Semantics, knowledge graphs and ontologies in practice

Jose Emilio Labra Gayo
WESO Research group
University of Oviedo, Spain

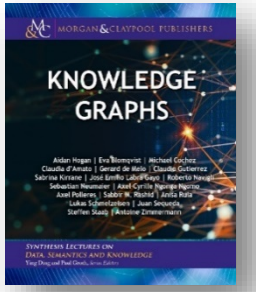
About me…

- Founded WESO (Web Semantics Oviedo) research group
  - Practical applications of semantic technologies since 2004
  - Several domains: e-Government, e-Health
- Some books:
  - "*Web semántica*" (in Spanish), 2012
  - "*Validating RDF data*", 2017
  - "Knowledge Graphs", 2021
- …and software:
  - SHaclEX (Scala library, implements ShEx & SHACL)
  - RDFShape (RDF playground)

http://labra.weso.es

2012

2017 HTML version:
http://book.validatingrdf.com

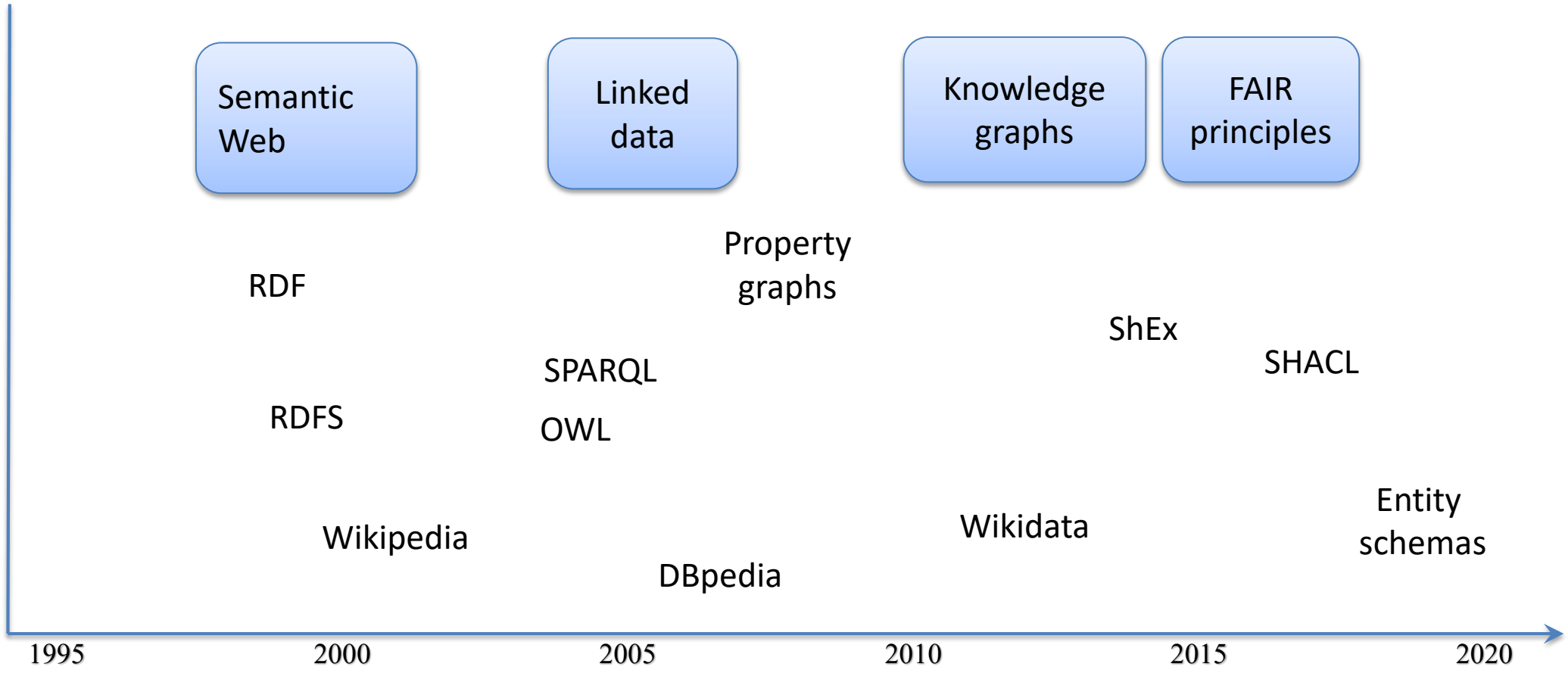


2021, HTML version
https://kgbook.org/

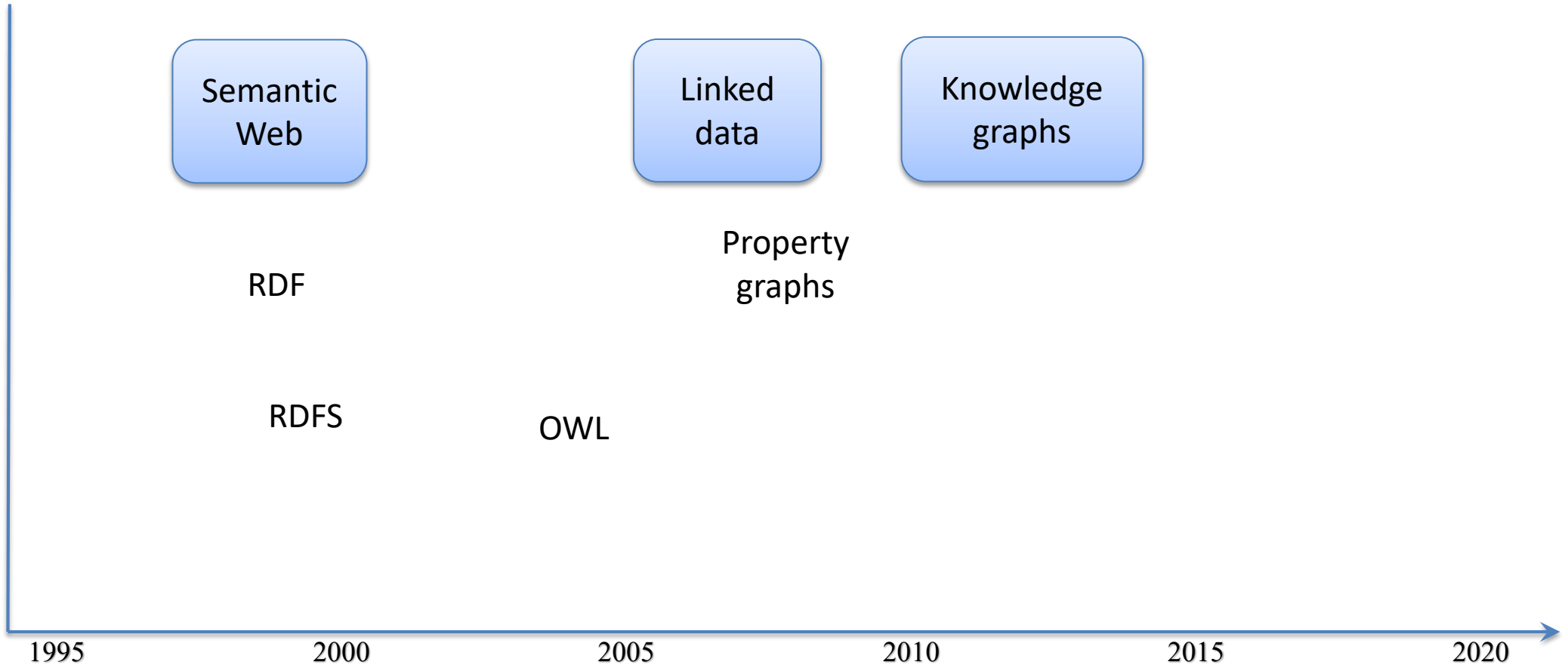
Schedule

Day	Title	Topics
Day 1.	Semantic Technologies and Knowledge graphs	Semantic Web Linked data Knowledge graphs RDF data model Property graphs Wikibase graphs Examples and applications
Day 2.	RDF data modelling and SPARQL	Data modelling exercises with RDF and turtle SPARQL
Day 3.	Validating RDF data	Shape Expressions (ShEx) SHACL Validating Knowledge Graphs
Day 4.	Advanced topics	ShEx and SHACL compared Reasoning RDFS OWL Nanopublications

Roadmap


Semantic Web
Linked data
Knowledge graphs
FAIR principles
Property graphs
RDF
ShEx
SHACL
SPARQL
RDFS
OWL
Entity schemas
Wikipedia
Wikidata
DBpedia
1995
2000
2005
2010
2015
2020

Roadmap


Semantic Web
Linked data
Knowledge graphs
Property graphs
RDF
RDFS
OWL
1995
2000
2005
2010
2015
2020

Semantic Web

Semantic Web = vision of the data Web

Goal: Automatically share and reuse data on the Web

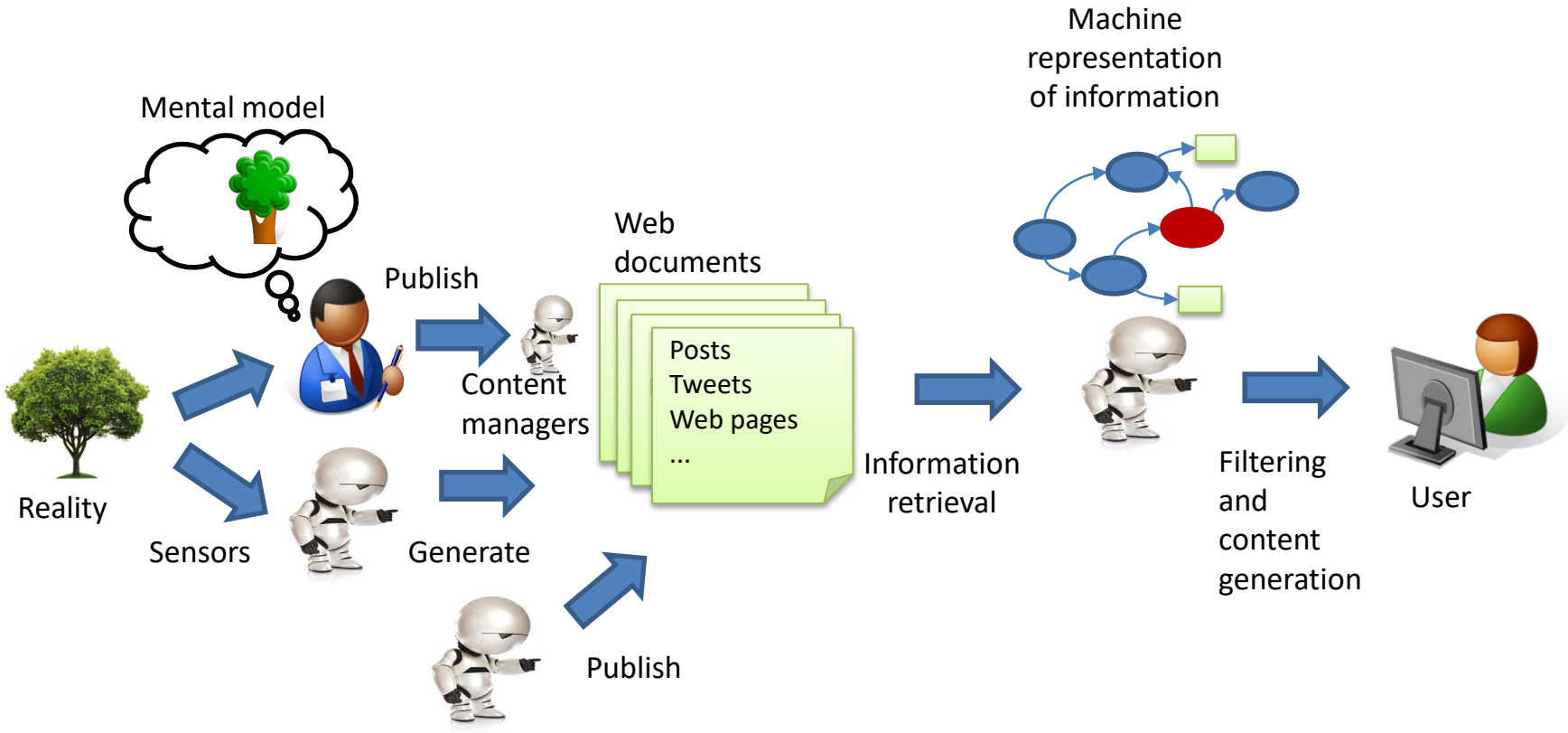
Not only documents/web pages, but also data

Long term project

- The goal is not to destroy the current web
  - Gradually adopt better practices
- Improve publication/reuse techniques
- Let machines process (understand?) more data
- Give more value to information

Tim Berners-Lee
Source: Wikipedia

Machines in the Web



Web information is constantly manipulated by machines
Semantic web goal ⇒ facilitate that manipulation

¿People vs Machines?

Creativity, imagination
Unpredictable (make errors)
Get tired with repetitive tasks
Understanding based on context

Programmed for certain tasks
Predictable (without errors*)
No problem for repetitive tasks
Dificulties to understand the context

*when they are well programmed

Representing context for machines

Example: "Oviedo has a temperature of 36"

Decomposed in:

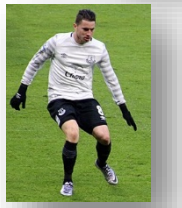
Oviedo...has a temperature of...36

Oviedo?

Oviedo, a city in Spain

Oviedo, another city in Florida, USA

Bryan Oviedo, a football player



How can we remove ambiguity?

