Shaping other types of Knowledge Graphs

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  - Wikibase and Wikidata graphs
  - Property Graphs
  - RDF-Star
- Applications:
  - Inferring shapes from data, Knowledge Graphs Subsets, etc.

Shaping other types of knowledge graphs

We present some work on extending ShEx for:

- Wikidata and Wikibase graphs: WShEx
- RDF Star (RDF 1.2): ShEx-Star
- Property graphs: P-ShEx
- RDF with nodes as properties: ShEx-N

Note: This work is more theoretical and *work in progress*

We start reviewing ShEx from a more theoretical point of view

* Although we use ShEx in the presentation, similar extensions could be done using SHACL

Conceptual model of RDF graphs

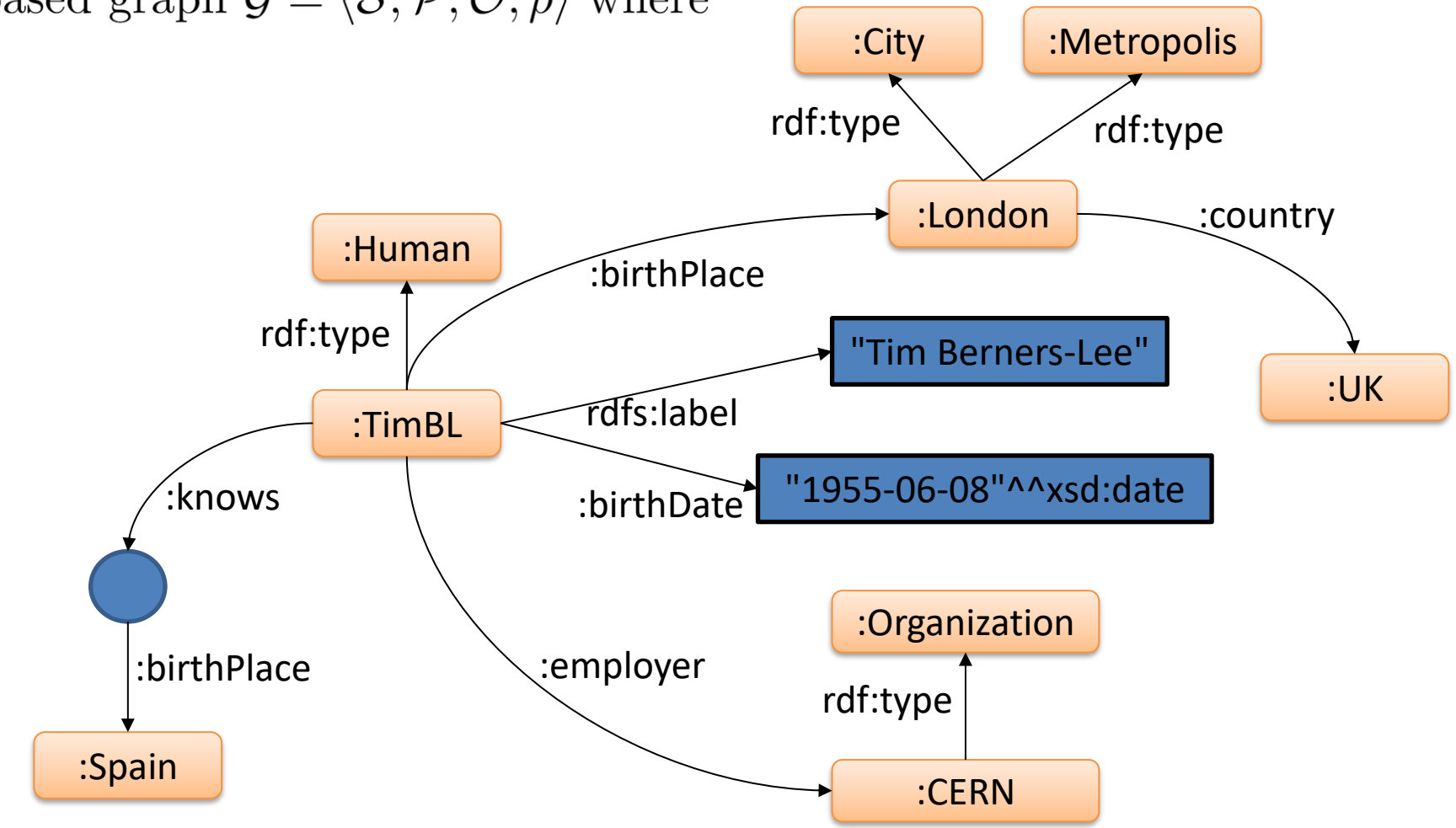
Given a set of IRIs $\mathcal{I}$, a set of blank nodes $\mathcal{B}$ and a set of literals Lit an *RDF graph* is a triple based graph $\mathcal{G} = \langle \mathcal{S}, \mathcal{P}, \mathcal{O}, \rho \rangle$ where

