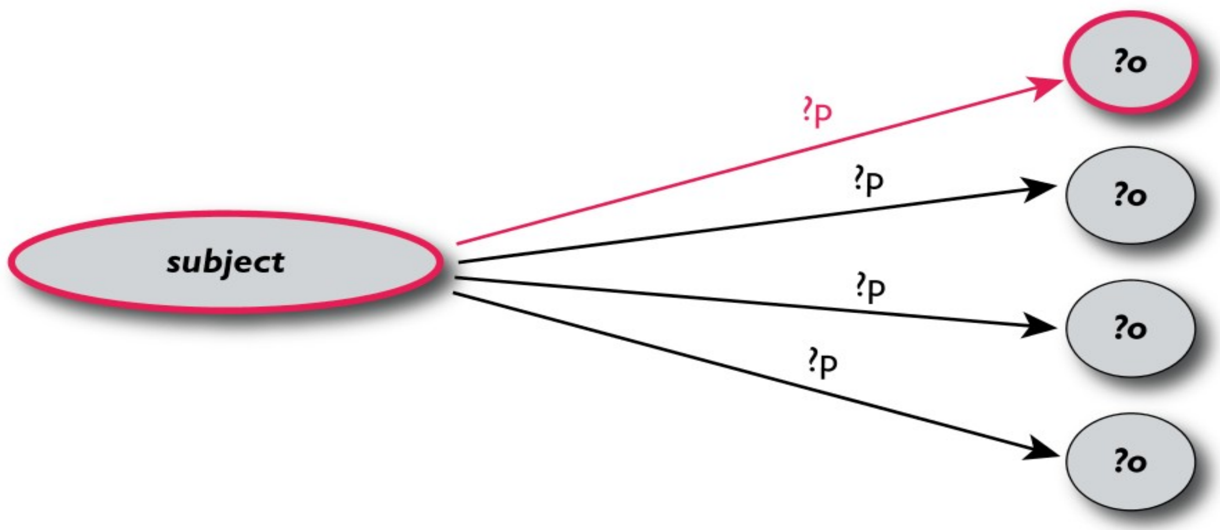
> General: graph patterns

- The fundamental idea: generalize the approach to graph patterns:
  - the pattern contains unbound symbols
  - by binding the symbols (if possible), subgraphs of the RDF graph are selected
  - if there is such a selection, the query returns the bound resources
- SPARQL
  - is based on similar systems that already existed in some environments
  - is a programming language-independent query language

> Our Jena example in SPARQL

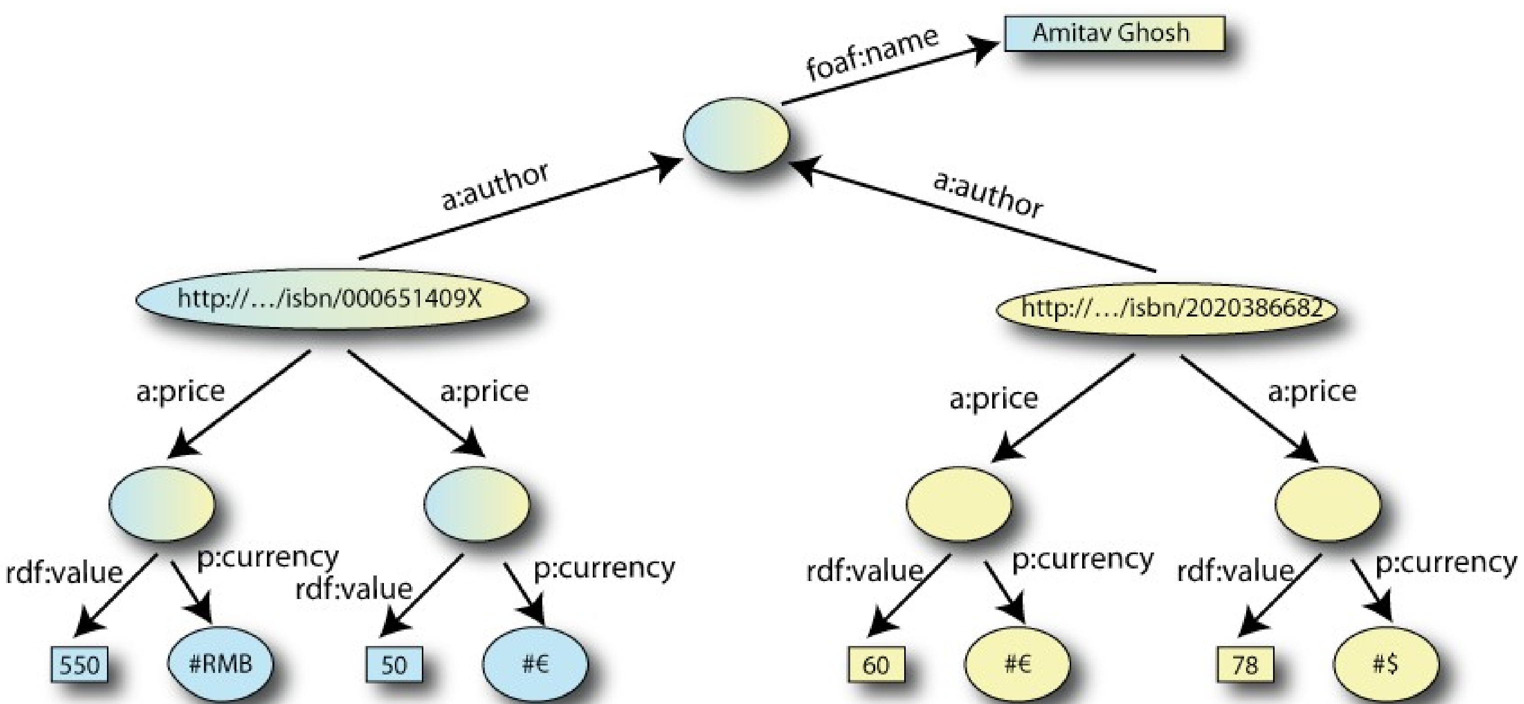
```
SELECT ?p ?o
WHERE {subject ?p ?o}
```

- The triples in **`WHERE`** define the graph pattern, with **`?p`** and **`?o`** "unbound" symbols
- The query returns *all* **`p`**,**`o`** pairs



> Simple SPARQL example

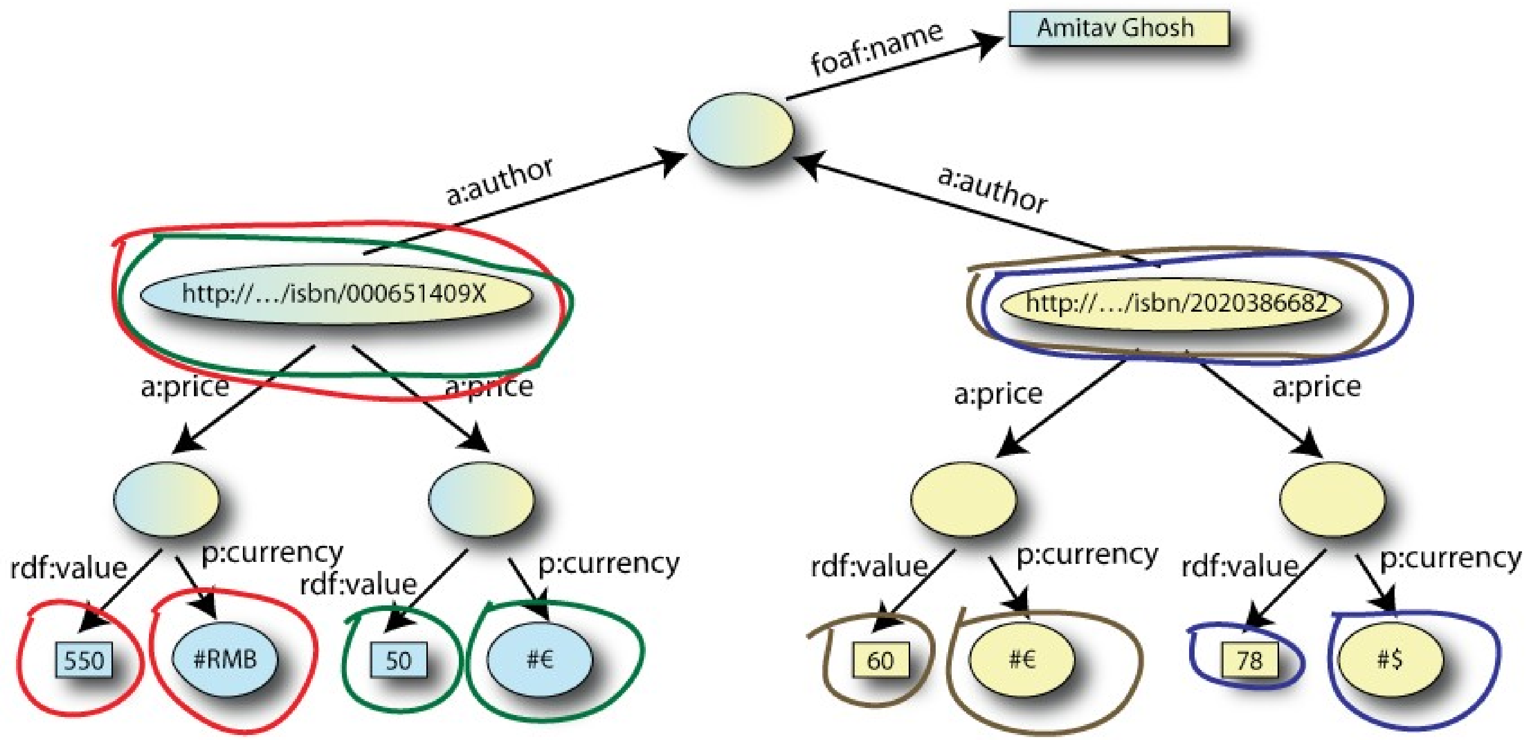
```
SELECT ?isbn ?price ?currency # note: not ?x!
WHERE { ?isbn a:price ?x. ?x rdf:value ?price. ?x p:currency ?currency.}
```



> Simple SPARQL example

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

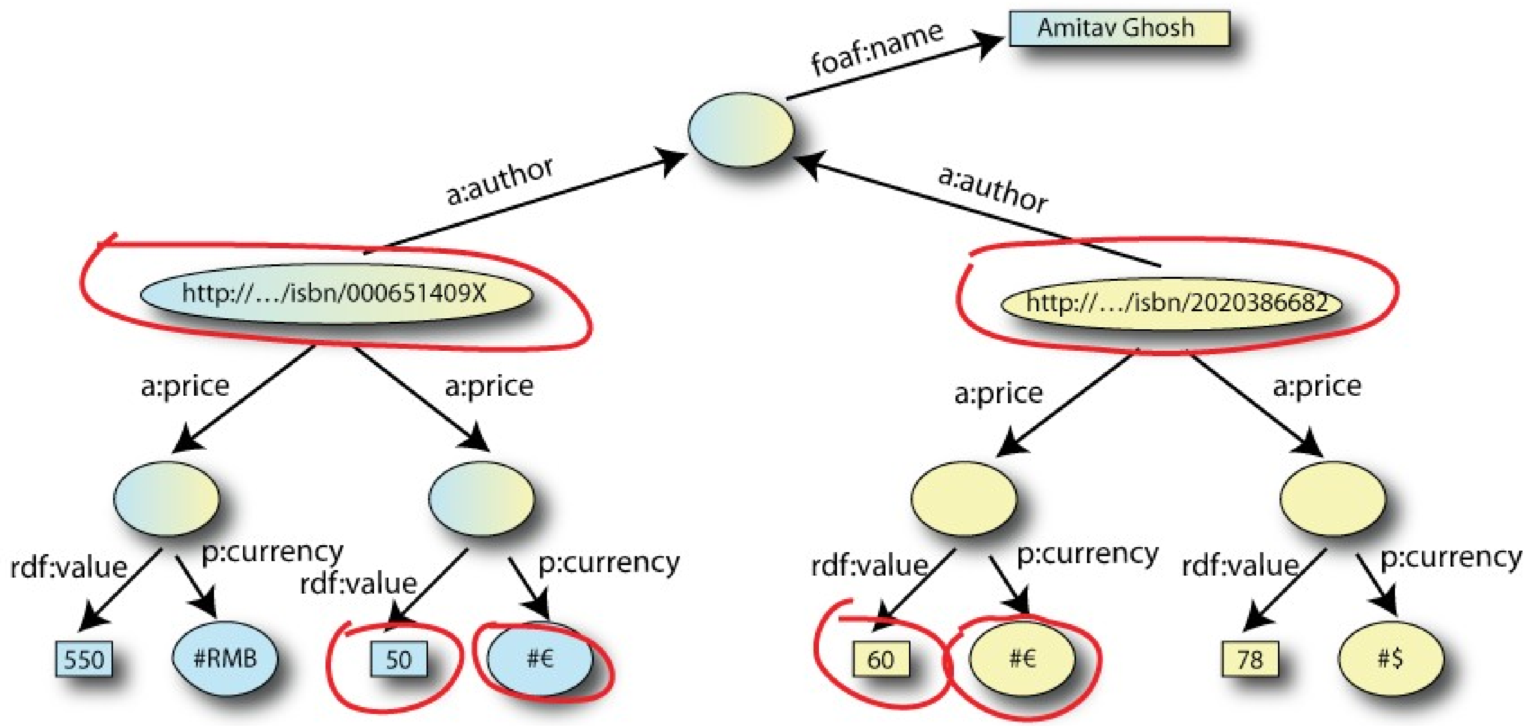
- Returns:
  [[<..49X>,550,RMB], [<..49X>,50,€], [<..6682>,60,€], [<..6682>,78,$]]