Using URIS

https://www.oviedo.es/

https://www.cityofoviedo.net/

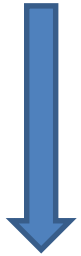
https://twitter.com/bryan_oviedo

Representing context for machines

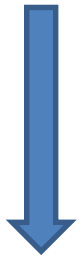
Example: "Oviedo has a temperature of 36"

Decomposed in:

Oviedo...has a temperature of...36



...has a temperature of... http://example.org/hasTemperature



Is there an existing URI
for "hasTemperature" property?

http://purl.obolibrary.org/obo/PATO_0000146

Representing context for machines

Example: "Oviedo has a temperature of 36"

Decomposed in:

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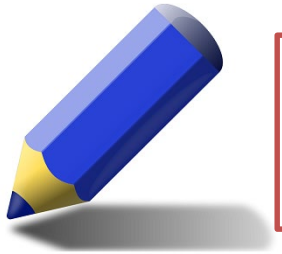


Is the previous representation accurate enough?
- Identify some problems about the previous definition...
- Identify several possibilities to improve that representation

RDF

RDF = Resource description framework

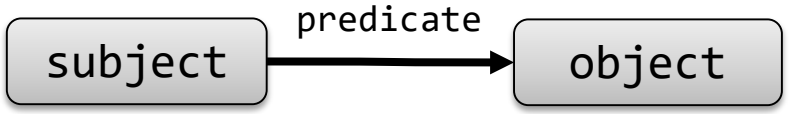
Based on triples and URIs to represent properties and nodes

Short history

- Around 1997 - PICS, Dublin core, Meta Content Framework
- 1997 1st Working draft https://www.w3.org/TR/WD-rdf-syntax-971002, RDF/XML
- 1999 1st W3C Rec https://www.w3.org/TR/1999/REC-rdf-syntax-19990222/, XML Syntax, first applications RSS, EARL
- 2004 - RDF Revised https://www.w3.org/TR/2004/REC-rdf-concepts-20040210/, SPARQL, Turtle, Linked Data
- 2014 - RDF 1.1 https://www.w3.org/TR/rdf11-concepts/, SPARQL 1.1, JSON-LD

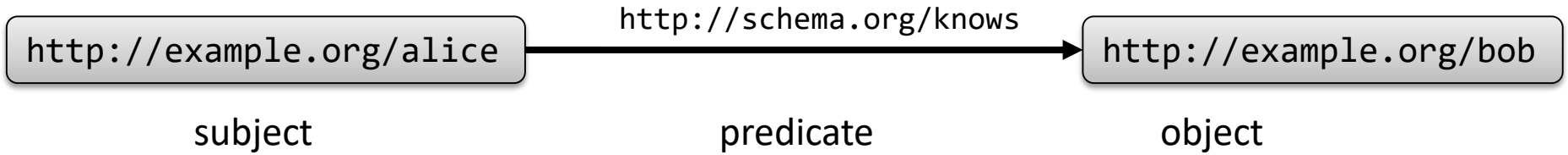
RDF Data Model

RDF is made from statements



Statment = a triple (subject, predicate, object)

Example:



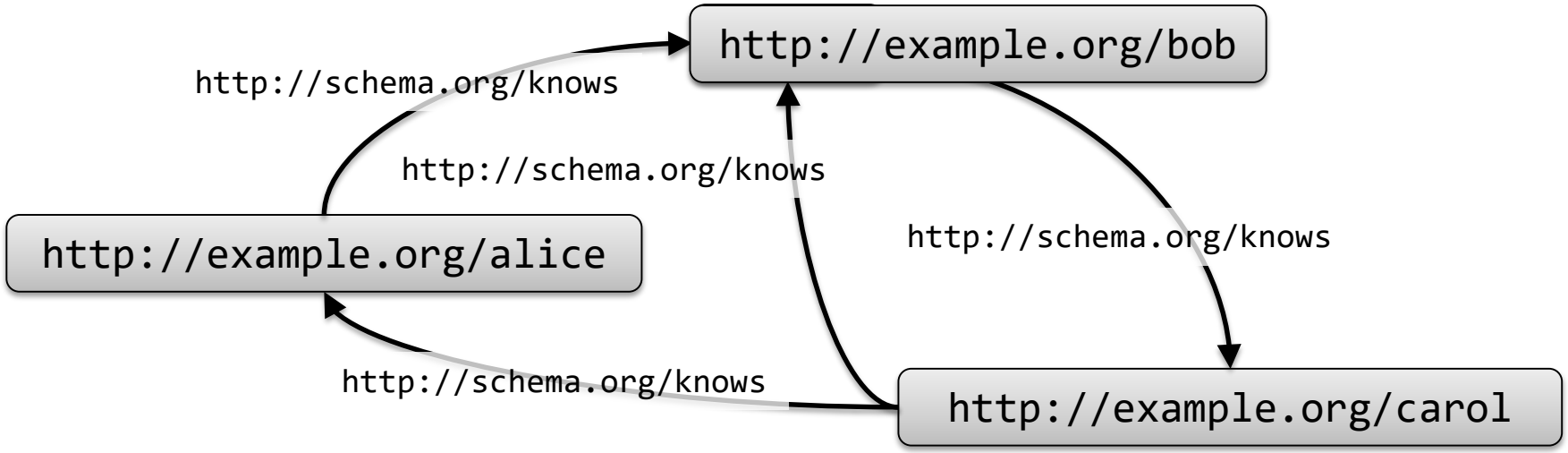
N-Triples representation

```
<http://example.org/alice> <http://schema.org/knows> <http://example.org/bob> .
```

Set of statements = RDF graph

RDF data model = directed graph

Example:



N-triples representation

```
<http://example.org/alice>   <http://schema.org/knows>   <http://example.org/bob> .
<http://example.org/bob>     <http://schema.org/knows>   <http://example.org/carol> .
<http://example.org/carol>   <http://schema.org/knows>   <http://example.org/alice> .
<http://example.org/carol>   <http://schema.org/knows>   <http://example.org/bob> .
```

subject predicate object

Turtle notation

Human readable notation that simplifies N-Triples

Allows namespace declarations

N-Triples

```
<http://example.org/alice>  <http://schema.org/knows>  <http://example.org/bob> .
<http://example.org/bob>    <http://schema.org/knows>  <http://example.org/carol> .
<http://example.org/carol>  <http://schema.org/knows>  <http://example.org/alice> .
<http://example.org/carol>  <http://schema.org/knows>  <http://example.org/bob> .
```

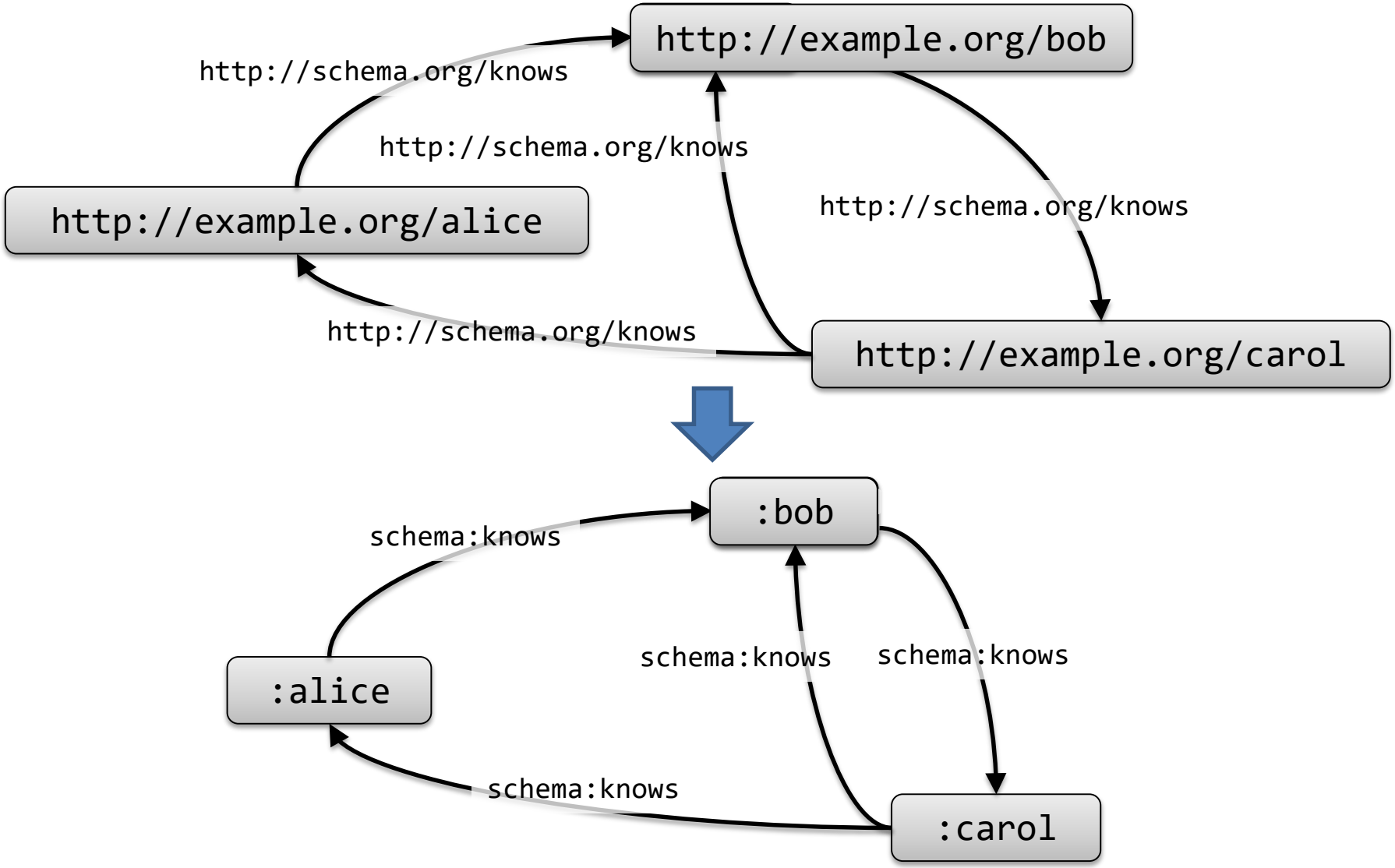
Turtle

```
prefix :       <http://example.org/>
prefix schema: <http://schema.org/>

:alice schema:knows :bob .
:bob   schema:knows :carol .
:carol schema:knows :bob .
:carol schema:knows :alice .
```

Note:
We will see later other Turtle simplifications

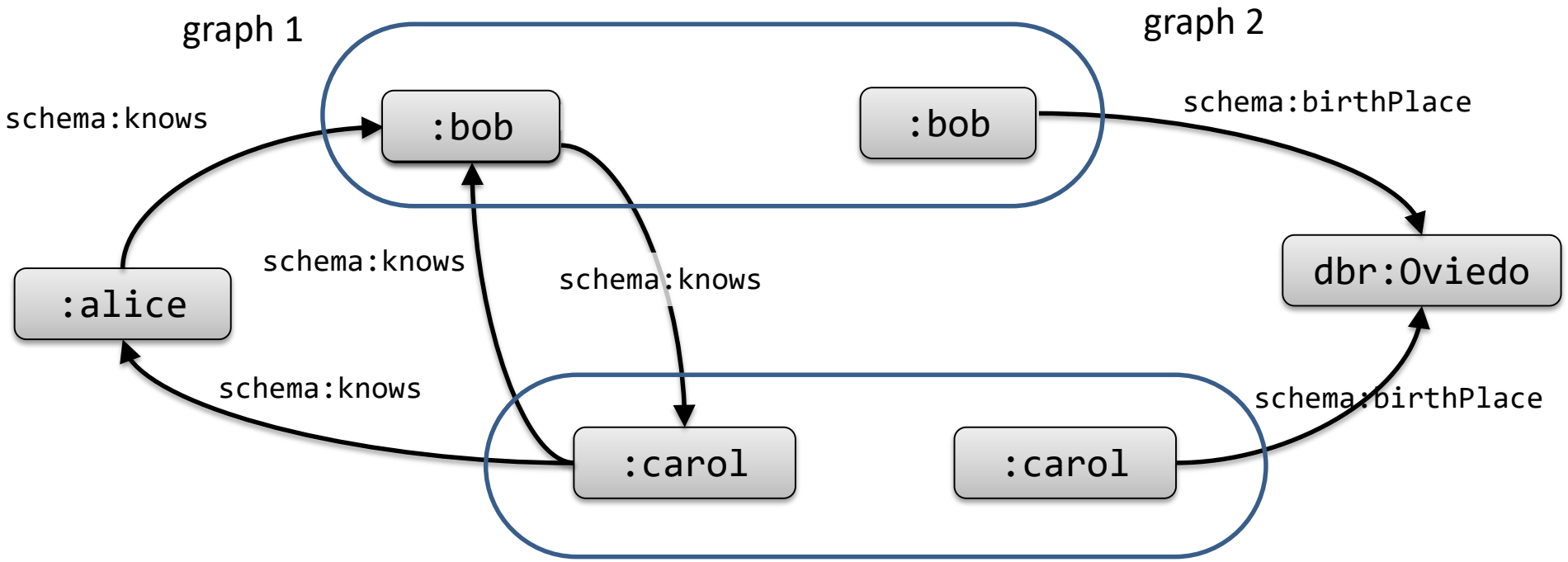
Namespaces simplification



RDF is compositional

RDF graphs can be merged to obtain a bigger graph

Automatic data integration



RDF is compositional

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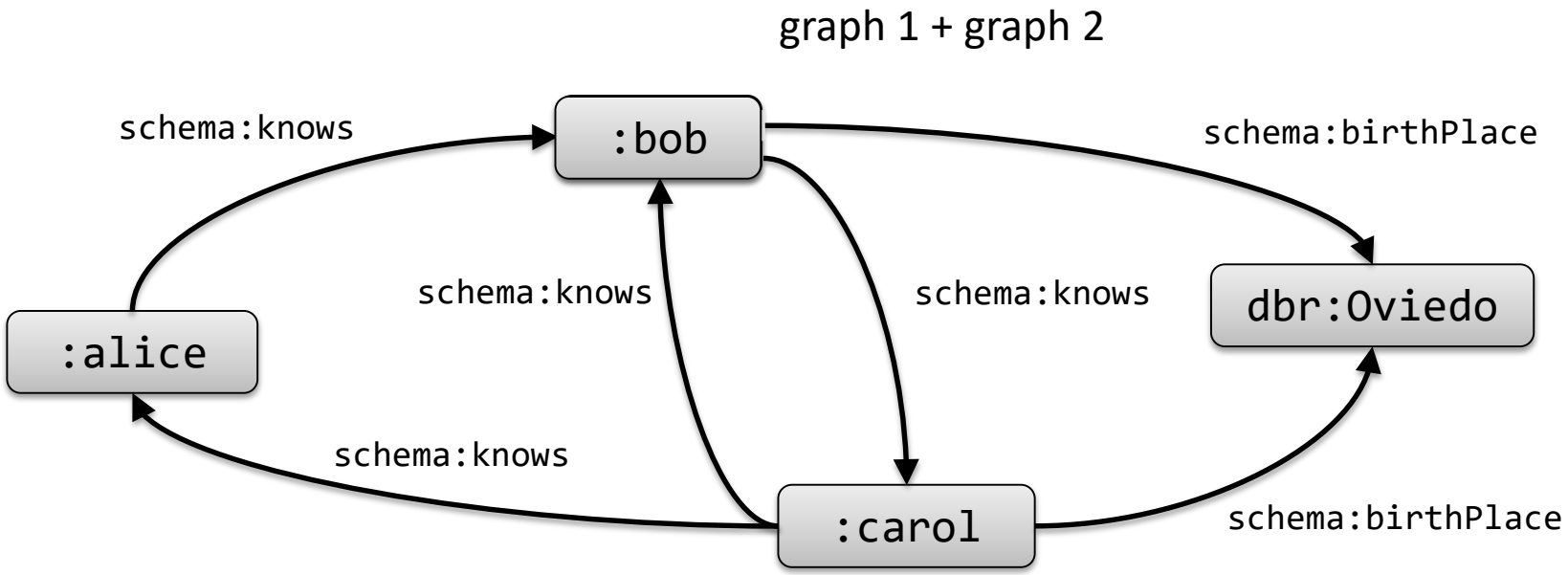
Automatic data integration



