

# THE ROLE OF SEMANTICS IN DATA MANAGEMENT

AN INTRODUCTION TO SEMANTIC WEB, ONTOLOGIES & LINKED DATA

# Outline

- From the Web to the Semantic Web (a.k.a. the Web of Data)
  - An a-priori semantics for data
- Ontologies
- Semantic Web approach
- Semantic Web technology
- Linked (Open) Data

# Let's start from the Web (1.0)

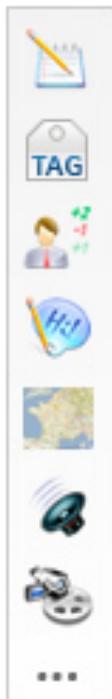
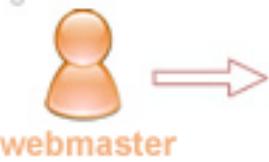
- The Web is a system of interlinked documents, accessed via Internet
- You can view Web pages and use hyperlinks to navigate between them
- People can easily access any of these documents
- This is the largest source of information ever
- *This is Web 1.0 or the Read-only Web*

# Then, we moved to Web 2.0

- Authors started to use Ajax
- People started to share multimedia content (photos and videos)
- People started to interact on social networks
- People started to publish content in blogs
- People started to contribute to wikis
- People started to use tags and RSS
- *This is Web 2.0 or the Read-Write Web*

## Web 1.0

blog.aysoon.com



Internet Surfers  
Contributors

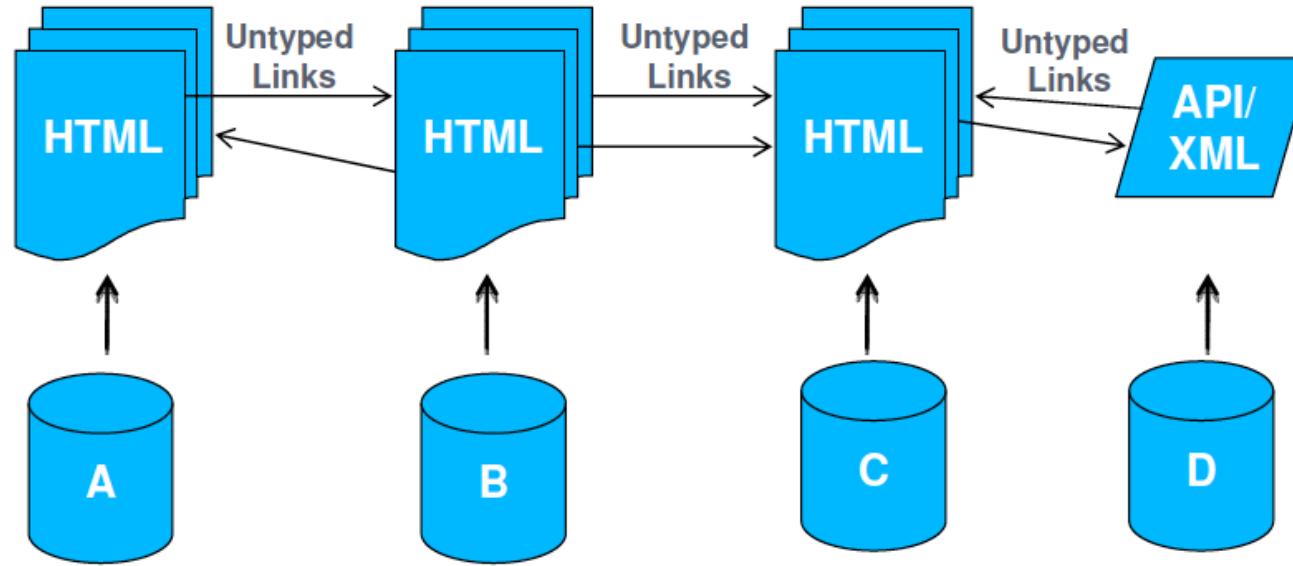


Online  
Social Network

Web 2.0

# Web 1.0 and Web 2.0

# Web of Documents



Primary objects: **documents**

Links between **documents** (or parts of them)

Degree of structure in data: fairly **low**

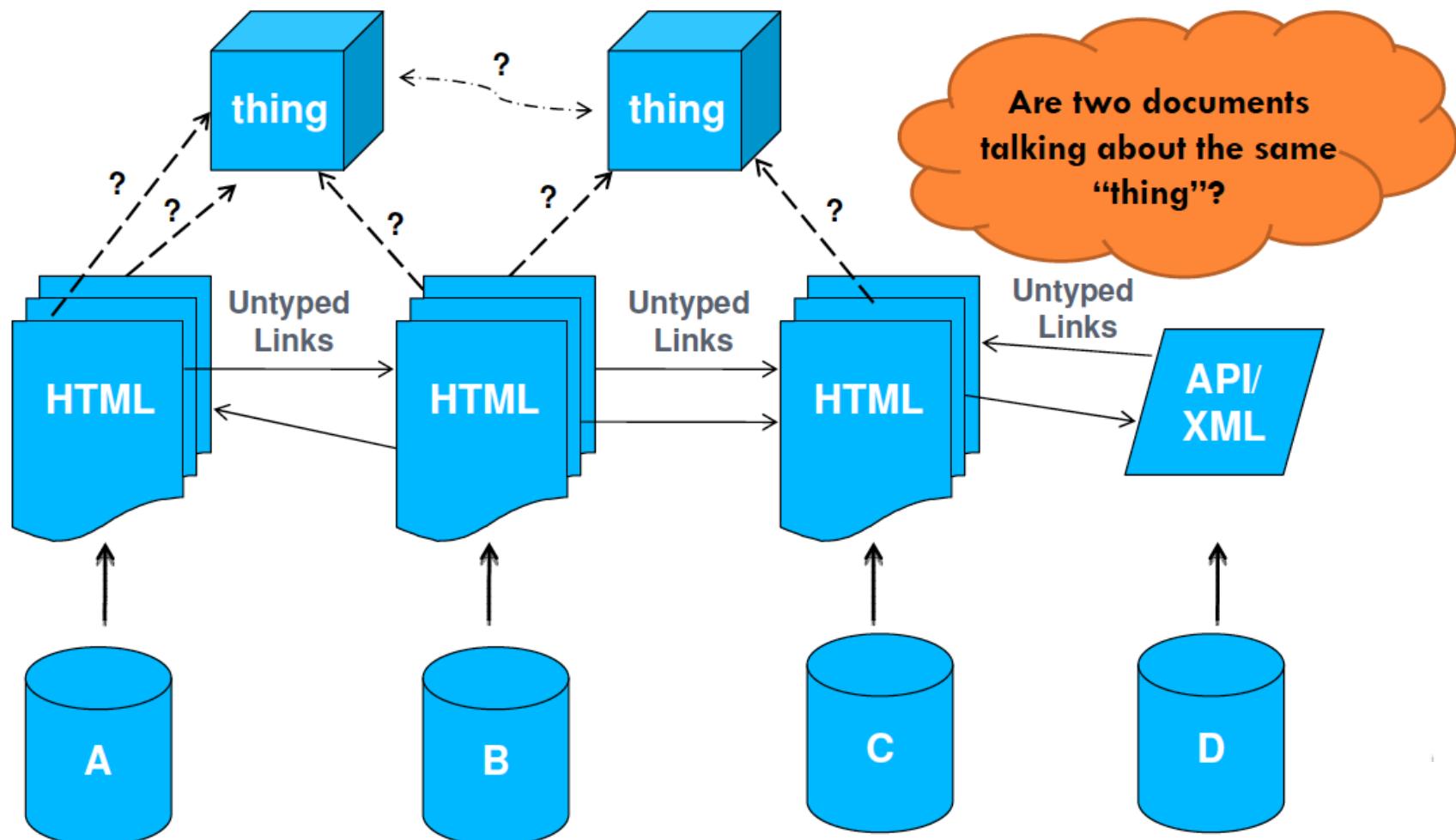
**Implicit** semantics of contents

Designed for: **human consumption**

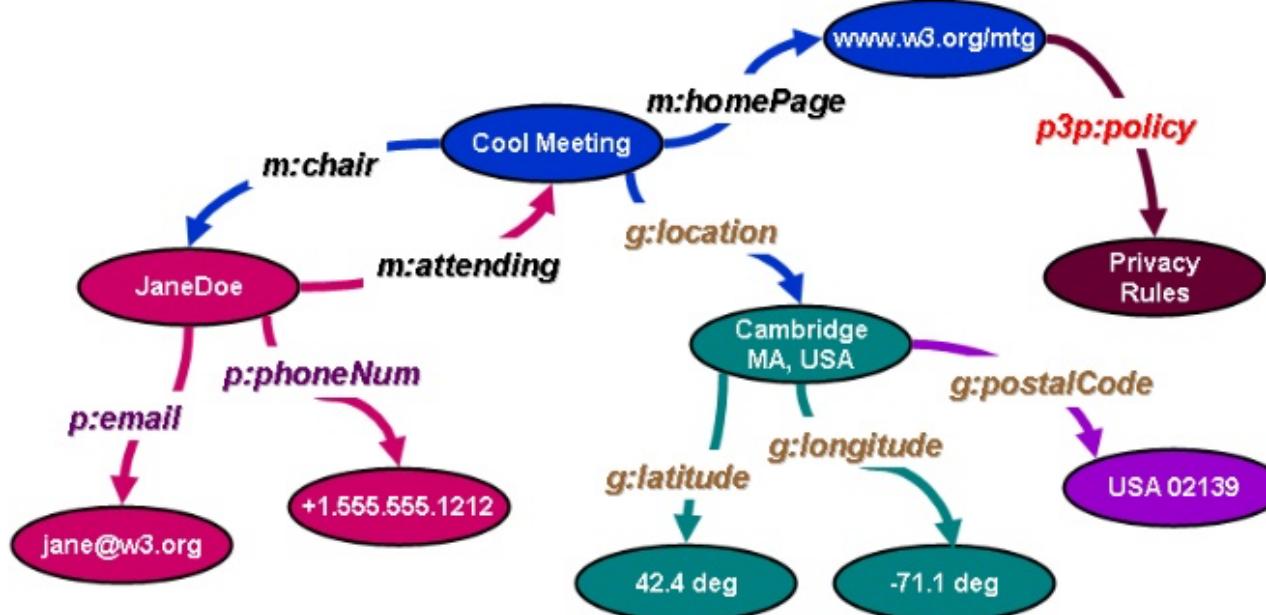
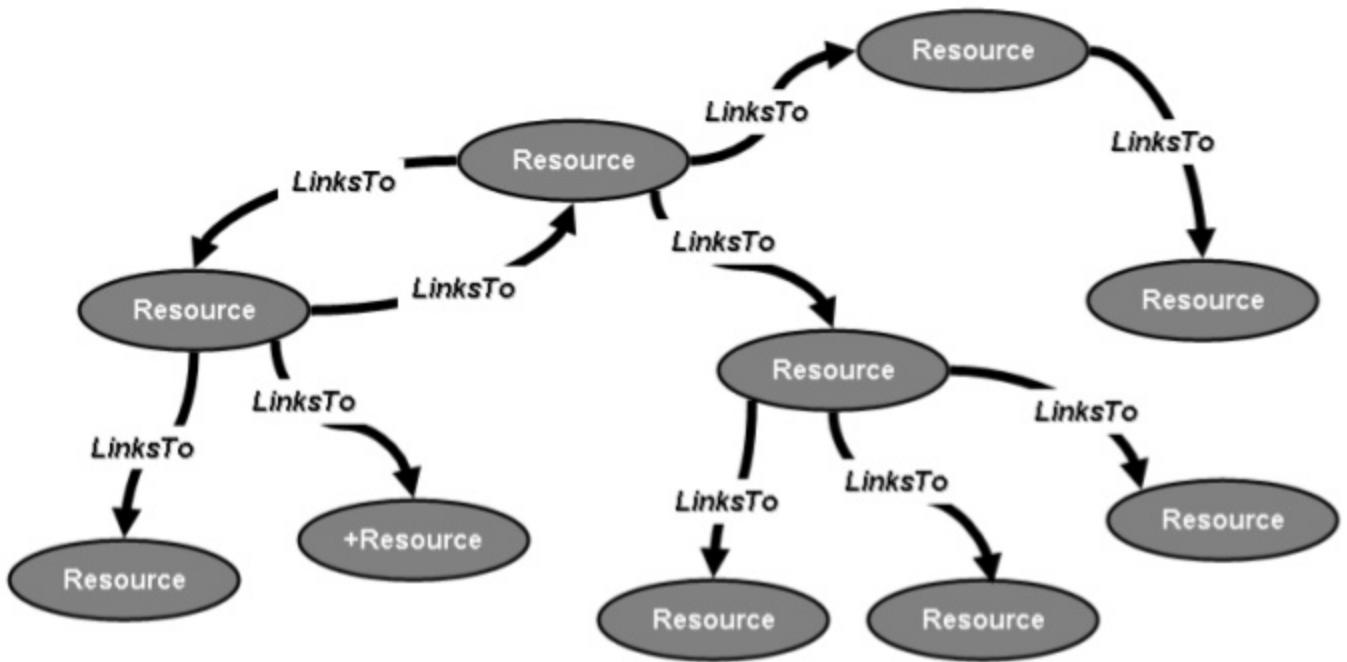
# The problem

- Web pages are written in HTML
- HTML describes the *structure* of information
- HTML describes the *syntax* not the *semantics*
- if computers can understand the meaning behind information
  - they can learn what we are interested in
  - they can help us in better finding what we want
- we need to describe the *semantics* and find precise answers to complex questions
- this is what the *Semantic Web* is about
- this is Web 3.0:

# The problem



# the Web is about documents



## the Semantic Web is about things:

- it can recognize entities
- it can understand the relationship between things

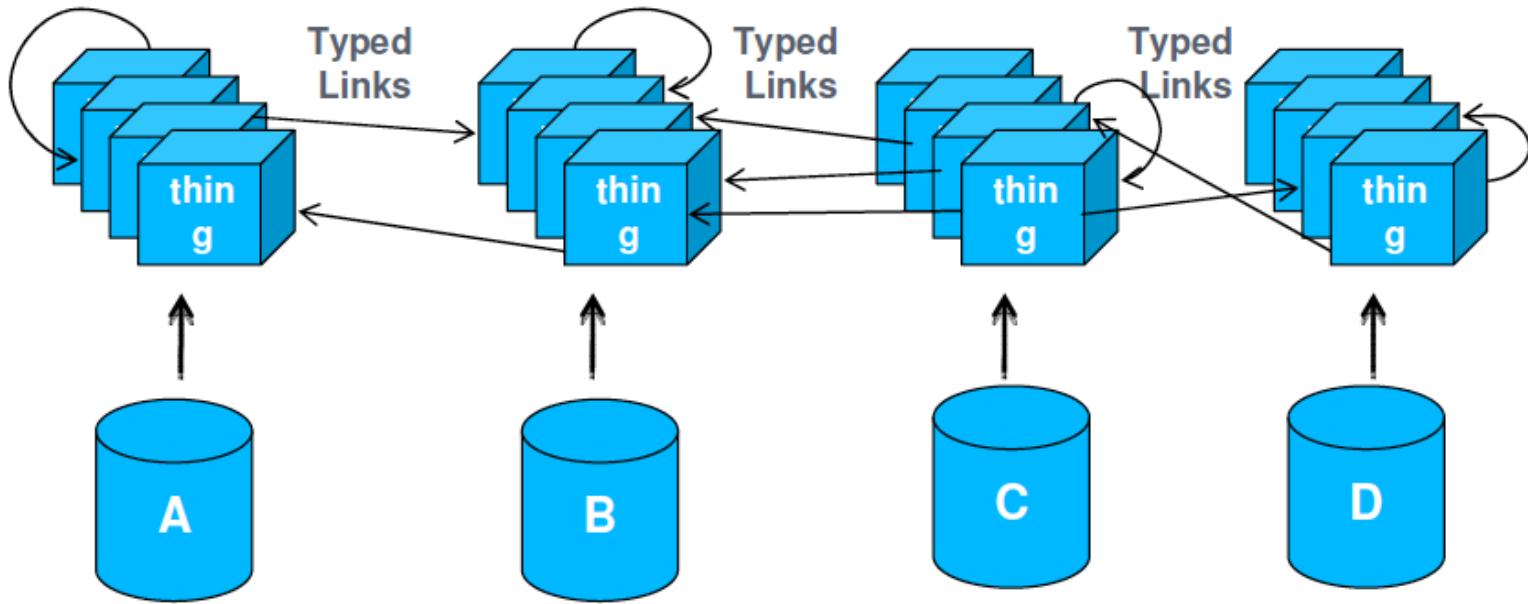
# How

- Ex-post approach
  - information analysis
  - web scraping
  - natural language processing → see NLP course
- Expensive!
  - human intervention
  - hard to maintain

