Shaping Knowledge Graphs
ESWC’25 Tutorial

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

About me…

http://labra.weso.es

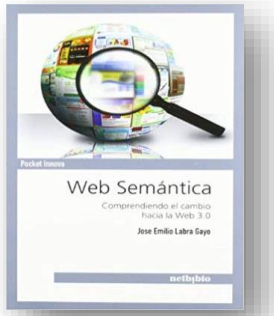
Main researcher at WESO (Web Semantics Oviedo)

Some books:

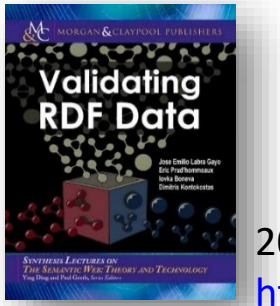
- "*Web semántica*" (in Spanish), 2012
- "*Validating RDF data*", 2017
- "Knowledge Graphs", 2021

…and software:

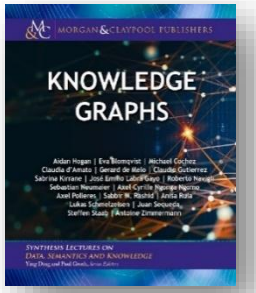
- SHaclEX (Scala library, implements ShEx & SHACL)
- RDFShape (RDF playground)
- rudof (RDF & Shapes library in Rust)



2012



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



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

Contents

- Introduction to Knowledge graphs
- Types of Knowledge Graphs:
  - RDF, Property graphs, Wikibase, RDF-Star
- Shaping RDF: ShEx & SHACL
- Shaping Other types of Knowledge graphs
  - Wikibase and Wikidata graphs
  - Property Graphs
  - RDF-1.2
- Applications:
  - Inferring shapes from data, Knowledge Graphs Subsets, etc.

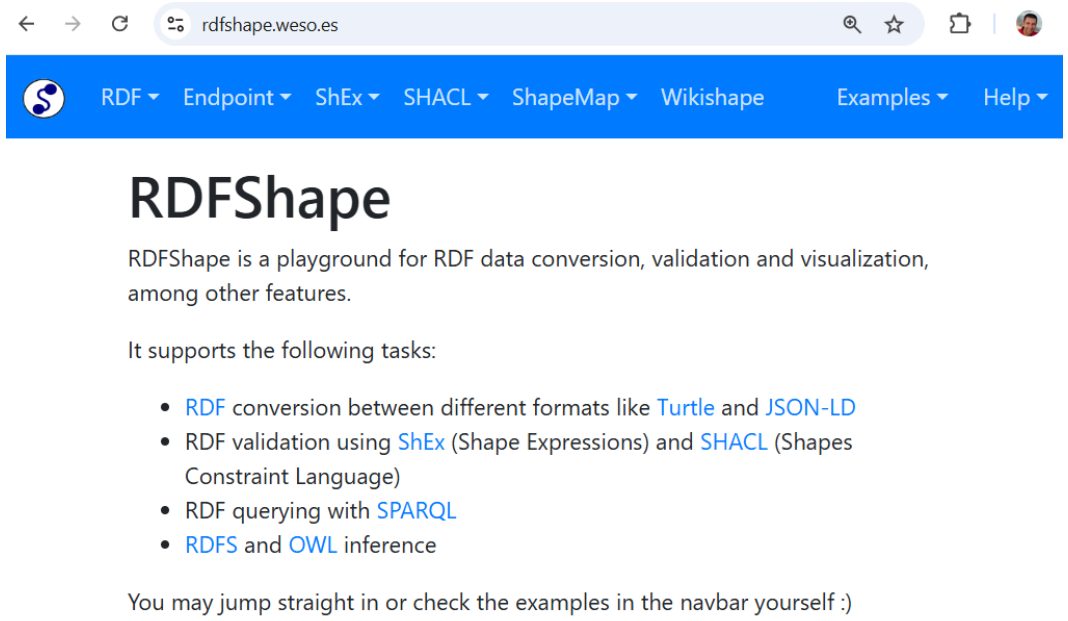
Tutorial materials

https://github.com/validatingrdf/Tutorial

Interactive – through the web

RDFShape: RDF playground + ShEx/SHACL support

Wikishape: Tailored to Wikibase



Command line

rudof (Rust): Binaries in Windows, Linux, Mac

RUDOF

Other command line tools:

Shex-s: ShEx, WShEx

SHACL-s: SHACL

wdsub: Subsets

Interactive (Jupyter)