Turtle syntax

Some simplifications

Prefix declarations

; when triples share the subject

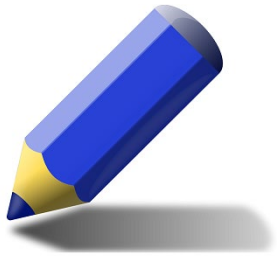
```
:alice schema:birthPlace dbr:Oviedo .
:alice schema:knows      :bob .
```

```
:alice schema:birthPlace dbr:Oviedo ;
       schema:knows      :bob .
```

, when triples share subject and object

```
:carol  schema:knows      :alice .
:carol  schema:knows      :bob .
```

```
:carol schema:knows :alice, :bob .
```



Turtle syntax

Exercise: simplify

```
prefix :       <http://example.org/>
prefix schema: <http://schema.org/>
prefix dbr:    <http://dbpedia.org/resource>


:alice schema:knows      :bob .
:bob   schema:knows      :carol .
:carol schema:knows      :bob .
:carol schema:knows      :alice .
:bob   schema:birthPlace dbr:Spain .
:carol schema:birthPlace dbr:Spain .
```

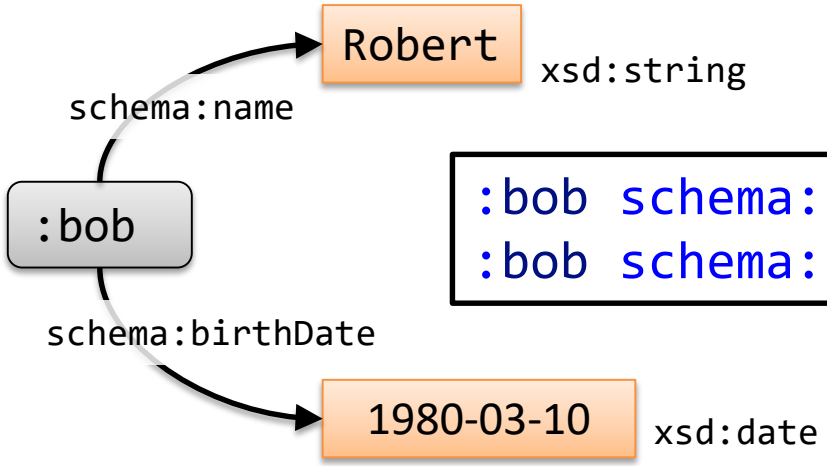
```
prefix ex:     <http://example.org/>
prefix schema: <http://schema.org/>
prefix dbr:    <http://dbpedia.org/resource>

:alice schema:knows      :bob , :carol.
:bob   schema:knows      :carol ;
       schema:birthPlace dbr:Spain .
:carol schema:knows      :bob, :alice ;
       schema:birthPlace dbr:Spain .
```

Try it: https://tinyurl.com/y9wbdycp

RDF Literals

- Objects can also be literals
  - Literals contain a lexical form and a datatype
  - Typical datatypes = XML Schema primitive datatypes
    - If not specified, a literal has datatype `xsd:string`

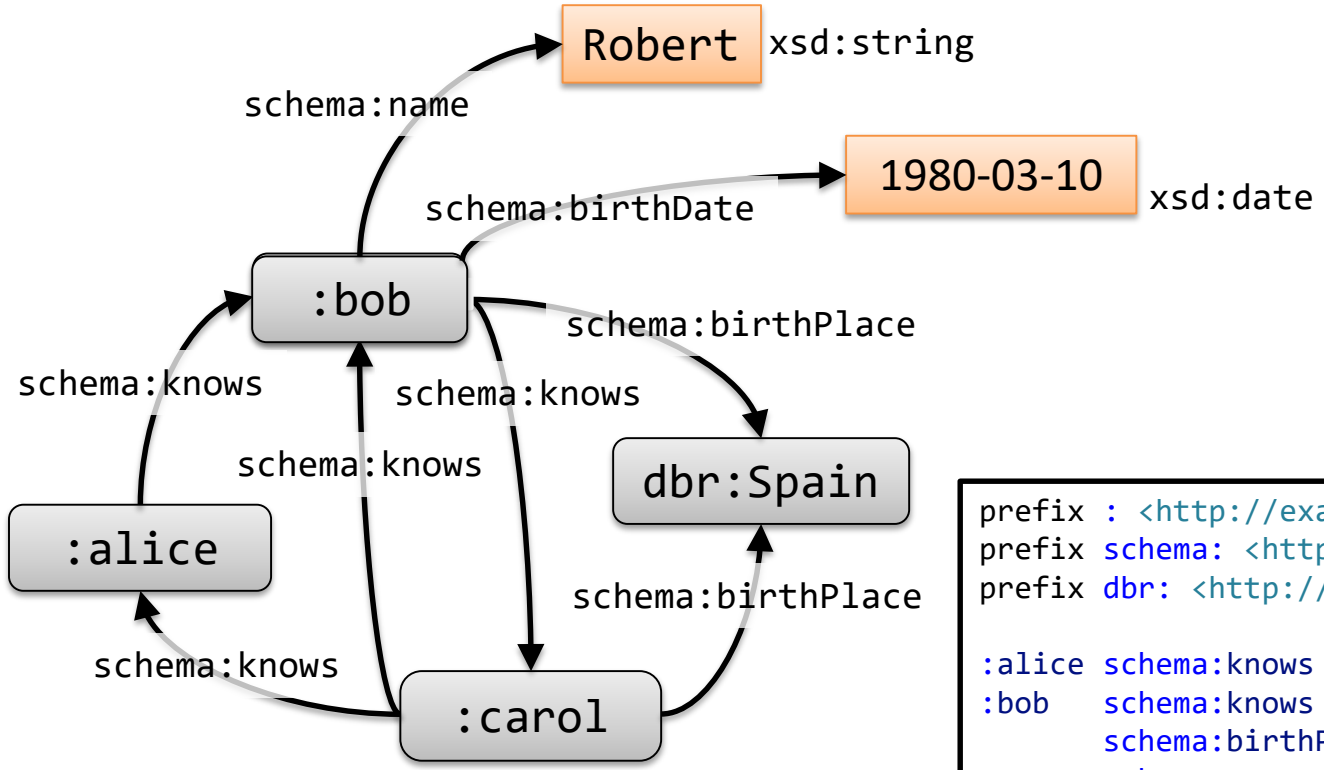


Turtle notation

```
:bob schema:name       "Robert" ;
:bob schema:birthDate "1980-03-10"^^<xsd:date>.
```

Remember...RDF is compositional

Merging previous data

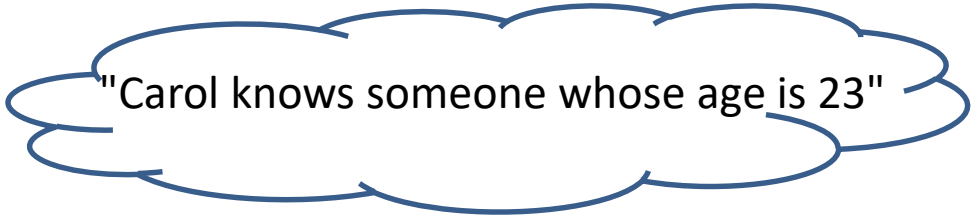



```
prefix : <http://example.org/>
prefix schema: <http://schema.org/>
prefix dbr: <http://dbpedia.org/resource>

:alice schema:knows      :bob , :carol.
:bob   schema:knows      :carol ;
       schema:birthPlace dbr:Spain;
       schema:name       "Robert";
       schema:birthDate  "1980-03-10"^^<xsd:date>.
:carol schema:knows      :bob, :alice ;
       schema:birthPlace dbr:Spain .
```

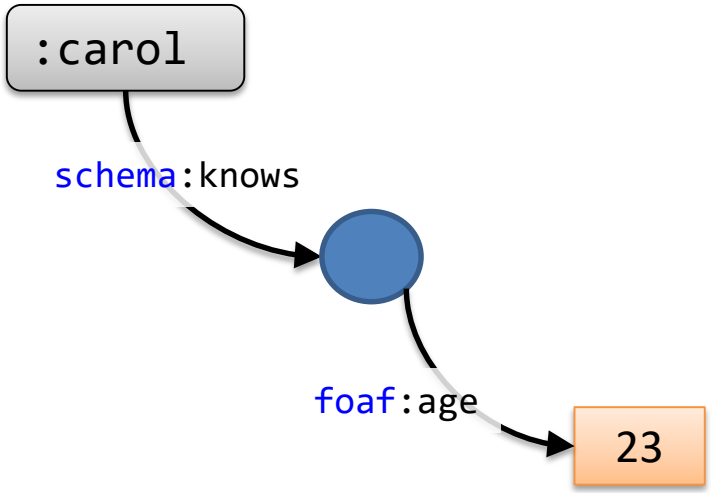
Blank nodes

Subjects and objects can also be Blank nodes



Turtle notation with local identifier

```
:carol schema:knows    _:x .
_:x    foaf:age        23 .
```



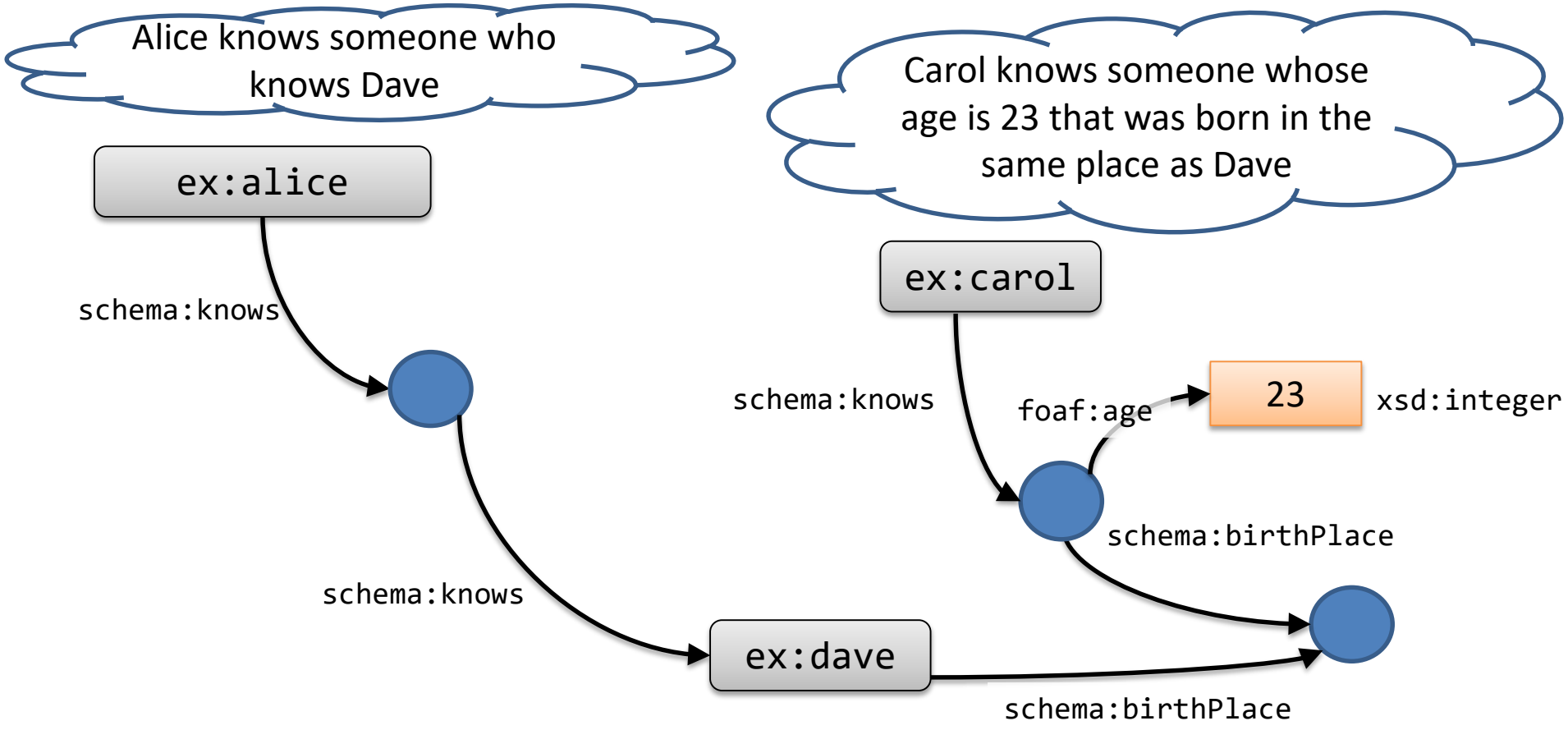
Turtle notation with square brackets

```
:carol schema:knows [foaf:age 23 ] .
```

Mathematical meaning:

$\exists x(\text{schema:knows}(\text{:carol}, x) \wedge \text{foaf:age}(x, 23))$

Blank nodes

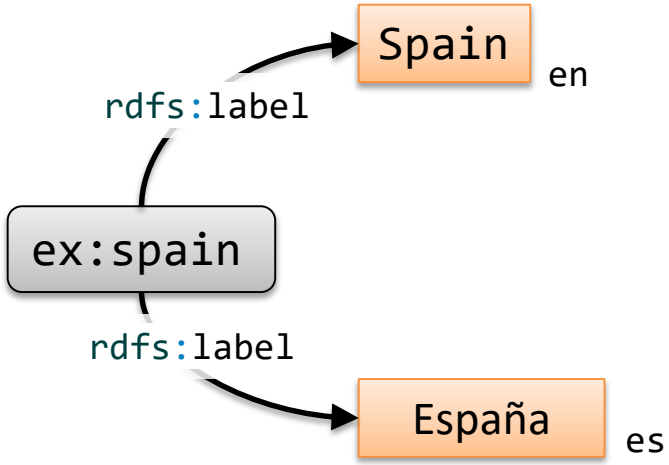



```
:alice schema:knows      [ schema:knows :dave ] .
:carol schema:knows      [ :age                23 ;
                           schema:birthPlace _:p ] .
:dave schema:birthPlace _:p .
```