# How

- A priori approach
  - embedding semantic annotations into data
  - we need a *data model* for describing «things» (resources) and their interrelations
  - we need some languages to
    - *specify things and their interrelations* and
    - *perform reasoning* about them

# Semantic Web a.k.a. Web of Data



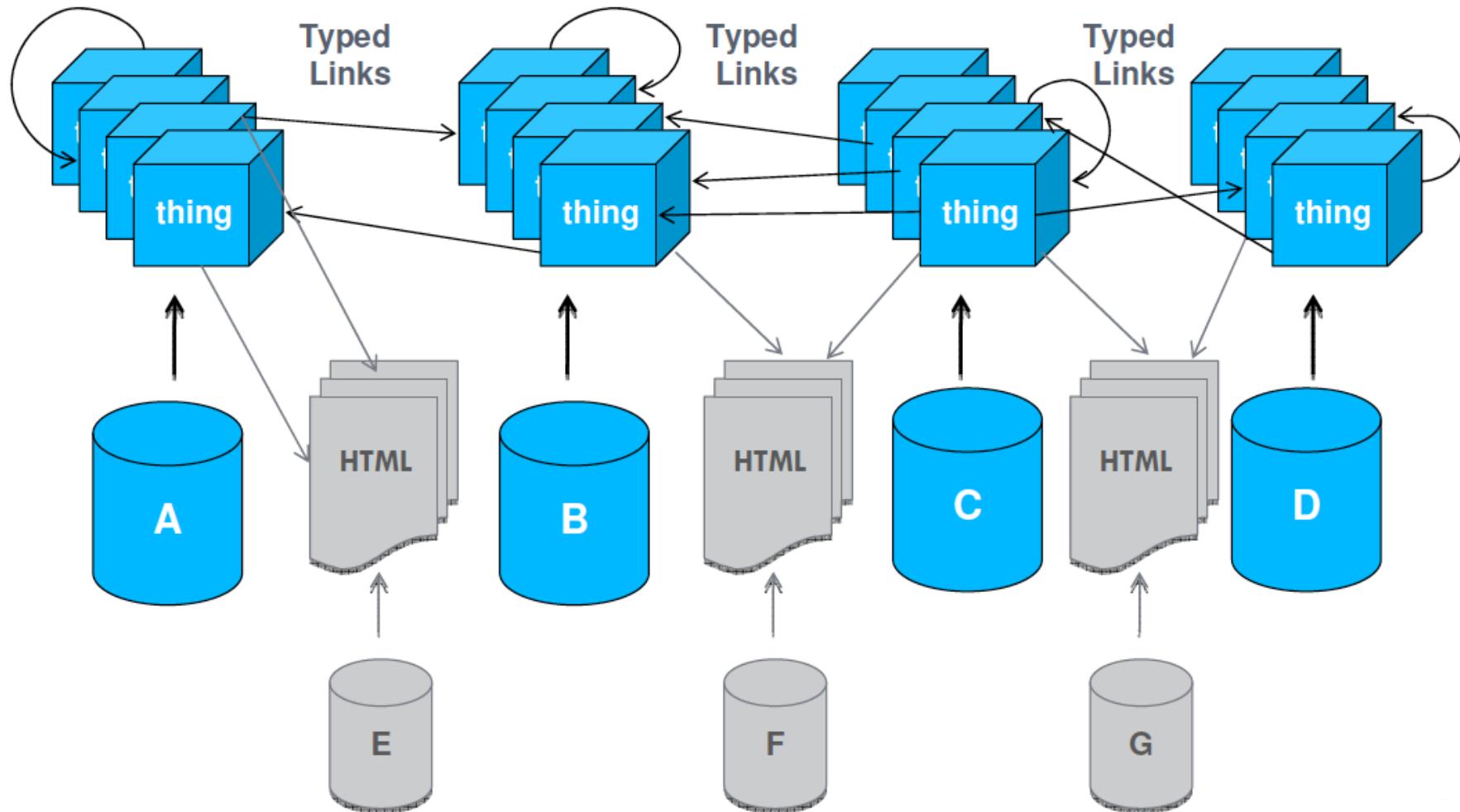
Primary objects: “**things**” (or description of things)  
Links between “**things**”

Degree of Structure: **High**

**Explicit** semantics of contents **and** links

Designed for: Both **machines and humans**

# Semantic Web a.k.a. Web of Data



# An example

*Find me genes involved in signal transduction that  
are related to pyramidal neurons.*

# A general search

**223,000 hits, 0 results**

**Google** pyramidal neurons signal transduction [Search](#) [Advanced Search Preferences](#) [Now! View and manage your Google accounts](#)

[Web](#) [Books](#) Results 1 - 10 of about 223,000 for [pyramidal neurons signal transduction](#) (0).

**Book results for pyramidal neurons signal transduction**

 [Cerebral Signal Transduction](#) - by Maarten Eduard Anton Reith - 440 pages  
[Neuroprotective Signal Transduction](#) - by Mark Paul. Mattson - 347 pages  
[Toxins And Signal Transduction](#) - by Yehuda Gutman, Philip Lazarovici - 520 pages

**Neurotrophin-3 and brain-derived neurotrophic factor activate ...**  
... and brain-derived neurotrophic factor activate multiple signal transduction events but are not survival factors for hippocampal pyramidal neurons. ...  
[www.ihop-net.org/UniPub/iHOP/pm/646092.html?pmid=8752100](http://www.ihop-net.org/UniPub/iHOP/pm/646092.html?pmid=8752100) - 12k -  
[Cached](#) - [Similar pages](#) - [Note this](#)

**K<sup>+</sup> channel regulation of signal propagation in dendrites of ...**  
Pyramidal neurons receive tens of thousands of synaptic inputs on their dendrites. ...  
**Signal Transduction\*** Substances Potassium Channel Blockers ...  
[www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&list\\_uids=9202119&dopt=Abstract](http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&list_uids=9202119&dopt=Abstract) - [Similar pages](#) - [Note this](#)

**Dopamine modulates inwardly rectifying potassium currents in ...**  
Using outside-out patches of mPFC pyramidal neurons, which preclude involvement of ...  
**Signal Transduction/drug effects** **Signal Transduction/physiology** ...  
[www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&list\\_uids=15044547&dopt=Abstract](http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&list_uids=15044547&dopt=Abstract) - [Similar pages](#) - [Note this](#)  
[ More results from [www.ncbi.nlm.nih.gov](http://www.ncbi.nlm.nih.gov) ]

**Loss of Hippocampal CA3 Pyramidal Neurons in Mice Lacking STAM1 ...**  
Loss of Hippocampal CA3 Pyramidal Neurons in Mice Lacking STAM1 ... and to be involved in the regulation of intracellular signal transduction mediated by ...  
May 12, 2009 [mcb.asm.org/cgi/content/abstract/21/11/3807](http://mcb.asm.org/cgi/content/abstract/21/11/3807) - [Similar pages](#) - [Note this](#)

# Domain-limited search

**2,580 potential results**

A service of the National Library of Medicine  
and the National Institutes of Health

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PubMed Nucleotide Protein Genome Structure OMIM PMC Journals Books

for signal transduction pyramidal neurons Go Clear Save Search

Limits Preview/Index History Clipboard Details

Display Summary Show 20 Sort By Send to

All: 2580 Review: 160 

Items 1 - 20 of 2580 Page 1 of 129 Next

1: [Naimark A, Barkai E, Matar MA, Kaplan Z, Kozlovska N, Cohen H,](#) Related Articles, Links  
Upregulation of neurotrophic factors selectively in frontal cortex in response to olfactory discrimination learning.  
Neural Plast. 2007;:13427.  
PMID: 17710248 [PubMed - in process]

2: [Nistico R, Piccirilli S, Sebastianelli L, Nistico G, Bernardi G, Mercuri NB,](#) Related Articles, Links  
The blockade of K(+)-ATP channels has neuroprotective effects in an in vitro model of brain ischemia.  
Int Rev Neurobiol. 2007;82:383-95.  
PMID: 17678973 [PubMed - indexed for MEDLINE]

3: [Schmidt-Hieber C, Jonas P, Bischofberger J,](#) Related Articles, Links  
Subthreshold dendritic signal processing and coincidence detection in dentate gyrus granule cells.  
J Neurosci. 2007 Aug 1;27(31):8430-41.  
PMID: 17670990 [PubMed - indexed for MEDLINE]

4: [Alvarez VA, Ridenour DA, Sahatci BL,](#) Related Articles, Links  
Distinct structural and ionotropic roles of NMDA receptors in controlling spine and synapse stability.  
J Neurosci. 2007 Jul 11;27(28):7365-76.  
PMID: 17626197 [PubMed - indexed for MEDLINE]

5: [Smith SS, Gong QH,](#) Related Articles, Links

# Specific databases

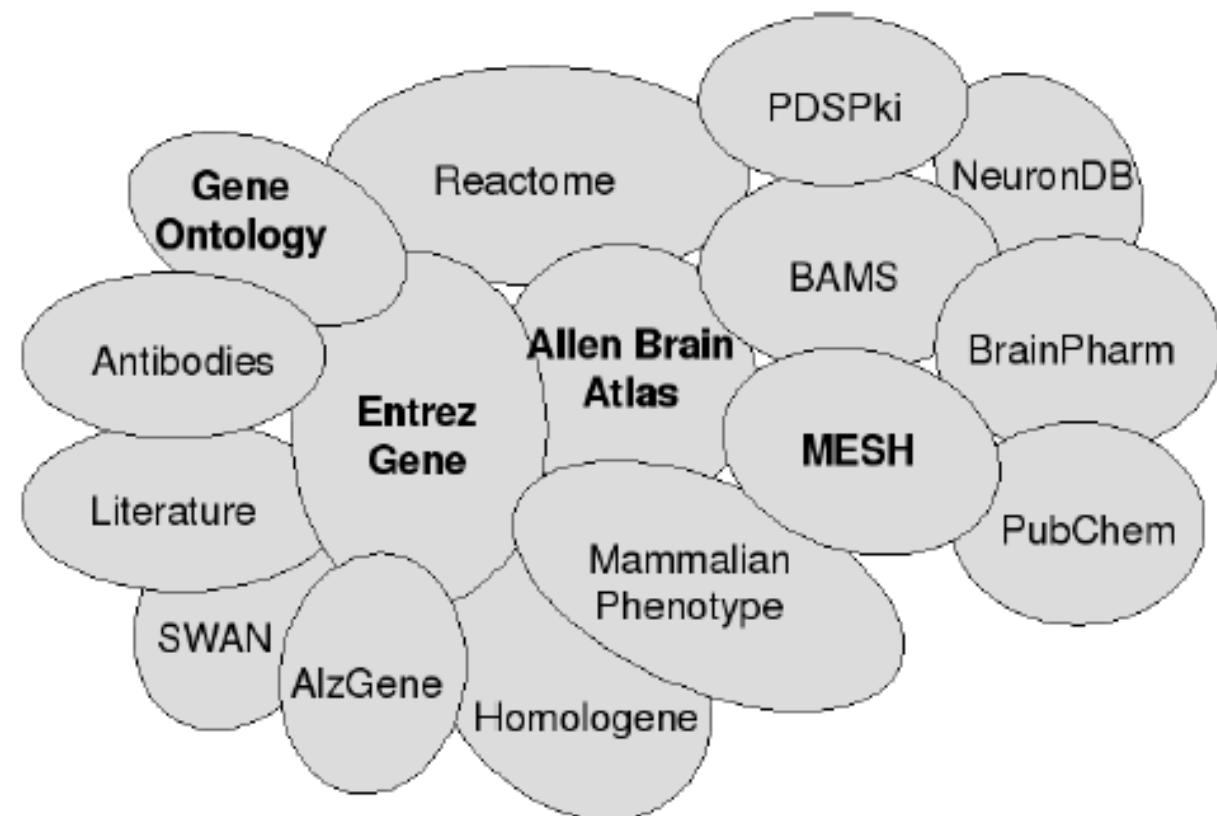
*Too many silos!*

2580	 PubMed: biomedical literature citations and abstracts	
959	 PubMed Central: free, full text journal articles	
none	 Site Search: NCBI web and FTP sites	
2	 Books: online books	
4	 OMIM: online Mendelian Inheritance in Man	
none	 OMIA: online Mendelian Inheritance in Animals	
10	 CoreNucleotide: Core subset of nucleotide sequence records	
none	 EST: Expressed Sequence Tag records	
34	 GSS: Genome Survey Sequence records	
16	 Protein: sequence database	
5	 Genome: whole genome sequences	
none	 Structure: three-dimensional macromolecular structures	
none	 Taxonomy: organisms in GenBank	
none	 SNP: single nucleotide polymorphism	
35	 Gene: gene-centered information	
10	 HomoloGene: eukaryotic homology groups	
none	 PubChem Compound: unique small molecule chemical structures	
none	 PubChem Substance: deposited chemical substance records	
none	 Genome Project: genome project information	
2	 dbGaP: genotype and phenotype	
none	 UniGene: gene-oriented clusters of transcript sequences	
none	 CDD: conserved protein domain database	
none	 3D Domains: domains from Entrez Structure	
none	 UniSTS: markers and mapping data	
none	 PopSet: population study data sets	
none	 GEO Profiles: expression and molecular abundance profiles	
none	 GEO DataSets: experimental sets of GEO data	
none	 Cancer Chromosomes: cytogenetic databases	
none	 PubChem BioAssay: bioactivity screens of chemical substances	
none	 GENSAT: gene expression atlas of mouse central nervous system	
none	 Probes: sequence-specific reagents	
1394	 Protein Clusters: a collection of related protein sequences	

# A Semantic Web approach

Integrate disparate databases...

- MeSH
- PubMed
- Entrez Gene
- Gene Ontology
- ...



# A Semantic Web Approach

...so that *one* query...

```
prefix go: <http://purl.org/obo/owl/GO#>
prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#>
prefix owl: <http://www.w3.org/2002/07/owl#>
prefix mesh: <http://purl.org/commons/resource/mesh/>
prefix sc: <http://purl.org/science/owl/sciencecommons/>
prefix ro: <http://www.owlfoundry.org/ro/ro.owl#>
prefix senselab: <http://purl.org/ycmi/senselab/neuron_ontology.owl#>

SELECT ?genename ?processname ?receptor_protein_name
WHERE {
  # PubMeSH includes ?gene_records mentioned in ?articles which are identified by pmid in ?pubmed_records.
  GRAPH <http://purl.org/commons/hds/pubmesh> {
    ?pubmed_record sc:has-as-minor-mesh mesh:D017966 .
    ?article sc:identified_by_pmid ?pubmed_record .
    ?gene_record sc:describes_gene_or_gene_product_mentioned_by ?article
  }
  # The Gene Ontology asserts that foreach ?protein, ?protein ro:has_function | ro:realized_as ?process .
  GRAPH <http://purl.org/commons/hds/goa> {
    ?protein rdfs:subClassOf ?restriction1 .
    ?restriction1 owl:onProperty ro:has_function .
    ?restriction1 owl:someValuesFrom ?restriction2 .
    ?restriction2 owl:onProperty ro:realized_as .
    ?restriction2 owl:someValuesFrom ?process .
  }
  # Also, foreach ?protein, ?protein has a parent class which is linked by some predicate to ?gene_record.
  ?protein rdfs:subClassOf ?protein_superclass .
  ?protein_superclass owl:equivalentClass ?restriction3 .
  ?restriction3 owl:onProperty sc:is_protein_gene_product_of_dna_described_by .
  ?restriction3 owl:hasValue ?gene_record .
  # Each ?process (that we are interested in) is a subclass of the signal transduction process
  GRAPH <http://purl.org/commons/hds/20070416/classrelations> {
    { ?process obo:part_of go:GO_0007166 }
    UNION
    { ?process rdfs:subClassOf go:GO_0007166 }
  }
  GRAPH <http://purl.org/commons/hds/gene> {
    ?gene_record rdfs:label ?genename
  }
  GRAPH <http://purl.org/commons/hds/20070416> {
    ?process rdfs:label ?processname
  }
}
```