rudof (Rust): Python bindings

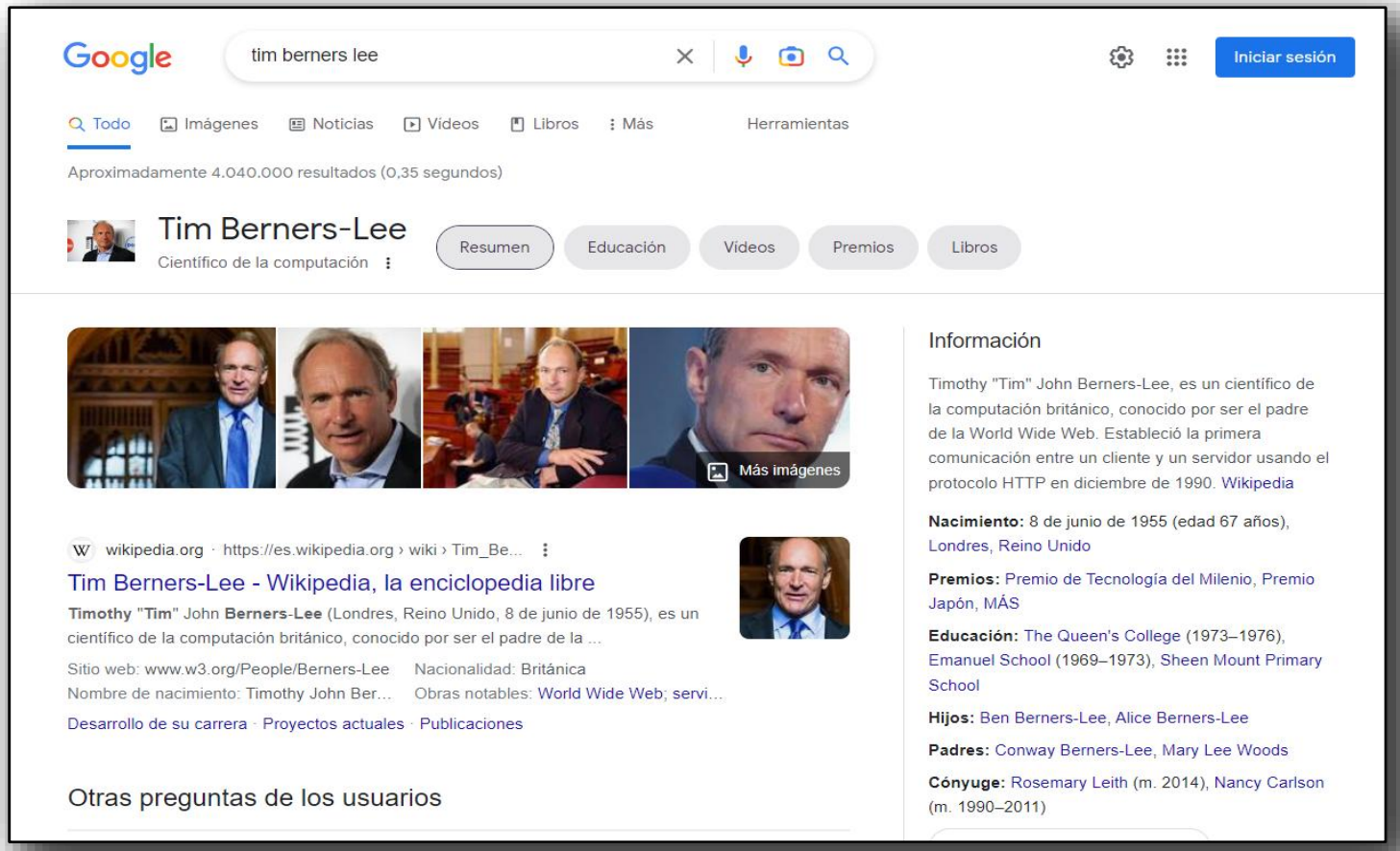
PyShEx

PySHACL

Example Google Colab

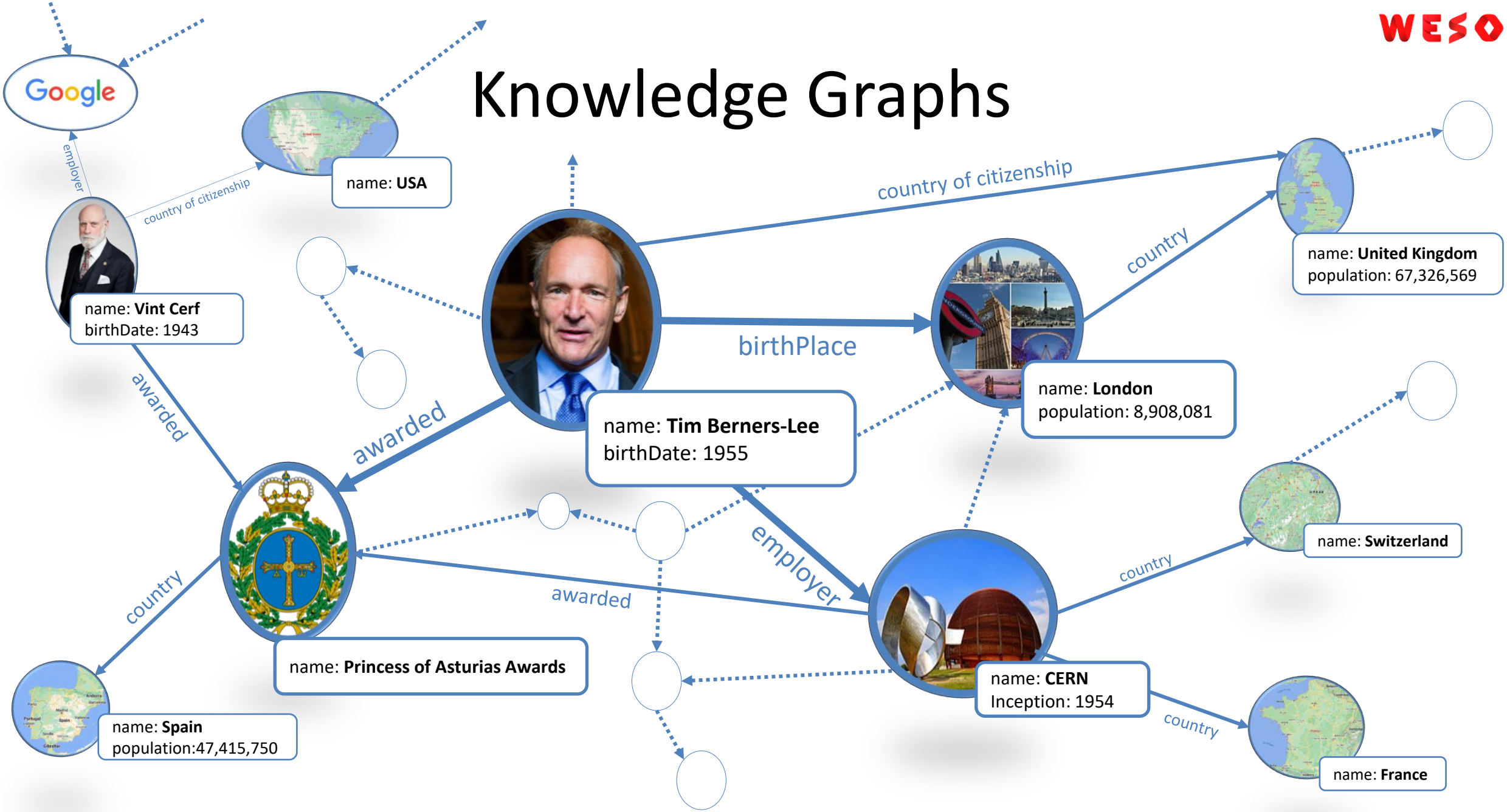
Knowledge Graphs

Current notion of Knowledge Graphs, popular after Google, 2012*



Link: https://www.blog.google/products/search/introducing-knowledge-graph-things-not/

Knowledge Graphs



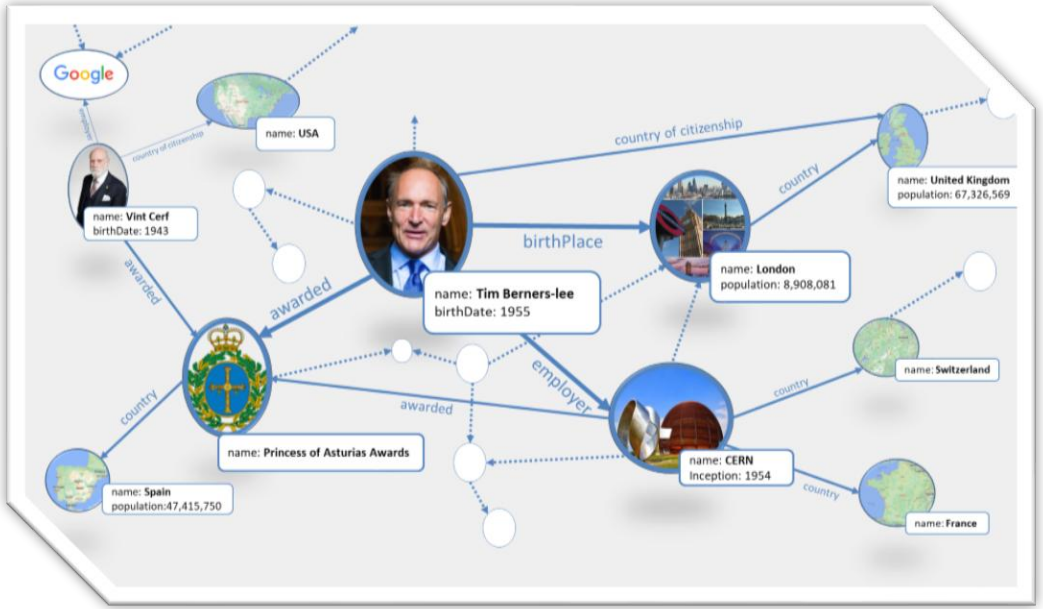
Knowledge Graphs

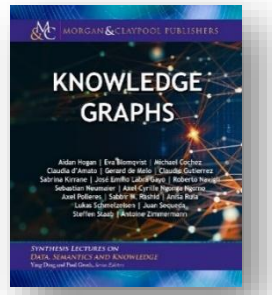
Knowledge graph = *a **graph of data***

*intended to accumulate and convey **knowledge** of the real world*

*whose nodes represent **entities** of interest and*

*whose edges represent **relations** between these entities.*





https://kgbook.org/

Applications of Knowledge Graphs

Improve search results

Question answering

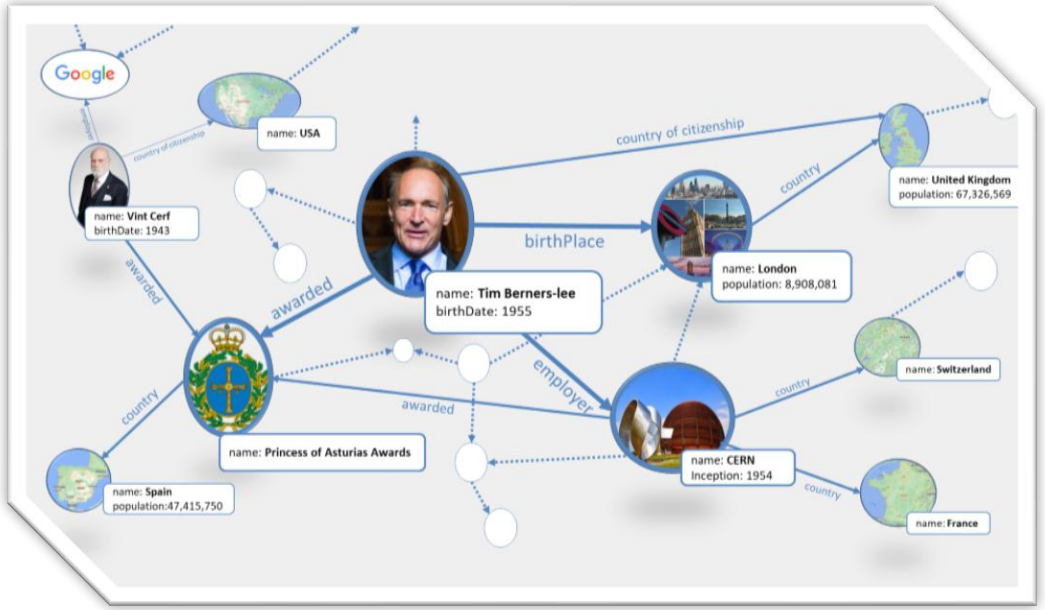
Data governance

Handling heterogenous data

Recommender systems

Chatbots and NLP

. . .