$\mathcal{S} = \mathcal{I} \cup \mathcal{B}$,

$\mathcal{P} = \mathcal{I}$,

$\mathcal{O} = \mathcal{I} \cup \mathcal{B} \cup Lit$

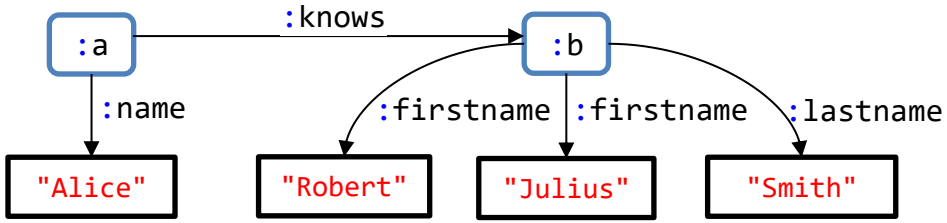
$\rho \subseteq \mathcal{S} \times \mathcal{P} \times \mathcal{O}$



ShEx example

A Shape mainly describes the neighbourhood of a node

- Triple Expressions
- Node constraints
- Cardinality




```
prefix : <http://example.org/>
prefix xsd: <http://www.w3.org/2001/XMLSchema#>

<Person> {
 :firstname xsd:string * ;
 :lastname  xsd:string
 :knows     @<Person>  *
}
```

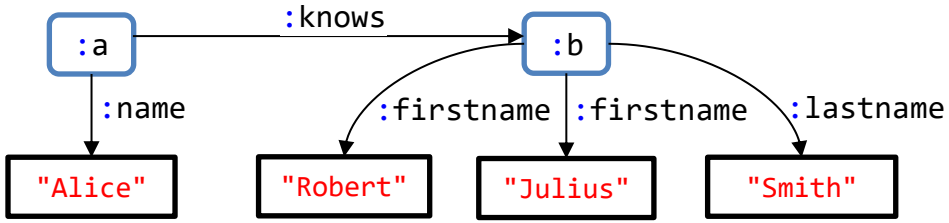
☹
☺

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

:a :name      "Alice" ;
   :knows     :b      .
:b :firstname "Robert", "Julius" ;
   :lastname  "Smith" .
```

ShEx example

ShEx accepts regular expresión operators on triple expressions

EachOf (;), OneOf (|), grouping




```
prefix :    <http://example.org/>
prefix xsd: <http://www.w3.org/2001/XMLSchema#>

<Person> {
    ( :name      xsd:string
    | :firstName xsd:string * ;
      :lastname  xsd:string
    ) ;
    :knows       @<Person> *
}
```

☺
```
prefix : <http://example.org/>

:a :name      "Alice" ;
   :knows     :b      .
:b :firstname "Robert", "Julius" ;
   :lastname  "Smith" .
```

☺
```
:a :name      "Alice" ;
   :knows     :b      .
:b :firstname "Robert", "Julius" ;
   :lastname  "Smith" .
```

☹
```
:c :name      "Carol" ;
   :firstname "Carol" ;
   :knows     :b      .
```

Abstract syntax of *Simplified* ShEx

ShEx schema is a tuple $<L, \delta>$

where L = set of labels and δ: $L \rightarrow se$

se	::=	cond	Basic boolean condition on nodes (node constraint)
	|	s	Shape
	|	se_1 AND se_2	Conjunction of se_1 and se_2
	|	$@l$	Shape label reference for $l \in L$
	|	CLOSED $\{te\}$	Closed shape
	|	$\{te\}$	Open shape
te	::=	$te_1; te_2$	Each of te_1 and te_2
	|	$te_1 \mid te_2$	Either te_1 or te_2
	|	$te*$	Zero or more te
	|	$\_ \xrightarrow{p} se$	Outgoing Triple with predicate p and object conforming to se
	|	$se \xrightarrow{p} \_$	Incoming triple with predicate p and subject conforming to se
	|	ϵ	Empty triple expression

Example with ShEx abstract syntax

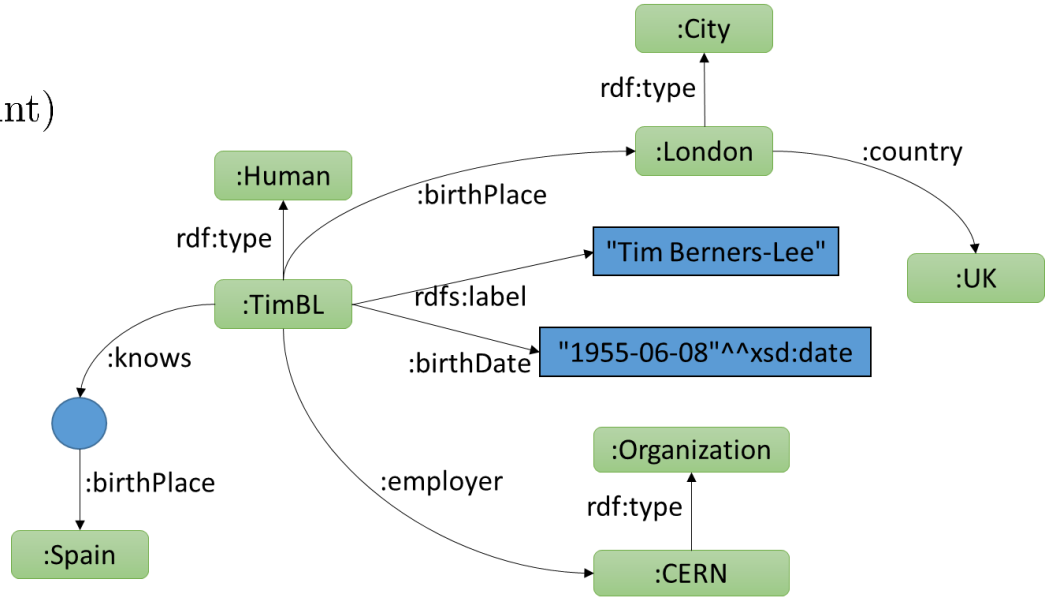
```
prefix :    <http://example.org/>
prefix xsd: <http://.../XMLSchema#>