> 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,€]]



> Other SPARQL features

- Some of the patterns may be optional
- Limit the number of returned results; remove duplicates
- Specify several data sources (via URI-s) within the query (essentially, a merge!)
- *Construct* a graph combining a separate pattern and the query results
- Use datatypes and/or language tags when matching a pattern

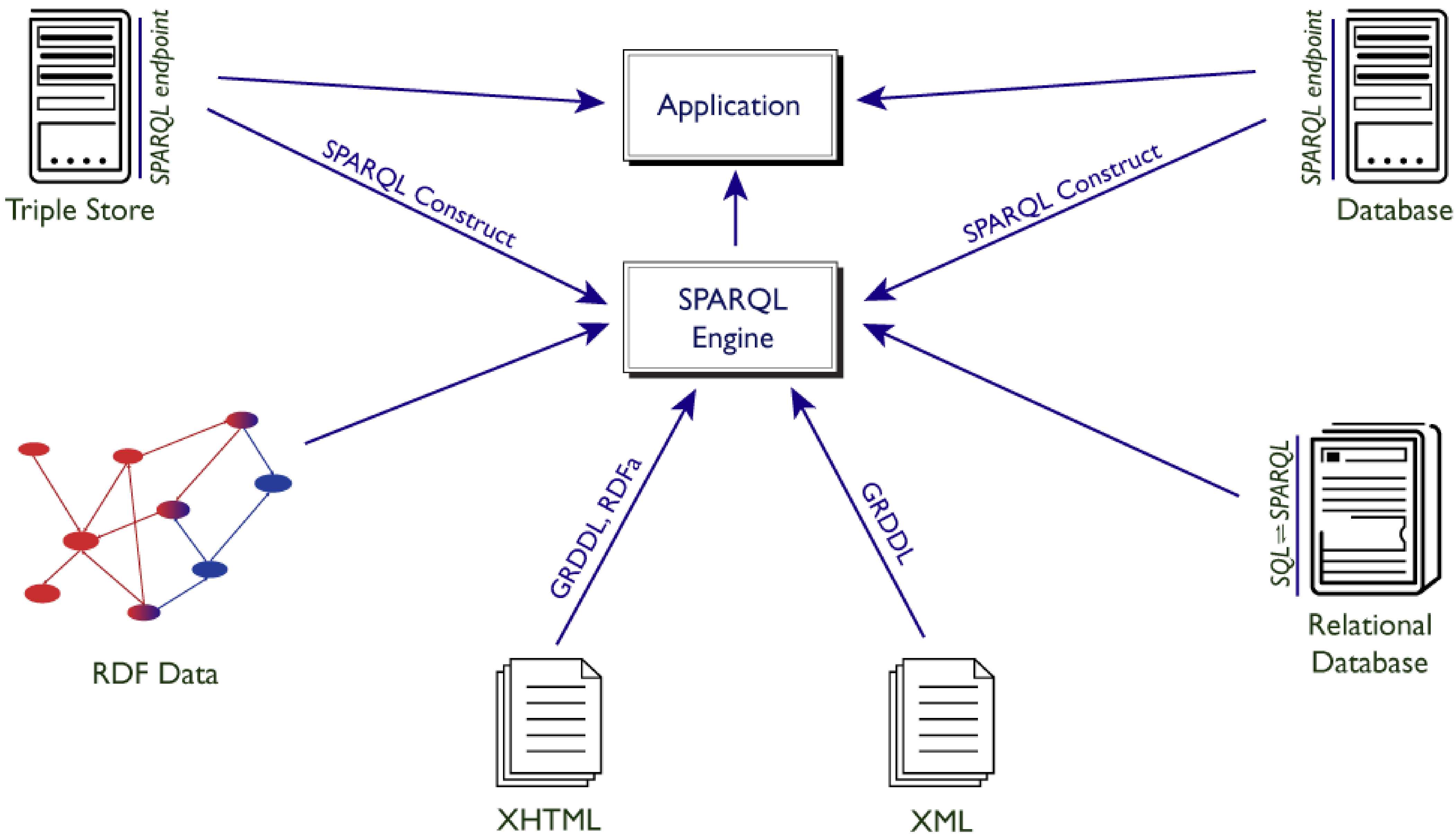
> SPARQL usage in practice

- SPARQL is usually used over the network
  - separate documents define the protocol and the result format
    - SPARQL Protocol for RDF with HTTP and SOAP bindings
    - SPARQL results in XML or JSON formats
- Big datasets usually offer “SPARQL endpoints” using this protocol
  - typical example: SPARQL endpoint to DBpedia

> A word of warning on SPARQL…

- Some features are missing
  - control and/or description on the entailment regimes of the triple store (RDFS? OWL-DL? OWL-Lite? …)
  - modify the triple store
  - querying collections or containers may be complicated
  - no functions for sum, average, min, max, …
  - ways of aggregating queries
  - …
- Delayed for a next version…

> SPARQL as a unifying point



> Ontologies (OWL)

> Ontologies

- RDFS is useful, but does not solve all possible requirements
- Complex applications may want more possibilities:
  - characterization of properties (not only listing their range and domain)
  - identification of objects with different URI-s
  - disjointness or equivalence of classes
  - construct classes, not only name them
  - more elaborate class hierarchies
  - can a program reason about some terms? E.g.:
    - “if «Person» resources «A» and «B» have the same «**`foaf:email`**» property, then «A» and «B» are identical”
  - restrict a property range when used for a specific class
  - etc.

> Ontologies (cont.)

- The term *ontologies* is used in this respect:

"defines the concepts and relationships used to describe and represent an area of knowledge"

- Ie, there is a need for Web Ontology Language(s)
  - RDFS can be considered as a simple ontology language
- Languages should be a compromise between
  - rich semantics for meaningful applications
  - feasibility, implementability

> Web Ontology Language = OWL

- OWL is an extra layer, a bit like RDF Schemas
  - own namespace, own terms
  - it relies on RDF Schemas
- It is a separate recommendation
- There is an active W3C Working Group working on *extensions* of the current standard
  - labeled as “OWL 2”
  - in what follows, some features will be referred to as “may come in future”, i.e., under consideration by that group

> OWL is complex…

- OWL is a large set of additional terms
- We will not cover the whole thing here…

> First some simple features

> Term equivalence

- For classes:
  - **`owl:equivalentClass`**: two classes have the same individuals
  - **`owl:disjointWith`**: no individuals in common
- For properties:
  - **`owl:equivalentProperty`**
    - remember the **`a:author`** vs. **`f:auteur`**?
- For individuals:
  - **`owl:sameAs`**: two URIs refer to the same concept (a.k.a. “individual”)
  - **`owl:differentFrom`**: negation of **`owl:sameAs`**

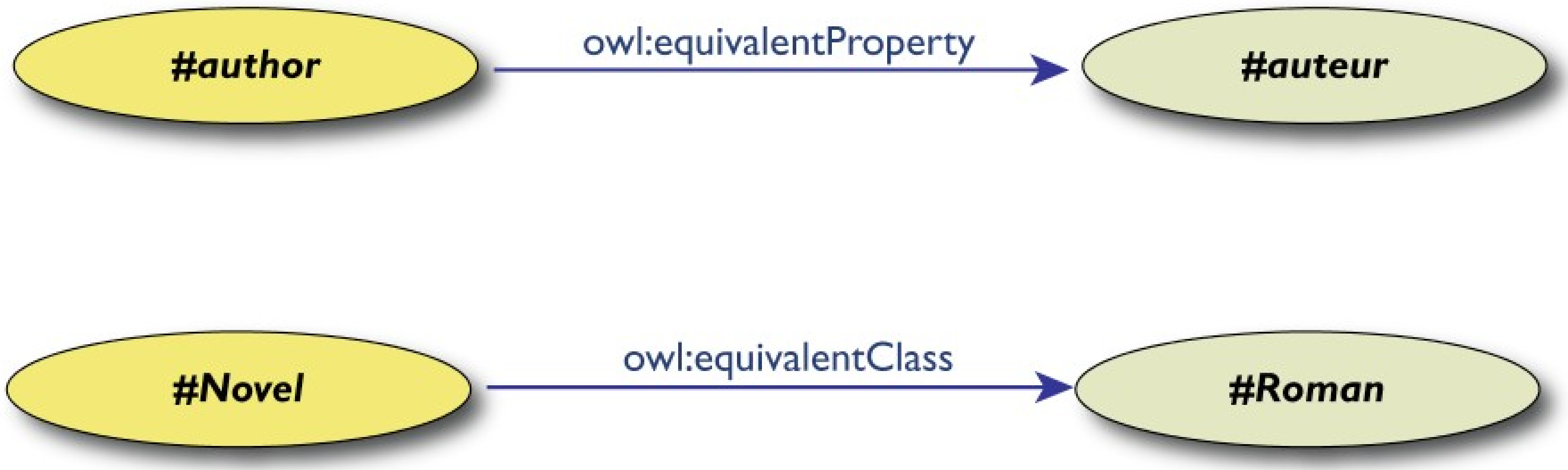
> Typical usage of `owl:sameAs`

- Linking our example of Kolkata from one data set (DBedia) to the other (Geonames):

```
<http://dbpedia.org/resource/Kolkata>
  owl.sameAs <http://sws.geonames.org/1275004/>;
```

- This is the main mechanism of “Linking” in the Linking Open Data project

> Other example: connecting to French

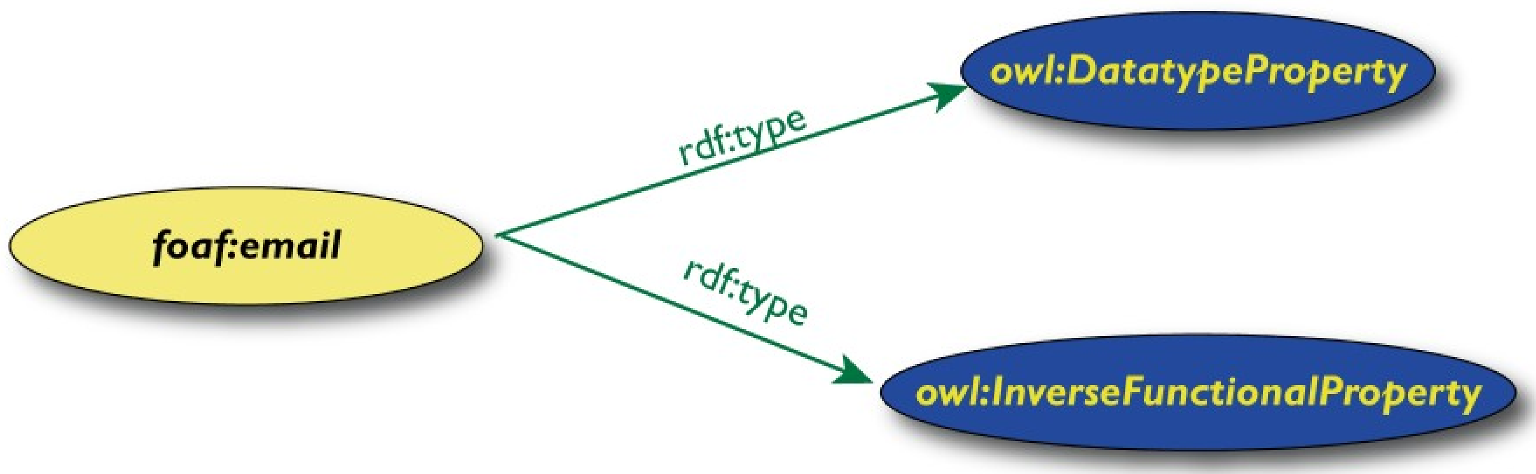


> Property characterization

- In OWL, one can characterize the behavior of properties (symmetric, transitive, functional, inverse functional…)
- OWL also separates *data* and *object* properties
  - “datatype property” means that its range are literals