Mesh: Pyramidal Neurons

Pubmed: Journal Articles

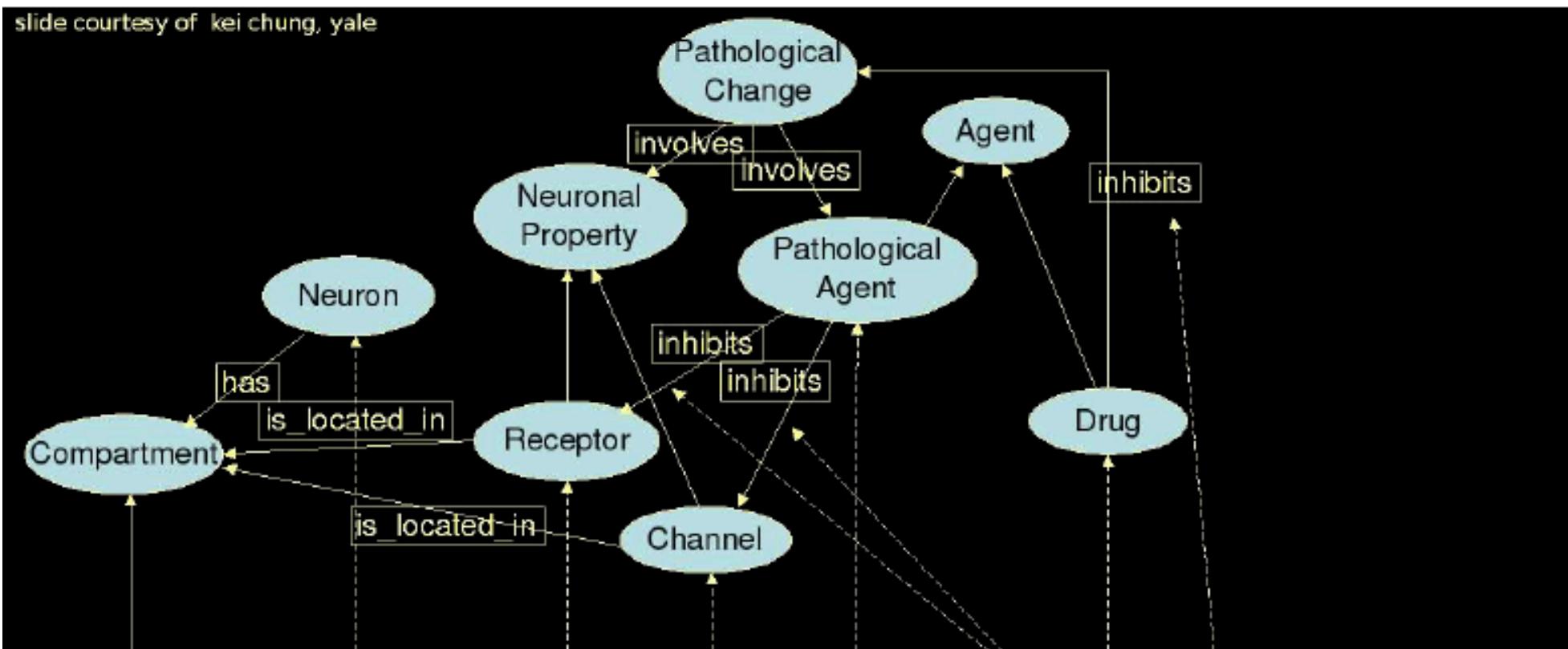
Entrez Gene: Genes

GO: Signal Transduction

# A Semantic Web Approach

...(trivially) spans several databases...

slide courtesy of kei chung, yale



Compartment	Cell: NeuronDB	Receptor	Channel	Pathological Agent (PA)	PA Action	Drug	Drug Action	Stage	Note	Detail
Soma	CA1 pyramidal neuron		IA	beta Amyloid	Inhibits			Early	<a href="#">View</a>	66240
	Olfactory bulb mitral cell	GabAA						Early	<a href="#">View</a>	66750
Dendrite	CA1 pyramidal neuron		IA	beta Amyloid	Inhibits			Early	<a href="#">View</a>	66240
	Olfactory bulb mitral cell	GabAA						Early	<a href="#">View</a>	66750
Unspecified	Oocyte		IL, high threshold	beta Amyloid	Inhibits			Early	<a href="#">View</a>	66252
May 12, 2009	CA1 pyramidal neuron			beta Amyloid	Inhibits			Early	<a href="#">View</a>	66753
	CA1 pyramidal neuron	NMDA	Ca	beta Amyloid	Inhibits		Inhibits	Early	<a href="#">View</a>	66758

# A Semantic Web Approach

## ...to deliver targeted results...

DRD1, 1812	adenylate cyclase activation
ADRB2, 154	adenylate cyclase activation
ADRB2, 154	arrestin mediated desensitization of G-protein coupled receptor protein signaling pathway
DRD1IP, 50632	dopamine receptor signaling pathway
DRD1, 1812	dopamine receptor, adenylate cyclase activating pathway
DRD2, 1813	dopamine receptor, adenylate cyclase inhibiting pathway
GRM7, 2917	G-protein coupled receptor protein signaling pathway
GNG3, 2785	G-protein coupled receptor protein signaling pathway
GNG12, 55970	G-protein coupled receptor protein signaling pathway
DRD2, 1813	G-protein coupled receptor protein signaling pathway
ADRB2, 154	G-protein coupled receptor protein signaling pathway
CALM3, 808	G-protein coupled receptor protein signaling pathway
HTR2A, 3356	G-protein coupled receptor protein signaling pathway
DRD1, 1812	G-protein signaling, coupled to cyclic nucleotide second messenger
SSTR5, 6755	G-protein signaling, coupled to cyclic nucleotide second messenger
MTNR1A, 4543	G-protein signaling, coupled to cyclic nucleotide second messenger
CNR2, 1269	G-protein signaling, coupled to cyclic nucleotide second messenger
HTR6, 3362	G-protein signaling, coupled to cyclic nucleotide second messenger
SRIK2, 2898	glutamate signaling pathway
GRIN1, 2902	glutamate signaling pathway
GRIN2A, 2903	glutamate signaling pathway
GRIN2B, 2904	glutamate signaling pathway
ADAM10, 102	integrin-mediated signaling pathway
GRM7, 2917	negative regulation of adenylate cyclase activity
LRP1, 4035	negative regulation of Wnt receptor signaling pathway
ADAM10, 102	Notch receptor processing
ASCL1, 429	Notch signaling pathway
HTR2A, 3356	serotonin receptor signaling pathway
ADRB2, 154	transmembrane receptor protein tyrosine kinase activation (dimerization)
PTPRG, 5793	transmembrane receptor protein tyrosine kinase signaling pathway
EPHA4, 2043	transmembrane receptor protein tyrosine kinase signaling pathway
NRTN, 4902	transmembrane receptor protein tyrosine kinase signaling pathway

# What's the trick?

- Agreement on common terms and relationships
- Incremental, flexible data structure
- Good-enough modeling
- Query interface tailored to the data model
- key concept: **ontology for the Web**

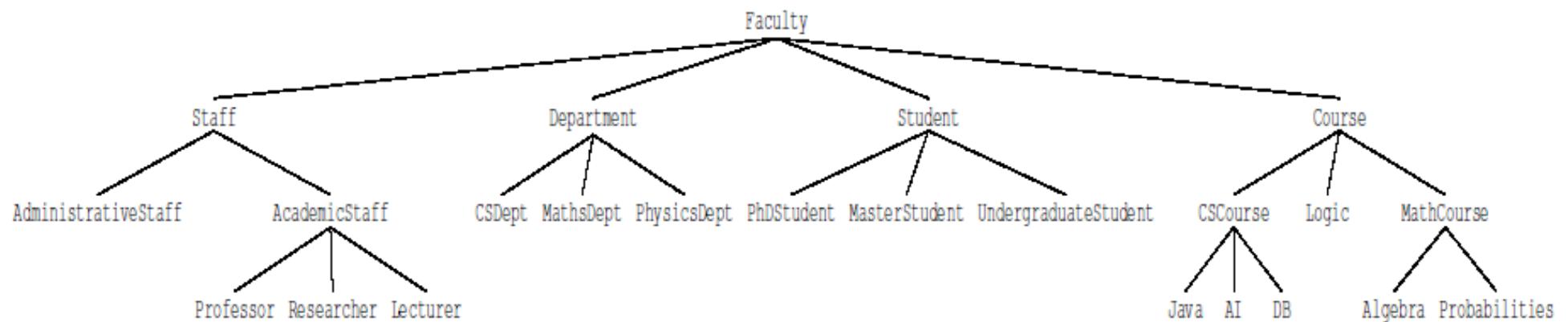
# Ontologies

# Ontologies

- Formal descriptions providing **human** users a shared understanding of a given domain
  - ▶ A controlled vocabulary
- Formally defined so that it can also be processed by **machines**
- **Logical semantics** that enables **reasoning**.
- Reasoning is the key for different important tasks of Web data management, in particular
  - ▶ to answer queries (over possibly distributed data)
  - ▶ to relate objects in different data sources enabling their integration
  - ▶ to detect inconsistencies or redundancies
  - ▶ to refine queries with too many answers, or to relax queries with no answer

# Classes and Class Hierarchies

- Backbone of the ontology
- AcademicStaff is a **Class**
- (A class will be interpreted as a **set** of objects)
- AcademicStaff **isa** Staff
- (isa is interpreted as set inclusion)



# Relations

- Declaration of **relations** with their **signature**
- (Relations will be interpreted as binary relations between objects)
- TeachesIn(AcademicStaff, Course)
  - ▶ if one states that “ $X$  TeachesIn  $Y$ ”, then  $X$  belongs to AcademicStaff and  $Y$  to Course,
- TeachesTo(AcademicStaff, Student),
- Leads(Staff, Department)

# Instances

- Classes have **instances**
- Dupond is an instance of the class Professor
- it corresponds to the fact: Professor(Dupond)
  
- Relations also have **instances**
- (Dupond,CS101) is an instance of the relation TeachesIn
- it corresponds to the fact: TeachesIn(Dupond,CS101)
  
- The instance statements can be seen as (and stored in) a **database**

# Ontology = schema + instance

- Schema

- ▶ The set of class and relation names
- ▶ The **signatures** of relations and also **constraints**
- ▶ The constraints that are used for two purposes
  - ★ checking data consistency (like dependencies in databases)
  - ★ inferring new facts

- Instance

- ▶ The set of facts
- ▶ The set of base facts together with the inferred facts should satisfy the constraints

- Ontology (i.e., Knowledge Base) = Schema + Instance

# Reasoning

- The use of logic as ontology semantics enables reasoning
- For instance, from the following facts:

- Leads(Dupond, CS Department)
- Leads(Staff, Department)

it follows that

- Staff(Dupond)
- Department(CS Department)

# The Semantic Web

- Augments the World Wide Web through the usage of specific **ontologies**
- Represents the Web's information in a machine-readable fashion
- Enables...
  - ... targeted search
  - ... data browsing
  - ... automated agents

# Semantic Web technologies

- A family of technology standards that ‘play nice together’, including:
  - Flexible data model
  - Distributed query language
  - Expressive ontology language

*The technologies enable us to build applications and solutions that were not possible, practical, or feasible traditionally.*

# The Semantic Web approach

*How does a Semantic Web approach help us merge data sets, infer new relations, and integrate outside data sources?*

*Thanks to Ivan Herman for this example*

# The Semantic Web approach

- Map the various data onto an abstract data representation (**instances and schema of some ontology**)
- Make the data independent of its internal representation
- Merge the resulting representations
- Start making queries on the whole
  - Queries not possible on the individual data sets

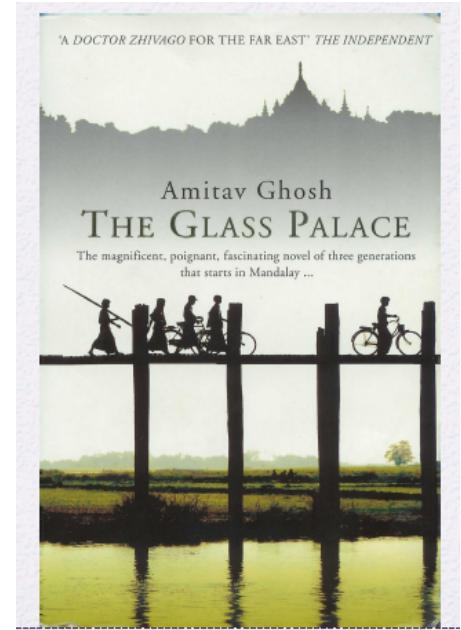
# Dataset “A”: a simplified book store

## Books

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

## Authors

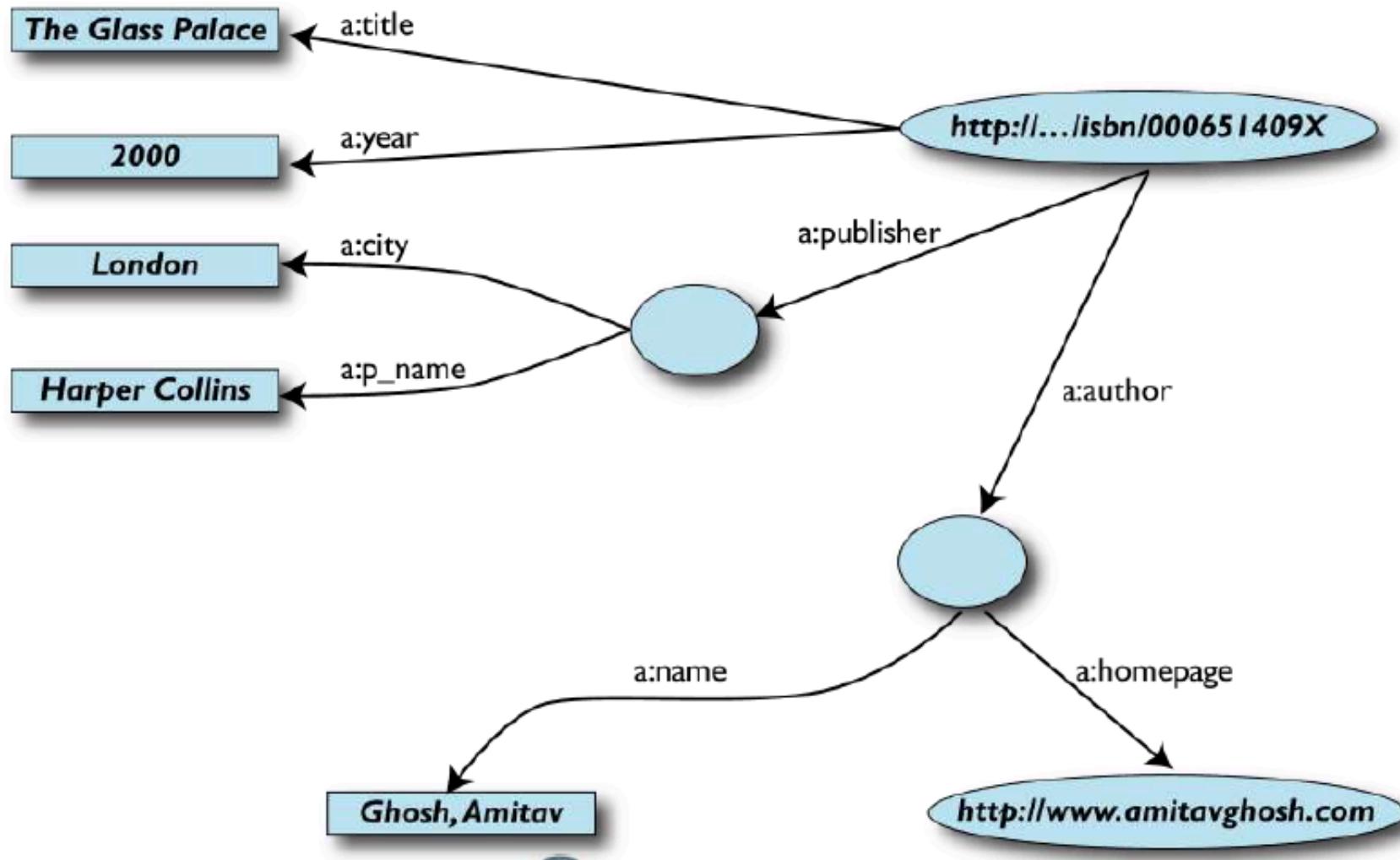
ID	Name	Home page
id_xyz	Ghosh, Amitav	<a href="http://www.amitavghosh.com">http://www.amitavghosh.com</a>