Language tagged strings

String literals can be qualified by a language tag

They have datatype `rdfs:langString`

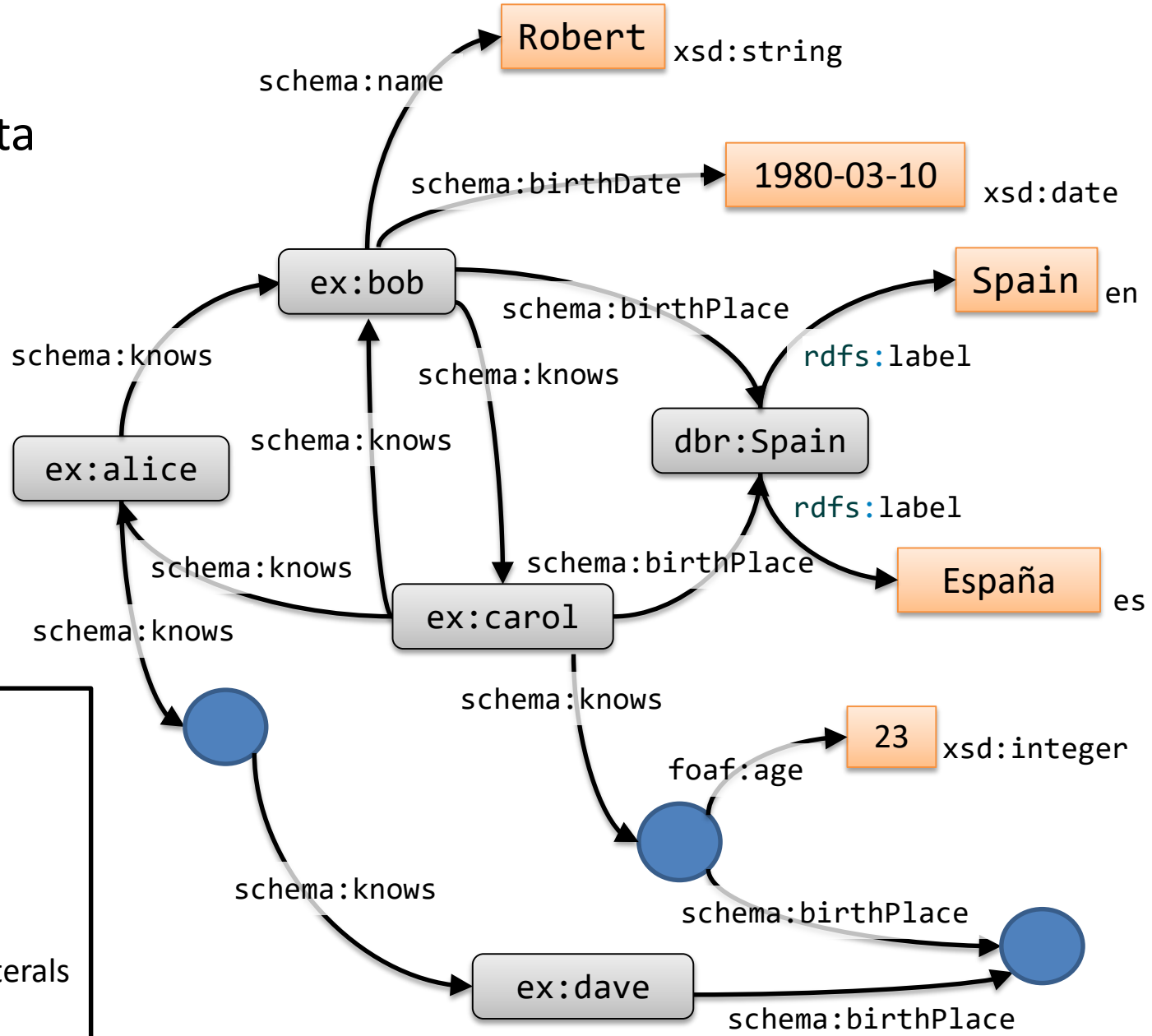


Turtle notation

```
ex:spain rdfs:label "Spain"@en .
ex:spain rdfs:label "España"@es .
```

RDF data model

Example of RDF data



3 types of nodes
- IRIs
- Blank nodes
- Literals

Subjects: URIs or Blank nodes
Objects: URIs, Blank nodes or literals
Predicates always URIs

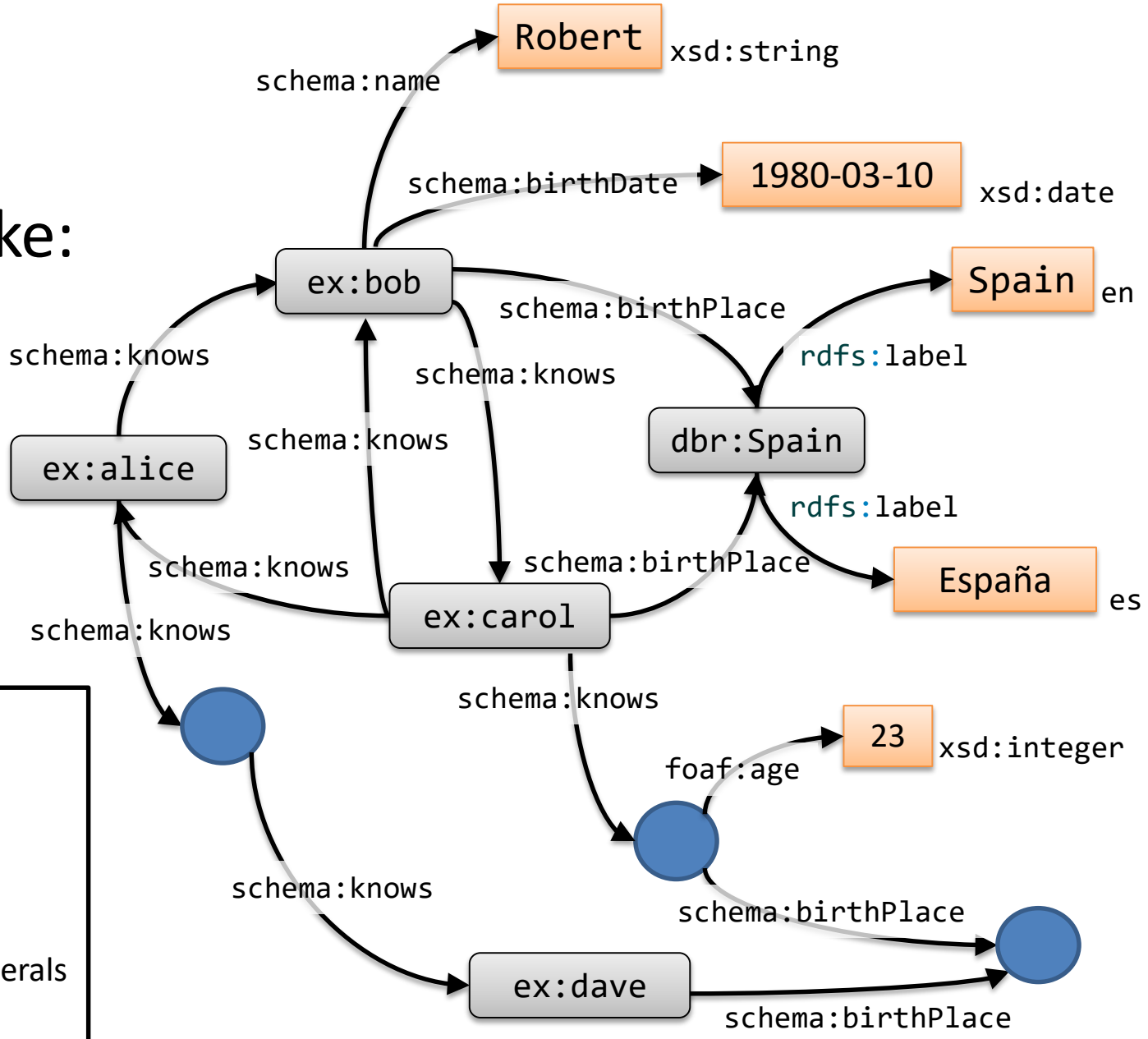
Formal definition of RDF data model

Most papers have something like:

Given a set of IRIs $\mathcal{I}$,
a set of blank nodes $\mathcal{B}$
and a set of literals Lit
an *RDF graph* is a tuple $\mathcal{G} = \langle \mathcal{S}, \mathcal{P}, \mathcal{O}, \rho \rangle$
where
$\mathcal{S} = \mathcal{I} \cup \mathcal{B}$,
$\mathcal{P} = \mathcal{I}$,
$\mathcal{O} = \mathcal{I} \cup \mathcal{B} \cup Lit$
$\rho \subseteq \mathcal{S} \times \mathcal{P} \times \mathcal{O}$

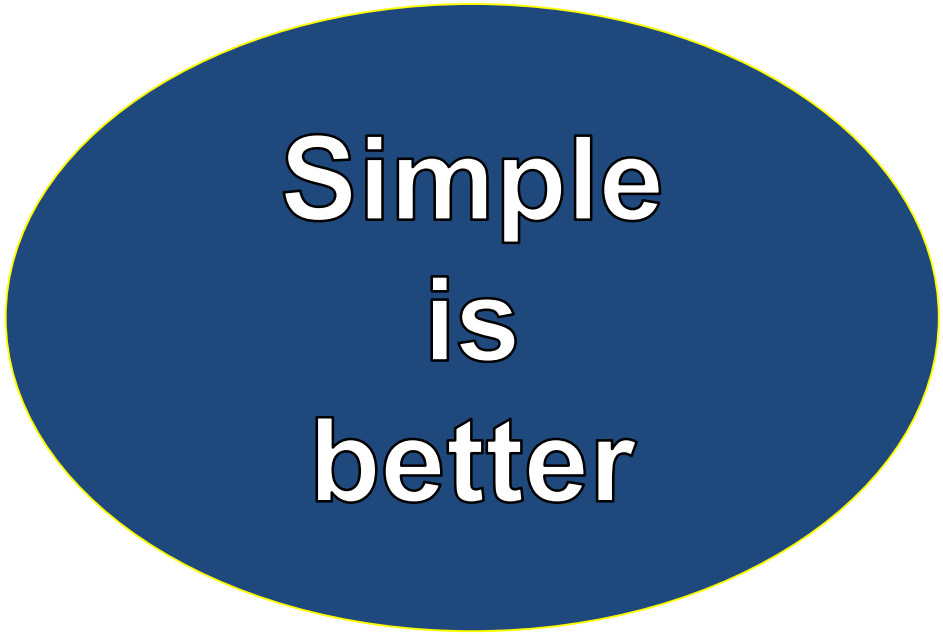
3 types of nodes
- IRIs
- Blank nodes
- Literals

Subjects: URIs or Blank nodes
Objects: URIs, Blank nodes or literals
Predicates always URIs



...and that's all about the RDF data model

The RDF Data model is very simple



RDF ecosystem

RDF Syntaxes (RDF/XML, N-Triples, Turtle, JSON-LD,...)

Shared entities, vocabularies, ontologies (RDFS, OWL, SKOS,...)

Query language (SPARQL, TripleStores...)

RDF description and validation (ShEx, SHACL)

RDF syntaxes

First syntax based on XML: RDF/XML

N-Triples (enumerates all triples separated by dots)

Turtle (human readability)

JSON-LD

...other syntaxes...

....lots of syntaxes but a unique data model

RDF/XML

First syntax

Not very popular

```
<rdf:RDF xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
         xmlns="http://example.org/"
         xmlns:schema="http://schema.org/">
<rdf:Description rdf:about="http://example.org/carol">
 <schema:knows>
  <rdf:Description rdf:about="http://example.org/bob">
   <schema:knows rdf:resource="http://example.org/carol"/>
   <schema:name>Robert</schema:name>
   <schema:birthDate rdf:datatype="xsd:date">1980-03-10</schema:birthDate>
  </rdf:Description>
 </schema:knows>
 <schema:knows>
  <rdf:Description rdf:about="http://example.org/alice">
   <schema:knows rdf:resource="http://example.org/bob"/>
   <schema:knows rdf:resource="http://example.org/carol"/>
  </rdf:Description>
 </schema:knows>
 <schema:knows rdf:parseType="Resource">
  <age rdf:datatype="http://www.w3.org/2001/XMLSchema#integer">23</age>
 </schema:knows>
 </rdf:Description>
</rdf:RDF>
```

N-Triples

For testing and easy parsing

...just triples separated by dots

```
<http://example.org/carol> <http://schema.org/knows>     <http://example.org/bob> .
<http://example.org/carol> <http://schema.org/knows>     <http://example.org/alice> .
<http://example.org/carol> <http://schema.org/knows>     _:x .
_:x                        <http://example.org/age>      "23"^^<http://www.w3.org/2001/XMLSchema#integer> .
<http://example.org/alice> <http://schema.org/knows>     <http://example.org/bob> .
<http://example.org/alice> <http://schema.org/knows>     <http://example.org/carol> .
<http://example.org/bob>   <http://schema.org/knows>     <http://example.org/carol> .
<http://example.org/bob>   <http://schema.org/name>      "Robert" .
<http://example.org/bob>   <http://schema.org/birthDate> "1980-03-10"^^<xsd:date> .
```

Turtle

Concise

Designed to be human-readable

```
prefix :       <http://example.org/>
prefix schema: <http://schema.org/>

:alice schema:knows :bob , :carol .
:bob   schema:knows :carol ;
       schema:name "Robert";
       schema:birthDate "1980-03-10"^^<xsd:date>.
:carol schema:knows :bob, :alice ;
       schema:knows [ :age 23 ] .
```

JSON-LD

Json for Linked Data

```
{
"@context" : {
"knows" : { "@id" : "http://schema.org/knows", "@type" : "@id" },
"age" : { "@id" : "http://example.org/age",
          "@type" : "http://www.w3.org/2001/XMLSchema#integer" },
"name" : { "@id" : "http://schema.org/name" },
"birthDate" : { "@id" : "http://schema.org/birthDate", "@type" : "xsd:date" },
"@vocab" : "http://example.org/",
"schema" : "http://schema.org/"
},
"@graph" : [
 { "@id" : "http://example.org/alice",
  "knows" : [ "http://example.org/bob", "http://example.org/carol" ] },
 { "@id" : "http://example.org/bob",
  "birthDate" : "1980-03-10",
  "knows" : "http://example.org/carol",
  "name" : "Robert" },
 { "@id" : "http://example.org/carol",
  "knows" : [ "http://example.org/bob", "http://example.org/alice", "_:x" ] },
 { "@id" : "_:x",
  "http://example.org/age" : 23 }
 ]
}
```

Other Turtle simplifications

RDF type property

Numbers

Collections

RDF type property

The `rdf:type` property declares the type of a resource

```
@prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>.
@prefix schema: <http://schema.org/> .

e:alice rdf:type schema:Person .
e:bob   rdf:type schema:Person .
```