Characterization example

- "**`foaf:email`**" is inverse functional (i.e., two different subjects cannot have identical objects)



> What this means is…

- If the following holds in our triples:

```
:email rdf:type owl:InverseFunctionalProperty.
<A> :email "mailto:a@b.c".
<B> :email "mailto:a@b.c".
```

- then the following holds, too:

```
<A> owl:sameAs <B>.
```

- I.e., *new relationships* were discovered again (beyond what RDFS could do)

> Other property characterizations

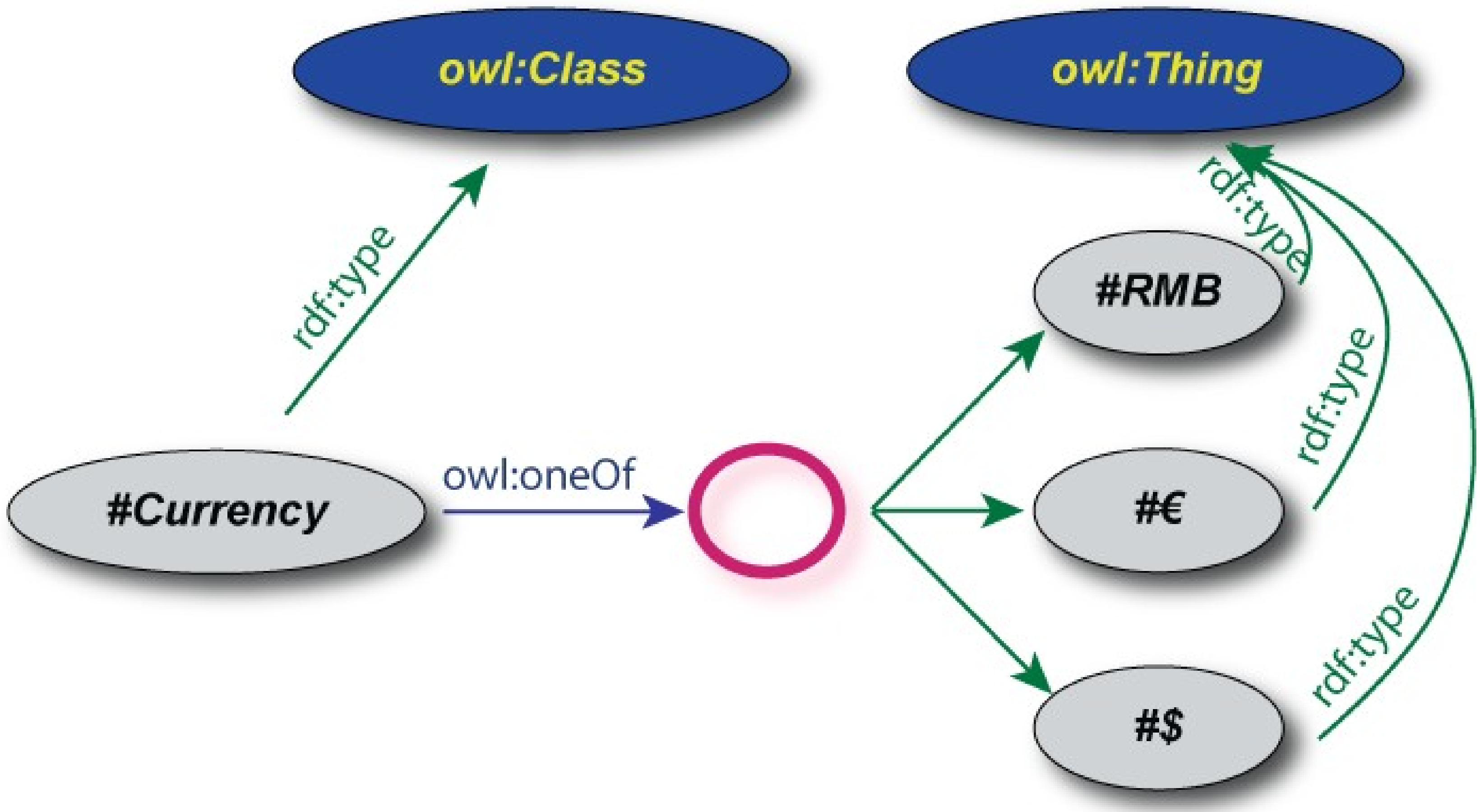
- Functional property ("**`owl:FunctionalProperty`**")
- Transitive property ("**`owl:TransitiveProperty`**")
- Symmetric property ("**`owl:SymmetricProperty`**")
- Inverse of another property ("**`owl:inverseOf`**")
- May come in future:
  - reflexive and irreflexive object properties
  - specify that properties are "disjoint"
  - combining ("chaining") properties (a generalization of transitivity)

> Classes in OWL

- In RDFS, you can subclass existing classes… that’s all
- In OWL, you can *construct* classes from existing ones:
  - enumerate its content
  - through intersection, union, complement
  - etc
- OWL makes a stronger distinction between *classes* and *individuals*
  - referring to its own **`Class`** and to “**`Thing`**”, respectively
    - of course, **`owl:Class`** is a subclass of **`rdfs:Class`**, i.e., it is a refinement

> OWL classes can be “enumerated”

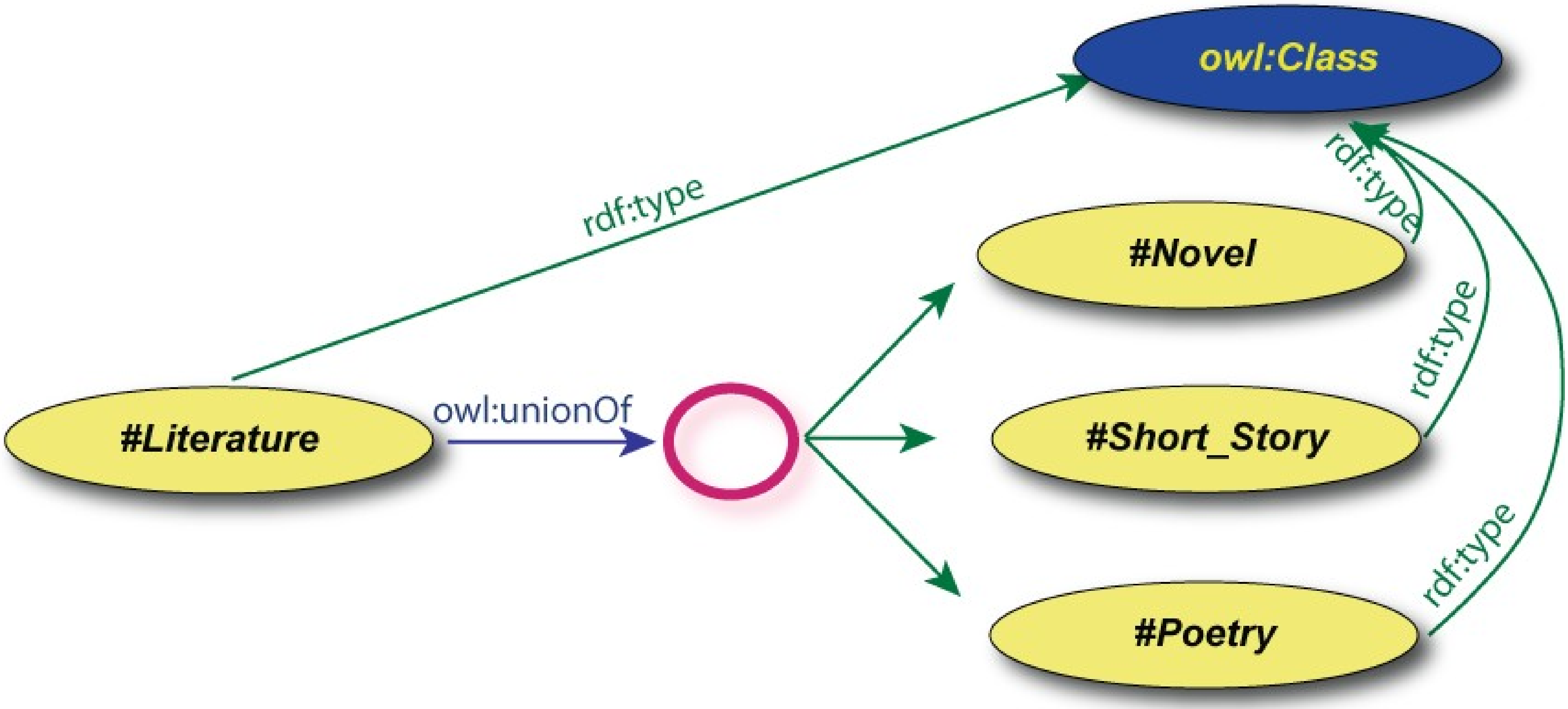
- The OWL solution, where possible content is explicitly listed:



(don’t worry about the syntax mapping…)

Union of classes

- Essentially, like a set-theoretical union:



- Other possibilities include: intersection, complement of

> What we have so far…

- The OWL features listed so far are already fairly powerful
- E.g., various databases can be linked via **`owl:sameAs`**, functional or inverse functional properties, etc.
- It is still possible to find all inferred relationship using a traditional rule engine
  - there are some restrictions on subclassing that one has to follow, though

> However… that may not be enough

- Very large vocabularies might require even more complex features
  - typical example: definition of all concepts in a health care environment
- One major issue is the way classes (i.e., “concepts”) are defined
- OWL includes those extra features but… the inference engines become (much) more complex

> Property value restrictions

- Classes are created by *restricting* the property values
- For example: how would I characterize a “listed price”?
  - it is a price (which may be a general term), but one that is given in one of the “allowed” currencies (say, €, RMB, or $)
  - more formally:
    - the value of “`p:currency`”, when applied to a resource on listed price, *must* take one of those values…
    - …thereby defining the class of “listed price”

> Restrictions expressed in RDF

```
:Listed_Price rdf:type owl:Class;
    rdfs:subClassOf [
      rdf:type             owl:Restriction;
      owl:onProperty       <http://…#currency>;
      owl:allValuesFrom    :Currency.
   ].
```

- "**`allValuesFrom`**" could be replaced by "**`someValuesFrom`**" to express another type of restriction
  - e.g., I could have said: there should be a price given in *at least one* of those currencies
- or "**`hasValue`**", when restricted to *one specific value*

> Similar concept: cardinality restriction

- In a property restriction, the issue was to restrict the possible *values* of a property
- In a cardinality restriction, the *number* of relations with that property is restricted
- Eg: “a book being on offer” could be characterized as having at *least one price property* (i.e., the price of the book has been established)

> Cardinality restriction

```
:Book_on_sale rdf:type owl:Class;
    rdfs:subClassOf [
      rdf:type                owl:Restriction;
      owl:onProperty          <http://…#price>;
      owl:minCardinality      "1"^^xsd:integer.
   ].
```

- could also be "**`owl:cardinality`**" or "**`owl:maxCardinality`**"

> But: OWL is hard!

- The combination of class constructions with various restrictions is extremely powerful
- What we have so far is following the same logic as before
  - extend the basic RDF and RDFS possibilities with new features
  - expect to infer new relationships based on those
- However… a full inference procedure is hard
  - not implementable with simple rule engines, for example
  - in some cases, it may even be impossible ☹

> OWL profiles

- The term OWL "profiles" comes to the fore:
  - restricting *which* terms can be used and *under what circumstances (restrictions)*
  - if one abides to those restrictions, then simpler inference engines can be used

> OWL profiles (cont.)

- In the *current* OWL standard, three such “profiles” are defined:
  - OWL Full: no restrictions whatsoever
  - OWL DL (and its “sub profile” OWL Lite): major restrictions to ensure implementability
- The current OWL 2 work will add new profiles
  - profiles that are simple enough to be implementable with simple rule engines (like the first few examples we had)
  - profiles that are optimized to a small number of class and property definition but a large amount of data
  - etc.