## Publishers

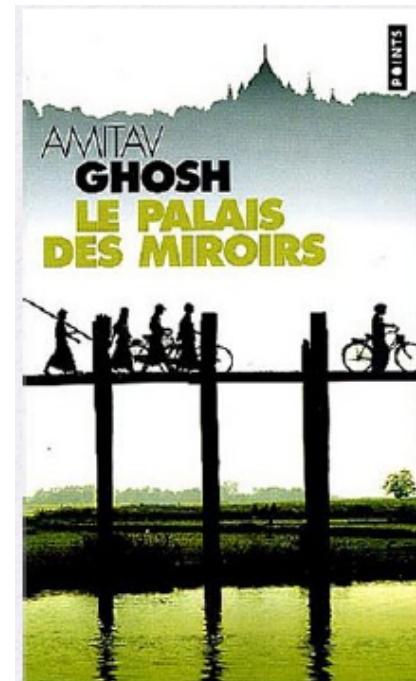
ID	Publisher Name	City
id_qpr	Harper Collins	London

1<sup>st</sup>: export your data as a set of relations among entities (ontology instance level)

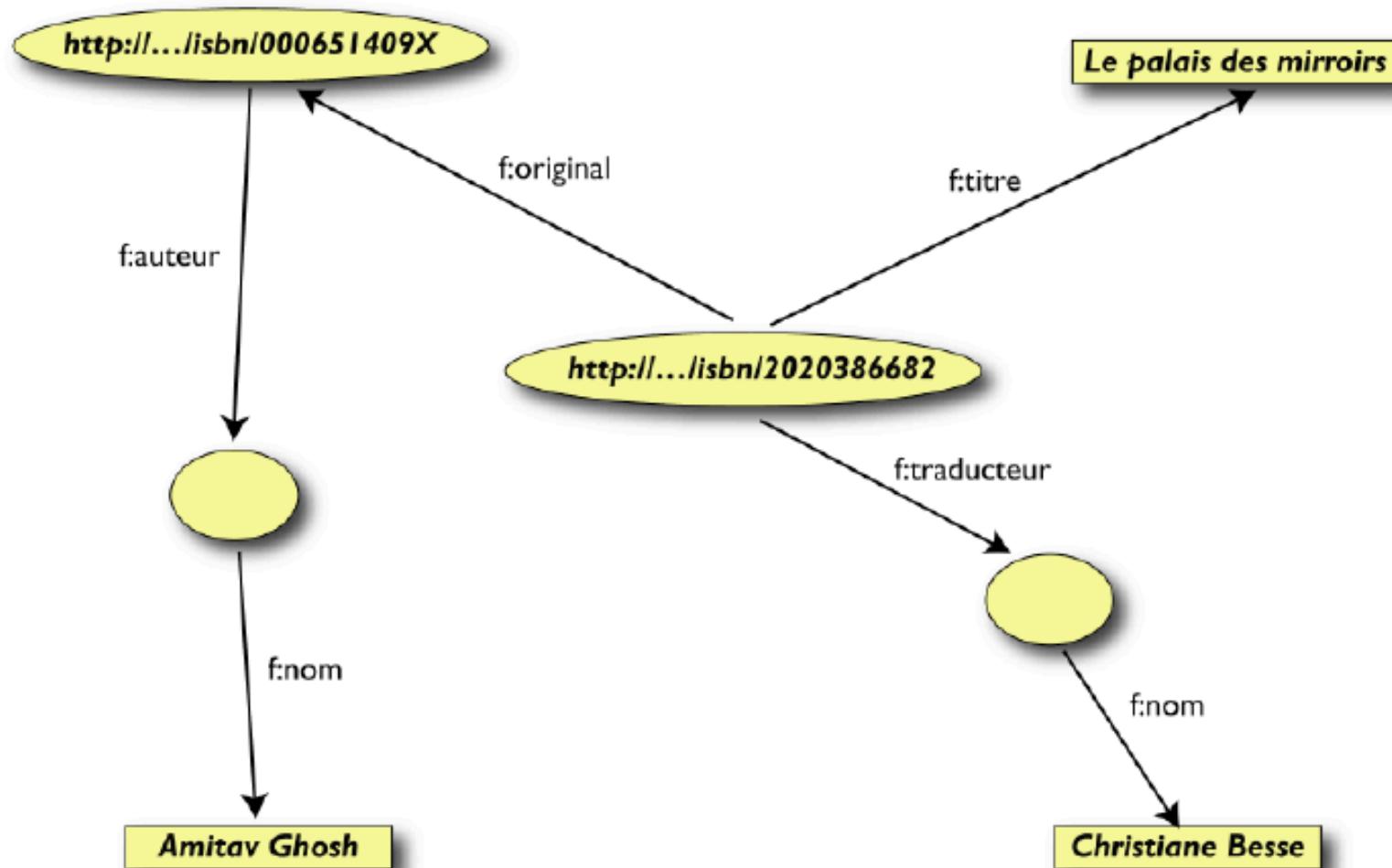


# Dataset “F”: another book store

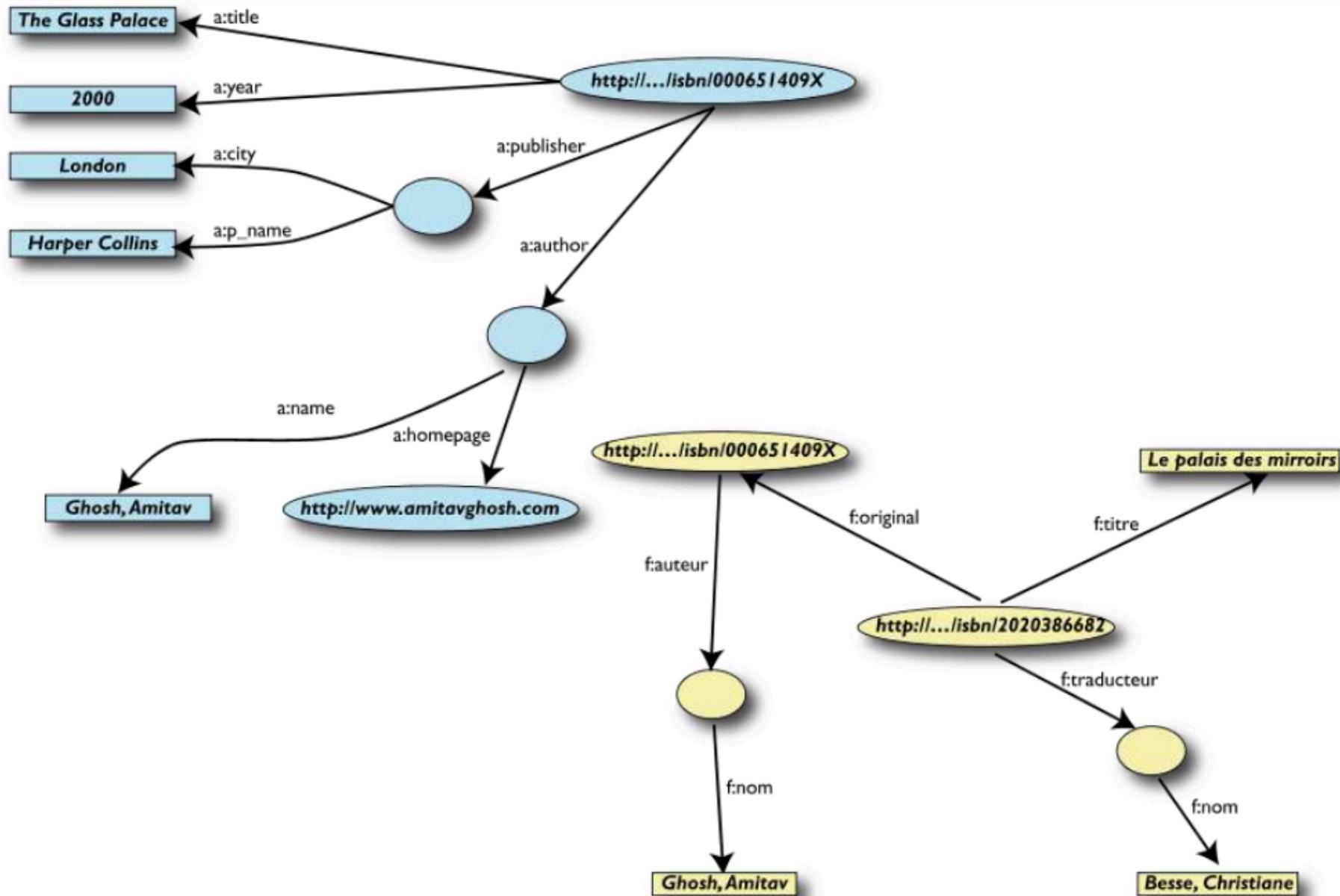
	A	B	D	E
1	ID	Titre	Traducteur	Original
2	ISBN0 2020386682	Le Palais des miroirs	A13	ISBN-0-00-651409-X
3				
6	ID	Auteur		
7	ISBN-0-00-651409-X	A12		
11	Nom			
12	Ghosh, Amitav			
13	Besse, Christianne			



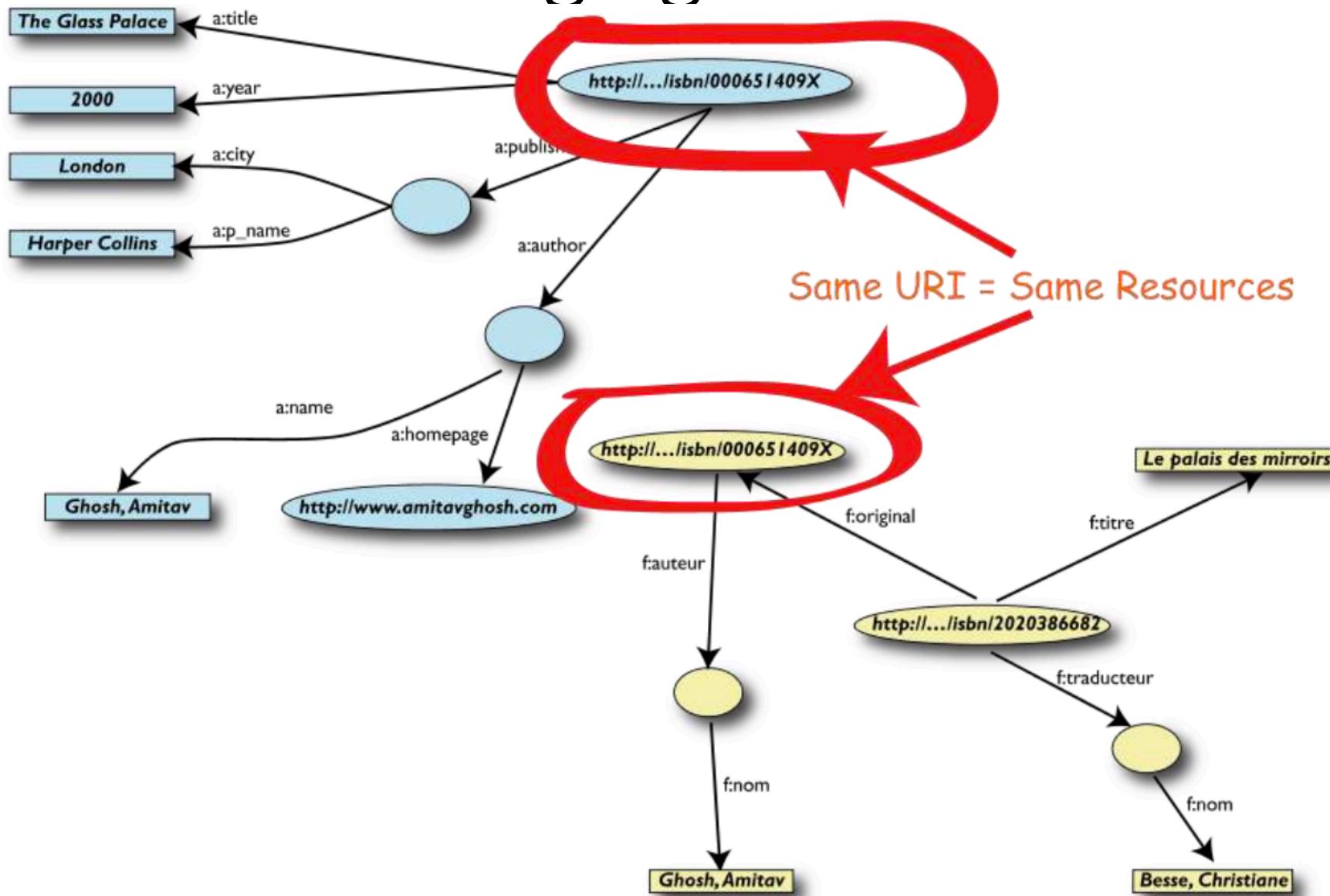
2<sup>nd</sup>: export your second set of data (ontology instance level)