`rdf:type` can be simplified as `a`

```
@prefix schema: <http://schema.org/> .

:alice a schema:Person .
:bob   a schema:Person .
```

Constants

Numbers and boolean values can be represented without quotes

They are parsed as XML Schema datatypes

Datatype	Shorthand example	Lexical example
xsd:integer	3	"3"^^xsd:integer
xsd:decimal	-3.14	"-3.14"^^xsd:decimal
xsd:double	3.14e2	"3.14e2"^^xsd:double
xsd:boolean	true	"true"^^xsd:boolean

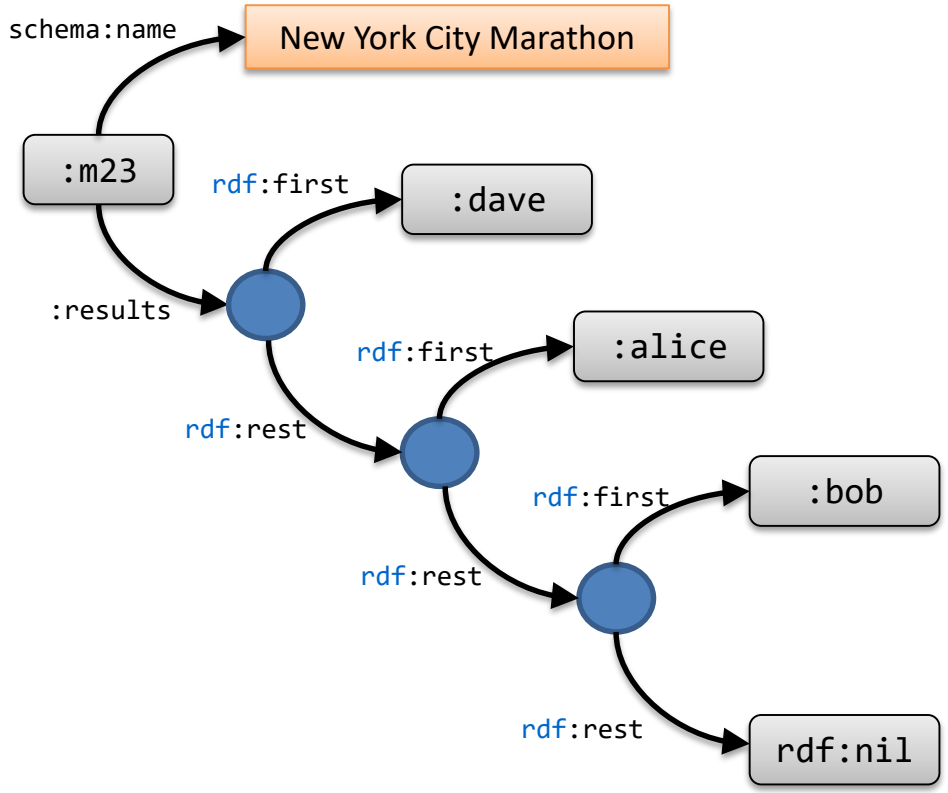
Collections

Ordered lists

```
:m23 schema:name "New York City Marathon ";
     :results    ( :dave :alice :bob ) .
```

Internally, represented as linked lists

```
:m23 schema:name "New York City Marathon ";
     :results _:1 .
_:1 rdf:first :dave ;
    rdf:rest _:2 .
_:2 rdf:first :alice ;
    rdf:rest _:3 .
_:3 rdf:first :bob ;
    rdf:rest rdf:nil .
```



SPARQL

SPARQL Protocol And RDF Query Language

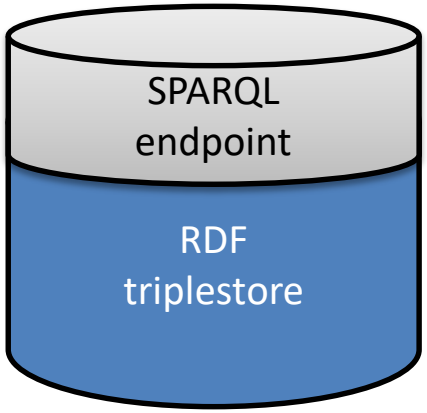
SPARQL 1.0 (2008), 1.1 (2013)

Syntax inspired by Turtle

Semantics based on graph patterns

SPARQL endpoints = services that implement SPARQL protocol

Triplestores = RDF databases

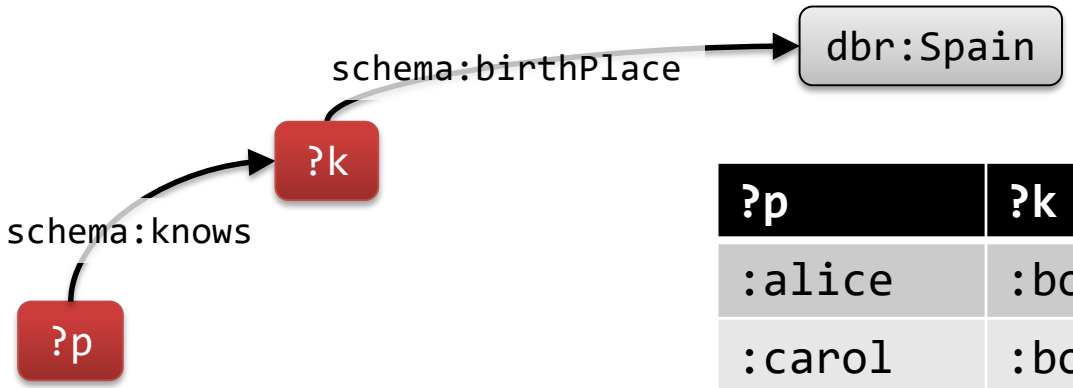


SPARQL example

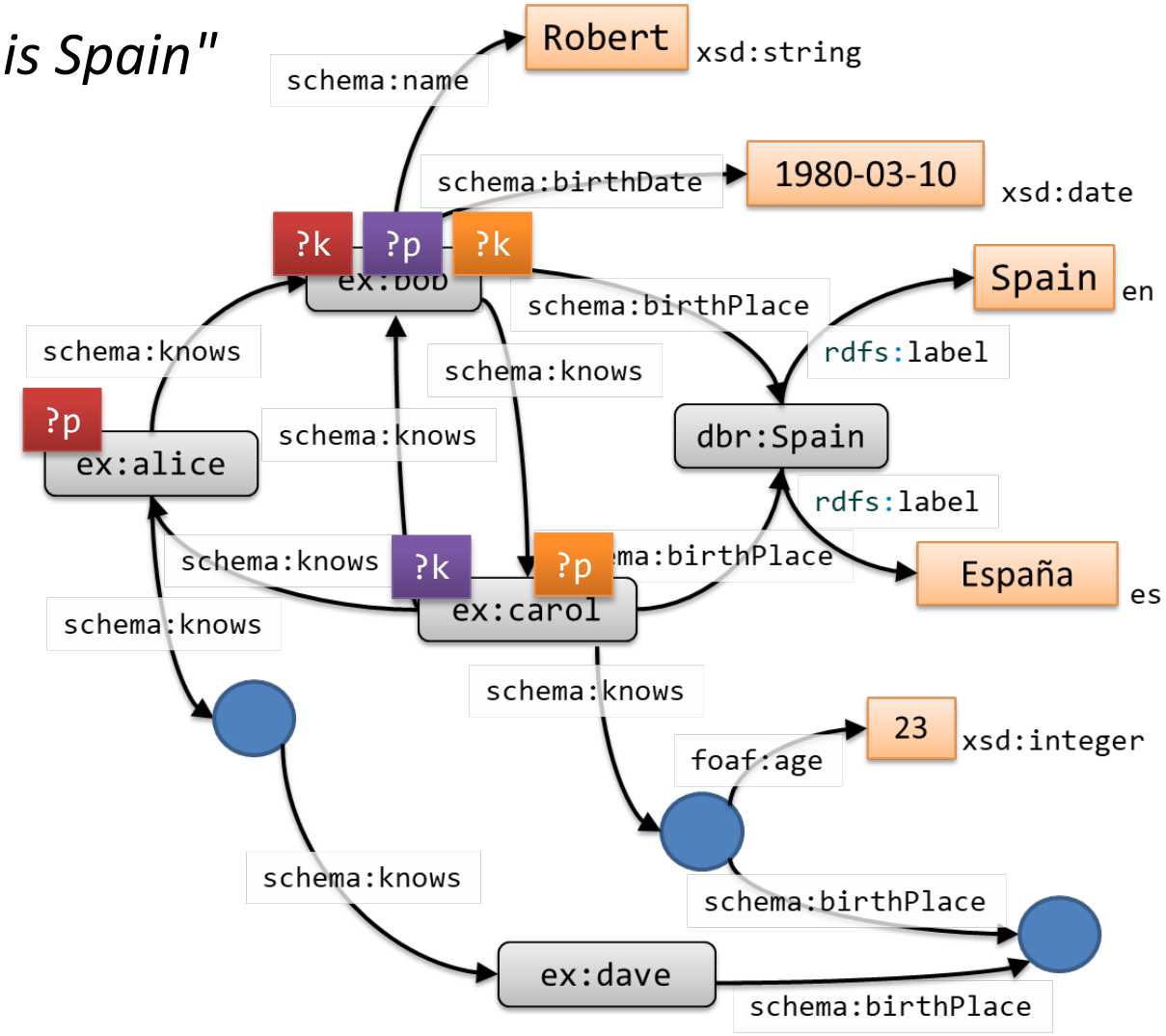
"People who knows someone whose birth place is Spain"

```
prefix schema: <http://schema.org/>
prefix dbr:    <http://dbpedia.org/resource/>

select ?p ?k where {
  ?p schema:knows      ?k  .
  ?k schema:birthPlace dbr:Spain
}
```



?p	?k
:alice	:bob
:carol	:bob
:bob	:carol



Shared entities and vocabularies

The use of URIs instead of plain strings facilitates:

- Merging data from heterogeneous sources
- Avoid ambiguity

Challenge: Agreeing on common entities and properties

Some popular vocabularies:

- schema.org: Joint effort from Google, Yahoo, Microsoft, Yandex
- Linked open vocabularies Project: http://lov.okfn.org/

Some popular vocabularies and namespaces

Alias	URL	Name	Some properties
rdf:	http://www.w3.org/1999/02/22-rdf-syntax-ns#	RDF	type, subject, predicate, object,…
rdfs:	http://www.w3.org/2000/01/rdf-schema#	RDF Schema	domain, range, Class, Property, subClassOf,…
owl:	http://www.w3.org/2002/07/owl#	OWL Ontologies	sameAs, intersectionOf, unionOf, …
dc:	http://purl.org/dc/elements/1.1/	Dublin Core	author, date, creator, …
Schema:	http://schema.org/	Schema.org	name, knows, etc.
skos:	http://www.w3.org/2008/05/skos#	SKOS	broader, narrower, …

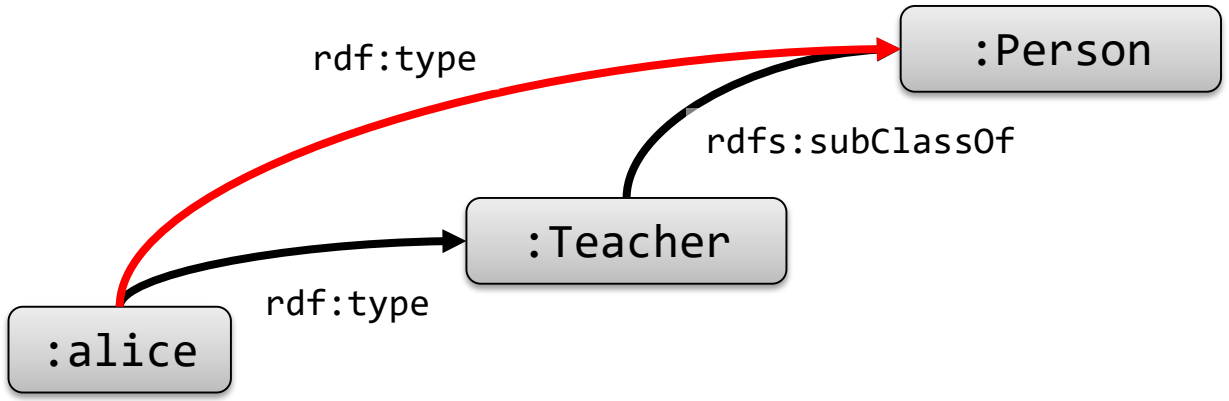
Service http://prefix.cc can be used to find the most popular prefix for some URI

The power of shared vocabularies

RDFS (Originally RDF Schema) defines common concepts

- Classes: `rdfs:Class`, `rdfs:Property`, `rdfs:Literal`
- Properties: `rdfs:domain`, `rdfs:range`, `rdfs:subClassOf`, …

RDFS processors can infer new triples



IF x `rdf:type` A AND A `rdfs:subClassOf` B
THEN x `rdf:type` B

From shared vocabularies to ontologies

OWL = Web Ontology Language.

OWL 1 (2004), OWL 2 (2009)

Based on description logics

Describe classes, properties, individuals and their relationships

Highly expressive and powerful inference mechanism

OWL example

Simple ontology, Terminological part (TBox)

$$Person \sqsubseteq = 2\, hasParent$$
$$Person \sqsubseteq \exists\, hasParent\, Male$$
$$Person \sqsubseteq \exists\, hasParent\, Female$$

$$Male \sqsubseteq \neg Female$$
$$Female \sqsubseteq \neg Male$$

```
:Person rdf:type owl:Class ;
 rdfs:subClassOf [
  rdf:type owl:Restriction ;
  owl:onProperty :hasParent ; owl:cardinality 2
 ], [
 rdf:type owl:Restriction ;
 owl:onProperty :hasParent ; owl:someValuesFrom :Male
 ], [
 rdf:type owl:Restriction ;
 owl:onProperty :hasParent ; owl:someValuesFrom :Female
 ] .

:Female owl:disjointWith :Male .
```

Instance data, assertional part = ABox

$$Person(alice)$$
$$hasParent(alice, bob)$$
$$hasParent(alice, carol)$$
$$Female(carol)$$

```
:alice rdf:type :Person ;
 :hasParent :bob,
            :carol .
:carol rdf:type :Female .
```

Inferred data

$$Male(bob)$$

```
:bob rdf:type :Male .
```

The example is not complete... what is missing?