Contents

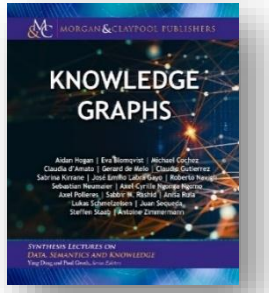
Types of Knowledge Graphs

Open Knowledge Graphs

- Cross-domain: Wikidata, Dbpedia, Freebase, YAGO, ...
- Domain specific
  - Academic: Open citations, SciGraph, Microsoft Academic Knowledge Graph, ...
  - Life sciences: UniProt, PubChem, PDB, ...
  - Government: EU Knowledge graph, ...
  - ...

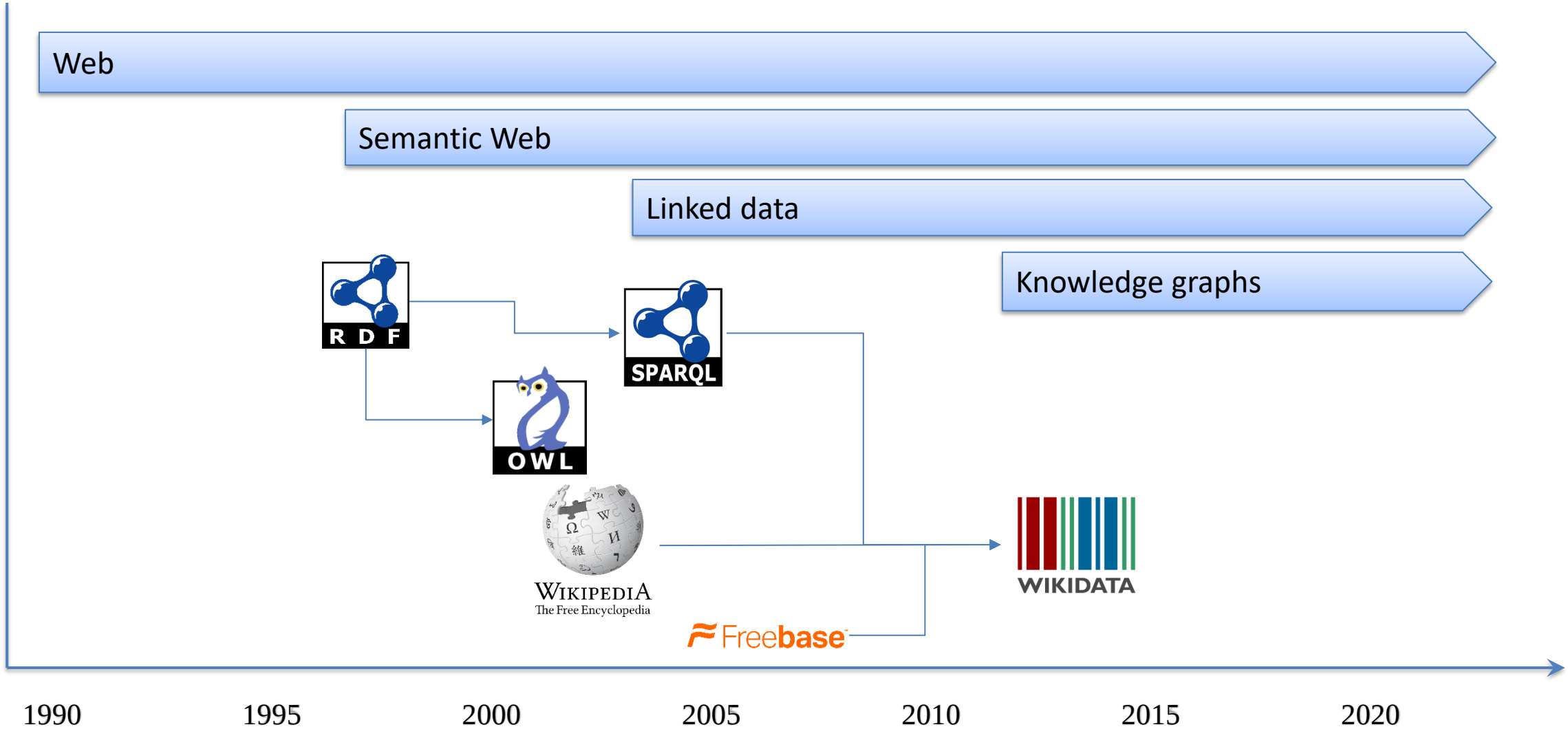
Enterprise Knowledge Graphs

- Web search: Google, Bing...
- Commerce: AirBnb, Amazon, eBay, Uber,...
- Social networks: Linkedin, Facebook,...
- Finance: Banca d'Italia, Bloomberg, Wells Fargo, Capital One,...
- ...



https://kgbook.org/

Evolution


Web
Semantic Web
Linked data
Knowledge graphs
RDF
SPARQL
OWL
WIKIPEDIA
The Free Encyclopedia
Freebase
WIKIDATA
1990
1995
2000
2005
2010
2015
2020

Knowledge Graphs models

3 popular knowledge graphs models

- RDF based
- Property graphs (Labeled property graphs)
- Wikibase graphs

RDF

Resource Description Framework

Lingua franca of the Semantic Web

- 1997 1st public 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/, RDF Model and Syntax
- 2004 - RDF Revised https://www.w3.org/TR/2004/REC-rdf-concepts-20040210/, Turtle
- 2008 - SPARQL 1.0, https://www.w3.org/TR/2008/REC-rdf-sparql-query-20080115/
- 2014 - RDF 1.1 https://www.w3.org/TR/rdf11-concepts/, SPARQL 1.1, JSON-LD
- 2017 - SHACL 1.0 https://www.w3.org/TR/2017/REC-shacl-20170720/
- 2025 - RDF 1.2 https://www.w3.org/TR/rdf12-concepts Statements about triples (RDF-Star)