<Person> {
    ( :name   xsd:string
    | :firstName xsd:string *;
      :lastname xsd:string
    ) ;
    :knwows @<Person> *
}
```

$$
\begin{array}{rcll}
L & = & \{Person\} & \\
\delta(Person) & = & \{ & (\_ \xrightarrow{name} String \mid \_ \xrightarrow{fistname} String^*; \_ \xrightarrow{lastname} String); \\
 & & & \_ \xrightarrow{knows} @Person\ * \\
 & & \} &
\end{array}
$$

Simplified ShEx for RDF

A ShEx Schema is a tuple $\langle \mathcal{L}, \delta \rangle$ where
$\mathcal{L}$ set of shape labels
$\delta : \mathcal{L} \rightarrow se$

se	::=	cond	Basic boolean condition on nodes (node constraint)
	|	s	Shape
	|	se_1 `AND` se_2	Conjunction
	|	$@l$	Shape label reference for $l \in \mathcal{L}$
s	::=	`CLOSED` $\{te\}$	Closed shape
	|	$\{te\}$	Open shape
te	::=	$te_1; te_2$	Each of te_1 and te_2
	|	$te_1 \mid te_2$	Some of te_1 or te_2
	|	$te*$	Zero or more te
	|	ϵ	Empty triple expression
	|	$\llcorner \xrightarrow{p} @l$	Triple constraint with predicate p



$$
\begin{array}{rcl}
\mathcal{L} & = & \{ \; Person, Place, Country, Organization, Date \} \\
\delta(Person) & = & \{ \; \llcorner \xrightarrow{birthDate} @Date; \; \llcorner \xrightarrow{birthPlace} @Place; \\
 & & \llcorner \xrightarrow{employer} @Organization* \; \} \\
\delta(Place) & = & \{ \; \llcorner \xrightarrow{country} @Country \} \\
\delta(Country) & = & \{ \; \} \\
\delta(Organization) & = & \{ \; \} \\
\delta(Date) & = & \text{xsd:Date}
\end{array}
$$

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  - RDF with nodes as properties
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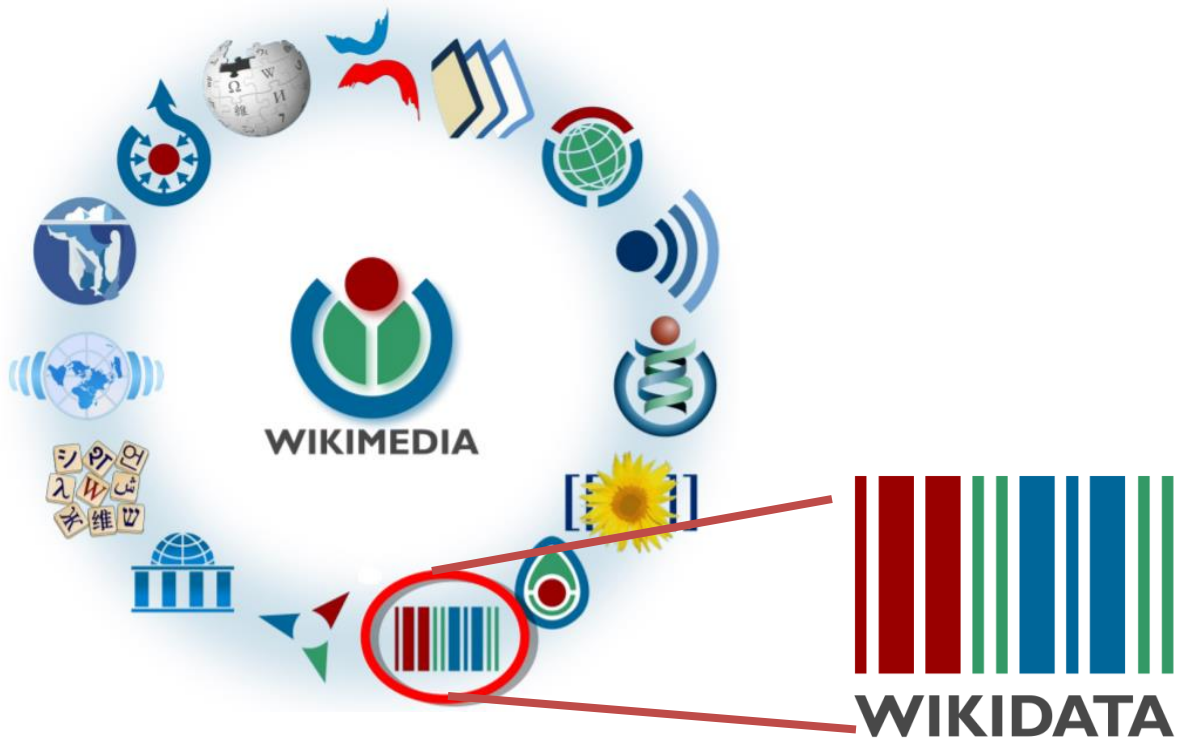
Wikidata

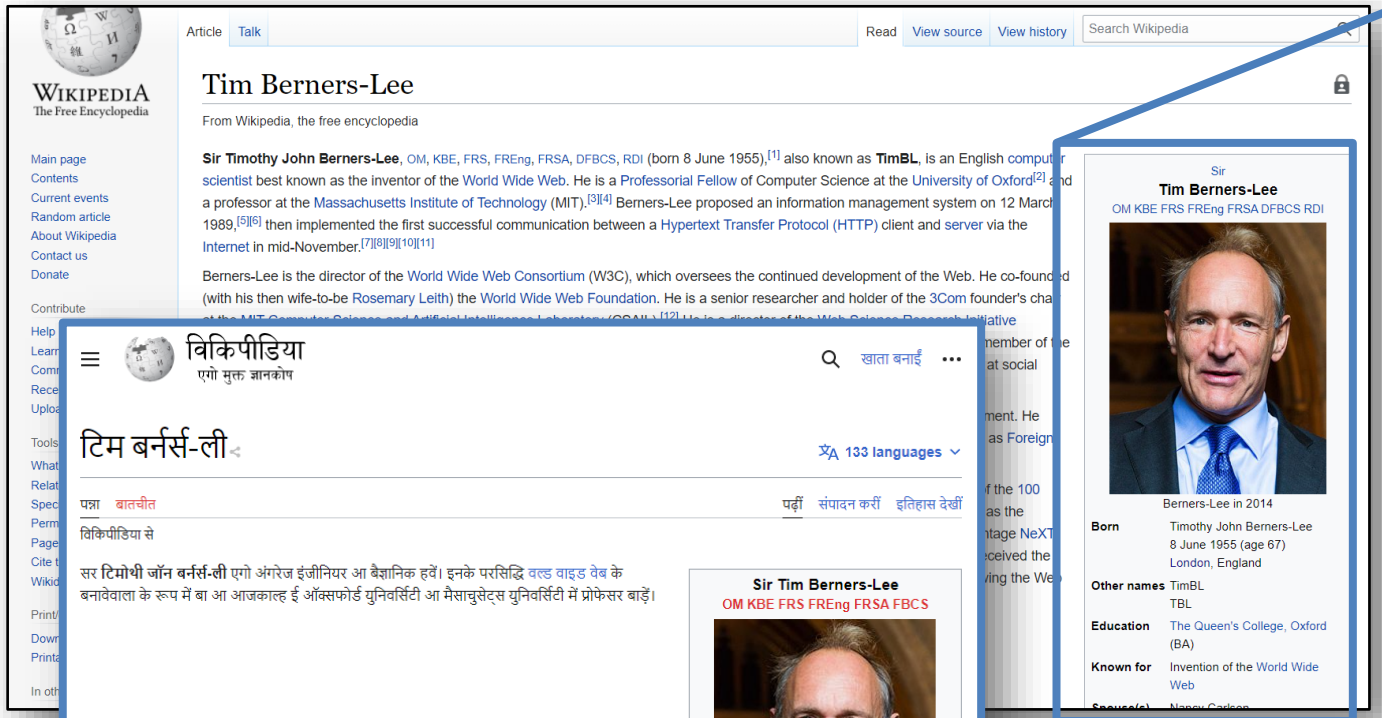
Created in 2012 as a collaborative knowledge graph