We need to declare that :bob ≠ :carol

```
[ rdf:type owl:AllDifferent ;
  owl:distinctMembers ( :bob
                        :carol
                      ) ] .
```

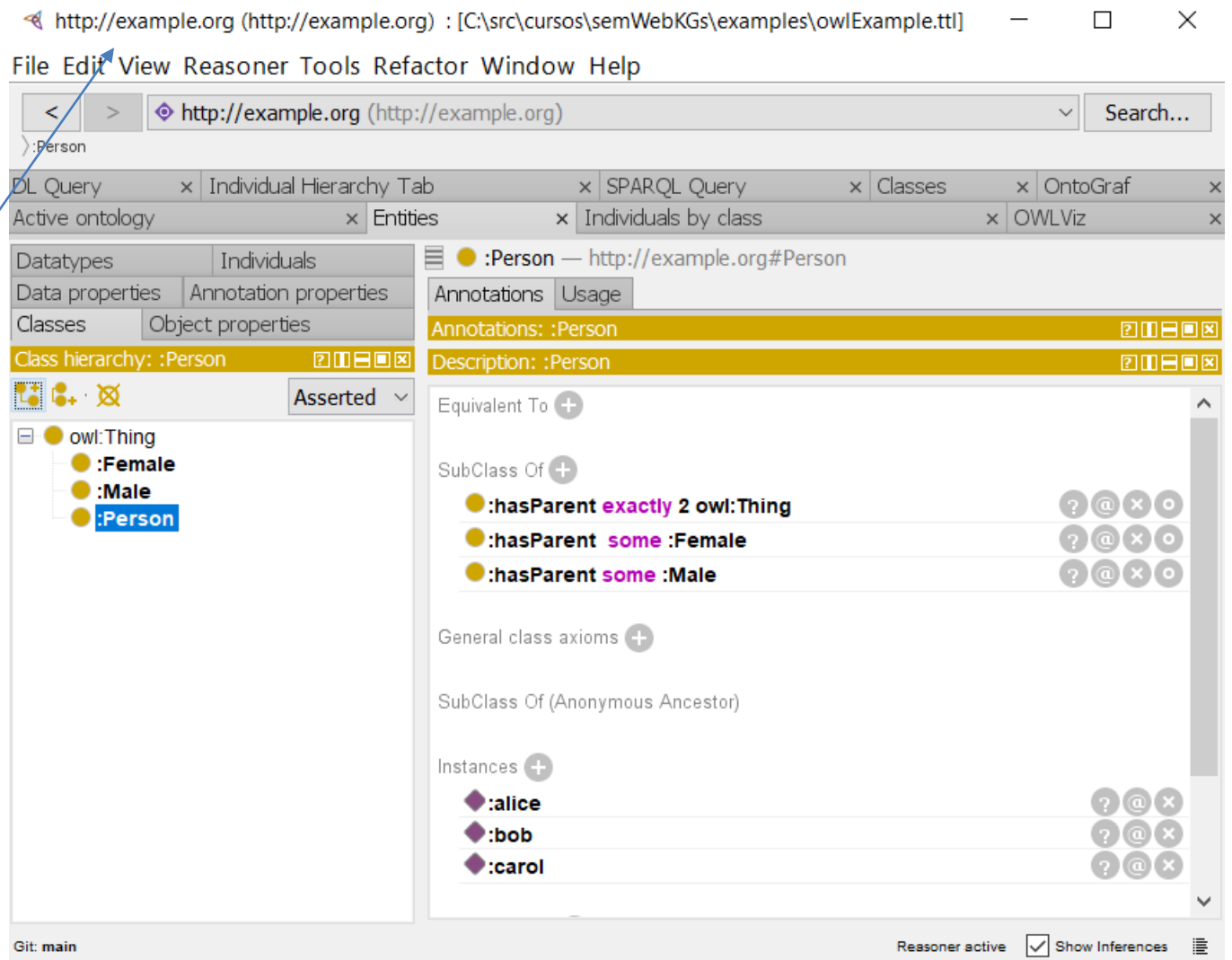
OWL

OWL = language to describe ontologies

Different kinds of ontologies:

- Upper level ontologies (SUMO, BFO, ...)
- Domain specific ontologies

Ontology editors like [Protégé editor]



Ontology concepts have a URI
They can be defined/stored in local files
How should we publish them?

Linked Data

Principles proposed by Tim Berners-Lee to publish data*:

1. Use URIs to denote things
2. Use HTTP URIs so that people can look up those names
3. When someone looks up a URI, provide useful information, using the standards (RDF, SPARQL)
4. Include links to other URIs. so that they can discover more things

* https://www.w3.org/DesignIssues/LinkedData.html

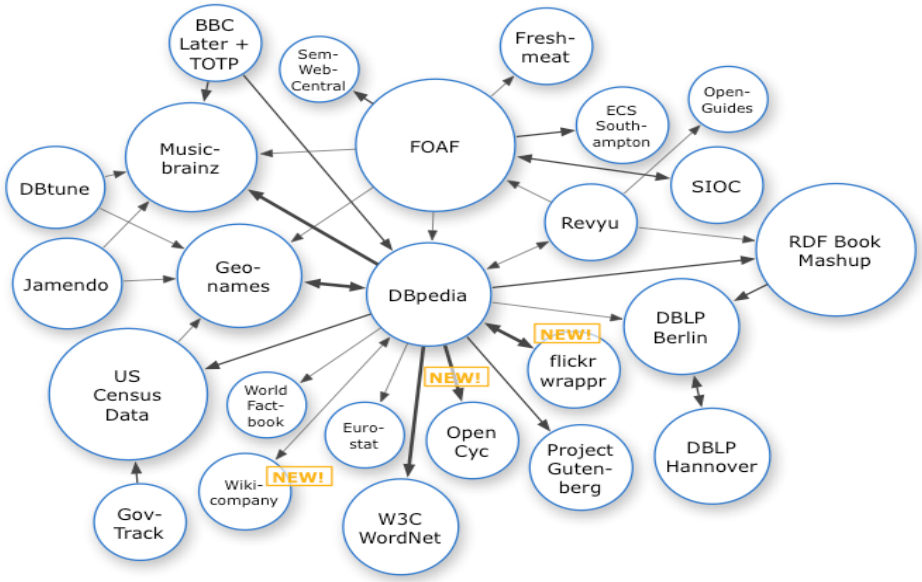
Why Linked data?

Best practices to publish data on the Web

To avoid the use of URIs as plain identifiers

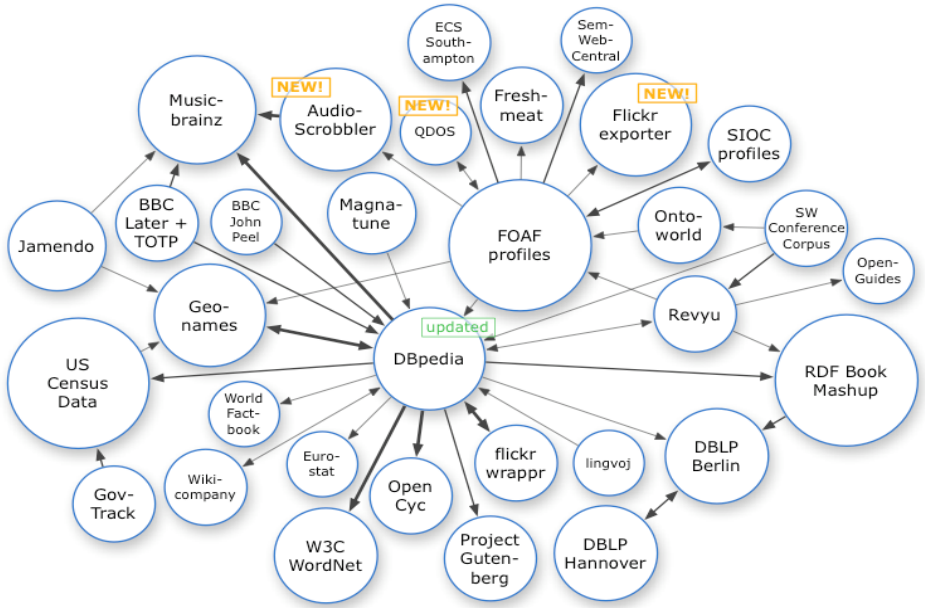
- A pattern very common when designing OWL ontologies
- URIs were mainly used as identifiers
- When dereferencing such URIs no useful information was retrieved
- It was breaking the idea of the web as an interlinked space

LOD (2007)



Evolución: https://lod-cloud.net/

LOD (2008)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Sem-Web-Central
Music-brainz
NEW!
Audio-Scrobbler
NEW!
QDOS
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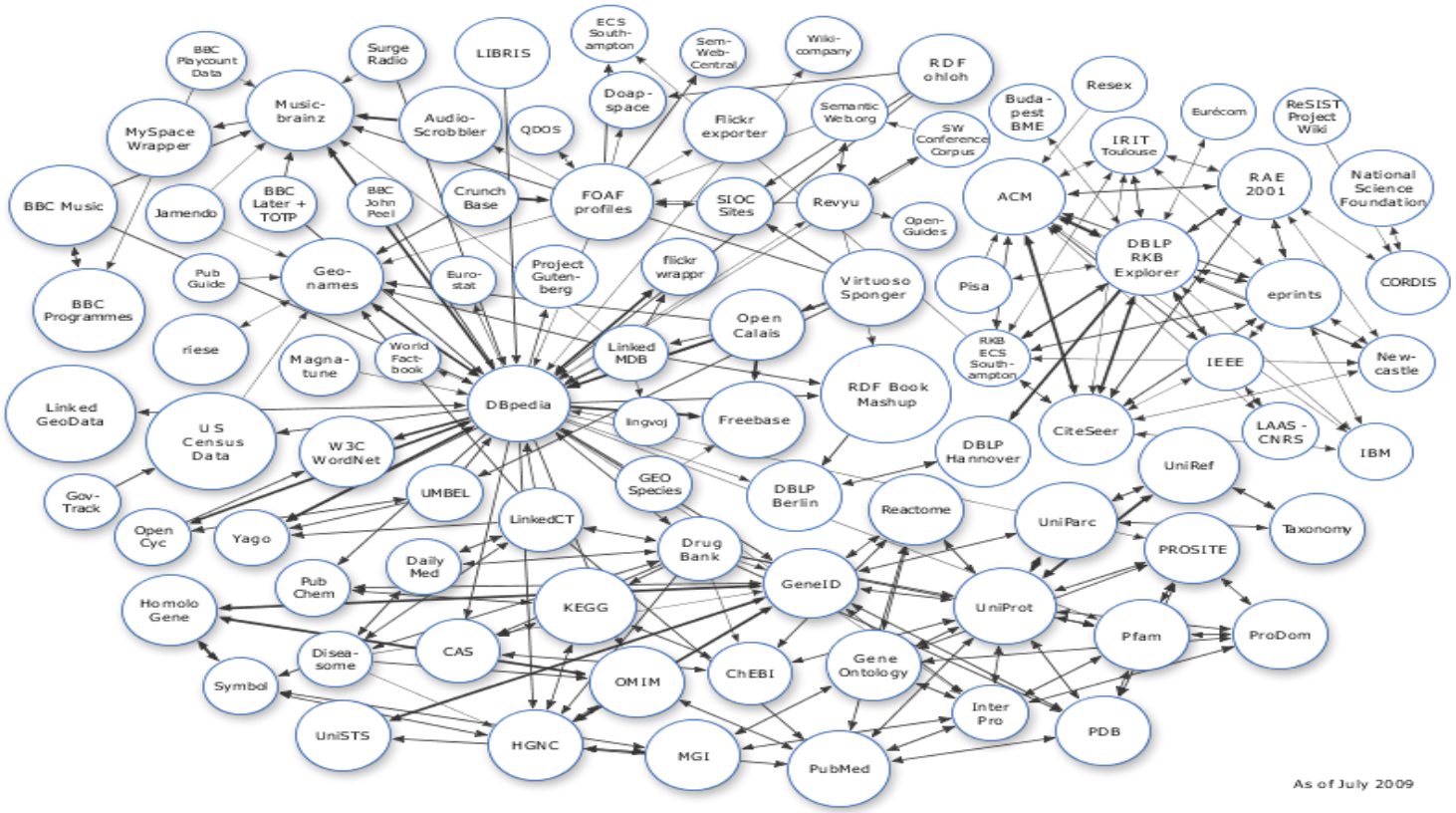
LOD (2009)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Open Cyc
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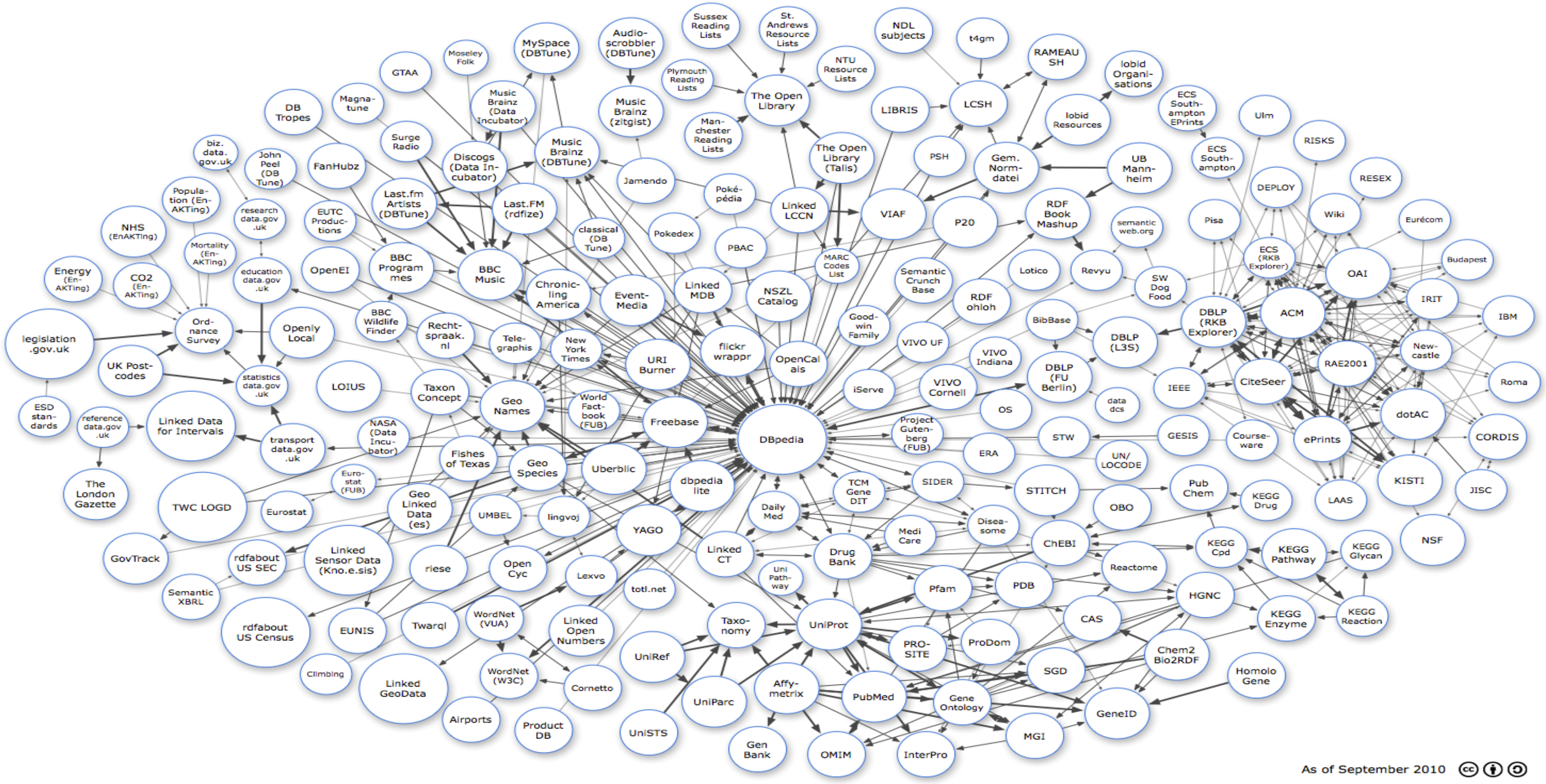
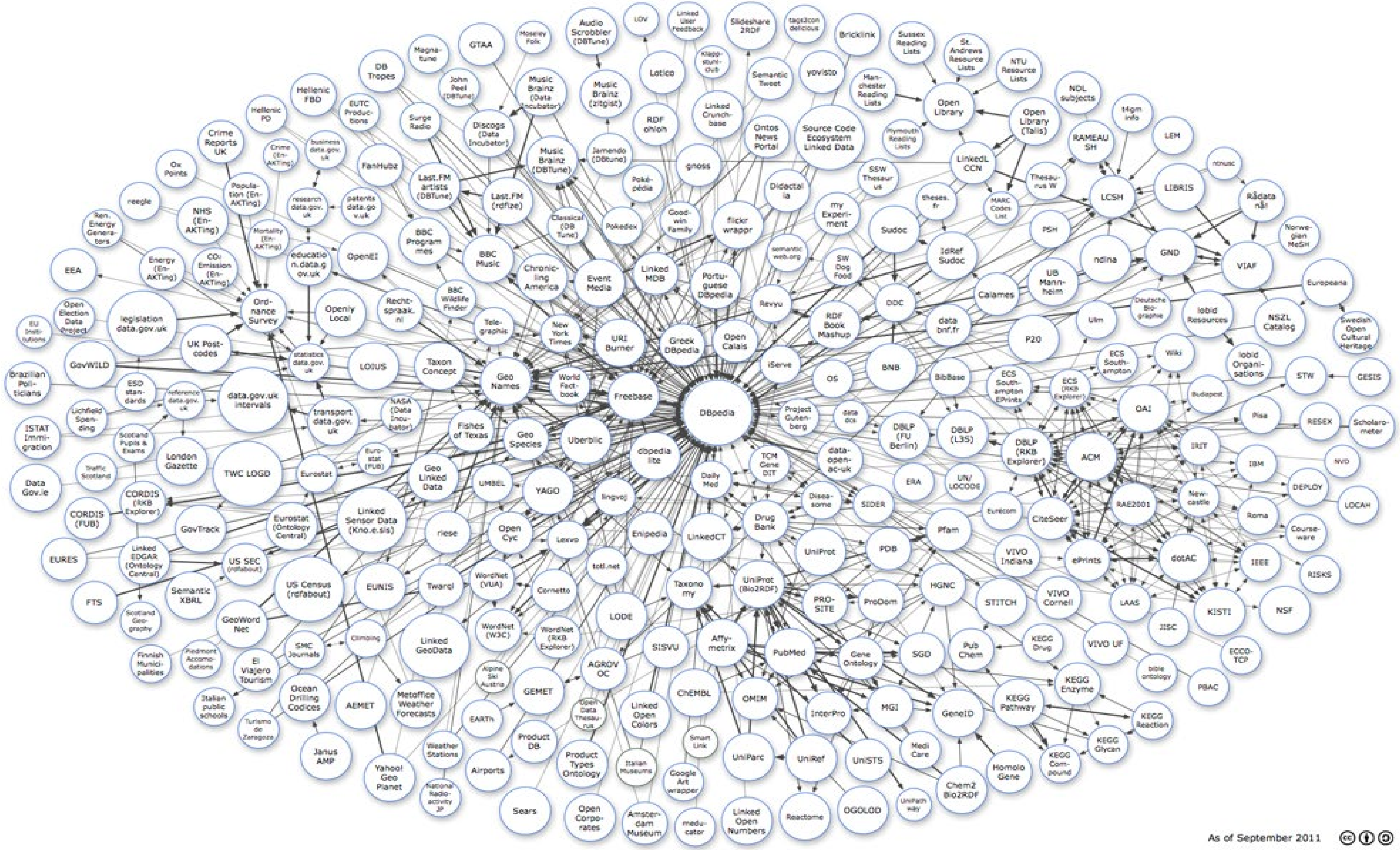
As of July 2009