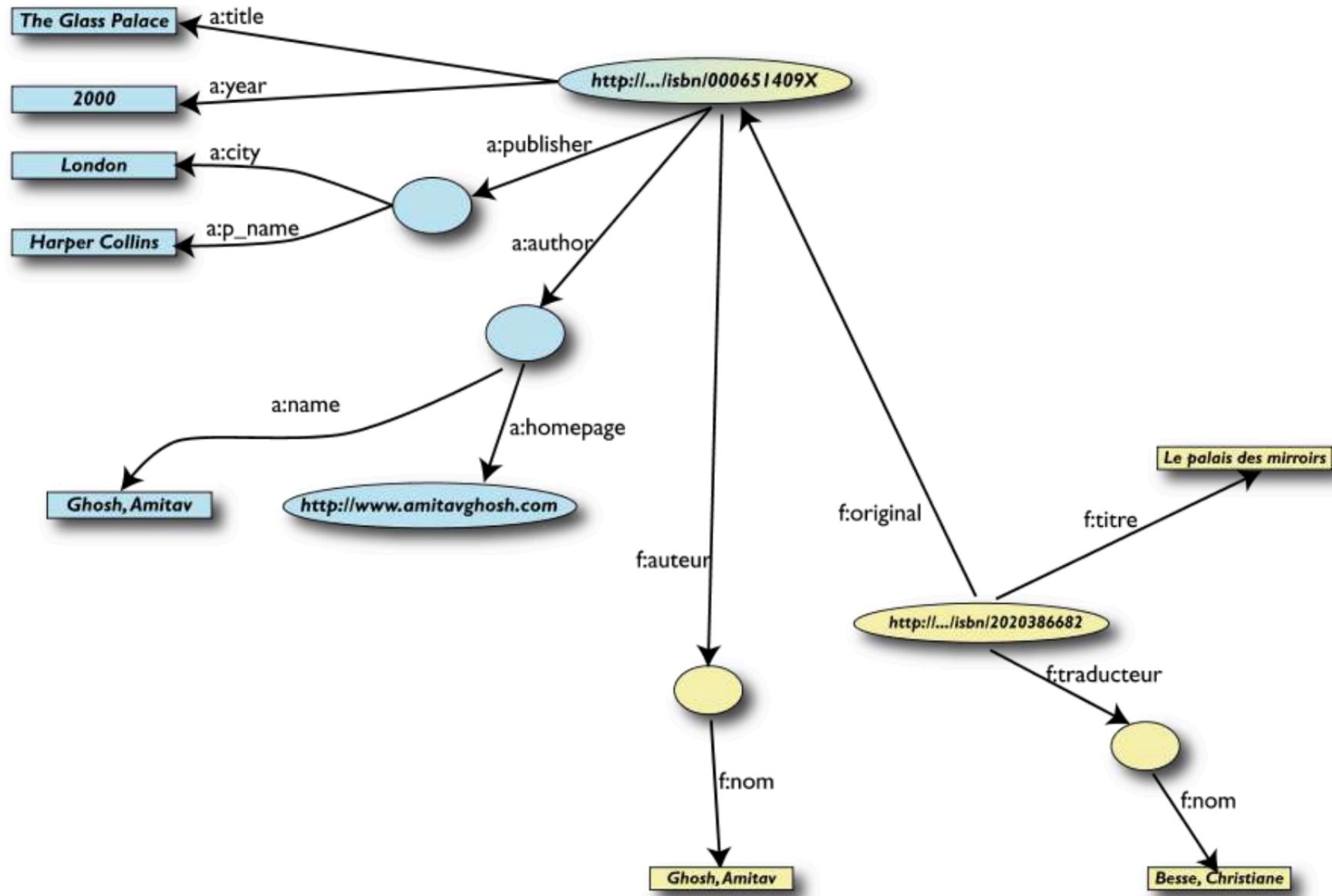
# 3<sup>rd</sup>: start merging data



# 3<sup>rd</sup>: start merging data



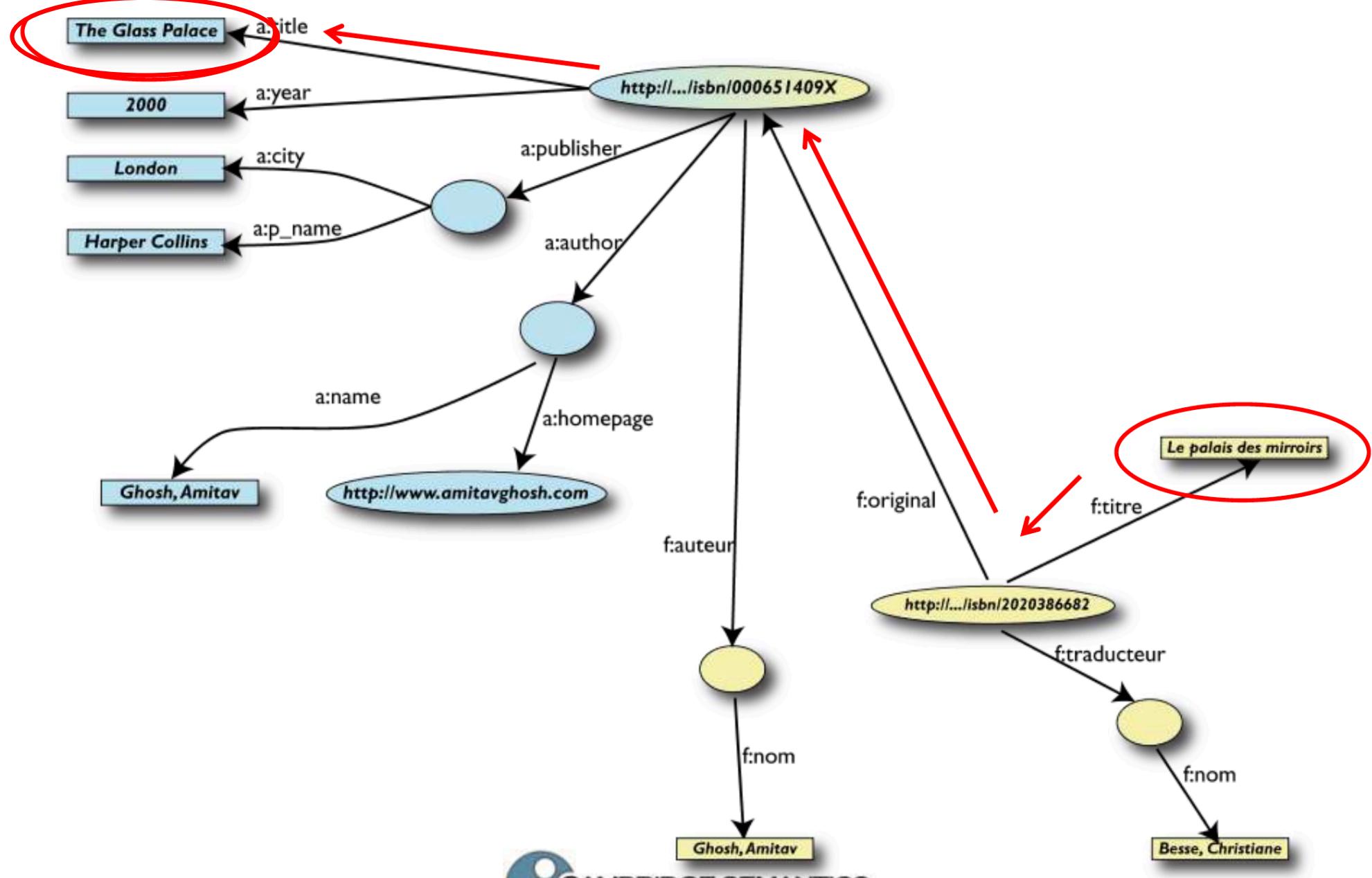
# 4<sup>th</sup>: merge identical resources



# Start executing queries ...

- User of data set “F” can now ask queries like:
  - “What is the title of the original version of Le “Palais des miroirs?”
- This information is not in the data set “F”...  
...but can be retrieved after merging with data set “A”!

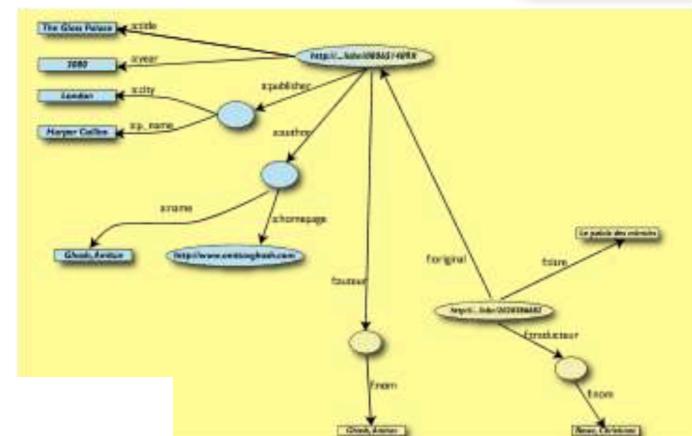
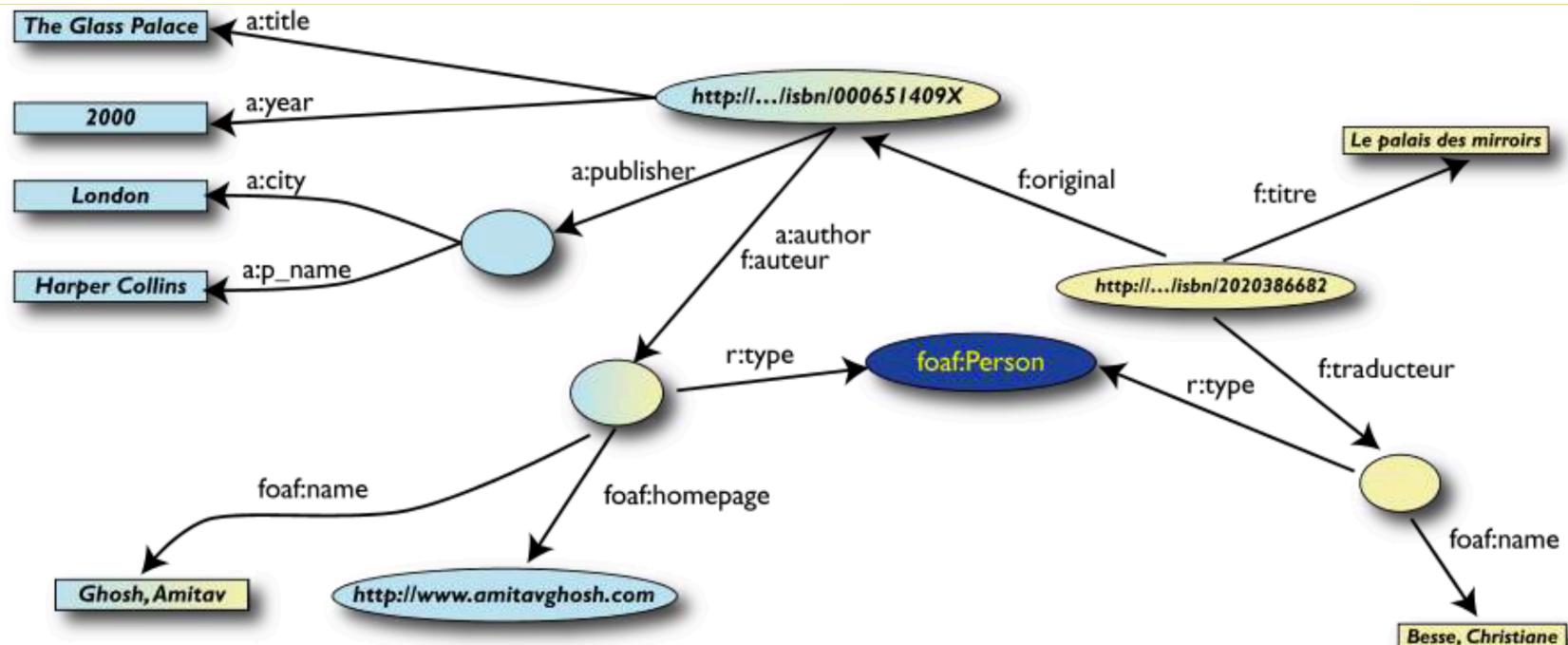
# 5<sup>th</sup>: query the merged dataset



# More can be achieved ...

- We “know” that a:author and f:auteur are really the same
- But our automatic merge does not know that!
- Let us add some extra information to the merged data:
  - a:author is the same as f:auteur
  - Both identify a Person, a category (type) for certain resources
  - Person is an **ontology concept**

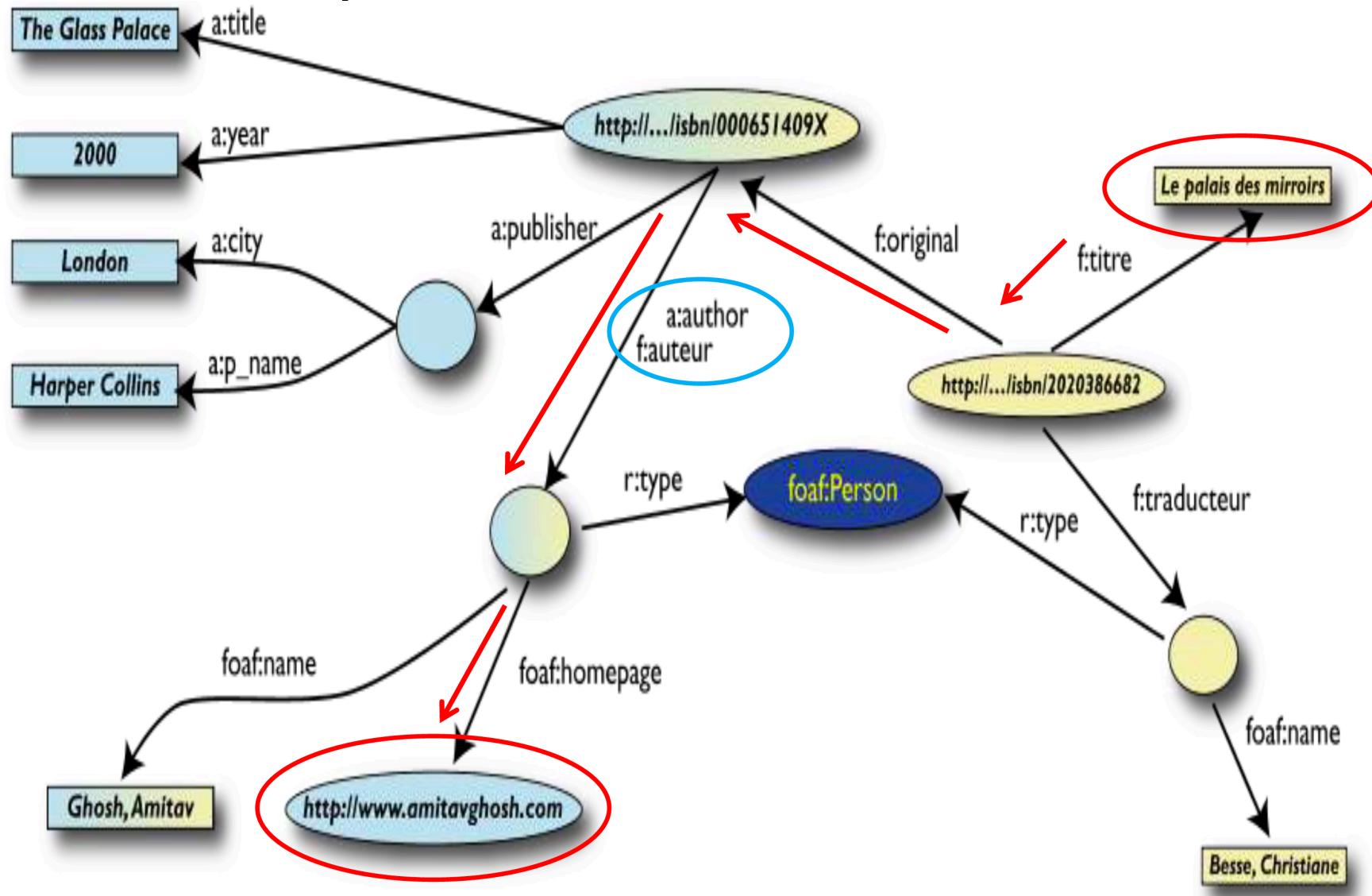
# 3<sup>rd</sup> revisited: use the extra knowledge (add ontology schema information)



# Start making richer queries

- User of data set “F” can now query:
  - “What is the home page of Le Palais des miroirs’s ‘auteur’?”
- The information is not in data set “F” or “A”...
- ...but was made available by:
  - Merging data sets “A” and “F”
  - Adding three simple “glue” statements