RDF graphs

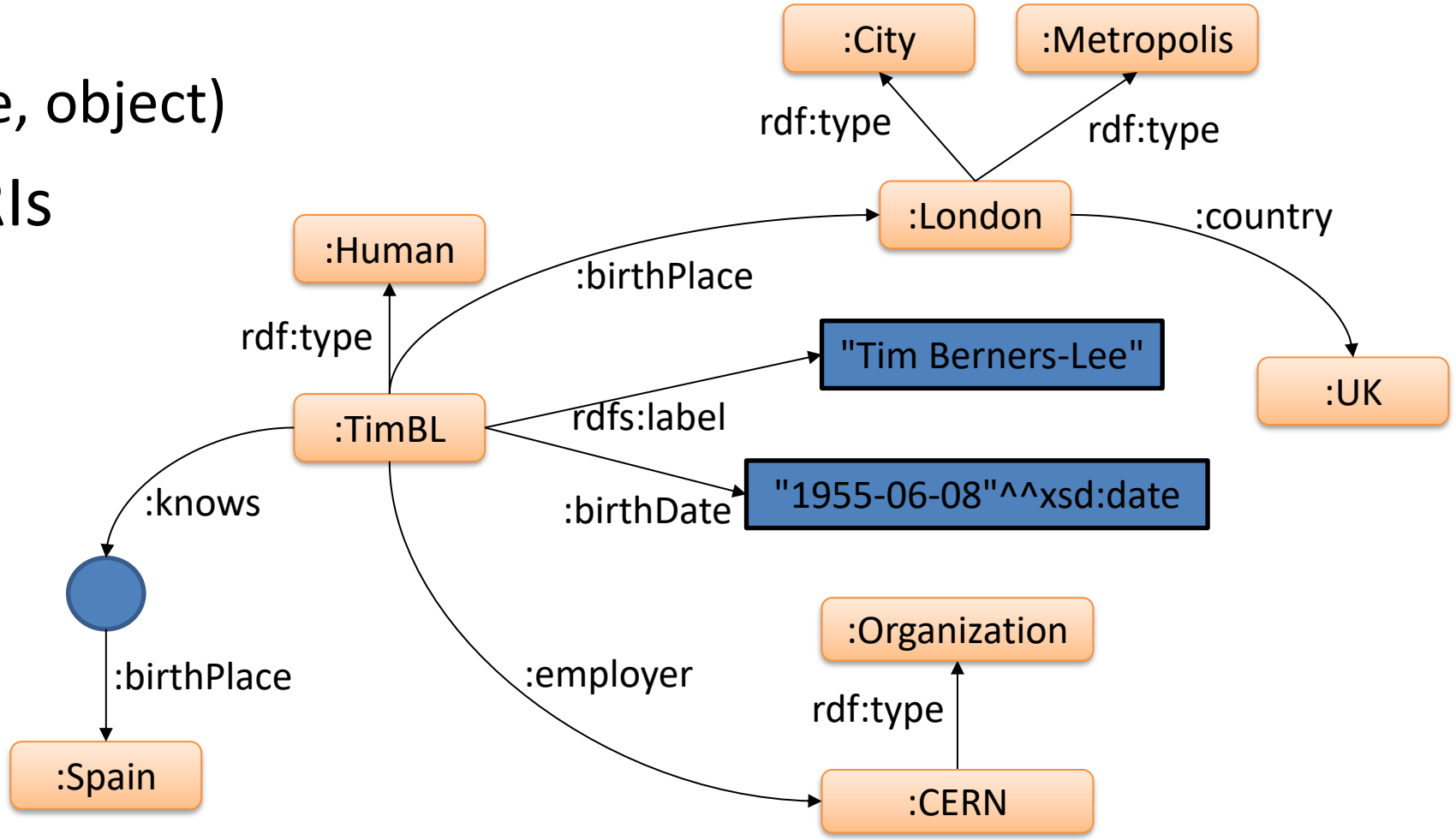
Based on triples

(subject, predicaje, object)

Most nodes are URIs

Interoperability

Simple & flexible



RDF ecosystem

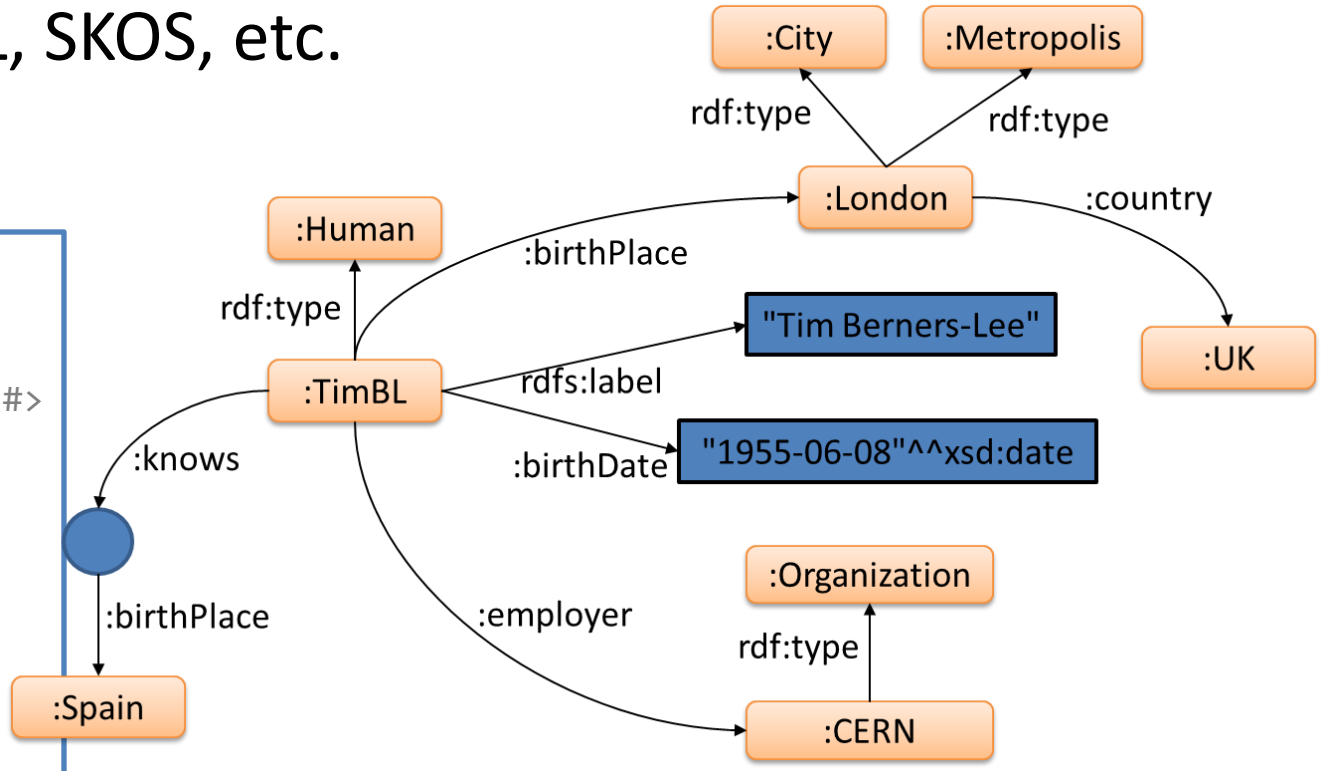
One data model, several syntaxes: Turtle, N-Triples, JSON-LD

Vocabularies: RDF Schema, OWL, SKOS, etc.

Turtle

```
prefix :       <http://example.org/>
prefix rdfs:   <http://www.w3.org/2000/01/rdf-schema#>
prefix xsd:    <http://www.w3.org/2001/XMLSchema#>
prefix rdf:    <http://www.w3.org/1999/02/22-rdf-syntax-ns#>

:timbl  rdf:type     :Human ;
        :birthPlace  :london ;
        rdfs:label   "Tim Berners-Lee" ;
        :birthDate   "1955-06-08"^^xsd:date ;
        :employer    :CERN ;
        :knows       _:1    .
:london rdf:type     :City, :Metropolis ;
        :country     :UK .
:CERN   rdf:type     :Organization .
_:1     :birthPlace  :Spain .
```



Try it:
https://rdfshape.weso.es/link/17313171788

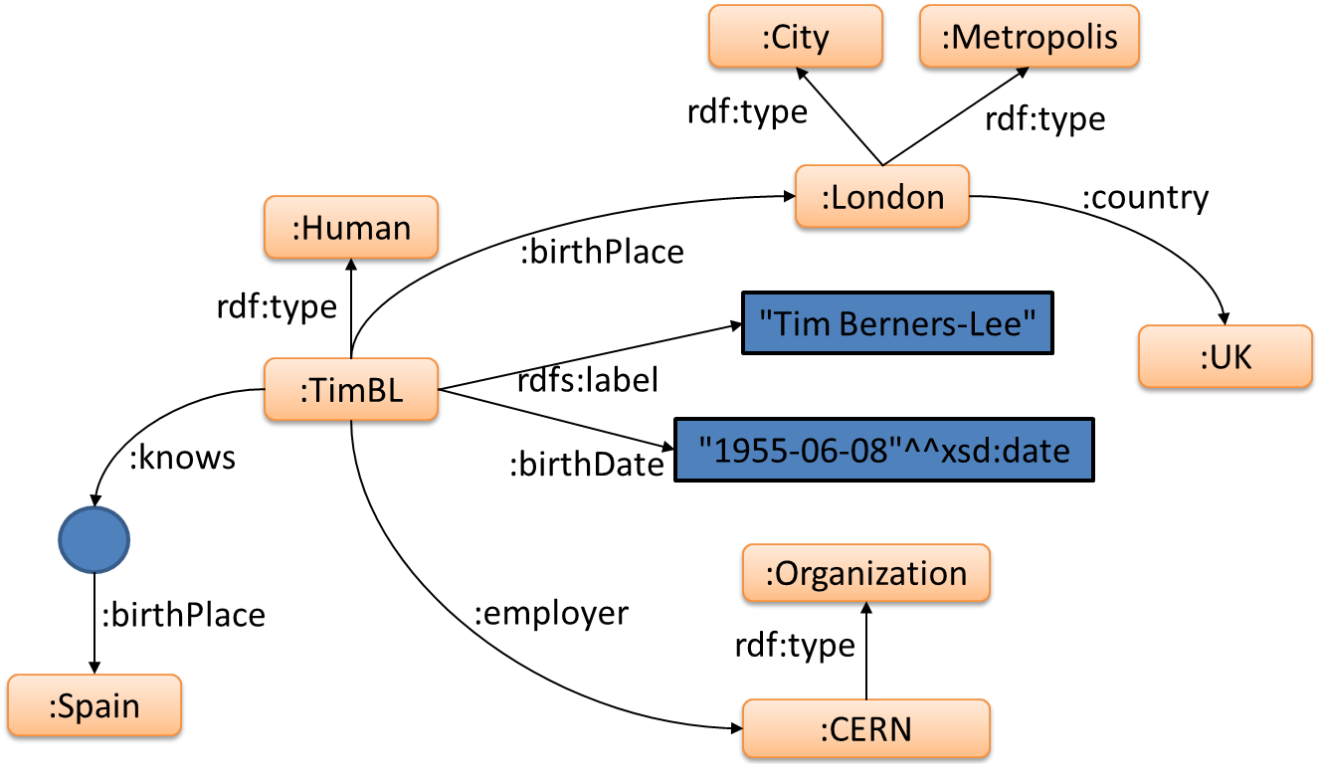
RDF ecosystem: SPARQL

SPARQL = RDF query language and protocol

Enables the creation of SPARQL endpoints

```
SELECT ?person ?date ?country WHERE {
 ?person :birthDate  ?date .
 ?person :birthPlace ?p .
 ?p      :country    ?country
}
```