> OWL Full

- No constraints on the various constructs
  - this means that:
    - Class can also be an individual, a URI can denote a property as well as a Class
      - e.g., it is possible to talk about class of classes, etc.
    - one could make statements on RDFS constructs (e.g., declare **`rdf:type`** to be functional…)
    - etc.
- But: *<u>an OWL Full ontology may be undecidable!</u>*

> OWL Description Logic (DL)

- A number of restrictions are defined
  - Classes, individuals, properties are strictly separated: a class *cannot* be an individual of another class
  - strict separation of the user's and the reserved (RDFS, OWL) terms
    - no statements on RDFS and OWL resources, for example
  - the values of user's object must be individuals
    - i.e., they are used to create relationships *between individuals*
  - no characterization of *datatype* properties (functional, etc)
  - …
- But: *well known inference algorithms exist!*

Note on OWL profiles

- OWL profiles are defined to reflect compromises:
  - expressibility vs. implementability
- Some application just need to express and interchange terms (with possible scruffiness): OWL Full is fine
  - they may build application-specific reasoning instead of using a general one
- Some applications need rigor, but only a simple set of statements: a rule engine based profile from OWL 2 might be o.k.
- Some applications need rigor and complex term classification; then OWL DL might be the good choice

> Ontology development

- The hard work is to *create* the ontologies
  - requires a good knowledge of the area to be described
  - some communities have good expertise already (e.g., librarians)
  - *OWL is just a tool to formalize ontologies*
- Large scale ontologies are often developed in a community process
- Ontologies should be *shared* and *reused*
  - can be via the simple namespace mechanisms…
  - …or via explicit inclusions
- Applications can also be developed with very small ontologies, though

> Ontologies examples

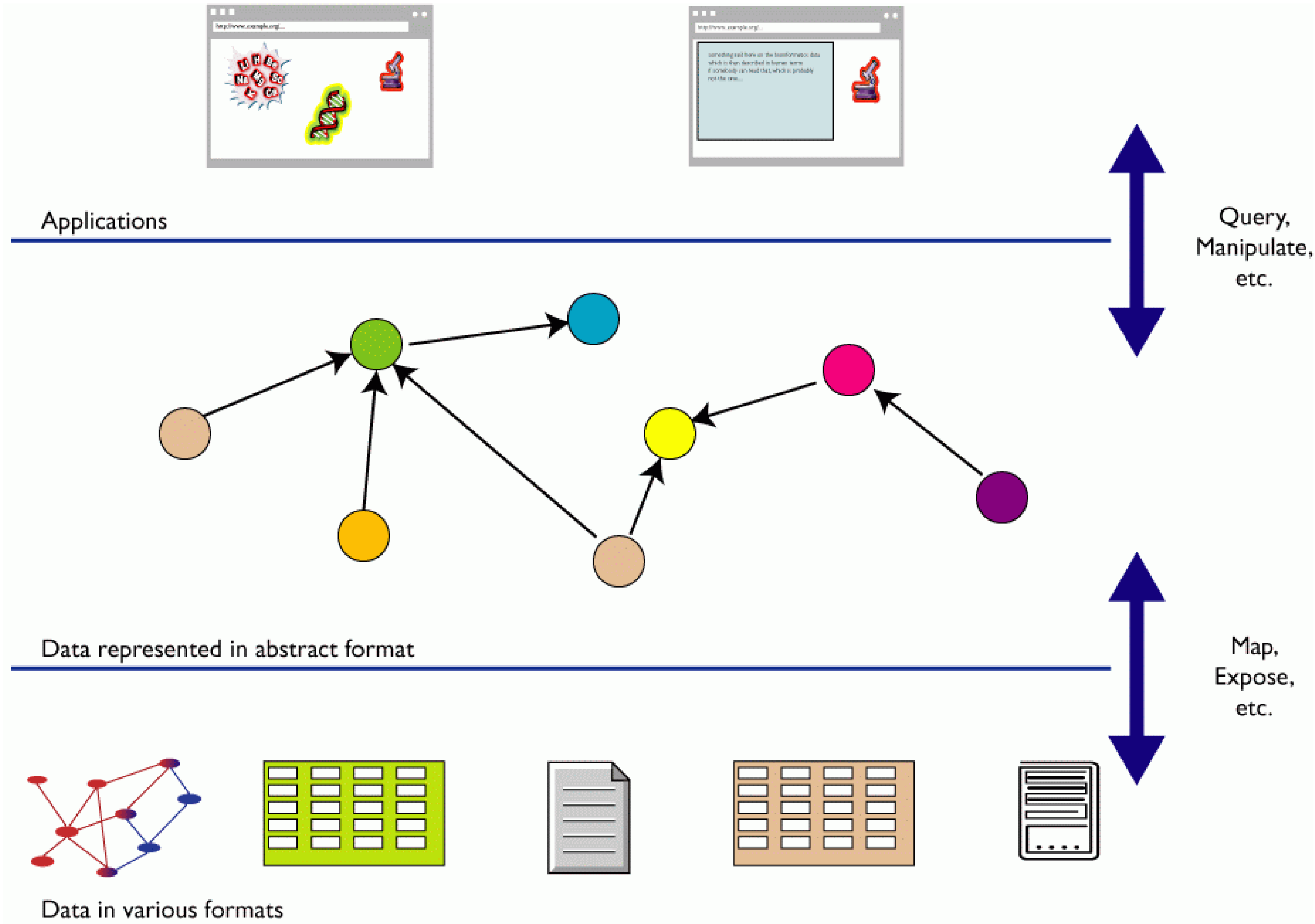
- International Country List
  - example for an OWL Lite ontology
- Large ontologies are being developed (converted from other formats or defined in OWL)
  - eClassOwl: eBusiness ontology for products and services, 75,000 classes and 5,500 properties
  - National Cancer Institute's ontology: about 58,000 classes
  - Open Biomedical Ontologies Foundry: a collection of ontologies, including the Gene Ontology to describe gene and gene product attributes in any organism or protein sequence and annotation terminology and data (UniProt)
  - BioPAX: for biological pathway data

> What have we achieved?

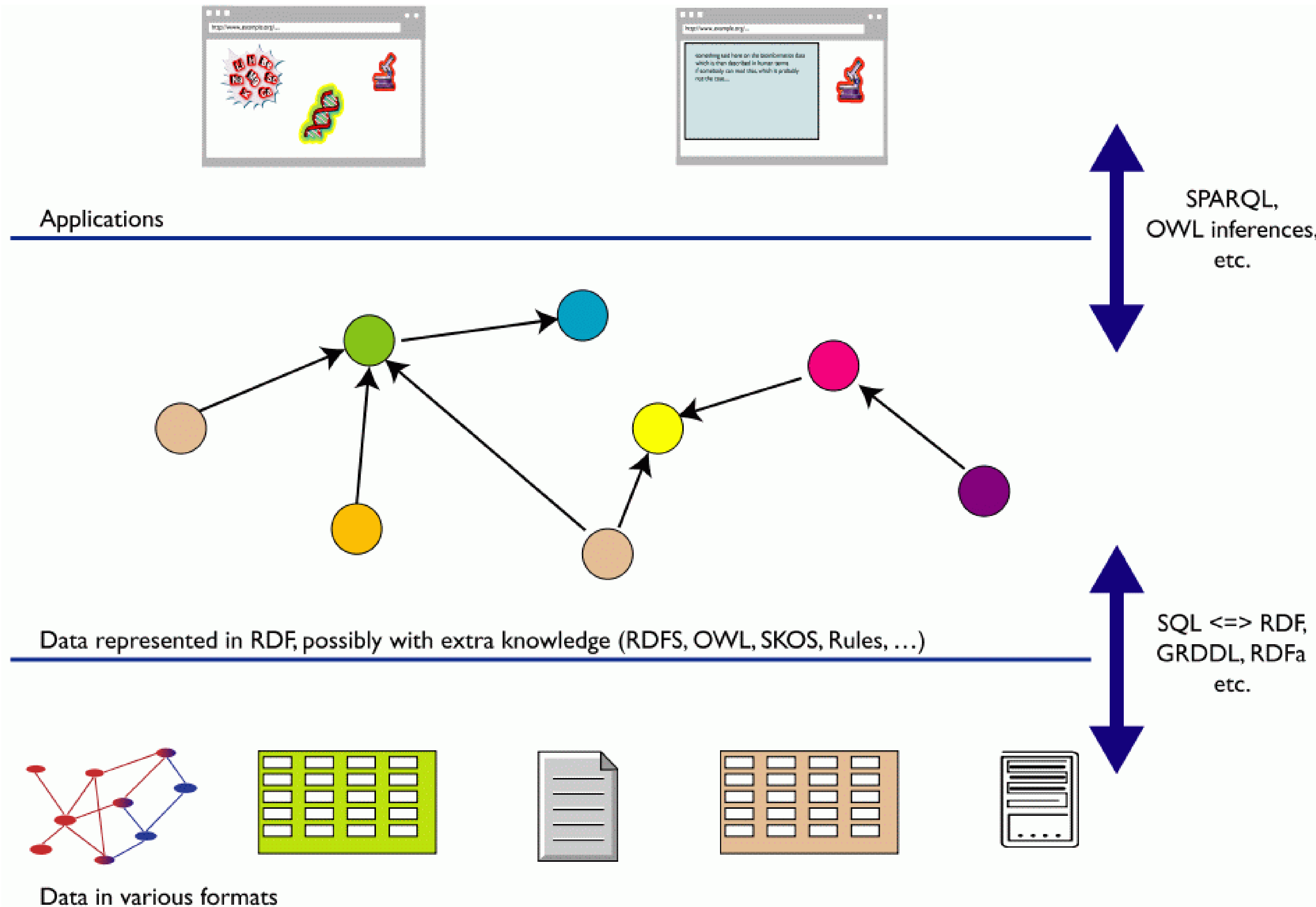
> We have not talked about everything…

- Some other aspects of SW are being developed
  - some at W3C, others are still research
- For example:
  - RIF: using general rule engines with SW data; also *interchange* rule descriptions (just like data are interchanged)
  - SKOS: general framework to express term structures like vocabularies, taxonomies, glossaries
    - eg, to interface bibliographic records

> Remember the integration example?



> Same with what we learned



> Available documents, tools

> Available specifications: Primers, Guides

- The “RDF Primer” and the “OWL Guide” give a formal introduction to RDF(S) and OWL
- GRDDL Primer and RDFa Primer have been published
- The W3C Semantic Web Activity Homepage has links to all the specifications

> “Core” vocabularies

- There are also a number “core vocabularies” (not necessarily OWL based)
  - Dublin Core: about information resources, digital libraries, with extensions for rights, permissions, digital right management
  - FOAF: about people and their organizations
  - DOAP: on the descriptions of software projects
  - Music Ontology: on the description of CDs, music tracks, …
  - SIOC: Semantically-Interlinked Online Communities
  - vCard in RDF
  - …
- One should never forget: ontologies/vocabularies must be shared and reused!

> Some books

- J. Davies, D. Fensel, F. van Harmelen: Towards the Semantic Web (2002)
- S. Powers: Practical RDF (2003)
- F. Baader, D. Calvanese, D. McGuinness, D. Nardi, P. Patel-Schneider: The Description Logic Handbook (2003)
- G. Antoniu, F. van Harmelen: Semantic Web Primer (2004)
- A. Gómez-Pérez, M. Fernández-López, O. Corcho: Ontological Engineering (2004)
- …

See the separate Wiki page collecting book references

> Further information

- Dave Beckett's Resources at Bristol University
  - *huge* list of documents, publications, tools, …
- Planet RDF aggregates a number of SW blogs
- Semantic Web Interest Group
  - a forum developers with archived (and public) mailing list, and a constant IRC presence on freenode.net#swig
  - anybody can sign up on the list

> Some SW Tools (***not*** an exhaustive list!)

- **Triple Stores**
  - RDFStore, AllegroGraph, Tucana
  - RDF Gateway, Mulgara, SPASQL
  - Jena's SDB, D2R Server, SOR
  - Virtuoso, Oracle11g
  - Sesame, OWLIM, Tallis Platform
  - …
- **Reasoners**
  - Pellet, RacerPro, KAON2, FaCT++
  - Ontobroker, Ontotext
  - SHER, Oracle 11g, AllegroGraph
  - …
- **Converters**
  - flickurl, TopBraid Composer
  - GRDDL, Triplr, jpeg2rdf
  - …
- **Search Engines**
  - Falcon, Sindice, Swoogle
  - …
- **Middleware**
  - IODT, Open Anzo, DartGrid
  - Ontology Works, Ontoprise
  - Profium' SIR, Software AG's EII
  - Thetus Publisher, Asio, SDS
  - …
- **Semantic Web Browsers**
  - Disco, Tabulator, Zitgist, OpenLink Viewer
  - …
- **Development Tools**
  - SemanticWorks, Protégé
  - Jena, Redland, RDFLib, RAP
  - Sesame, SWI-Prolog
  - TopBraid Composer, DOME
  - …
- **Semantic Wiki and CMS systems**
  - Semantic Media Wiki, Platypus
  - Visual knowledge, Drupal 7

Inspired by "Enterprise Semantic Web in Practice", Jeff Pollock, Oracle. See also W3C's Wiki Site.