- https://www.wikidata.org/
- Developed and supported by Wikimedia Deutschland
- Initial goal:
  - Support multilingual infoboxes in Wikipedia



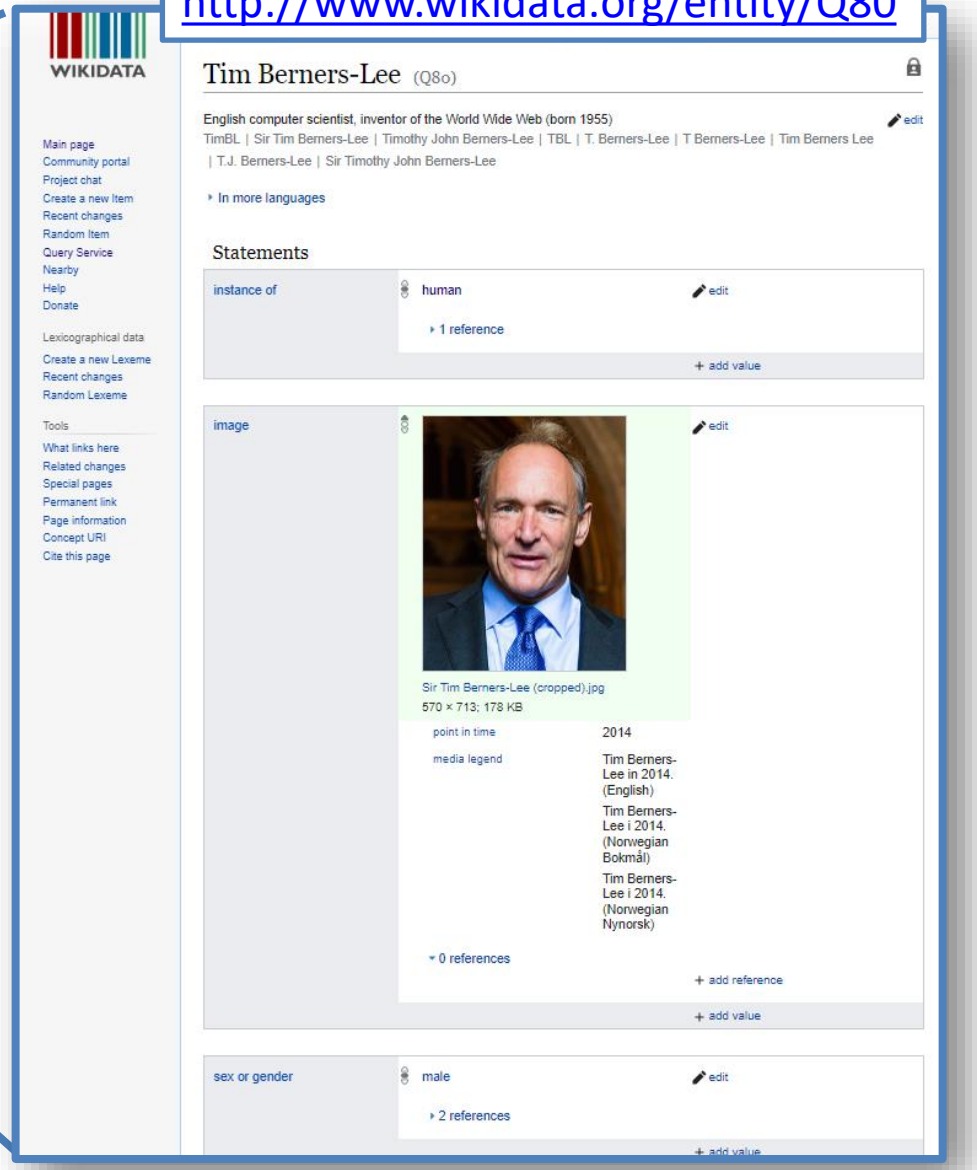
Wikidata as an example

English Wikipedia page of Tim Berners-Lee



Bihari Wikipedia of Tim Berners-Lee

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



Wikidata as a Commons Knowledge Graph

- Wikidata has proven a very successful Project
  - Showcases Semantic web and linked data
    - SPARQL query endpoint
    - Linked data browsing
  - Large adoption
    - 114,425,761 ítems, 2,271,032,314 edits (11/2024): https://www.wikidata.org/wiki/Wikidata:Statistics
- Free and open license: CC0
- Multilingual, collaborative
- Open Wikidata Query Service: Public SPARQL endpoint
  - Dumps freely available
- Nice applications like Scholia: https://scholia.toolforge.org/
  - Wikidata can be a data hub for other apps: IMDB, Wolfram, Reddit, Bionomia, iNaturalist, …
- Software that supports Wikidata = Wikibase

Wikibase

- Wikibase: Software suite that implements Wikidata (https://wikiba.se/)
  - Set of extensions of Media Wiki (https://www.mediawiki.org/wiki/Wikibase)
    - Implemented in PHP (backend) + Javascript (frontend)
  - Can be hosted locally through Docker
  - Also available Cloud service: Wikibase.cloud (https://www.wikibase.cloud/)
- Wikibase instance: Application using Wikibase software
  - Examples:
    - Rhizome: https://artbase.rhizome.org/
    - enslaved.org: https://enslaved.org/
  - More: Wikibase.world

Wikibase data model

The Wikibase data model mainly consists of:

- Entities (Items and properties), and
- Statements about entities

More information:

- Reference: https://www.mediawiki.org/wiki/Wikibase/DataModel
- Primer: https://www.mediawiki.org/wiki/Wikibase/DataModel/Primer

Wikibase data model: Entities

Entities can be

- Items (identified by Qxxx), example: http://www.wikidata.org/entity/Q80
- Properties (identified by Pxxx), example: http://www.wikidata.org/entity/P19
  - Properties have an associated datatype (several built-in datatypes)
    - **Item**: Example, example: P19 (*birthplace*)
    - **Geographic locations**, example: P625 (*coordinate location*), contains latitude, longiture, precisión, coordinate system)
    - **Quantity**, example: P1082 (*population*), contains: value, lower bound, higher bound, unit
    - **Dates and times**, example: P569 (*date of birth*), contain: time, precision, before, after, timezone, …
    - **Monolingual text**, example: P1477 (*birth name*)
    - … others: see reference

Entities can also have lexical information

Multilingual labels, descriptions and aliases

Reference:
https://www.mediawiki.org/wiki/Wikibase/DataModel

Wikibase data model: Statements

A statement consists of:

Claim:

- Property
- Value: Declaration of the posible value (snak in wikibase terms)
  - One specific value of the property datatype
  - `no_value`
  - `some_value` (unknown)
- Zero or more qualifiers (list of property-value pairs)

Zero or more references (list of property-value pairs)

Rank declaration: preferred, normal, deprecated

Wikibase data model: JSON serialization

The Wikibase dumps are exported as JSON following the data model

- Each line in the dump contains information about an item and its statements
- JSON representations can directly be obtained as:
  - https://www.wikidata.org/wiki/Special:EntityData/Q80.json

Example:


```
{ "id": "Q80", "type": "item",
  "labels": {"en": {"language": "en", "value": "Tim Berners-Lee" }, . . . },
  "descriptions": { . . . },
  "aliases": { . . . },
  "claims": { "P19": [
     { "id": "q60$50...",
       "mainsnak": { "snaktype": "value", "datatype": "wikibase-item",
         "datavalue": { "value": { "entity-type": "item", "id": "Q84", "numeric-id": 84 },  "type": "wikibase-entityid" }},
       "type": "statement",
       "rank": "normal",
       "qualifiers": { . . . },
       "references": [ . . . ]
     }
    ]
    . . .
  }, "sitelinks": { . . .}, "lastrevid": 2265292559,  "modified": "2024-10-26T11:36:19Z"
}
```


More information: https://doc.wikimedia.org/Wikibase/master/php/docs_topics_json.html

Wikibase datamodel: RDF serialization

Wikibase offers an RDF serialization of each entity

Several ways to get the RDF serialization*:

- SPARQL endpoint: Query service
- RDF Dumps
- Directly, example: https://www.wikidata.org/wiki/Special:EntityData/Q80.ttl

The RDF dump format is defined in: RDF_Dump_Format specification

OWL Wikibase ontology: http://wikiba.se/ontology

Several namespaces:

wd: for ítems

wdt: for properties

…

Custom reification model to serialize qualifiers and references

Serialization of values from compounded datatypes requires several triples

*There can be small differences between the RDF serializations as described here

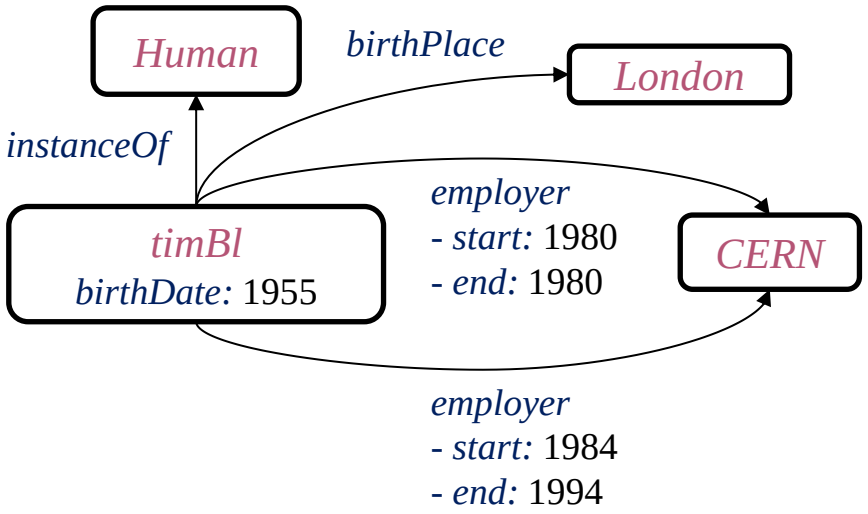
Wikibase RDF serialization (example)

Simplified RDF dump