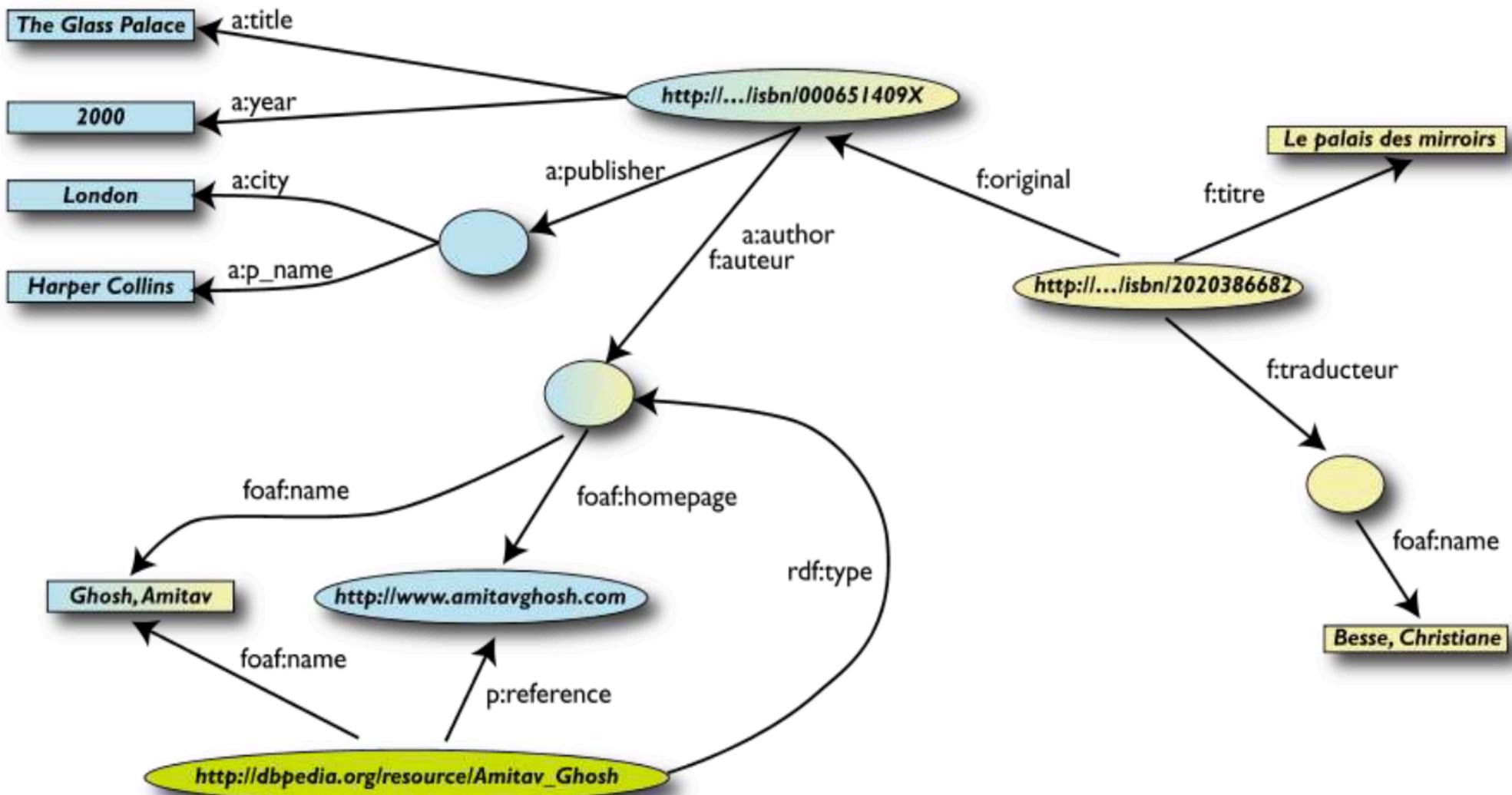
# Richer queries



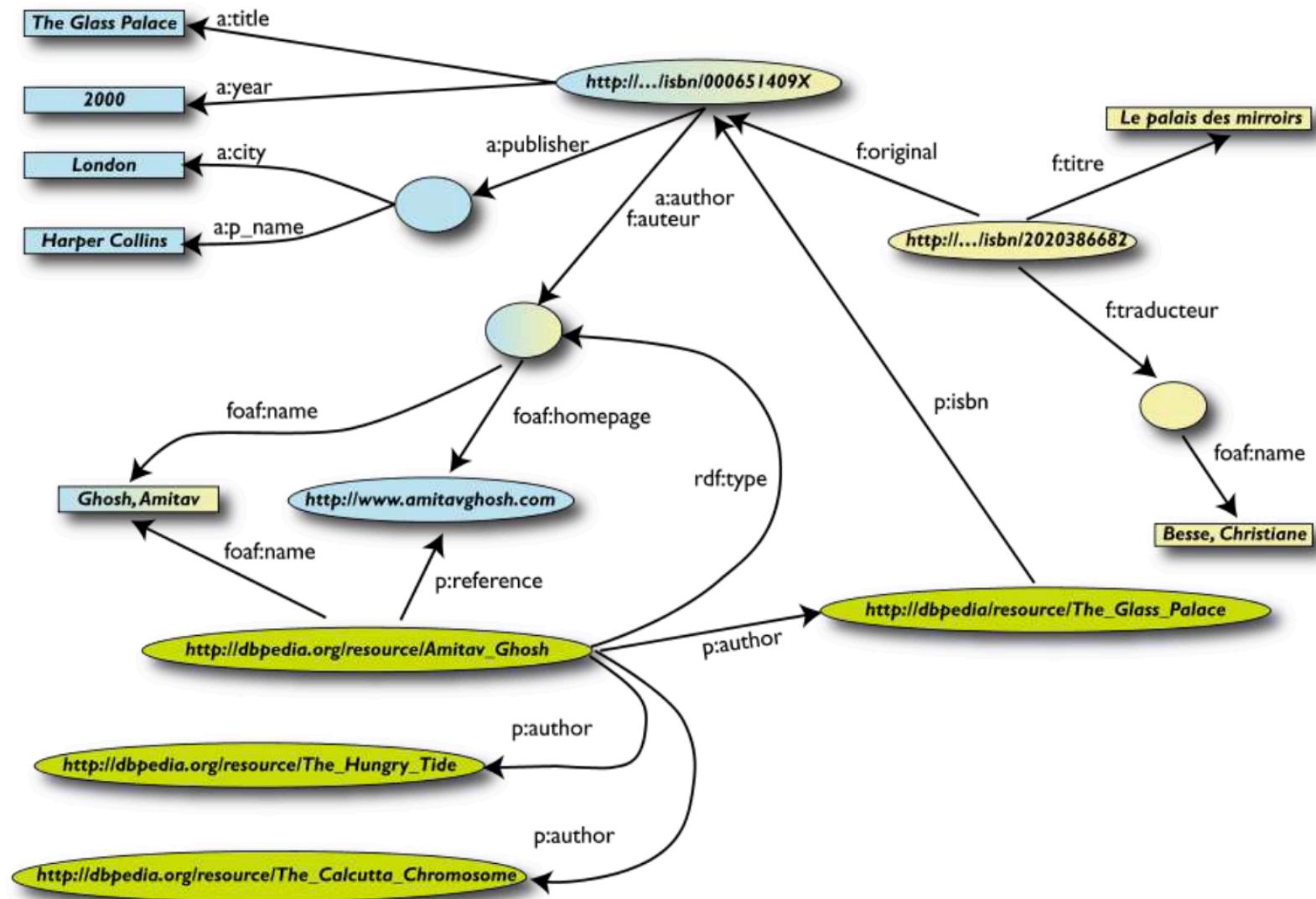
# Bring in other data sources

- We can integrate new information into our merged data set from other sources
  - e.g. additional information about author Amitav Ghosh
- Perhaps the largest public source of general knowledge is Wikipedia
- Structured data can be extracted from Wikipedia using dedicated tools (leading to the dbpedia data source)

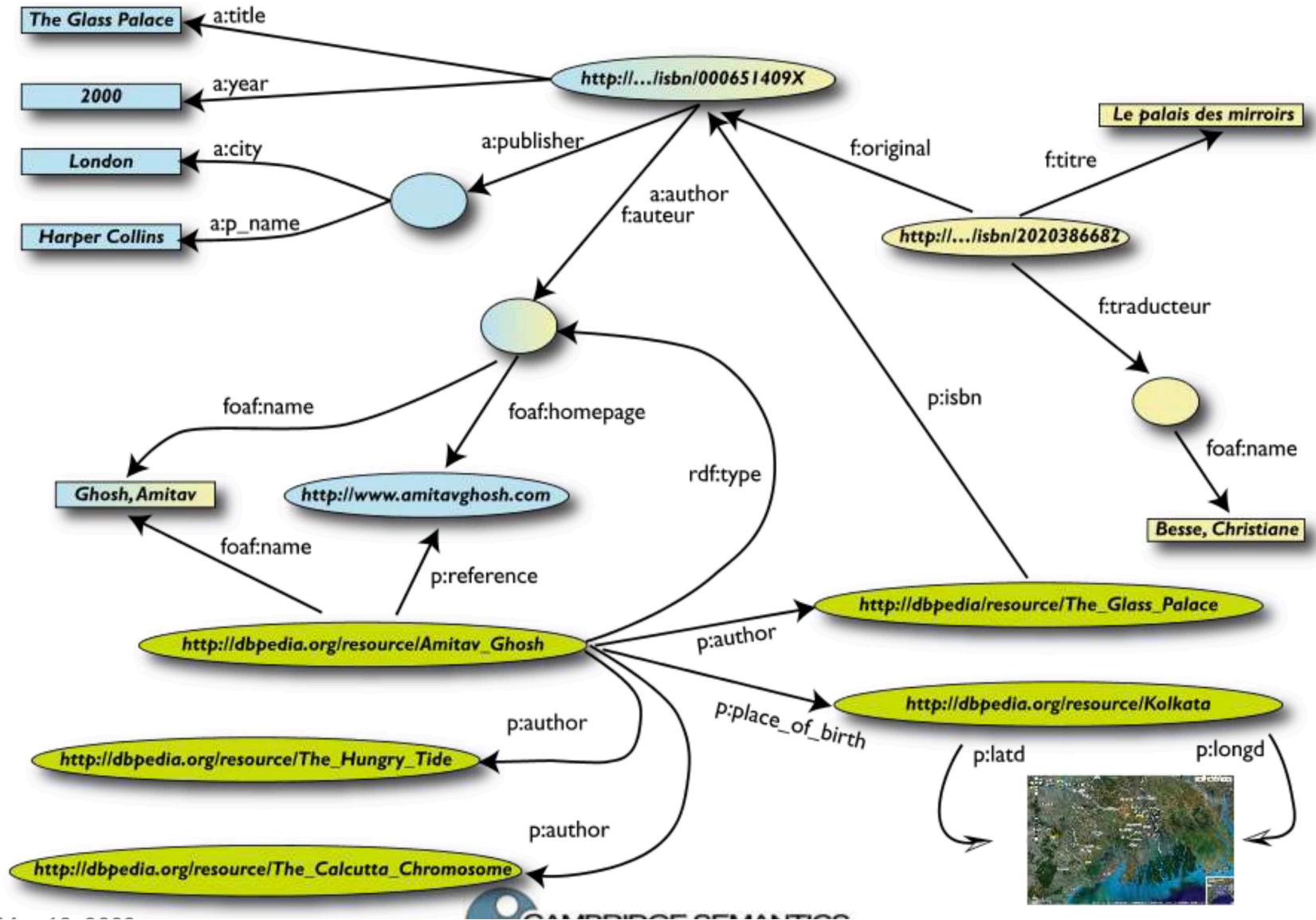
# 7<sup>th</sup>: merge with Wikipedia data



# 7<sup>th</sup>: merge with Wikipedia data



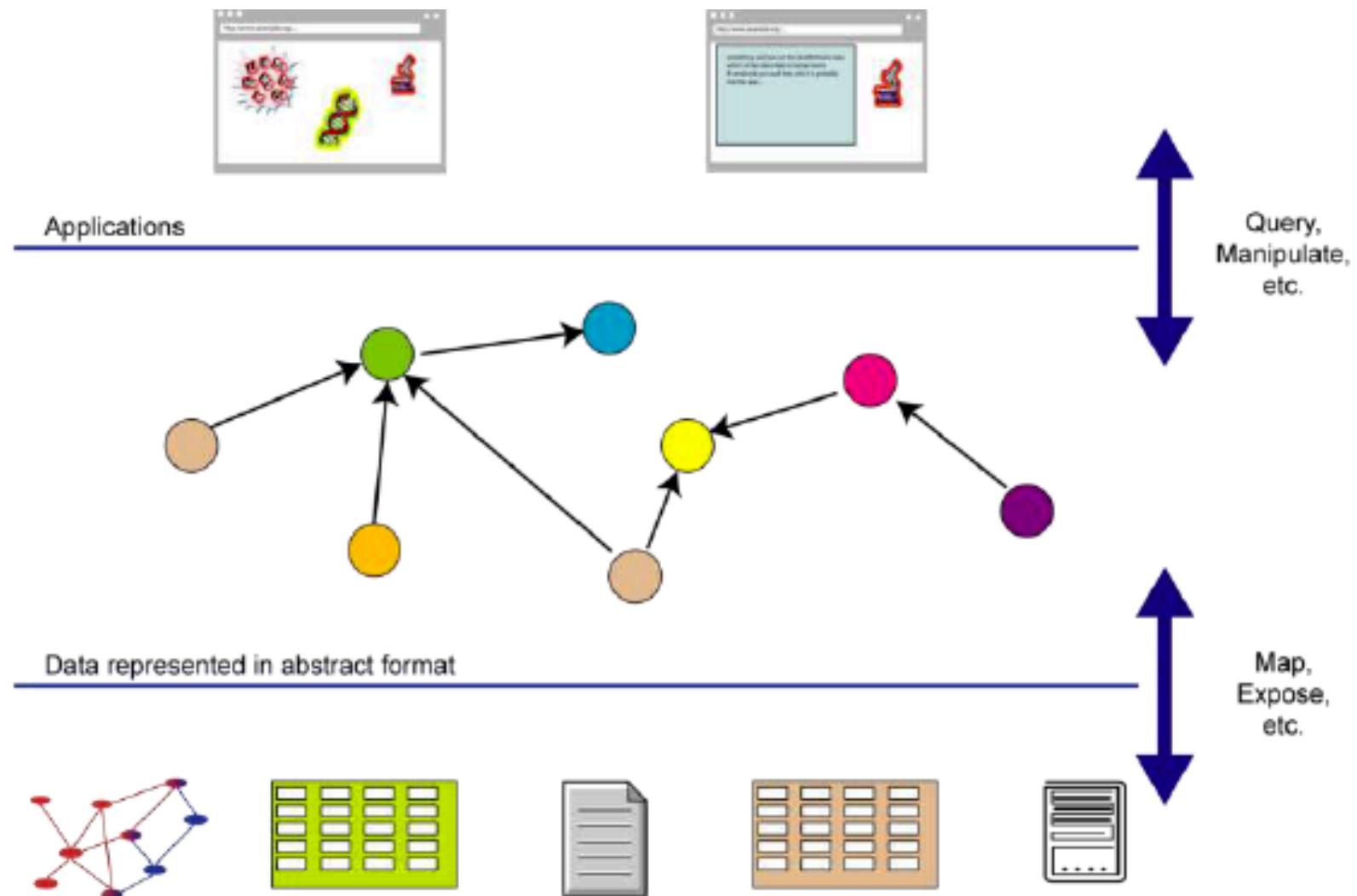
# 7th: merge with Wikipedia data



# What did we do?

- We combined different data sets that
  - ...may be internal or somewhere on the Web
  - ...are of different formats (RDBMS, Excel spreadsheet, (X)HTML, etc)
  - ...have different names for the same relations
- We could combine the data because some identifiers were identical i.e. the ISBNs in this case (i.e., they correspond to the same ontology instance)
- We could add some simple additional information (the “glue”) to help further merge data sets (through new ontology instances, ontology relations, ontology concepts)
- The result? Answer queries that could not previously be asked

# What did we do?



# The abstraction pays off because ...

- ...the graph representation is independent of the details of the native structures
- ...a change in local database schemas, HTML structures, etc. do not affect the whole “schema independence”
- ...new data, new connections can be added seamlessly & incrementally

*Semantic Web technologies make such integration possible*

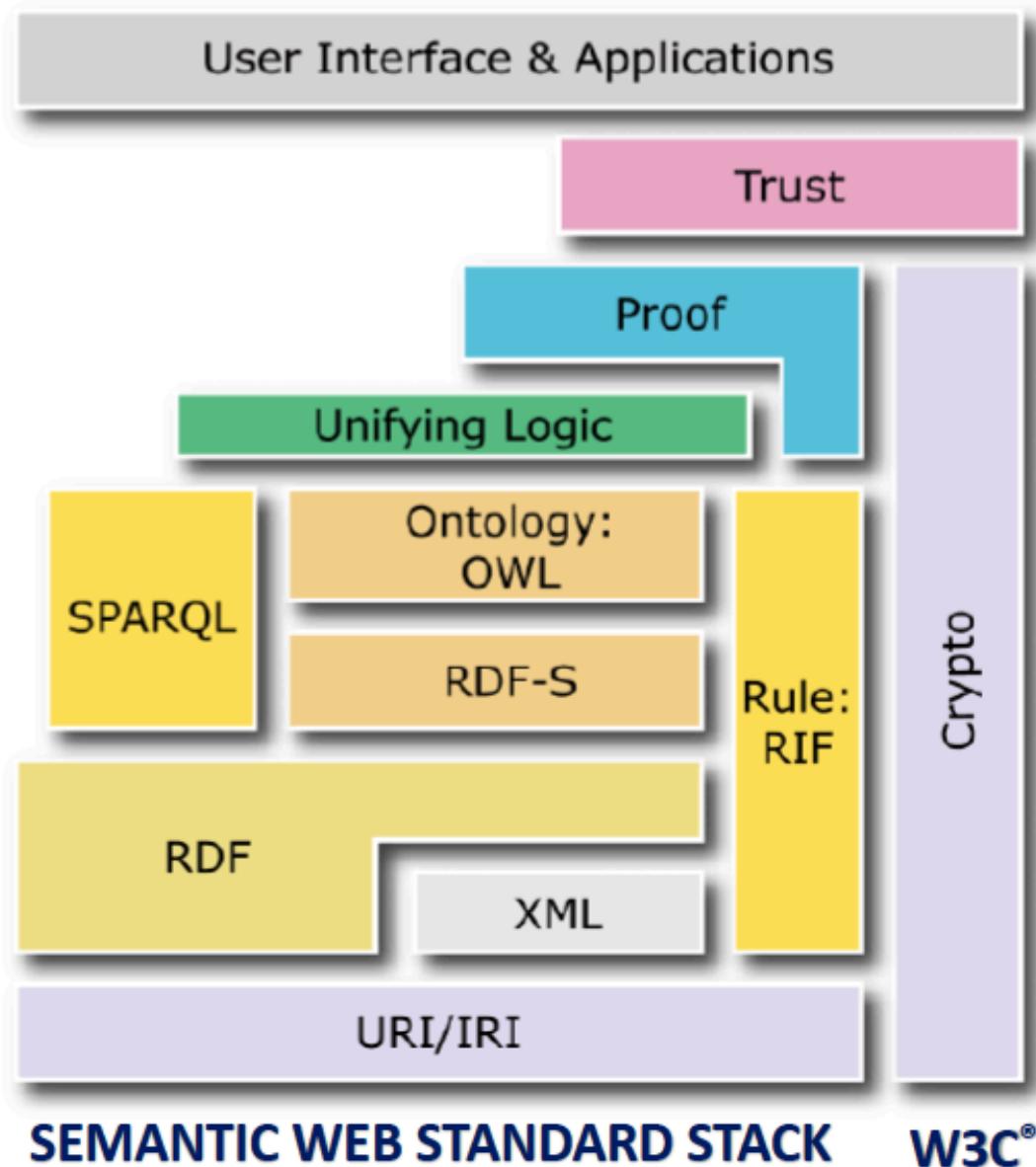
# The Semantic Web

- The Semantic Web is a Web in which the **resources** (things) are semantically described, through the usage of an **ontology**
- A resource is anything that can be referred to by a **URI** (Uniform Resource Identifiers)
  - a web page, identified by an URL
  - a fragment of an XML document, identified by an element node of the document
  - a web service
  - a thing, an object, a property, etc.
- Examples
  - <http://www.example.org/file.html#home>
  - [http://www.example.org/file2.xml#xpath\(//q\[@a=b\]\)](http://www.example.org/file2.xml#xpath(//q[@a=b]))
  - <http://www.example.org/form?a=b&c=d>