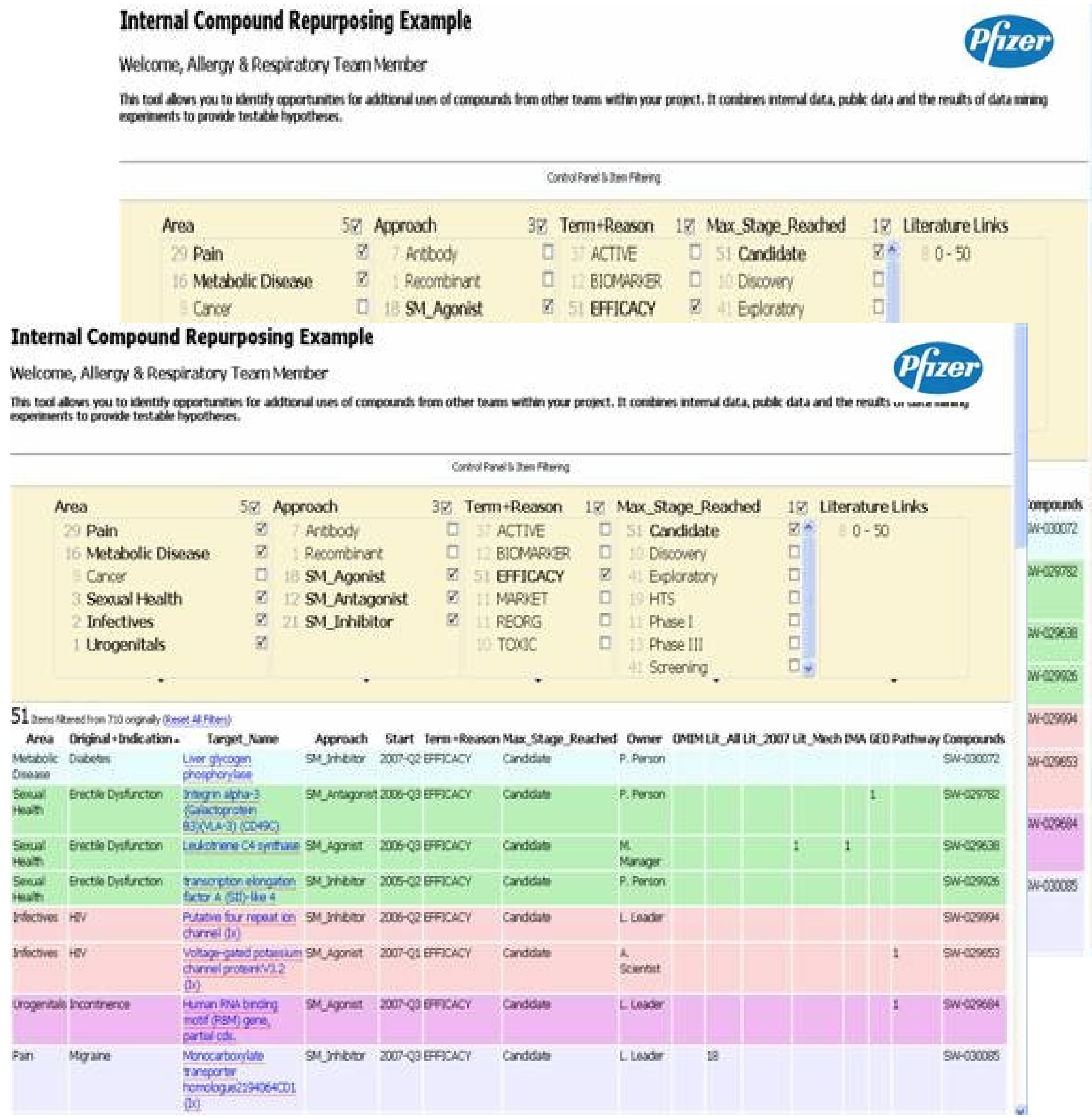
> So how do applications look like?

> Application patterns

- It is fairly difficult to “categorize” applications (there are always overlaps)
- With this caveat, some of the application patterns:
  - data integration (ie, integrating data from major databases)
  - intelligent (specialized) portals (with improved local search based on vocabularies and ontologies)
  - content and knowledge organization
  - knowledge representation, decision support
  - X2X integration (often combined with Web Services)
  - data registries, repositories
  - collaboration tools (eg, social network applications)

> Applications do not have to be complicated

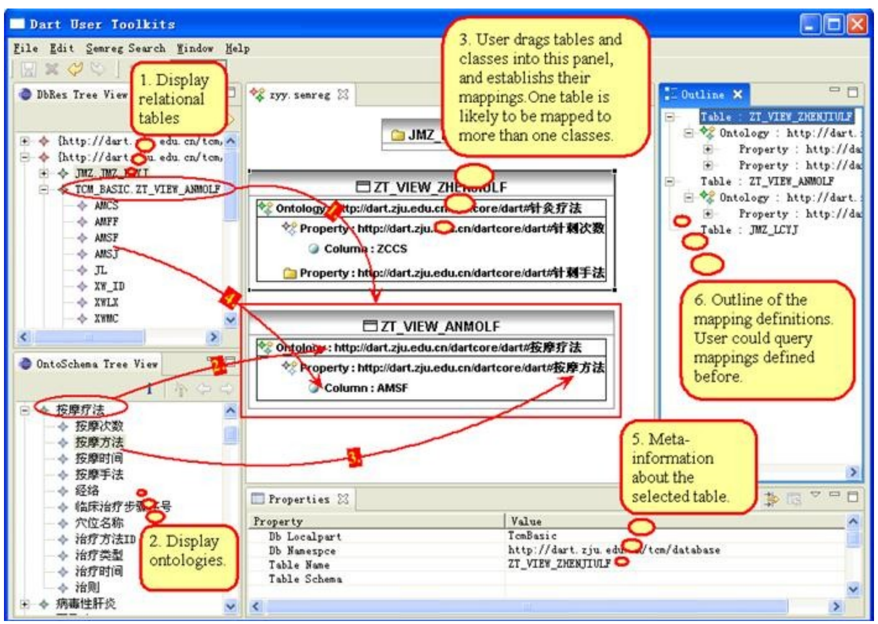
- Goal: reuse of older experimental data
- Keep data in databases or XML, just export key "fact" as RDF
- Use a faceted browser to visualize and interact with the result

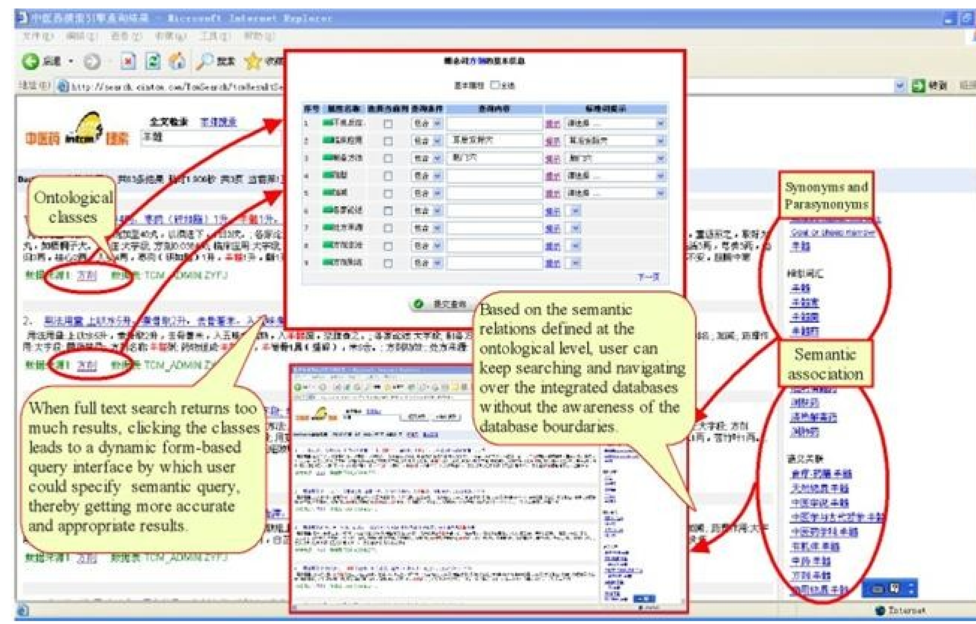


Courtesy of Nigel Wilkinson, Lee Harland, Pfizer Ltd, Melliyal Annamalai, Oracle (SWEO Case Study)

> Integrate knowledge for Chinese Medicine

- Integration of a large number of relational databases (on traditional Chinese medicine) using a Semantic Layer
  - around 80 databases, around 200,000 records each
- A visual tool to map databases to the semantic layer using a specialized ontology
- Form based query interface for end users

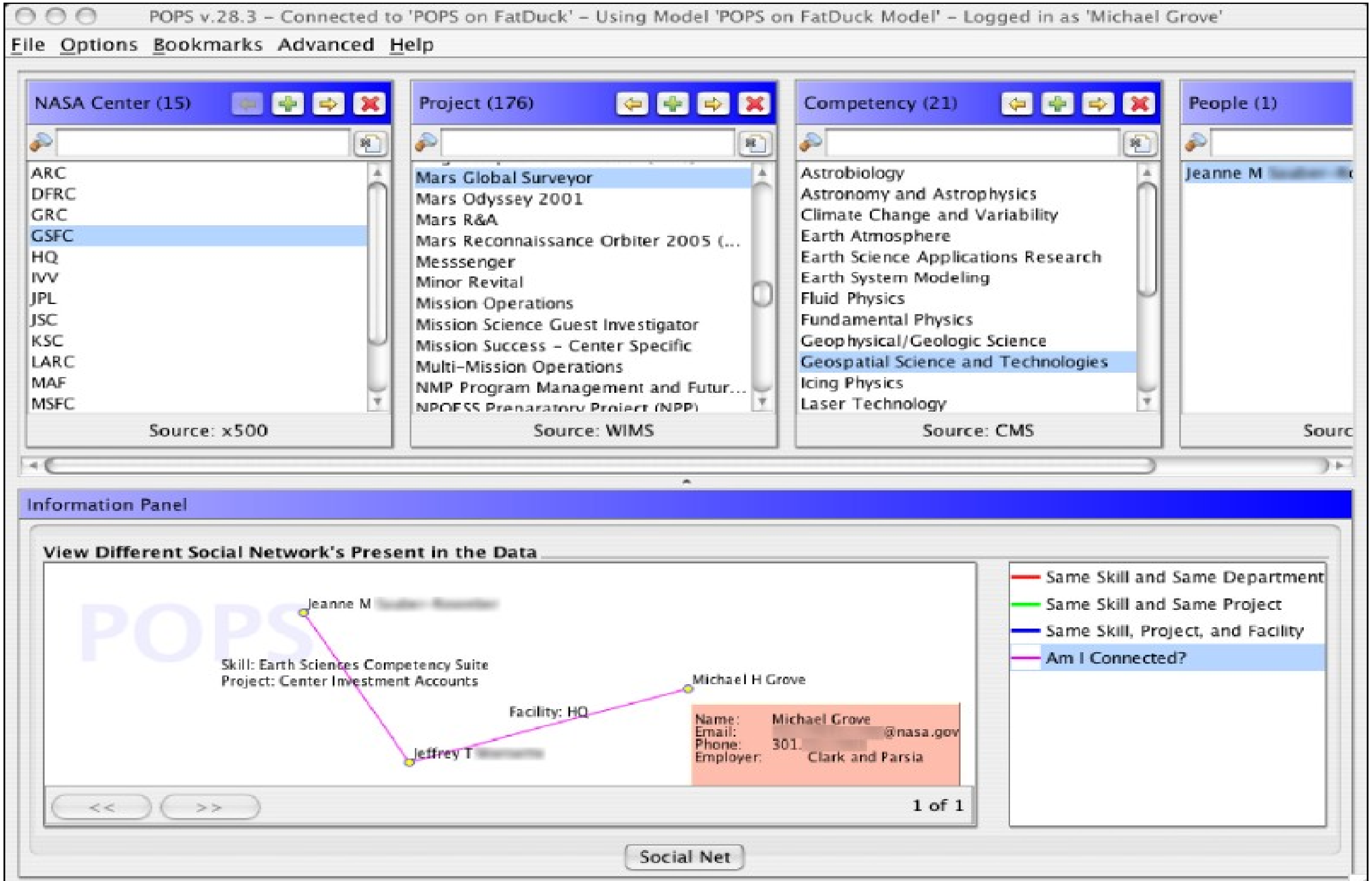




Courtesy of Huajun Chen, Zhejiang University, (SWEO Case Study)