?person	?date	?country
:timbl	1955-06-08	:UK



Try it: https://rdfshape.weso.es/link/17313175698

RDF1.2 (previously RDF-Star)

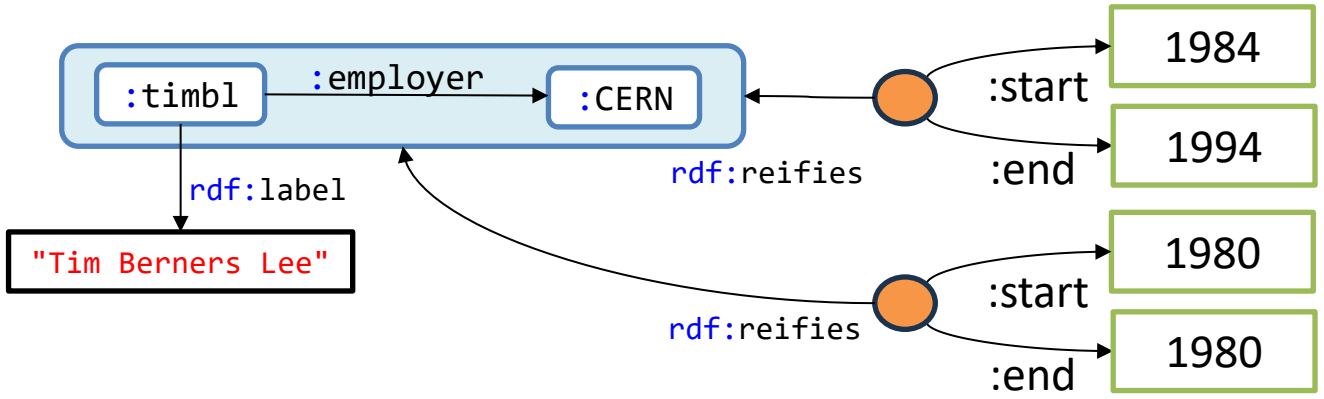
Currently under discussion (https://github.com/w3c/rdf-star-wg/wiki)

Add statements about triples (called triple terms)

Reifiers

```
:timbl rdfs:label "Tim Berners Lee“ ;
       :employer :CERN
                      {| :start "1984" ;
                         :end   "1994" |}
                      {| :start "1980" ;
                         :end   "1980" |} .
```

```
:timbl rdfs:label "Tim Berners Lee" ;
       :employer  :CERN .
_:r rdf:reifies   <<( :timbl :employer :CERN )>> .
_:r :start        "1984" ;
    :end          "1994" .
_:s rdf:reifies   <<( :timbl :employer :CERN )>> .
_:s :start        "1980" ;
    :end          "1980" .
```



Note:
In this example, we are asserting that Tim's employer is CERN

Non-asserted triple terms

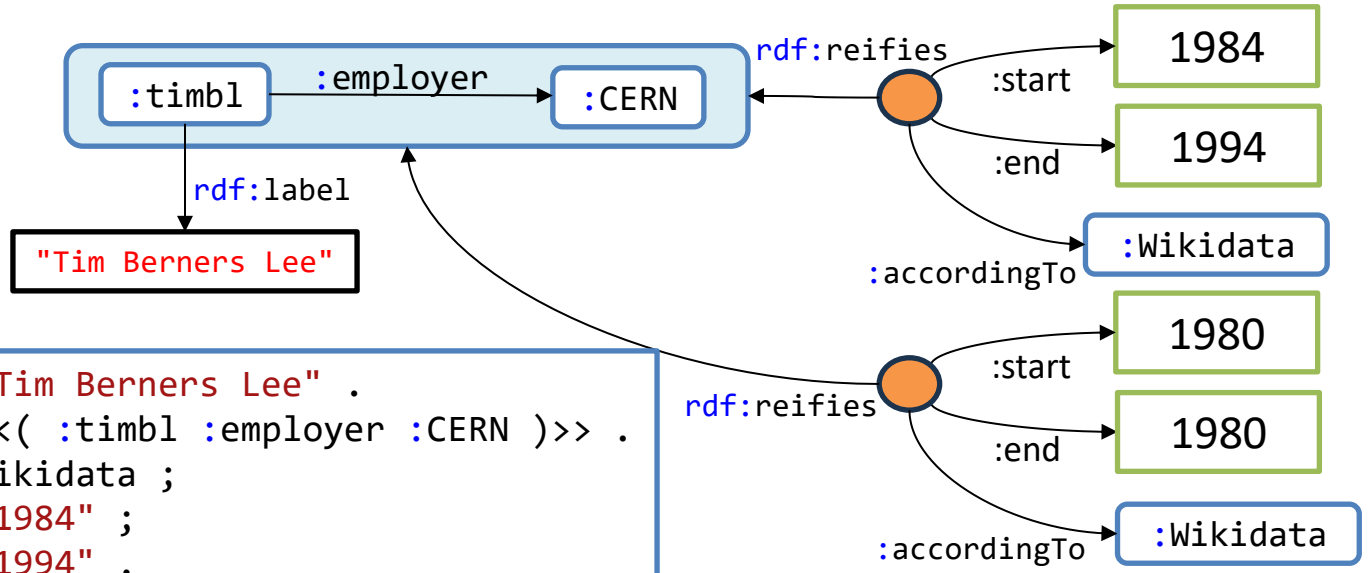
Triple terms can be reified without being asserted

We can say that Tim's employer is the CERN according to Wikidata

But we don't need to assert whether Tim's employer is the CERN or not

```
:timbl rdfs:label "Tim Berners Lee“ .
<< :timbl :employer :CERN >>
    :accordingTo :Wikidata ;
    :start       "1984" ;
    :end         "1994" .
<< :timbl :employer :CERN >>
    :accordingTo :Wikidata ;
    :start       "1980" ;
    :end         "1980" .
```

```
:timbl rdfs:label "Tim Berners Lee" .
_:1 rdf:reifies   <<( :timbl :employer :CERN )>> .
    :accordingTo :Wikidata ;
    :start       "1984" ;
    :end         "1994" .
_:2 rdf:reifies   <<( :timbl :employer :CERN )>> .
    :accordingTo :Wikidata ;
    :start       "1980" ;
    :end         "1980" .
```



Property graphs

Also called *labeled property graphs*

Since ~2007, very popular model in industry

- Neo4j, Amazon Neptune, Oracle, etc
- Several query languages: Cypher, Gremlin, PGQL, …

2024 - GQL has been published

- Recent publication of ISO/IEC FDIS 39075
- Developed by ISO/IEC JTC1 SC32 WG3: the “SQL” committee
- Influenced by Cypher, PGQL, etc.