```
wd:Q80 a wikibase:Item ;
  wdt:P31  wd:Q5 ;
  wdt:P19  wd:Q84 ;
  wdt:P569 "1955-06-08T00:00:00Z"^^xsd:dateTime ;
  wdt:P108 wd:Q42944 ;
  p:P108   s:Q80-fcba864c, :Q80-4fe7940f
  #...
  .

:Q80-4fe7940f a wikibase:Statement ;
  ps:P108 wd:Q42944 ;
  pq:P580 "1984-01-01T00:00:00Z"^^xsd:dateTime ;
  pq:P582 "1994-01-01T00:00:00Z"^^xsd:dateTime .

s:Q80-fcba864c a wikibase:Statement ;
    ps:P108 wd:Q42944 ;
    pq:P580 "1980-06-01T00:00:00Z"^^xsd:dateTime ;
    pq:P582 "1980-12-01T00:00:00Z"^^xsd:dateTime .
```



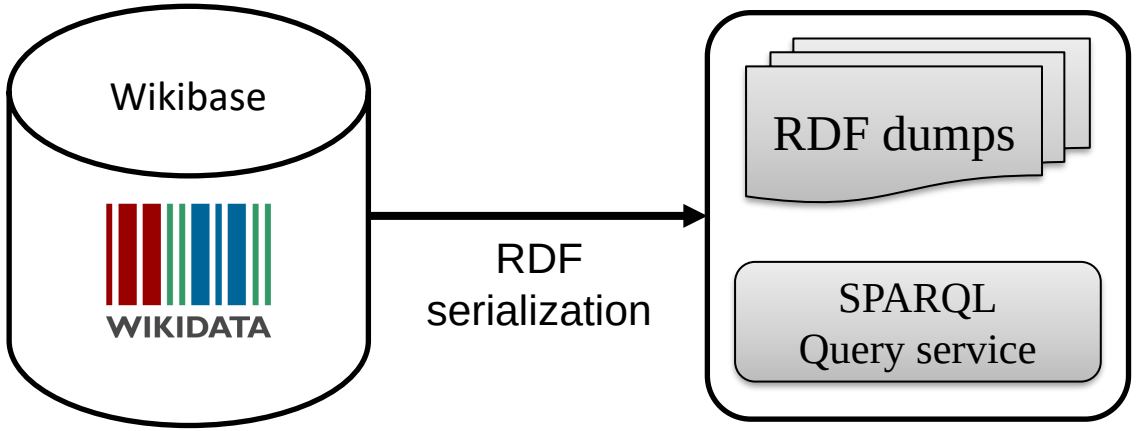
timBl	wd:Q80
London	wd:Q84
Human	wd:Q5
CERN	wd:Q42944
birthDate	wdt:P569
instanceOf	wdt:P31
birthPlace	wdt:P19
employer	wdt:P108
start	pq:P580
end	pq:P582

Wikibase and SPARQL

Wikibase graphs are also available through SPARQL endpoint

Internally, Wikibase has 2 DBs:

- Relational database (MariaDB)
- RDF Triplestore (Blazegraph)
  - Plans to update



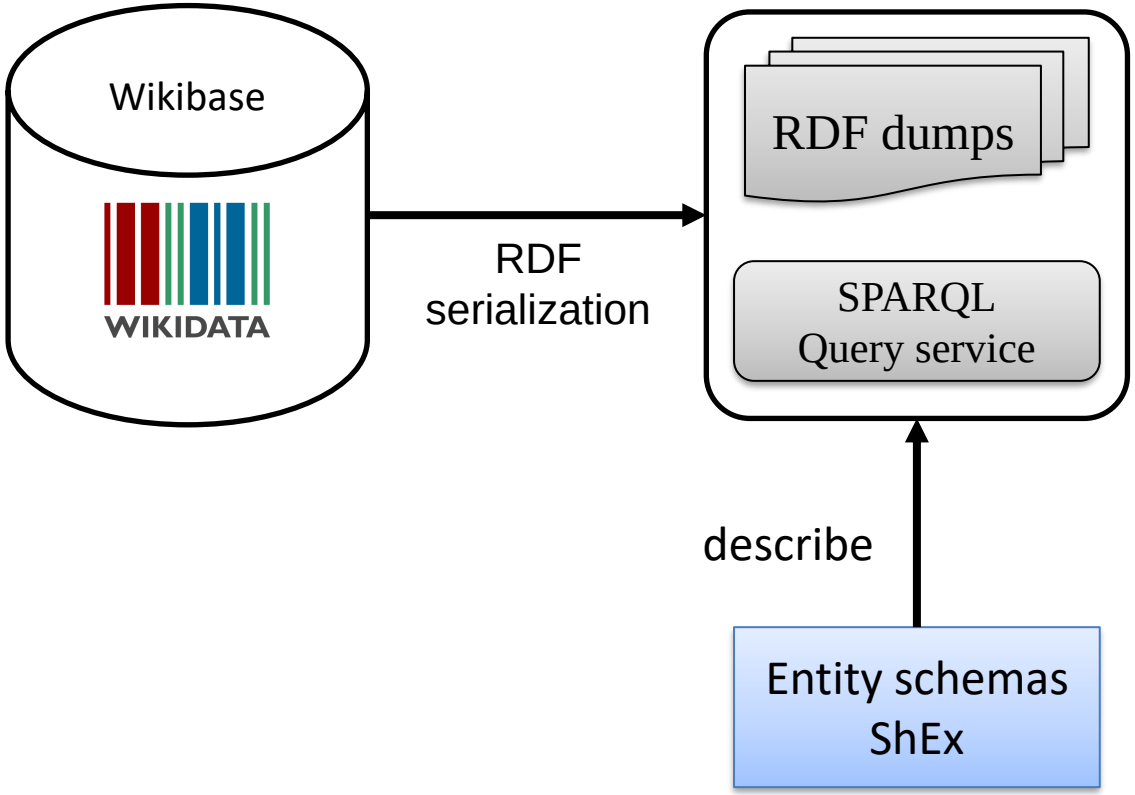