> Find the right experts at NASA

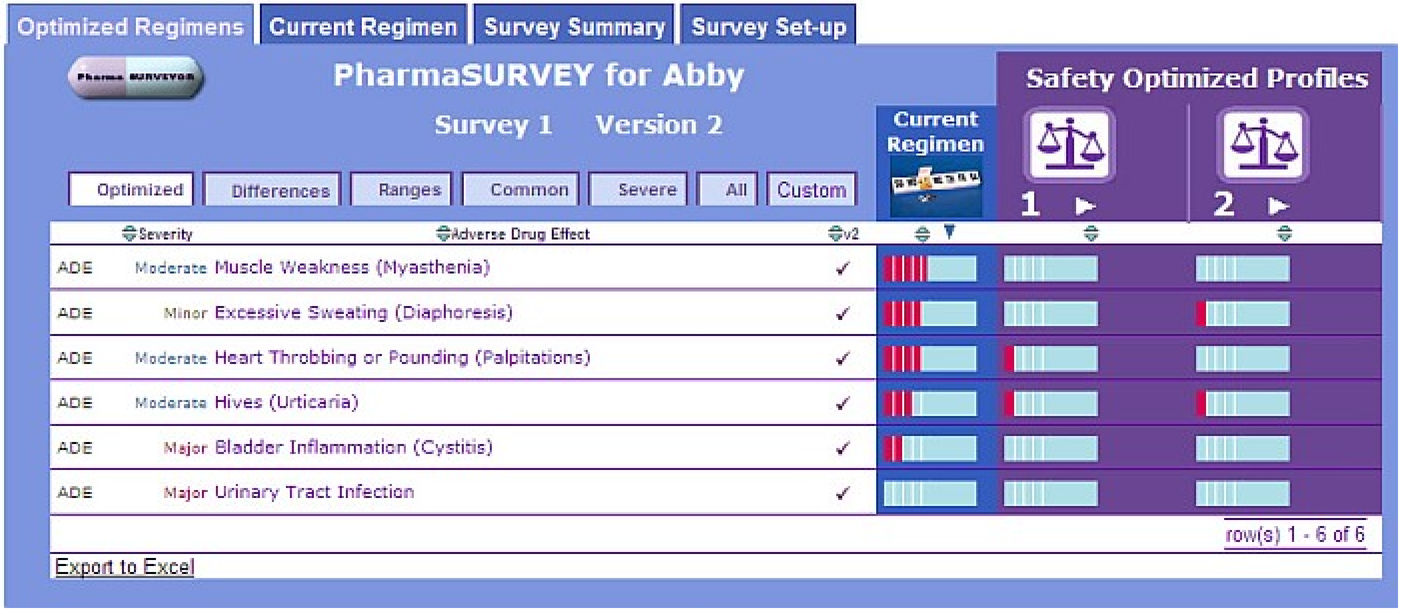
- Expertise locater for nearly 70,000 NASA civil servants using RDF integration techniques over 6 or 7 geographically distributed databases, data sources, and web services…



Michael Grove, Clark & Parsia, LLC, and Andrew Schain, NASA, (SWEO Case Study)

> Help in choosing the right drug regimen

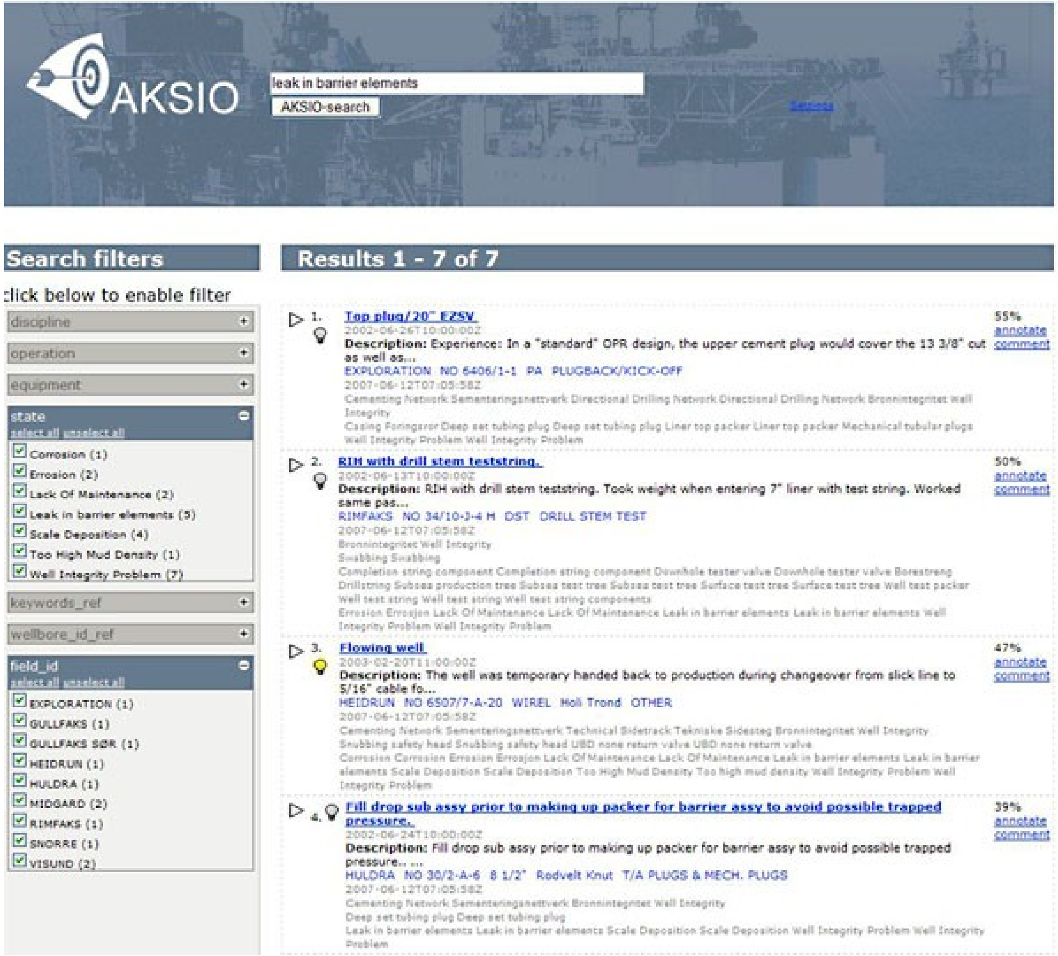
- Help in finding the best drug regimen for a specific case
  - find the best trade-off for a patient
- Integrate data from various sources (patients, physicians, Pharma, researchers, ontologies, etc)
- Data (eg, regulation, drugs) change often, but the tool is much more resistant against change



Courtesy of Erick Von Schweber, PharmaSURVEYOR Inc., (SWEO Use Case)

> Help for deep sea drilling operations

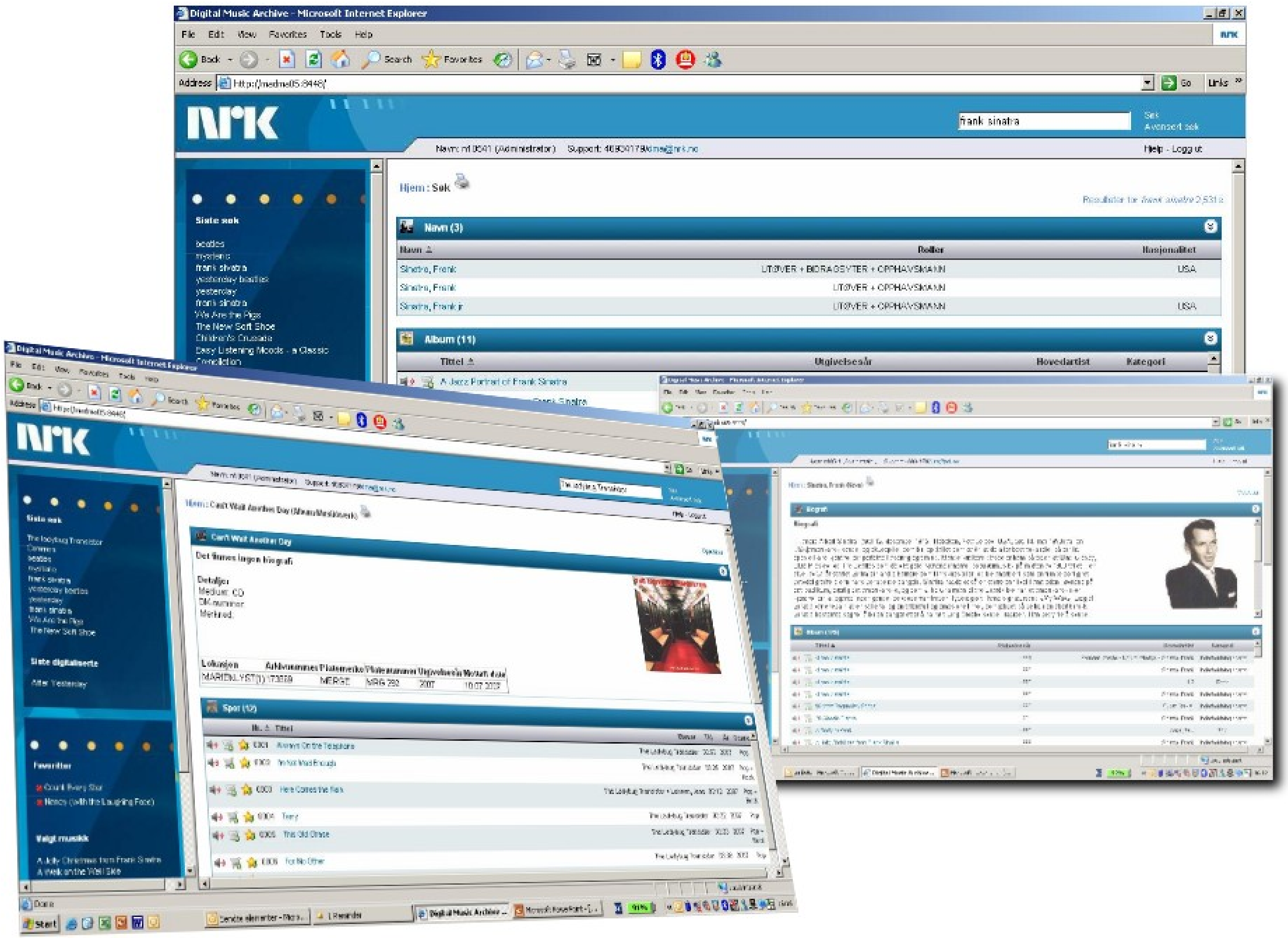
- Integration of experience and data in the planning and operation of deep sea drilling processes
- Discover relevant experiences that could affect current or planned drilling operations
  - uses an ontology backed search engine



Courtesy of David Norheim and Roar Fjellheim, Computas AS (SWEO Use Case)