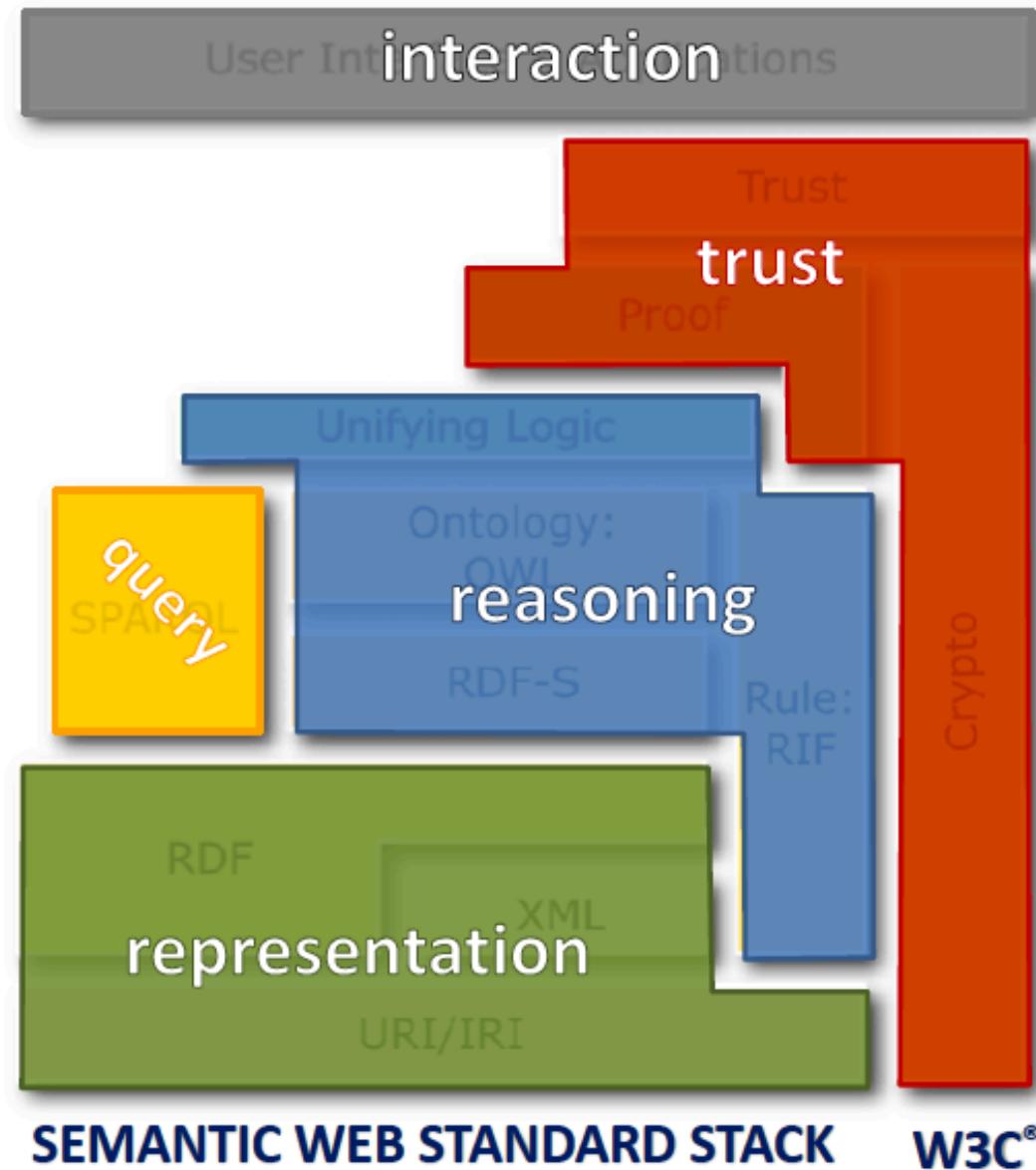


*"Now! That should clear up  
a few things around here!"*

# The Semantic Web Standard Stack



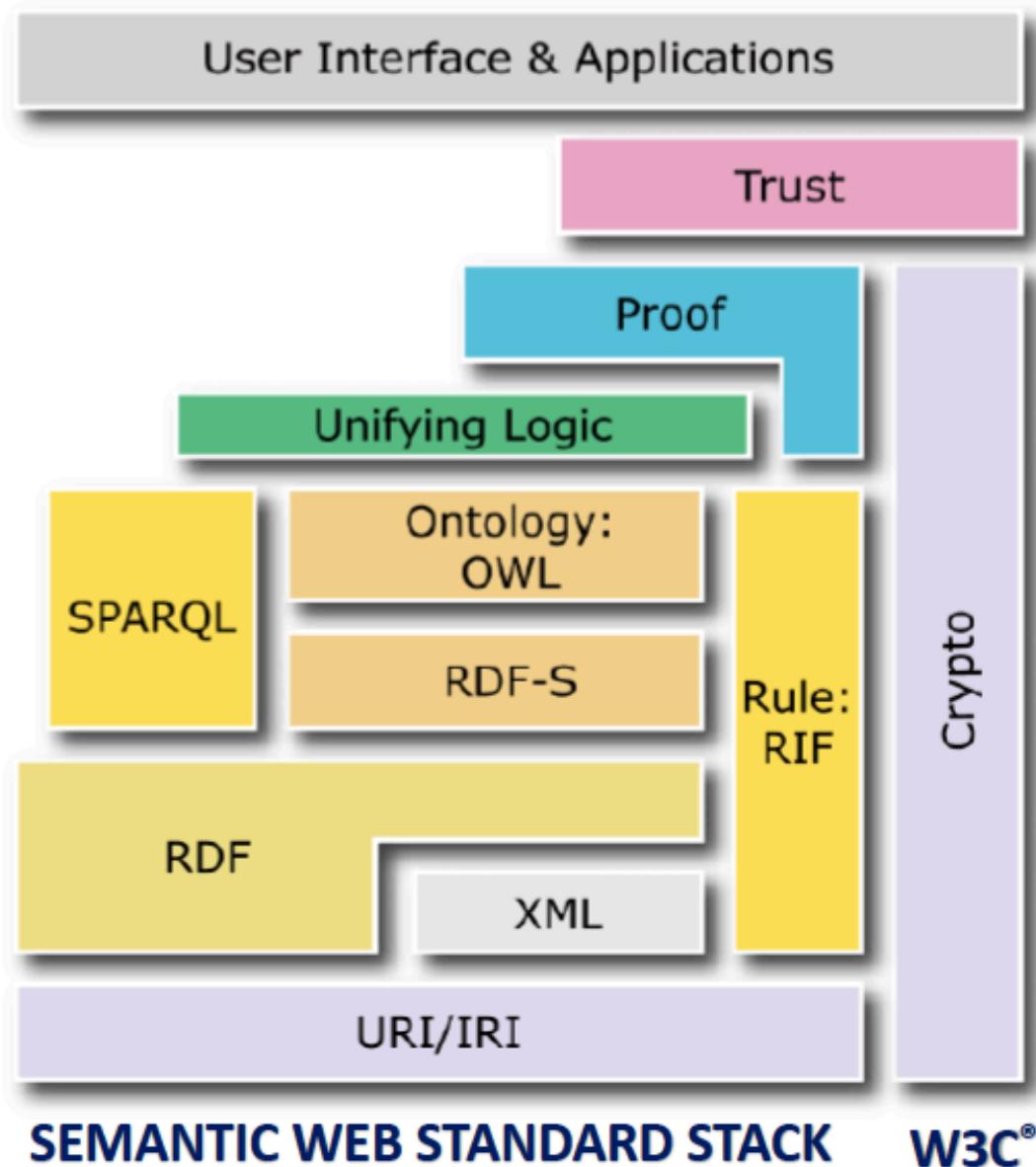
# The Semantic Web Standard Stack



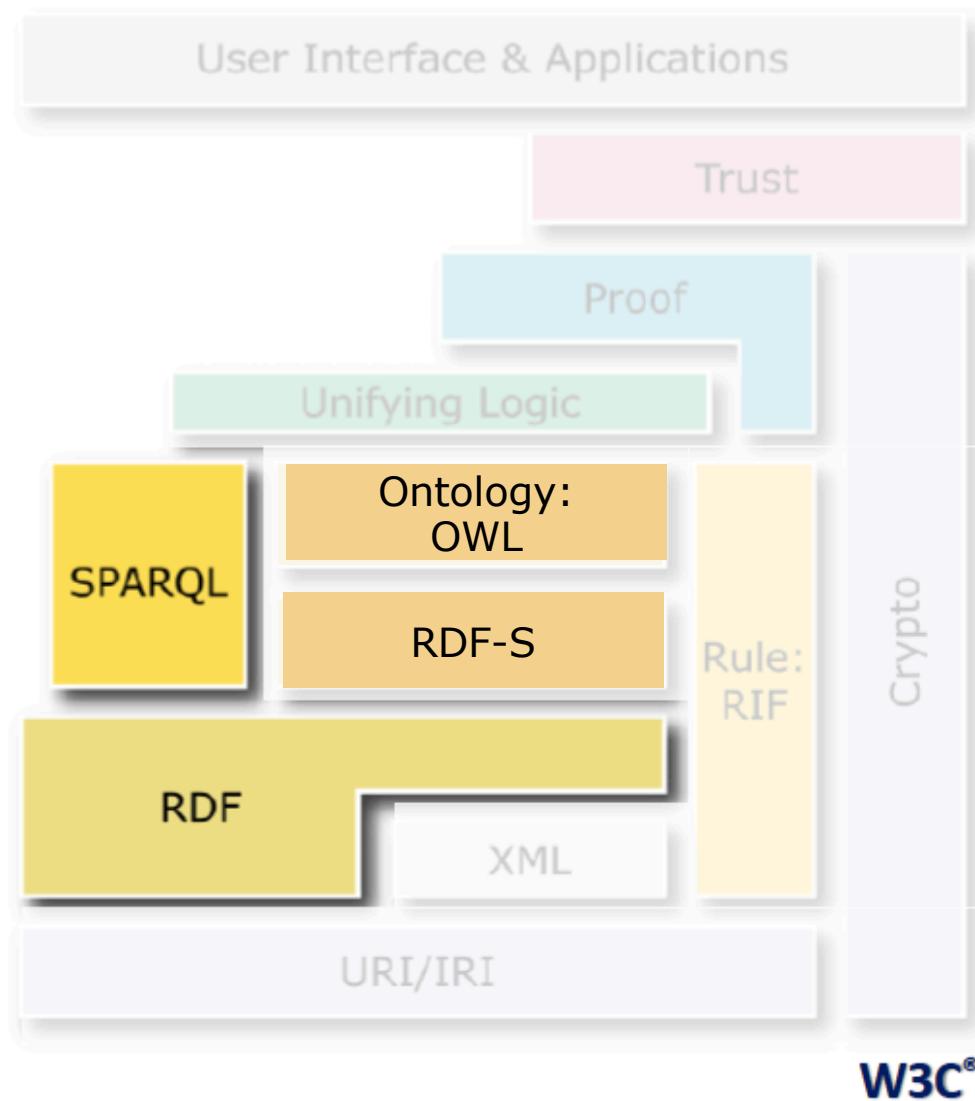
# Ontology Languages for the Semantic Web

- RDF: a very simple ontology language
- RDFS: Schema for RDF
  - ▶ Can be used to define richer ontologies
- OWL: a much richer ontology language

# The Semantic Web Standard Stack



# The Semantic Web Standard Stack



# W3C Linked Open Data Project

- Goal: “expose” open datasets in RDF on the Web
- Set RDF links among the data items from different datasets
- Set up, if possible, query endpoints

# Linked Open Data

- **Linked data** is just RDF (RDFS, OWL) data, linking together resources potentially described in different datasets
- **Linked open data** is just linked data freely accessible on the Web along with any required ontologies

# Properties of Linked (Open) Data

- Anyone can publish data on the Web of Linked Data
- Entities are connected by links
  - ▣ Creating a global data graph that spans data sources and enables the discovery of new data sources.
- Data is self-describing
  - ▣ If an application encounters data represented using an unfamiliar vocabulary, the application can resolve the URLs that identify vocabulary terms in order to find their RDFS or OWL definition.
- The Web of Data is open
  - ▣ Meaning that applications can discover new data sources at run-time by following links.

# Example: 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

# Example: DBpedia

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

```
dbpedia:Amsterdam
```

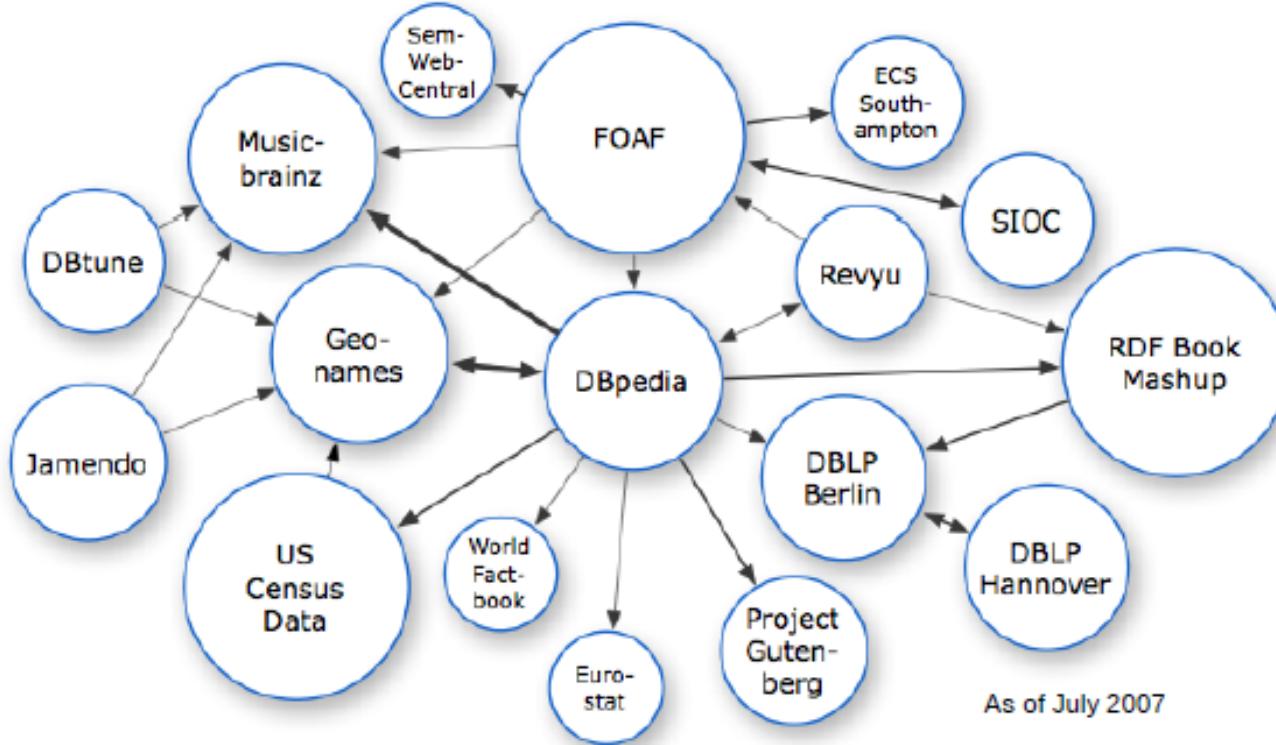
```
    dbterm:officialName "Amsterdam" ;  
    dbterm:longd "4" ;  
    dbterm:longm "53" ;  
    dbterm:longs "32" ;  
    dbterm:leaderName dbpedia:Lodewijk_Asscher ;  
    ...  
    dbterm:areaTotalKm "219" ;  
    ...
```

```
dbpedia:ABN_AMRO
```