LOD (2010)

WESO



LOD (2011)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YAGO
Uberblic
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Taxon Concept
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Eurostat
US SEC (rdfabout)
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EEA
Ordnance Survey
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OpenEI
London Gazette
Crime Reports UK
Hellenic FBD
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Flickr wrappr
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STW
GESIS
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Roma
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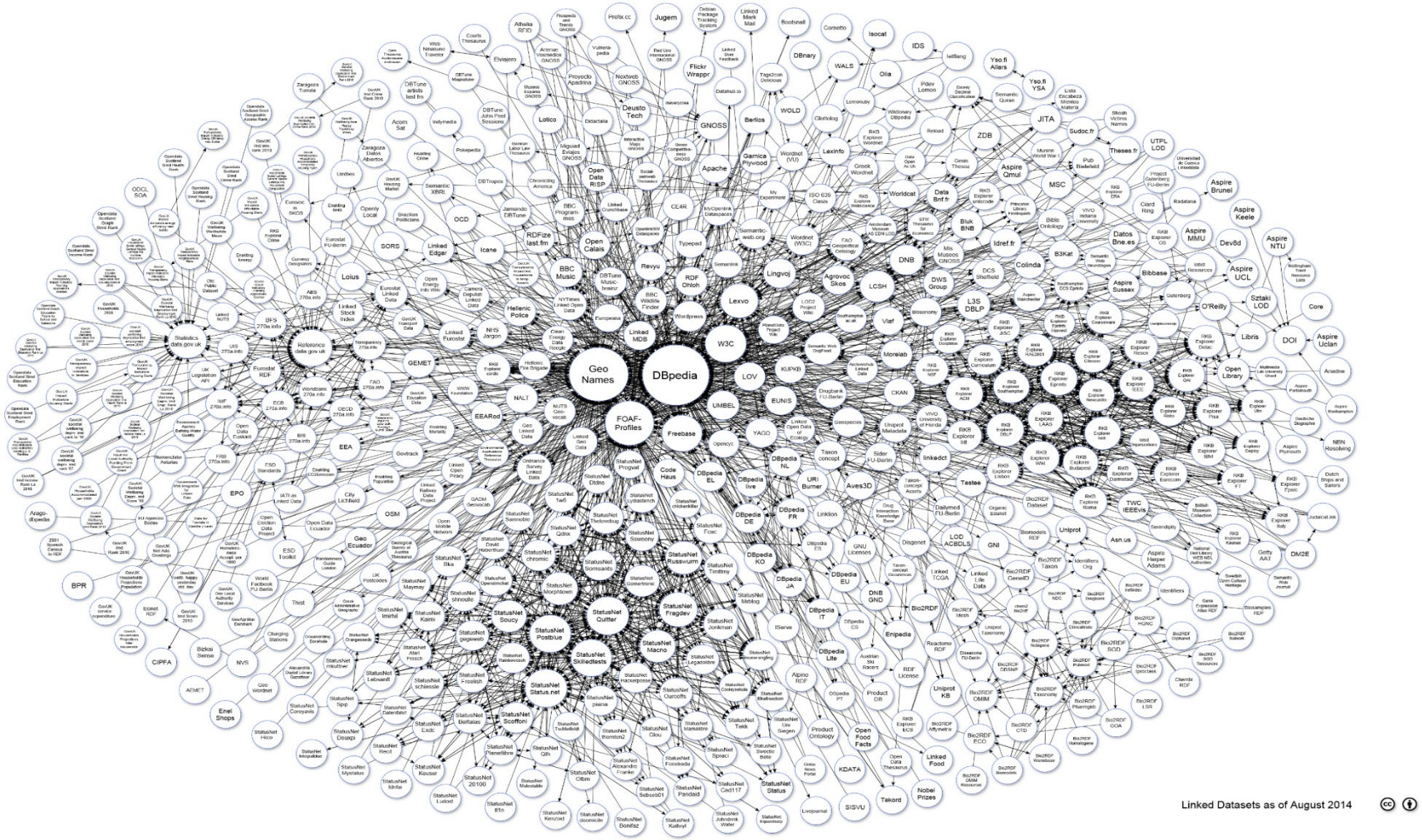
As of September 2011

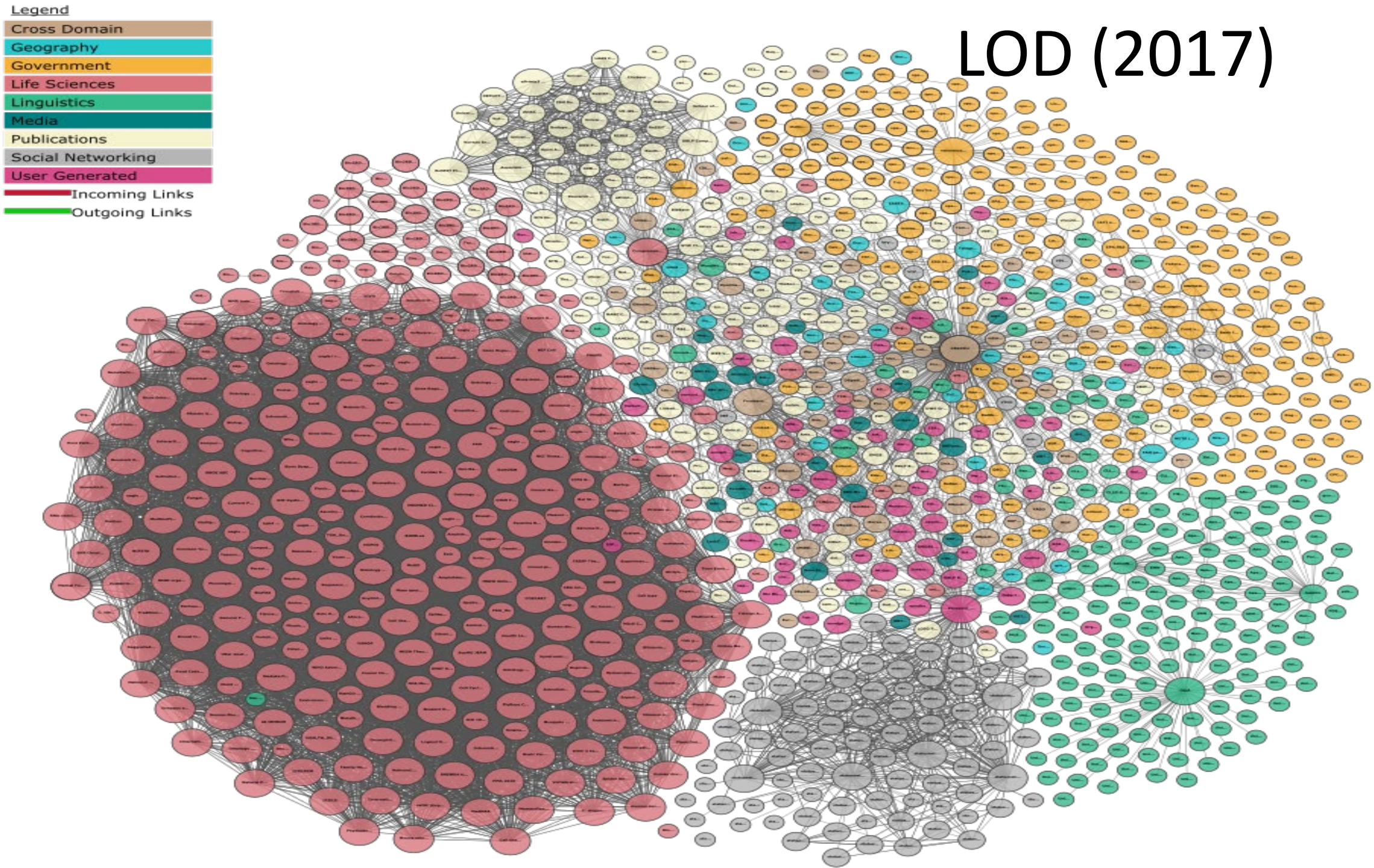
LOD (2014)