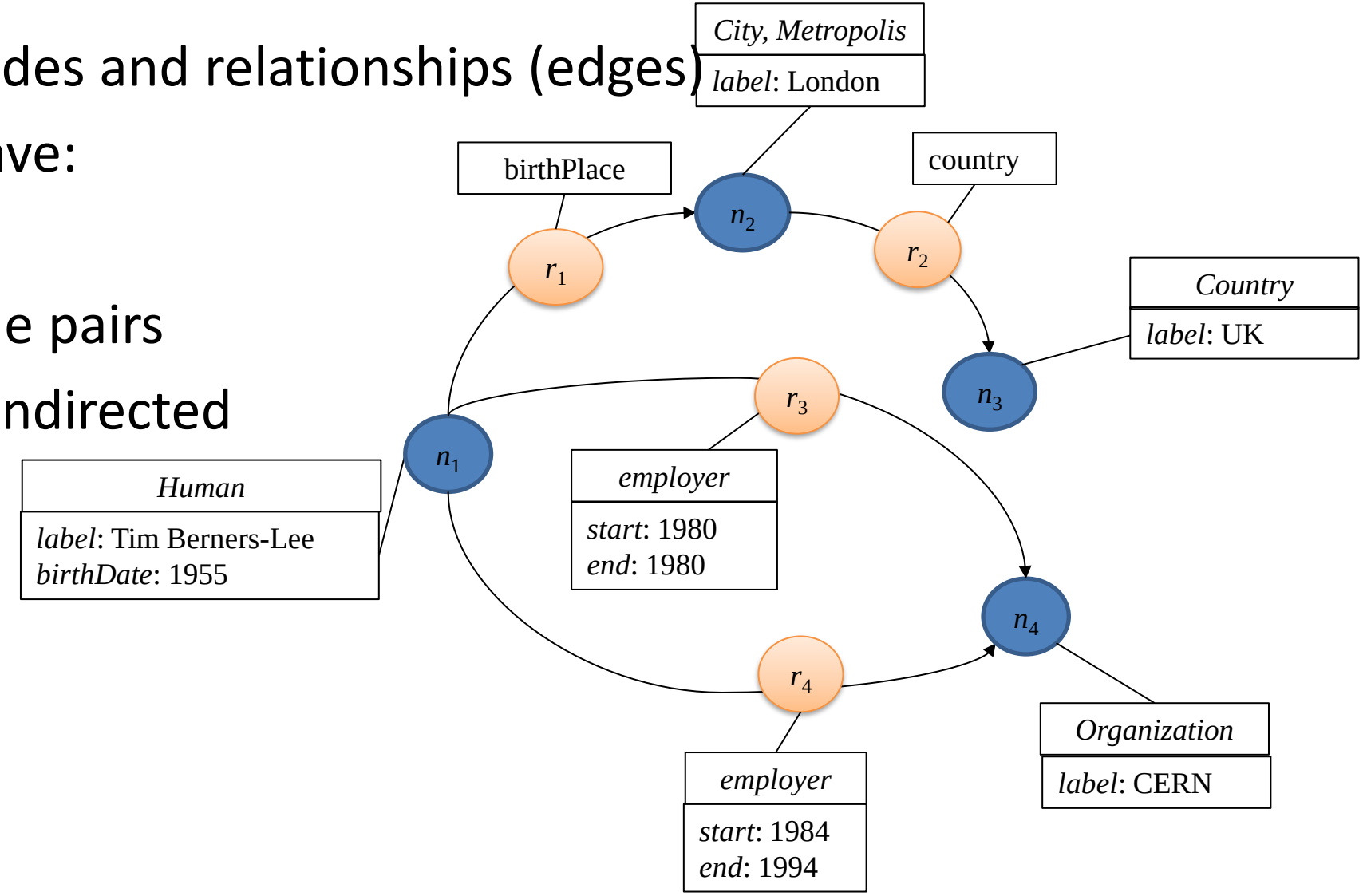
Property graphs

Graph structure with nodes and relationships (edges)

Nodes and edges can have:

- Labels
- A set of property-value pairs

Edges can be directed/undirected



Wikibase graphs

Popularized by Wikidata

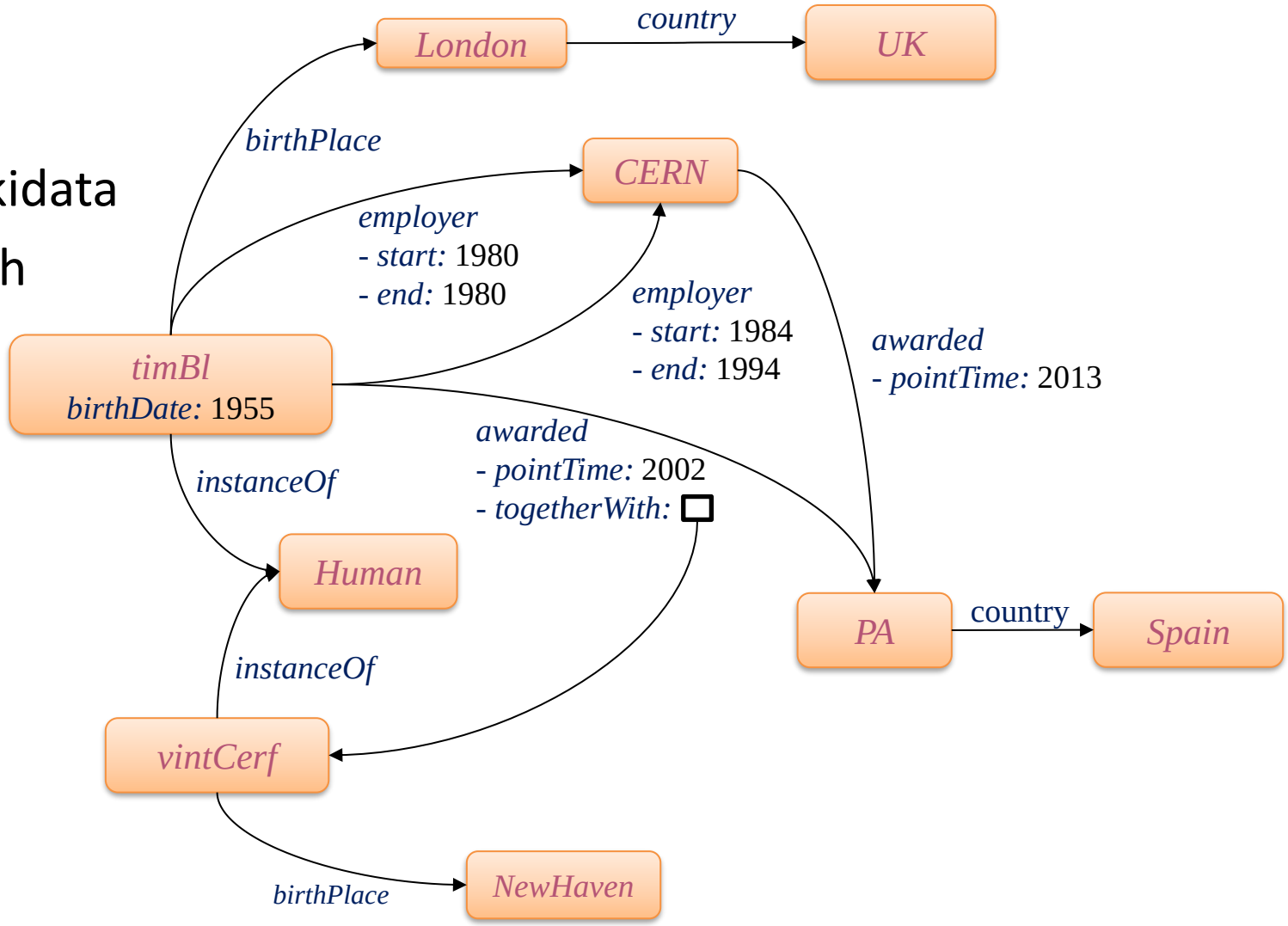
Wikibase = software supporting Wikidata

The values can be nodes in the graph

Example:

Tim Berners Lee

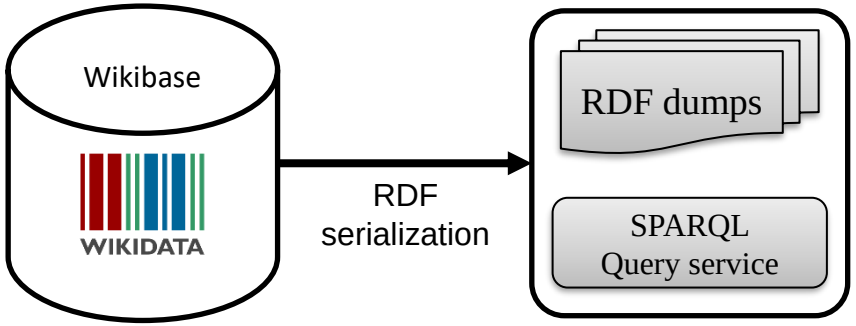
http://www.wikidata.org/entity/Q80



Wikibase graphs and SPARQL

Wikibase graphs generate RDF serializations for each item

SPARQL endpoint and Query service available




```
select ?name ?date?country where {
 wd:Q80 wdt:P1559 ?name .
 wd:Q80 wdt:P569  ?date .
 wd:Q80 wdt:P19   ?place .
 ?place wdt:P17   ?country
}
```