> Digital music asset portal at NRK

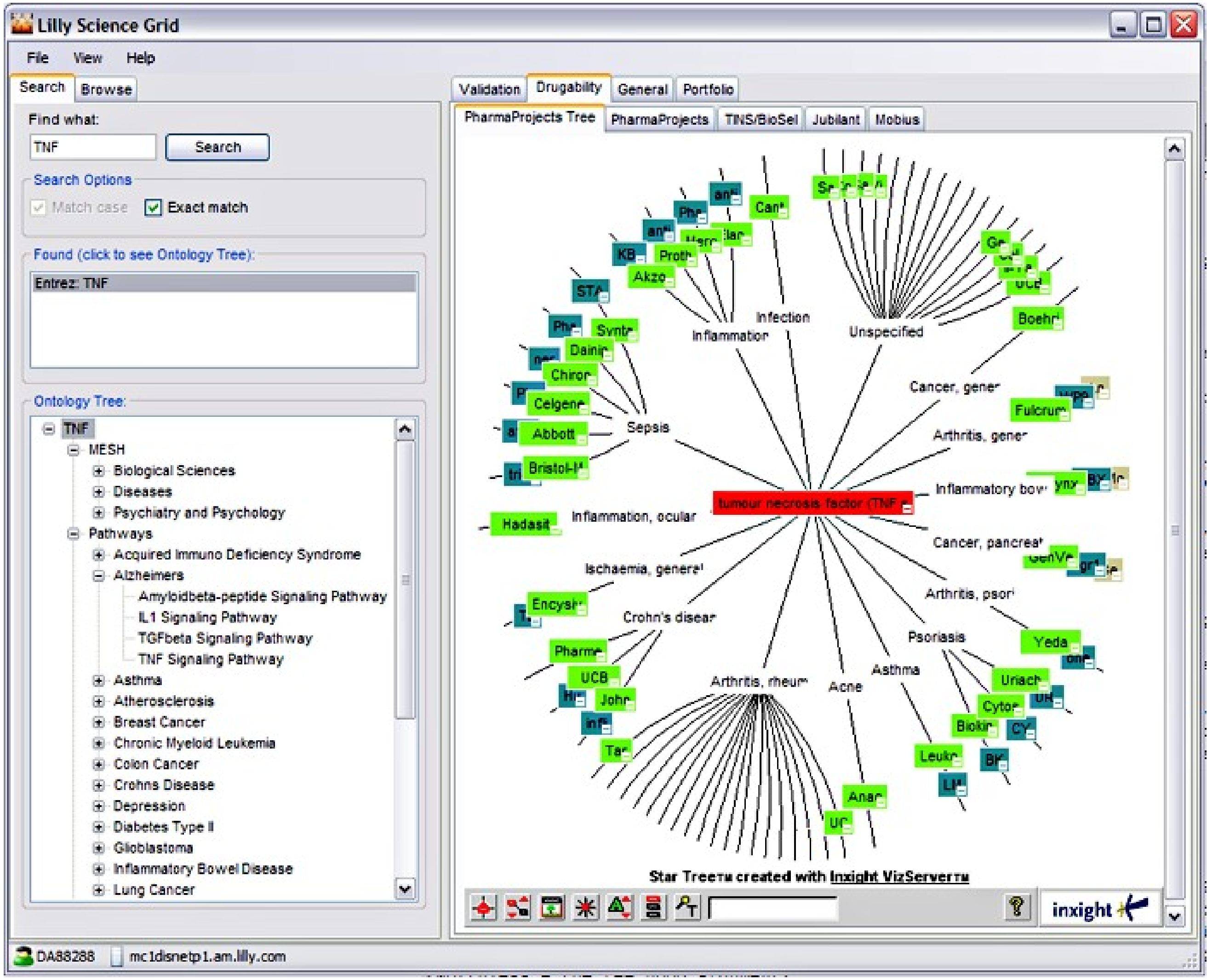
- Used by program production to find the right music in the archive for a specific show



Courtesy of Robert Engels, ESIS, and Jon Roar Tønnesen, NRK (SWEO Case Study)

> Eli Lilly’s Target Assessment Tool

- Better prioritization of possible drug target, integrating data from different sources and formats
- Integration, search, etc, via ontologies (proprietary and public)



Courtesy of Susie Stephens, Eli Lilly (SWEO Case Study)

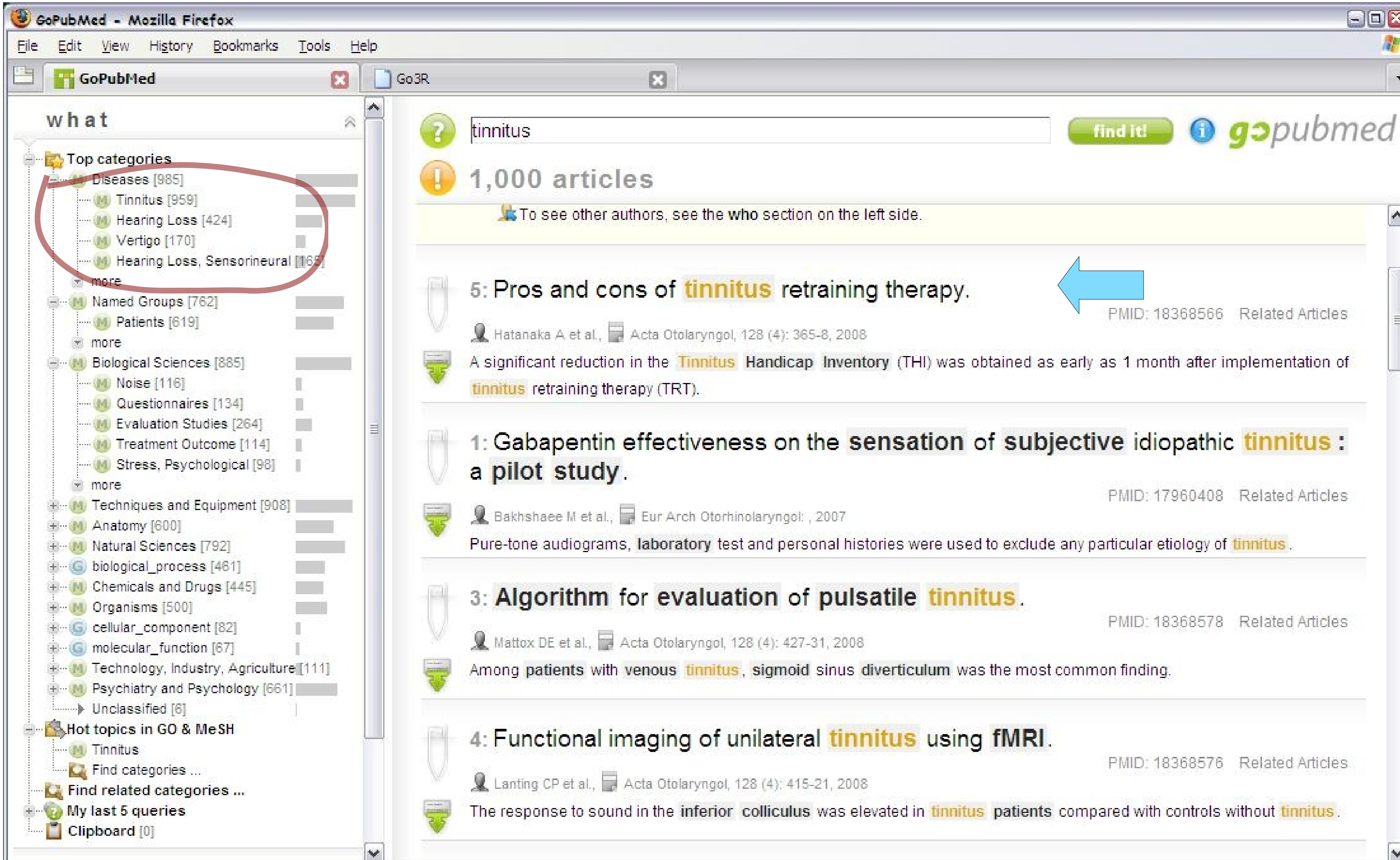
> Vodafone live!

- Integrate various vendors' product descriptions via RDF
  - ring tones, games, wallpapers
  - manage complexity of handsets, binary formats
- A portal is created to offer appropriate content
- Significant increase in content download after the introduction

Courtesy of Kevin Smith, Vodafone Group R&D (SWEO Case Study)

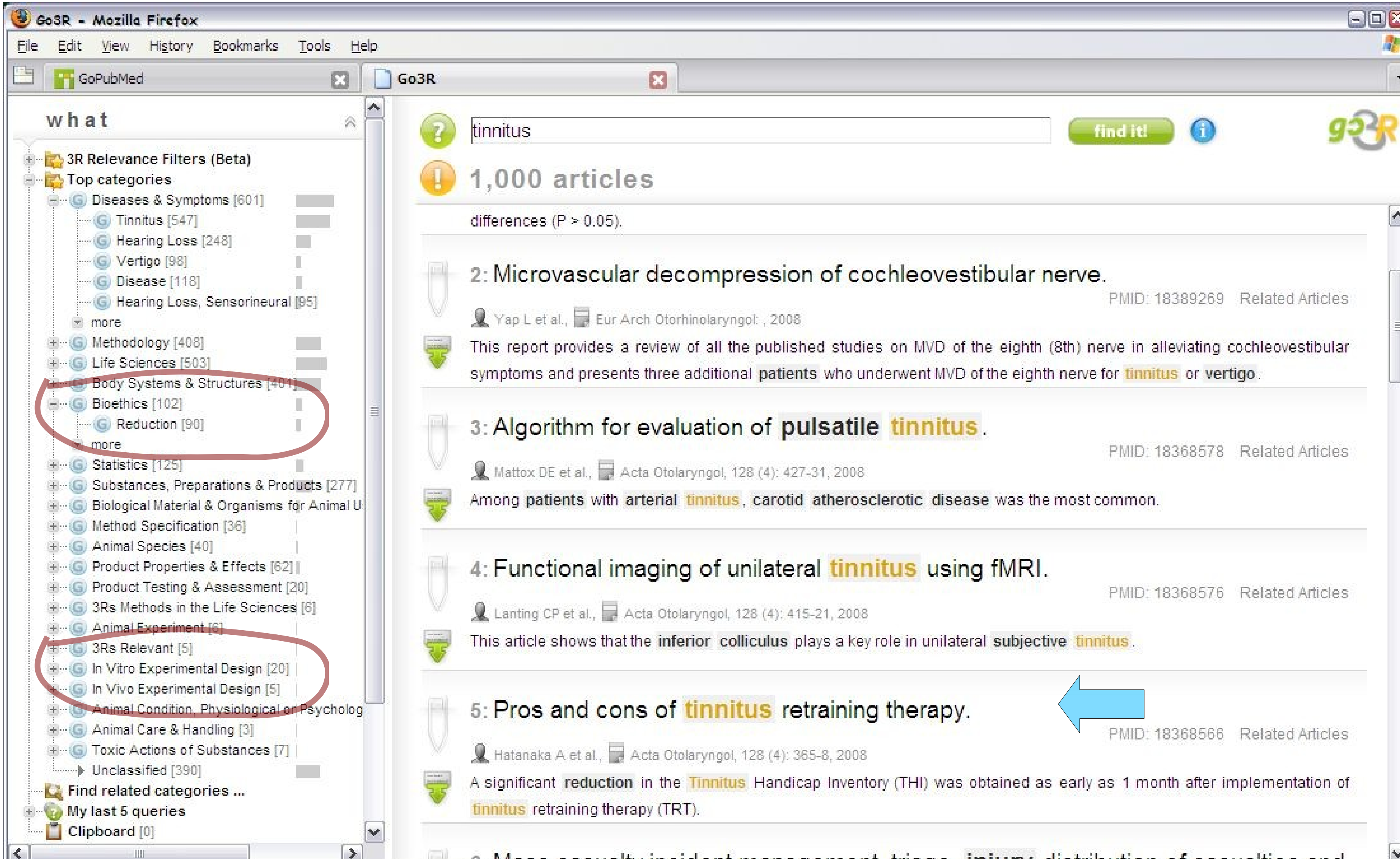
> Improved Search via Ontology (GoPubMed)

- Search results are re-ranked using ontologies
- Related terms are highlighted, usable for further search