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

Amsterdam	
	
The Keizersgracht at dusk	
Location of Amsterdam	
Coordinates:	52°22'23"N 4°53'32"E
Country	Netherlands
Province	North Holland
Government	
- Type	Municipality
- Mayor	Job Cohen [1] (PvdA)
- Aldermen	Lodewijk Asscher Carolin Gehrels Tjeerd Herrema Maarten van Poelgeest Marjke Vos
- Secretary	Erik Gerritsen
Area [2][3]	
- City	219 km² (84.8 sq mi)
- Land	160 km² (64.1 sq mi)
- Water	59 km² (23.0 sq mi)
- Urban	1,003 km² (387.3 sq mi)
- Metro	1,815 km² (700.8 sq mi)
Elevation [4]	2 m (7 ft)
Population (1 October 2008) [5][6]	
- City	760,209
- Density	4,459/km² (11,548.8/sq mi)
- Urban	1,304,422
- Metro	2,168,372
- Demonym	Amsterdammer
Time zone	CET (UTC+1)
- Summer (DST)	CEST (UTC+2)
Postcodes	1011 – 1109
Area code(s)	020
Website:	<a href="http://www.amsterdam.nl">www.amsterdam.nl</a> [7]

# Linked Open Data Project



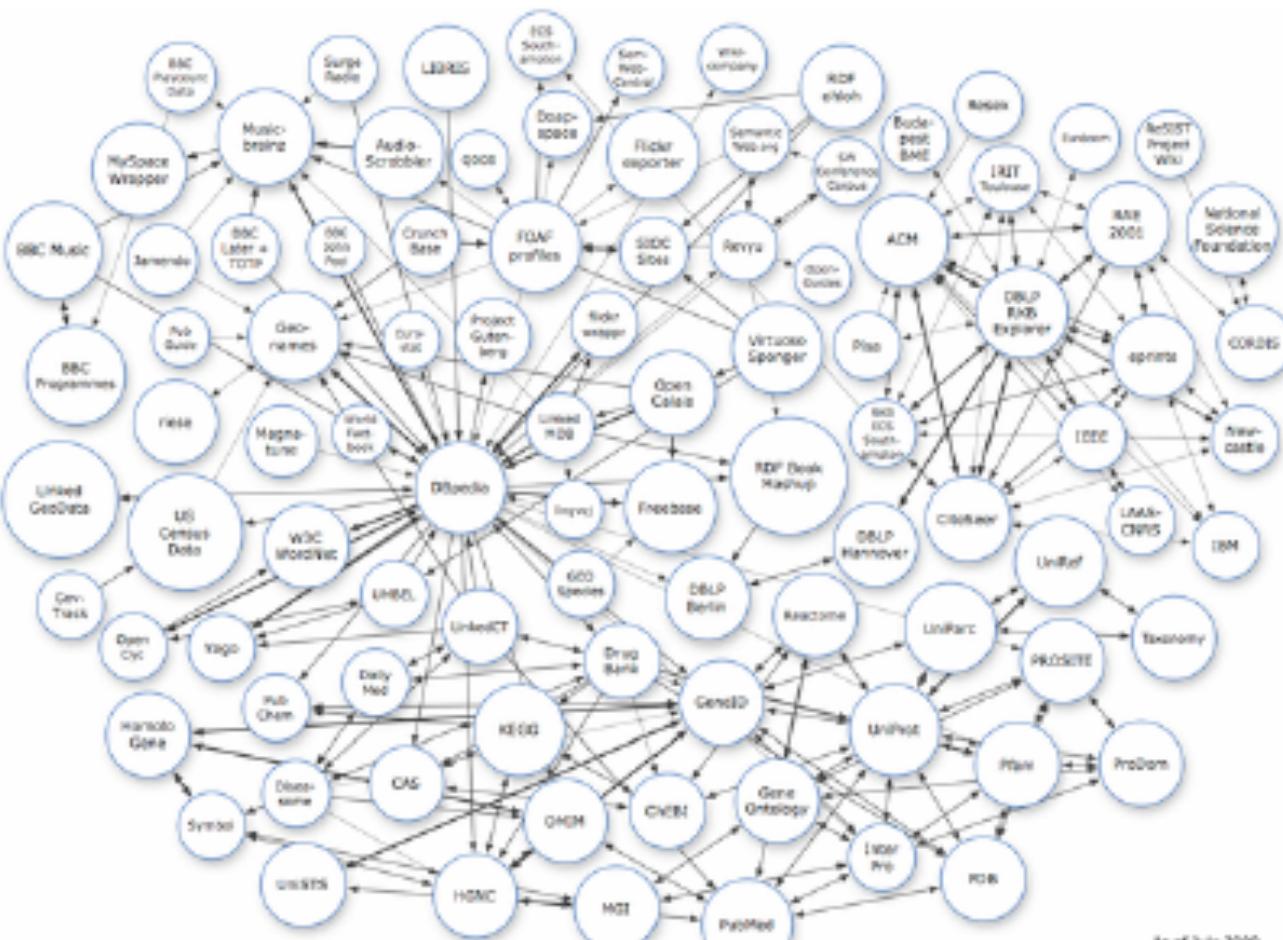
As of July 2007

# Linked Open Data Project



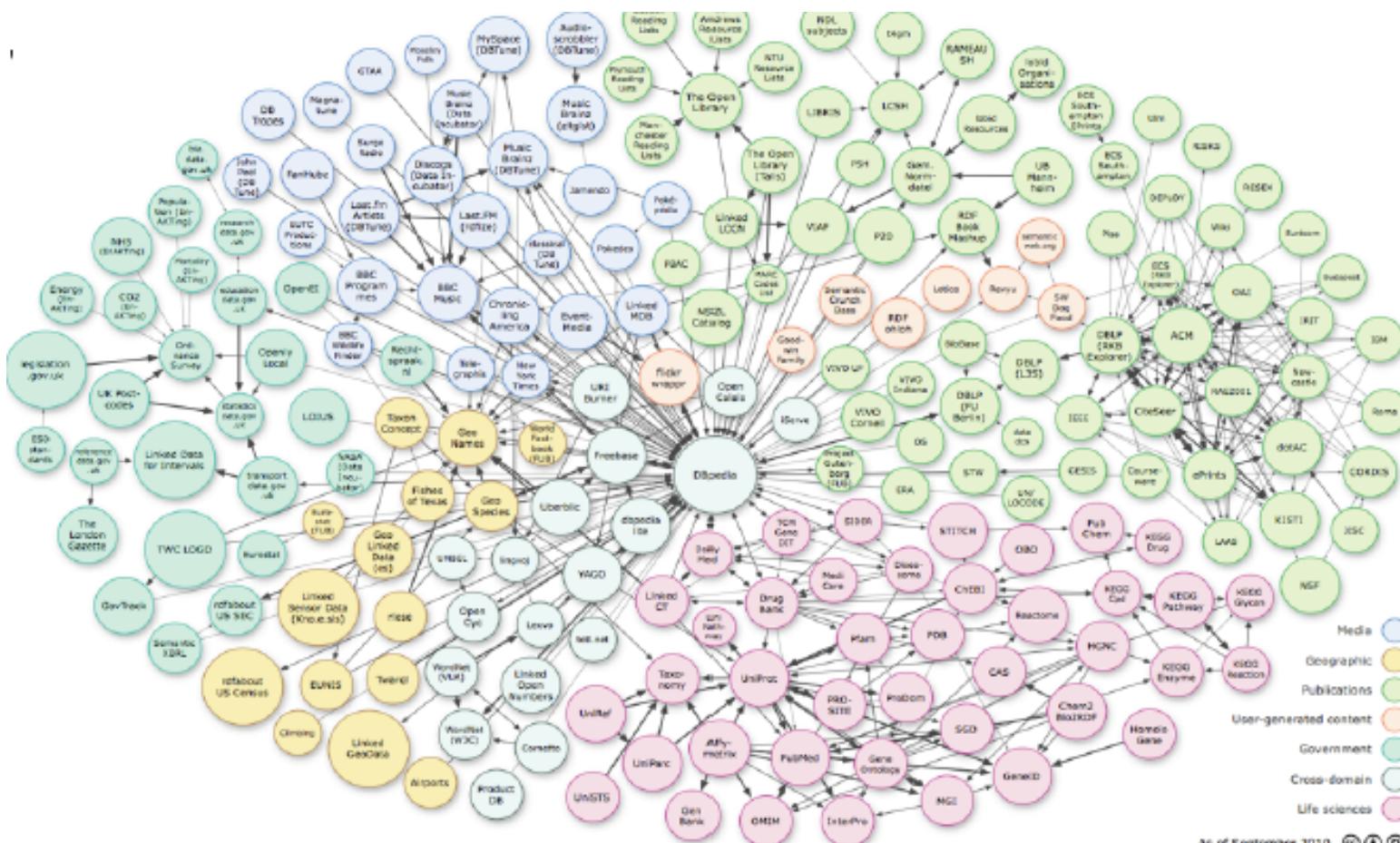
2008

# Linked Open Data Project



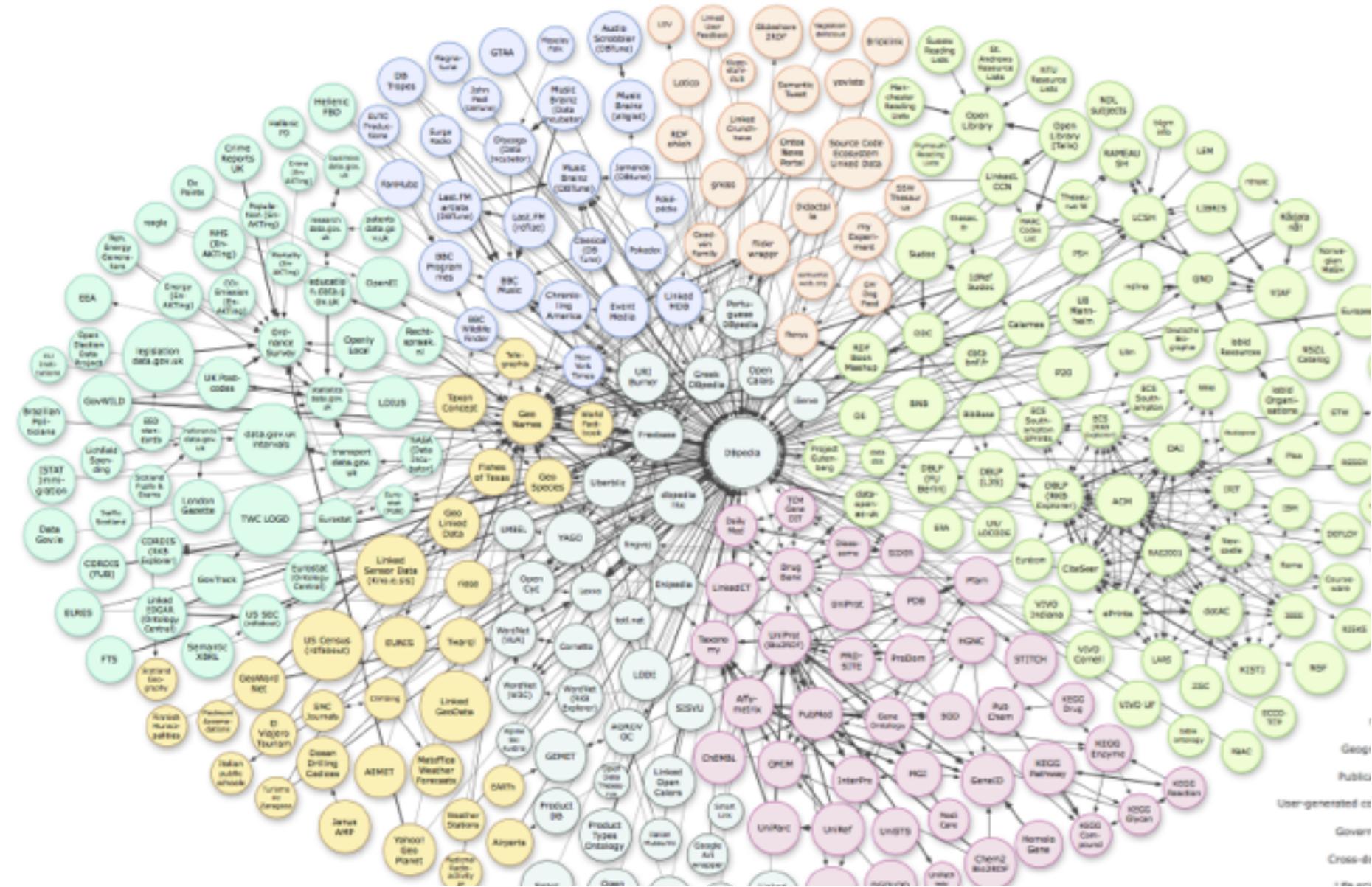
2009

# Linked Open Data Project

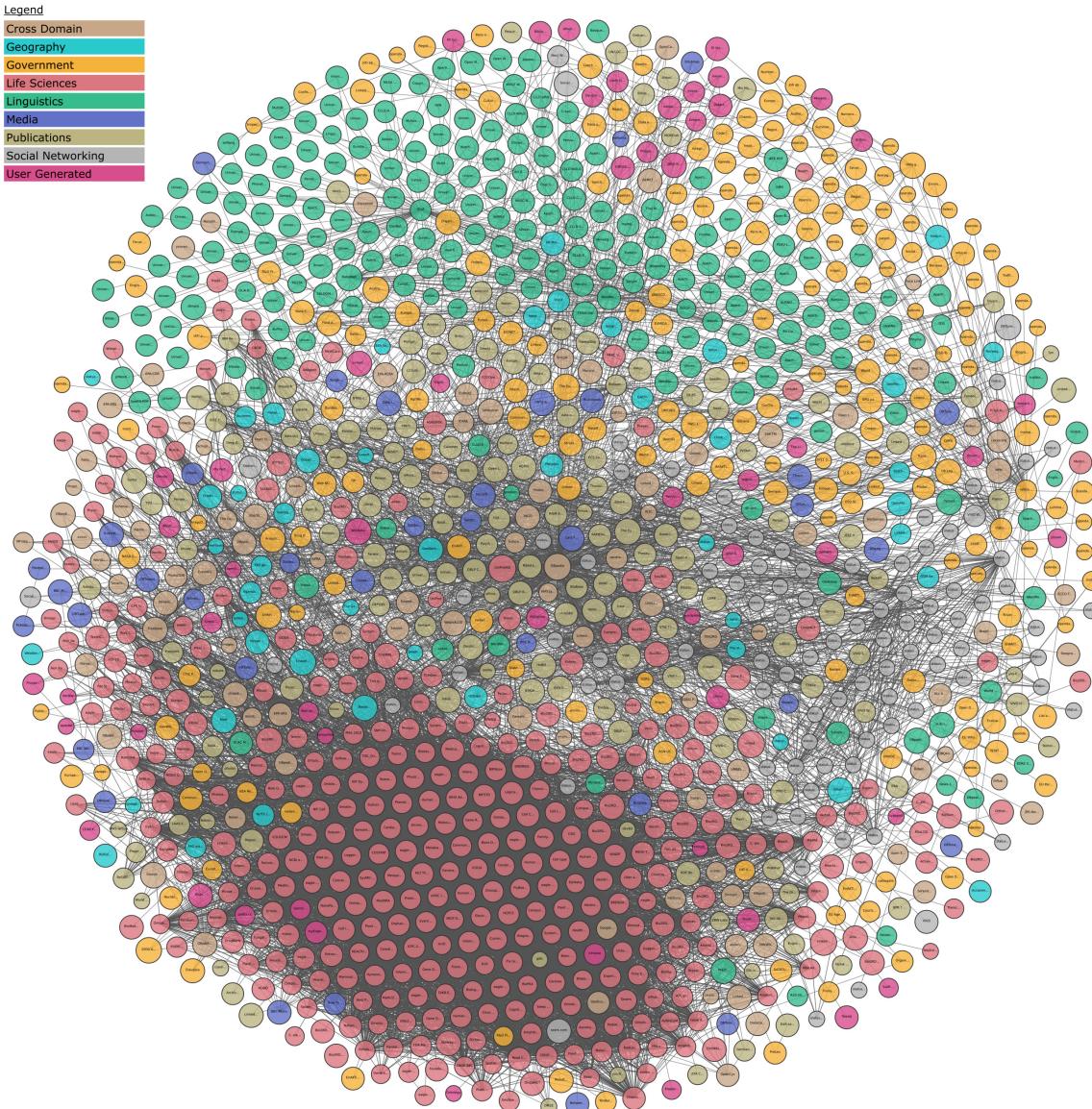


2010

# Linked Open Data Project



# Linked Open Data Project



The dataset contains  
1269 datasets with  
16201 links  
(as of May 2020)

<https://lod-cloud.net>