?name	?date	?country
Tim Berners-lee	1955-06-08	:UK

Try it: https://w.wiki/5yGu

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- Shaping other types of Knowledge graphs:
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  - Property Graphs
  - RDF-1.2
- Applications:
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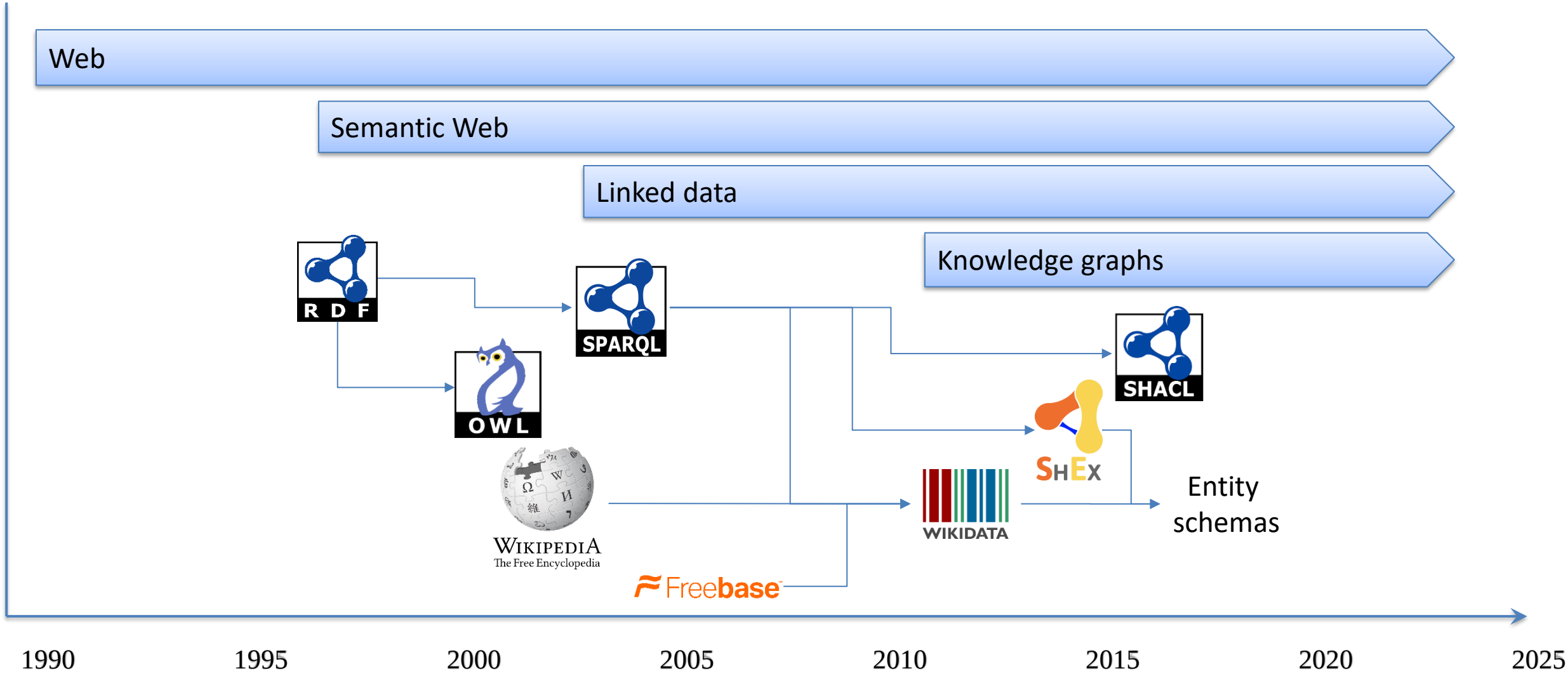
Evolution


Web
Semantic Web
Linked data
Knowledge graphs
R D F
SPARQL
OWL
SHACL
SHEX
WIKIPEDIA
The Free Encyclopedia
WIKIDATA
Freebase
Entity schemas
1990
1995
2000
2005
2010
2015
2020
2025

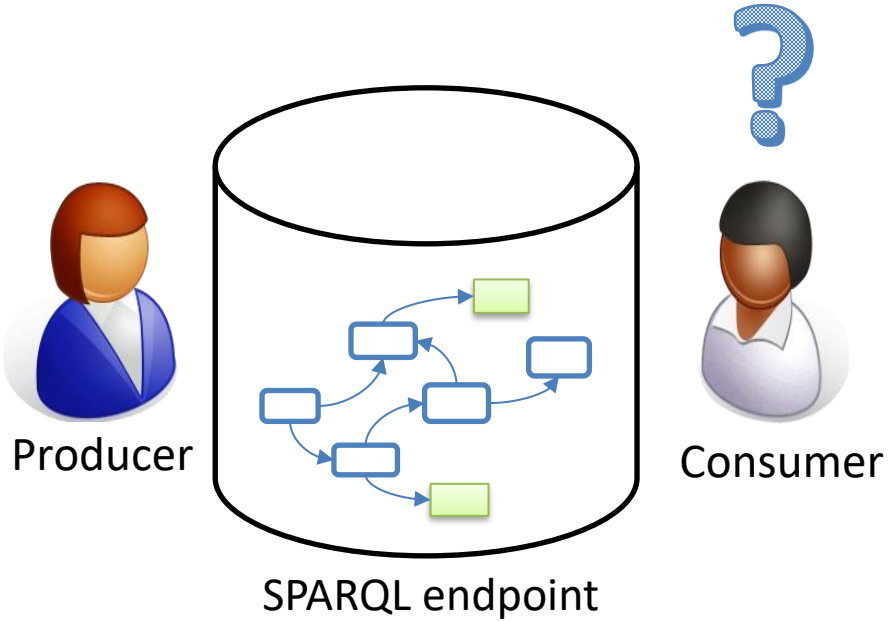
WESO

RDF, the good parts...

- RDF as an integration language
  - RDF as a *lingua franca* for semantic web and linked data
  - Basis for knowledge representation
- RDF flexibility
  - Data can be adapted to multiple environments
  - Reusable data by default
- RDF tools
  - RDF data stores & SPARQL
  - Several serializations: Turtle, JSON-LD, RDF/XML...
  - Can be embedded in HTML (Microdata/RDFa)

RDF, the other parts

- Consuming & producing RDF
  - Describing and validating RDF content
  - SPARQL endpoints are not well documented
    - Typical documentation = set of SPARQL queries
    - Difficult to know where to start doing queries



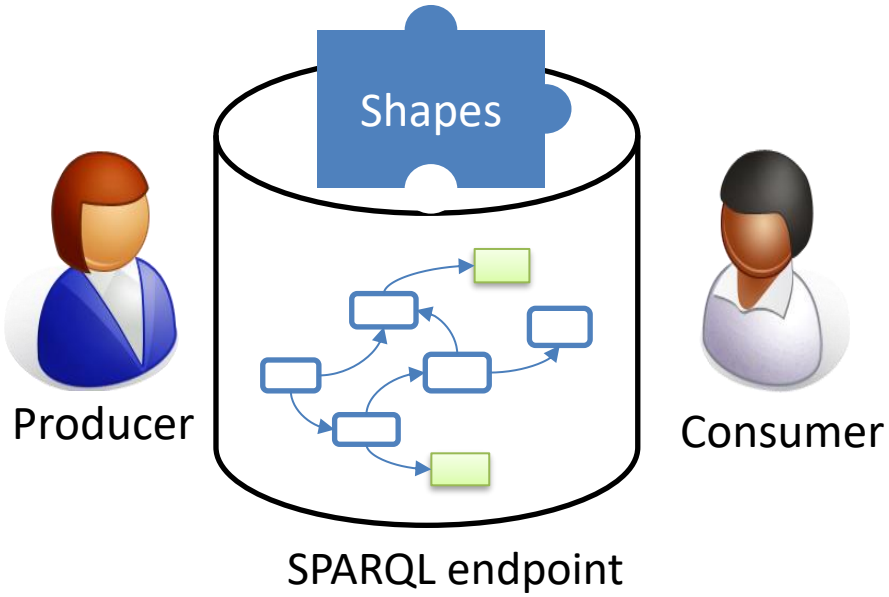
Why describe & validate RDF?

For producers

- Developers can understand the contents they are going to produce
- They can ensure they produce the expected structure
- Advertise and document the structure
- Generate interfaces

For consumers

- Understand the contents
- Verify the structure before processing it
- Query generation & optimization



In other technologies...

Technology	Schema
Relational Databases	DDL
XML	DTD, XML Schema, RelaxNG, Schematron
Json	Json Schema
RDF	?