WESO

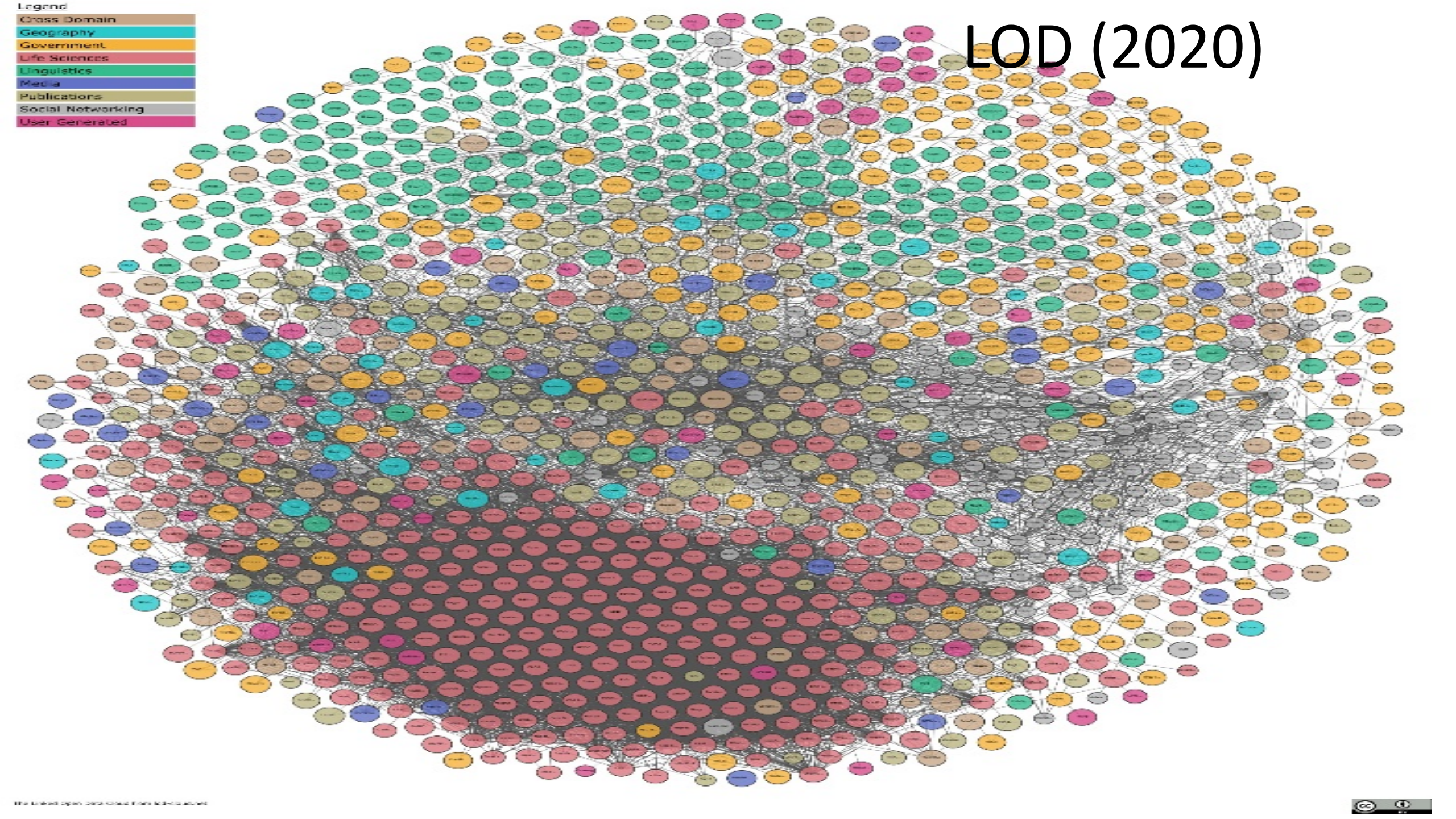


LOD (2017)

WESO



LOD (2020)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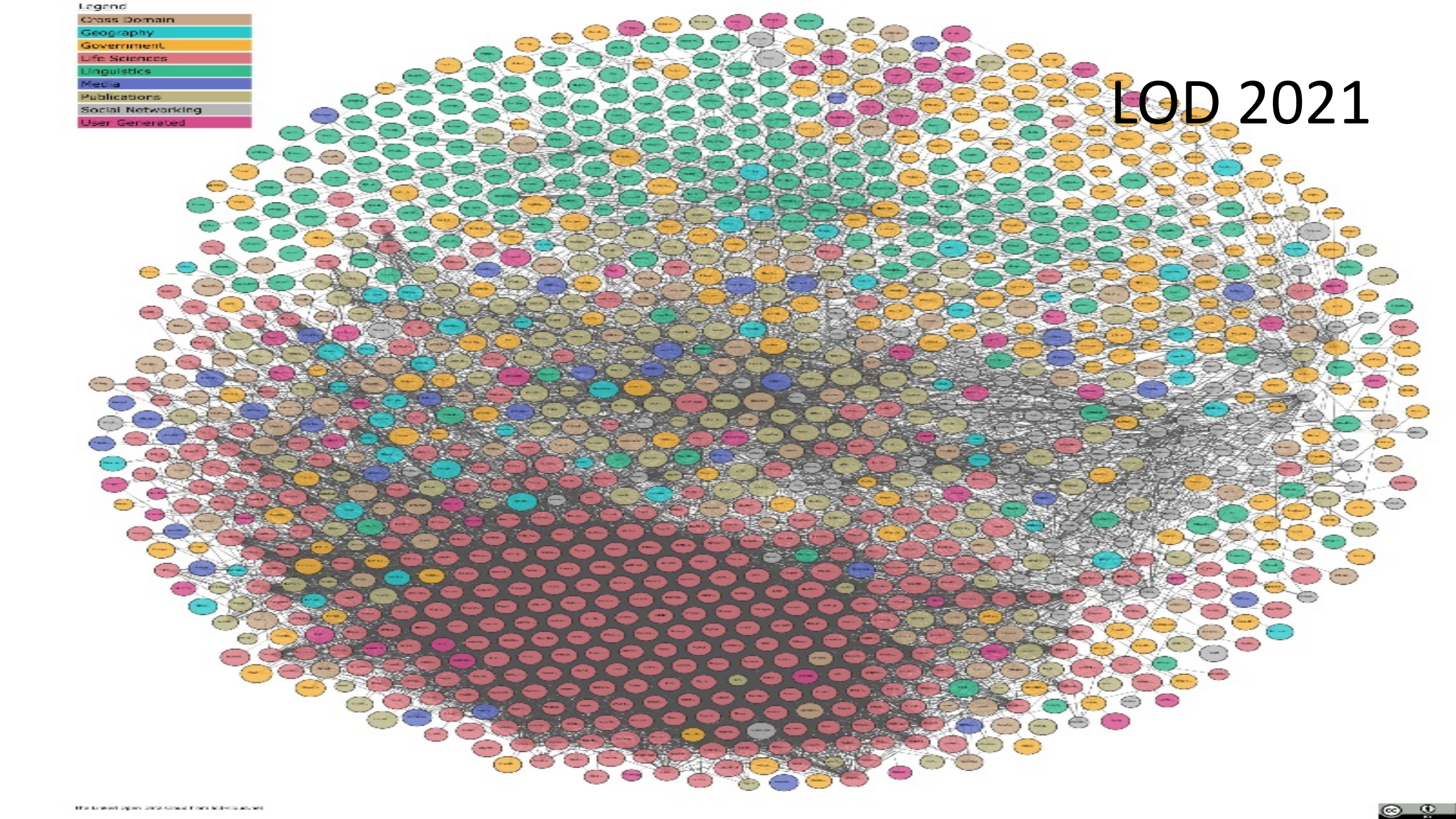
Life Sciences
Linguistics
Media
Publications
Social Networking
User Generated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LOD 2021

Knowledge Graphs

Knowledge graph = a **graph of data** intended to represent knowledge about some domain

- Nodes represent entities of interest
- Edges represent relations between these entities

Popularized by Google in 2012

Different types of knowledge graphs models

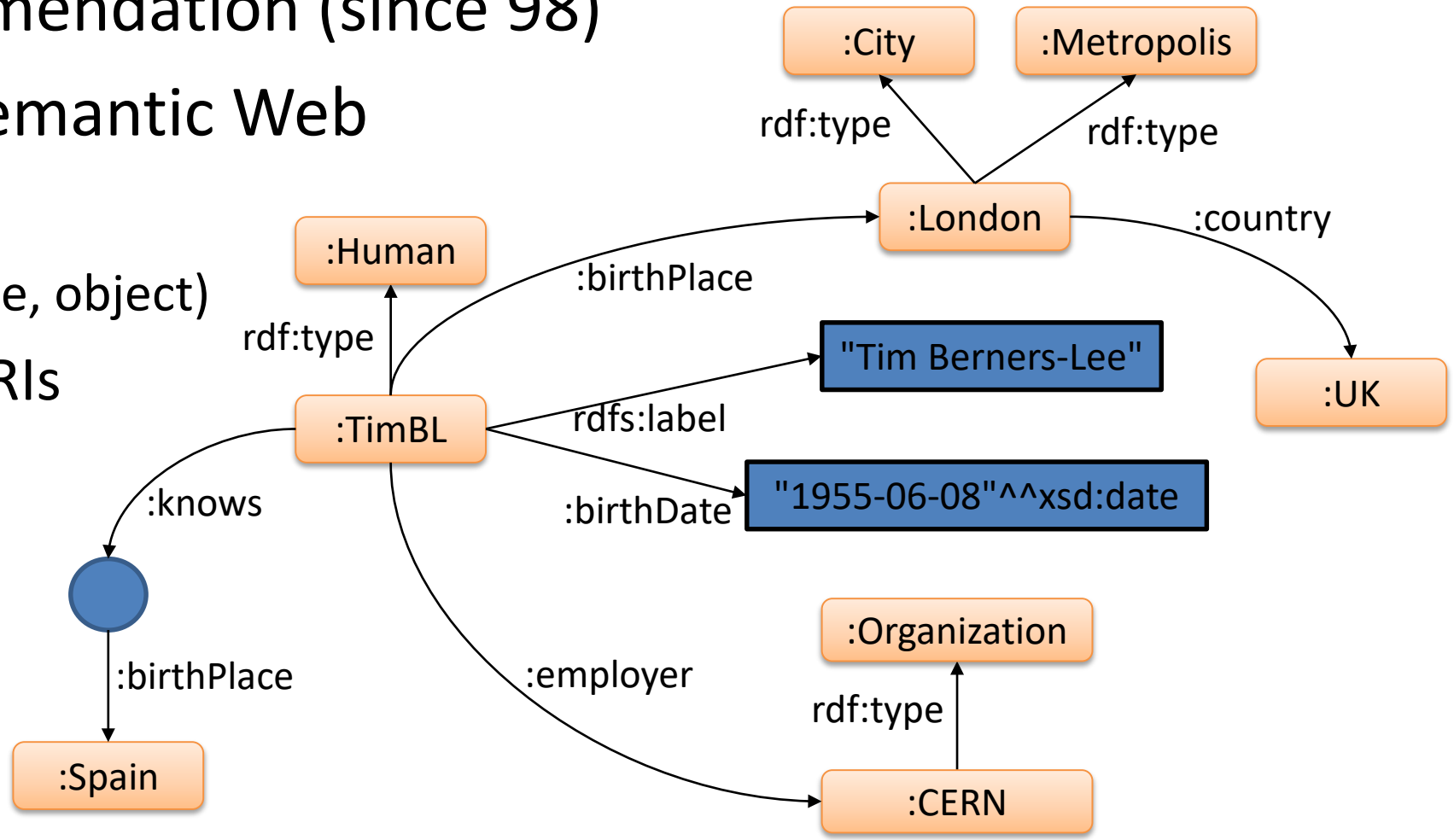
- RDF based
- Property graphs
- Wikibase graphs

RDF graphs

RDF = W3C recommendation (since 98)

Lingua franca of Semantic Web

- Based on triples
  - (subject, predicaje, object)
- Most nodes are URIs
  - Interoperability



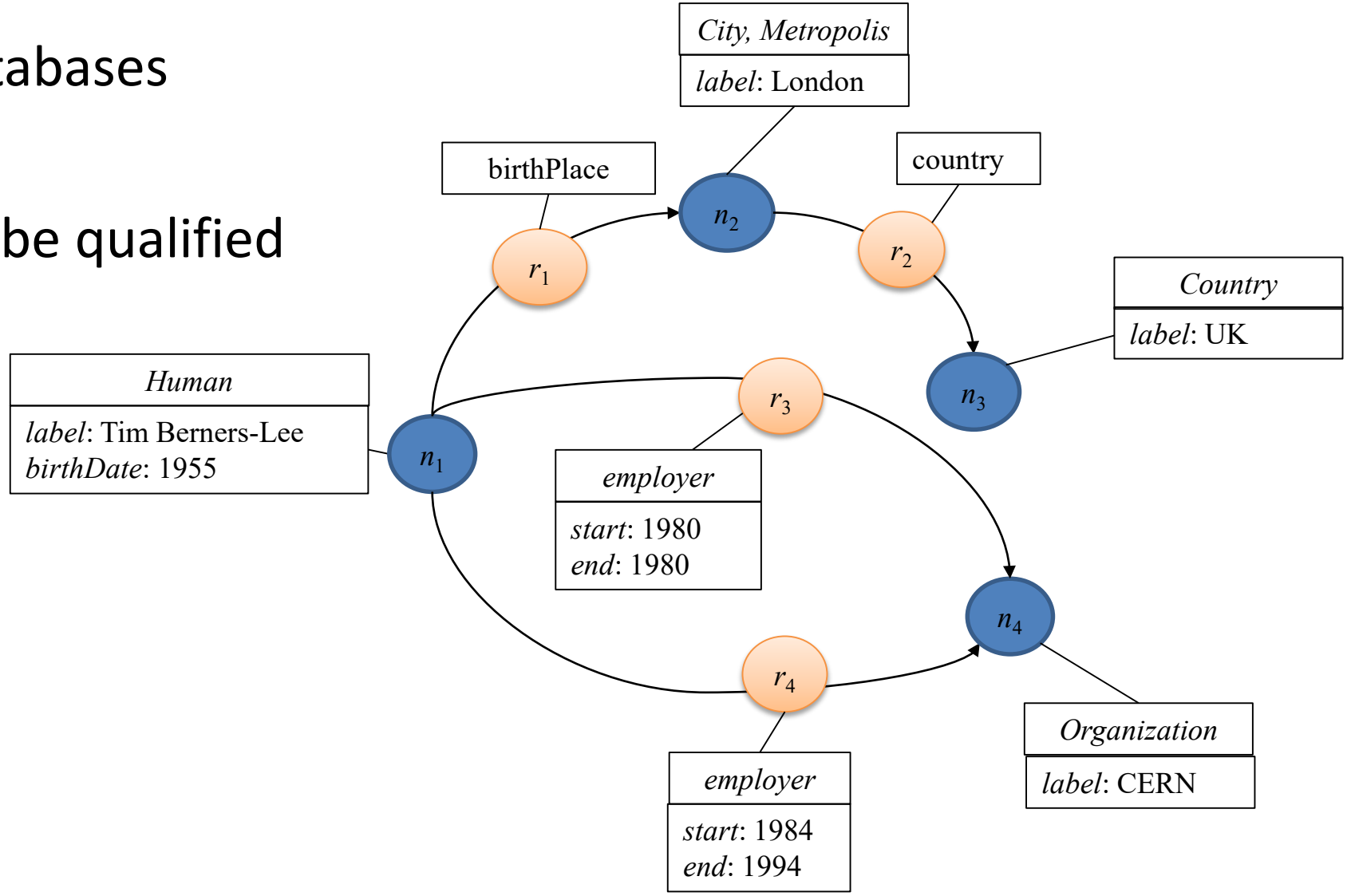
Property graphs

Popularized by graph databases

Example: Neo4J

Nodes and relations can be qualified

Nodes can have types



Wikibase graphs

Popularized by Wikidata

Wikibase = software supporting Wikidata

The values can be nodes in the graph

Example:

Tim Berners Lee

http://www.wikidata.org/entity/Q80