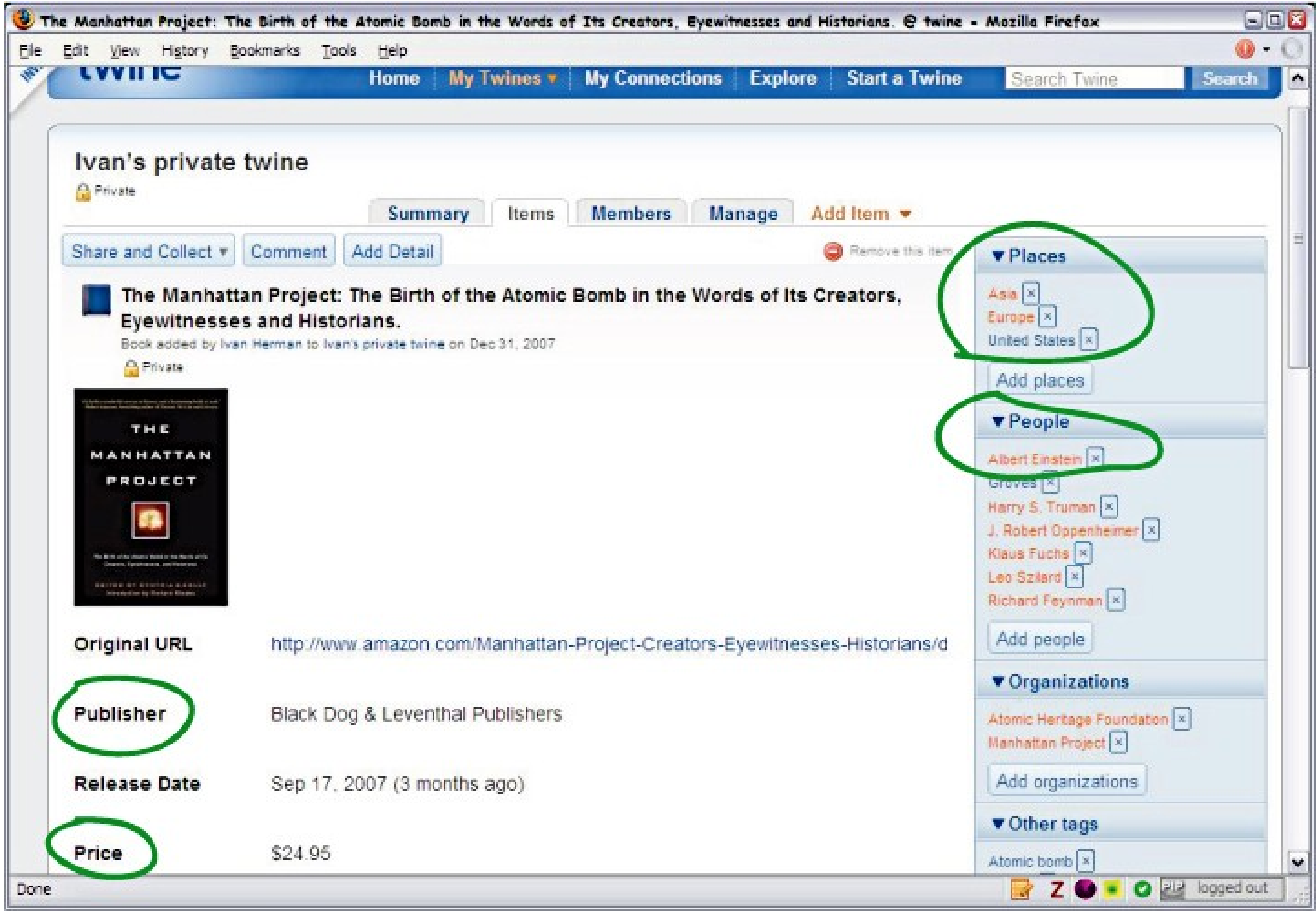
> Improved Search via Ontology (Go3R)

- Same dataset, different ontology
  - (ontology is on non-animal experimentation)



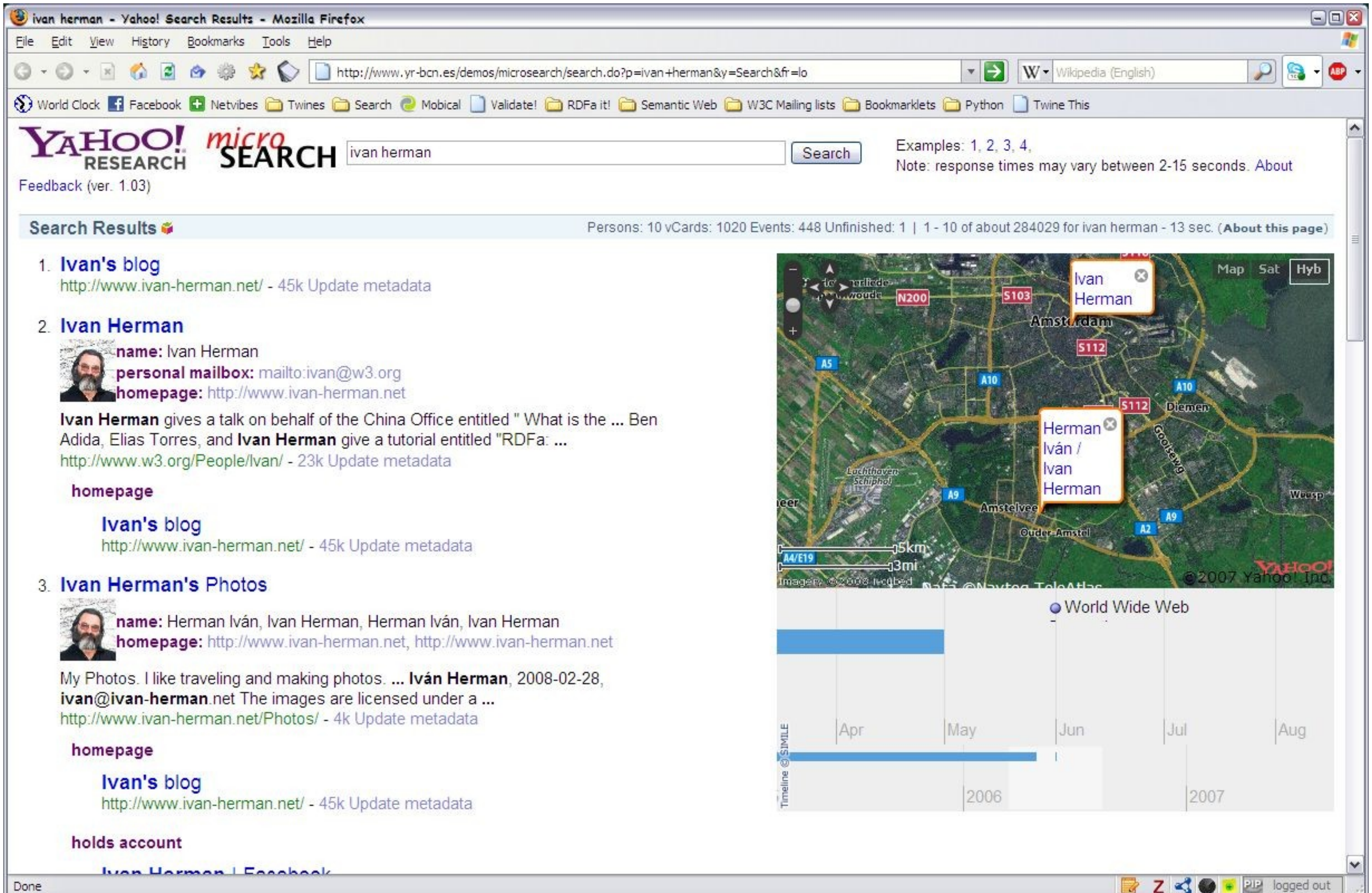
> Radar Network's Twine

- "Social bookmarking on steroids"
- Item relationships are based on ontologies
  - evolving over time
  - possibly enriched by users
- Internals in RDF, will be available via APIs and SPARQL



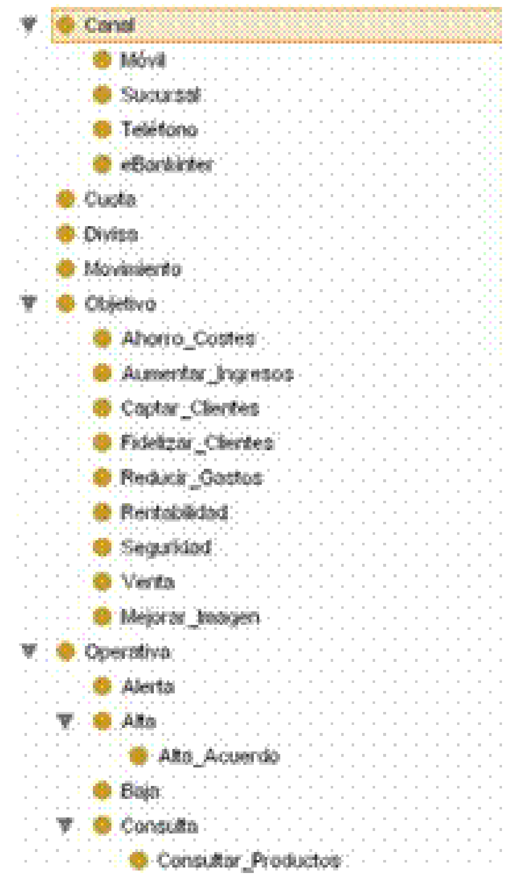
> Yahoo's microsearch

- Make use of RDF, RDFa, microformats, etc, in pages
  - E.g., geo location, or various spellings of a name are discovered:



> Suggestions’ database…

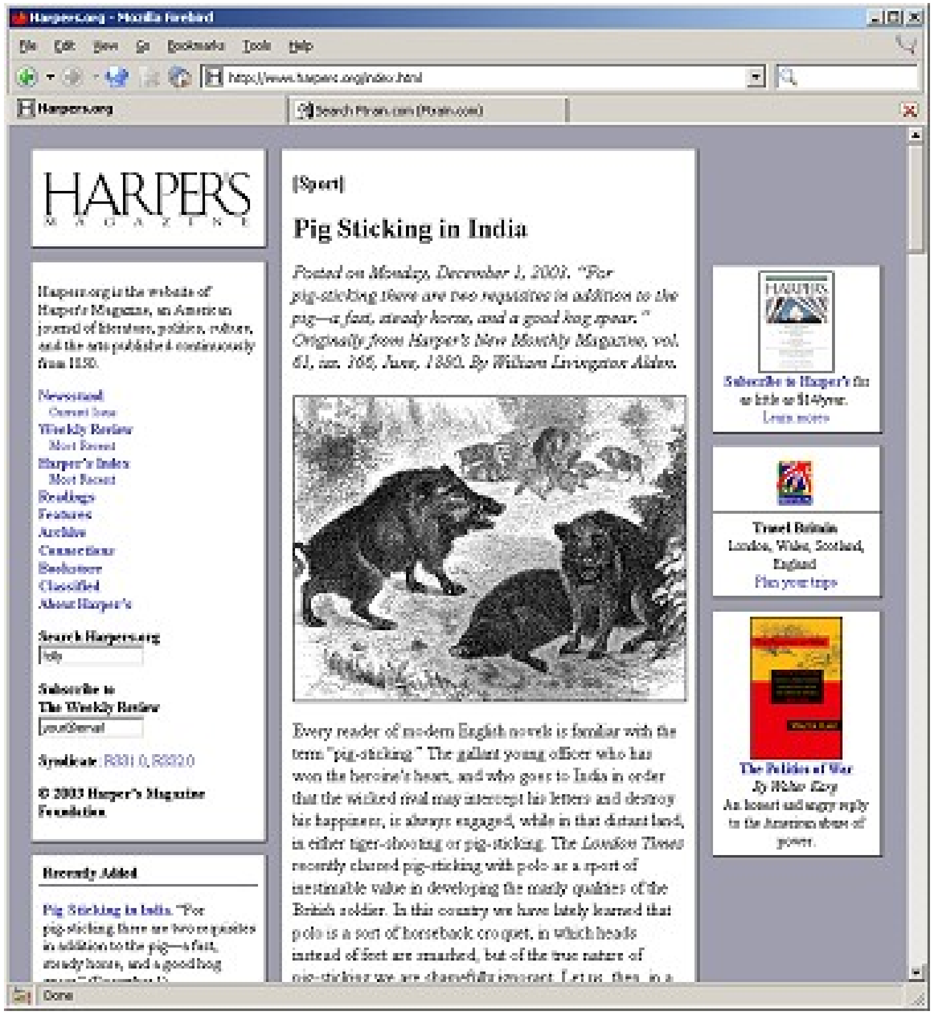
- Employees of the bank can submit new ideas for innovation, improving the business process, reduce costs, etc
- The entry system analyses the entry, shows similar ideas already in the system based on the *concepts* (not words)
- User gets immediate feedback, system gets better search, analysis, etc



Courtesy of José Luís Bas Uribe, Bankinter, and Richard Benjamins, iSOCO, (SWEO Case Study)

> Other examples…

- Sun's White Paper and System Handbook collections
- Nokia's S60 support portal
- Harper's Online Magazine
- Oracle's virtual pressroom
- Opera's community site
- Dow Jones' Synaptica



> Thank you for your attention!

- These slides are publicly available on:

`http://www.w3.org/2008/Talks/0421-Beijing-IH/`