Fill that gap

Schemas for RDF?

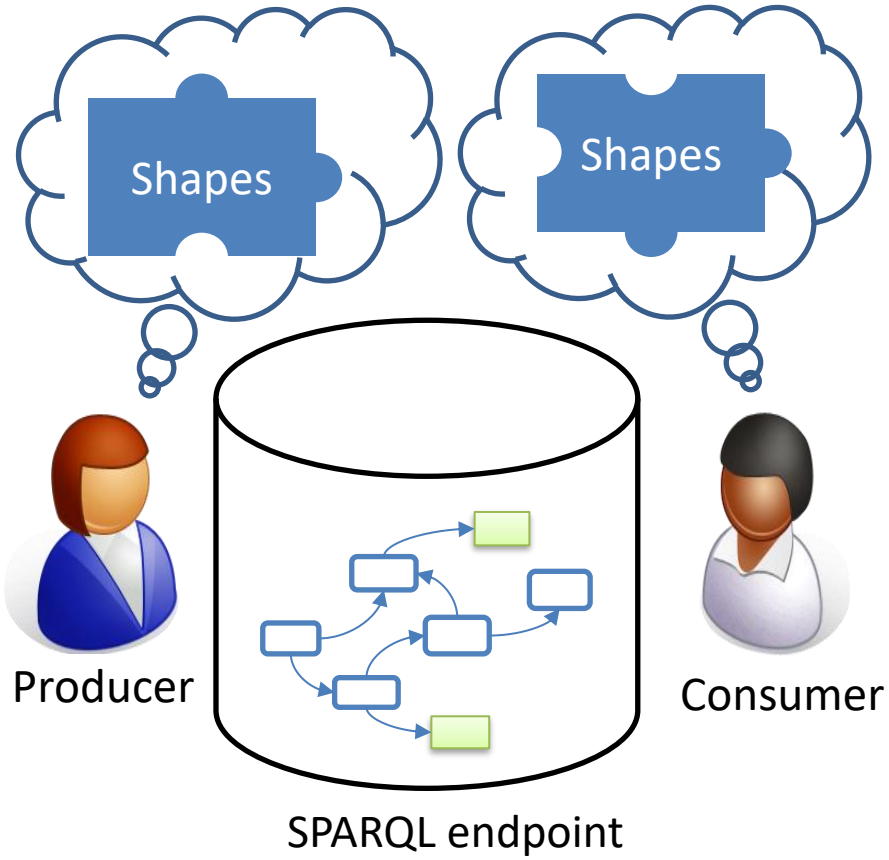
RDF flexibility doesn't want to impose a schema, but...

In practice, there are **implicit schemas**

- Assumed by producers and consumers

Shapes can make schemas explicit

- Handle malformed/incomplete data
- Avoid defensive programming



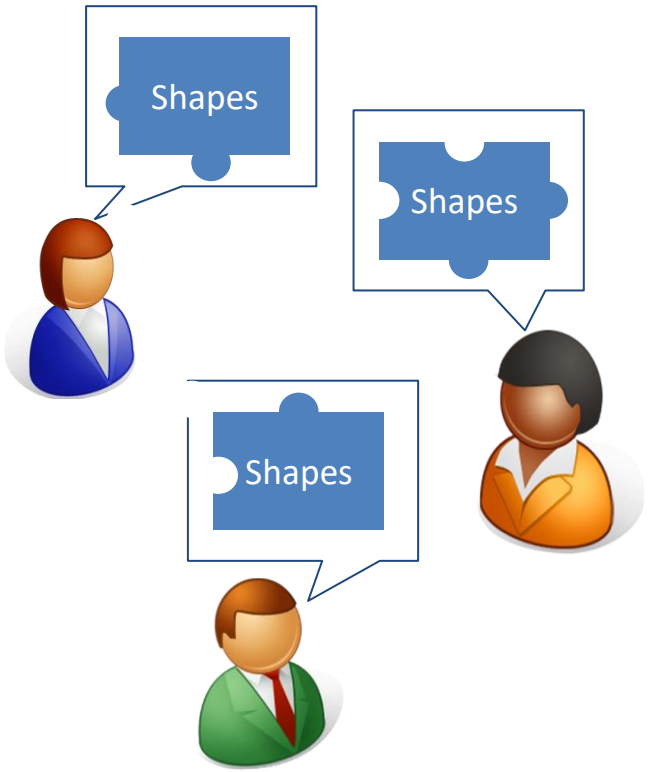
Shapes for consensus building

Help domain experts define their own data models

- Understandable by domain experts
- …and machine processable

Initial motivation: clinical data models (FHIR)

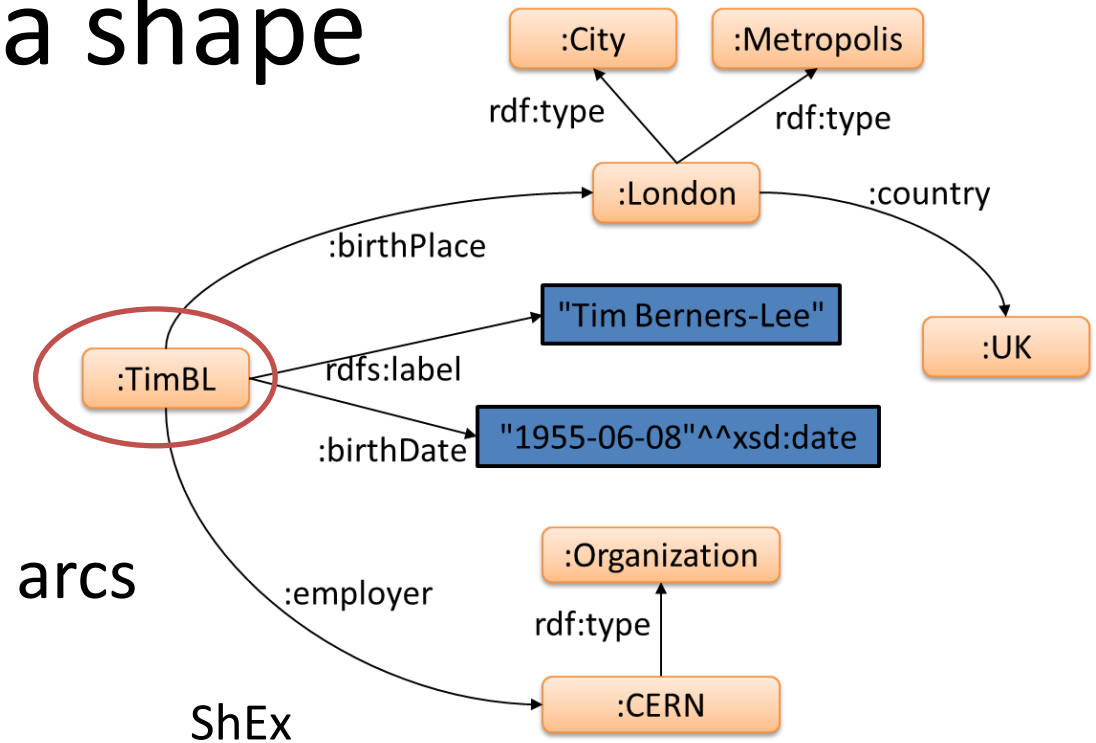
- Distributed data model
  - Different location, authorities,...
- Extensible data models



Example of a shape

A shape describes

- The form of a node (node constraint)
- Incoming/outgoing arcs from a node
- Possible values associated with those arcs



RDF Node

```
:timbl rdfs:label   "Tim Berners-Lee" ;
       :birthPlace  :london ;
       :birthDate   "1955-06-08"^^xsd:date ;
       :employer    :CERN .
```

ShEx

```
<Researcher> {
 rdfs:label   xsd:string          ;
 :birthPlace  @<Place>         ? ;
 :birthDate   xsd:date         ? ;
 :employer    @<Organization> * ;
}
```

Try it: https://rdfshape.weso.es/link/16685137872

ShEx & SHACL

2013 RDF Validation Workshop

- Conclusions of the workshop:
  - *There is a need of a higher level, concise language for RDF Validation*
- ShEx initially proposed (v 1.0)

2014 W3c Data Shapes WG chartered

2017 SHACL accepted as W3C recommendation

2017 ShEx 2.0 released as W3C Community group draft

2019 ShEx adopted by Wikidata

2025 IEEE ShEx (*work in progress*)

2025 Data Shapes WG chartered again for SHACL 1.2 (*work in progress*)