```
select ?name ?date?country where {
 wd:Q80 wdt:P1559 ?name .
 wd:Q80 wdt:P569  ?date .
 wd:Q80 wdt:P19   ?place .
 ?place wdt:P17   ?country
}
```

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

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

Wikibase and RDF: Entity Schemas

Idea: If we have RDF, we can use ShEx to describe and validate entities



Entity Schemas

They can be used to describe Wikidata entities

Adopted in 2019 as a new Wikidata namespace Exxx

Example:

https://www.wikidata.org/wiki/EntitySchema:E10

Directory of entity schemas:

https://www.wikidata.org/wiki/Wikidata:Database_reports/EntitySchema_directory

Example of an Entity Schema

Q80.ttl

```
wd:Q80 rdf:type wikibase:Item ;
  wdt:P31 wd:Q5 ;
  wdt:P19 wd:Q84 ;
  wdt:P569 "1955-06-08T00:00:00Z"^^xsd:dateTime ;
  wdt:P108 wd:Q42944 ;
  p:P108 s:Q80-fcba864c, :Q80-4fe7940f
  #...
  .

:Q80-4fe7940f rdf:type wikibase:Statement ;
  wikibase:rank wikibase:NormalRank ;
  ps:P108 wd:Q42944 ;
  pq:P580 "1984-01-01T00:00:00Z"^^xsd:dateTime ;
  pq:P582 "1994-01-01T00:00:00Z"^^xsd:dateTime .

s:Q80-fcba864c a wikibase:Statement ;
    wikibase:rank wikibase:NormalRank ;
    ps:P108 wd:Q42944 ;
    pq:P580 "1980-06-01T00:00:00Z"^^xsd:dateTime ;
    pq:P582 "1980-12-01T00:00:00Z"^^xsd:dateTime .
```

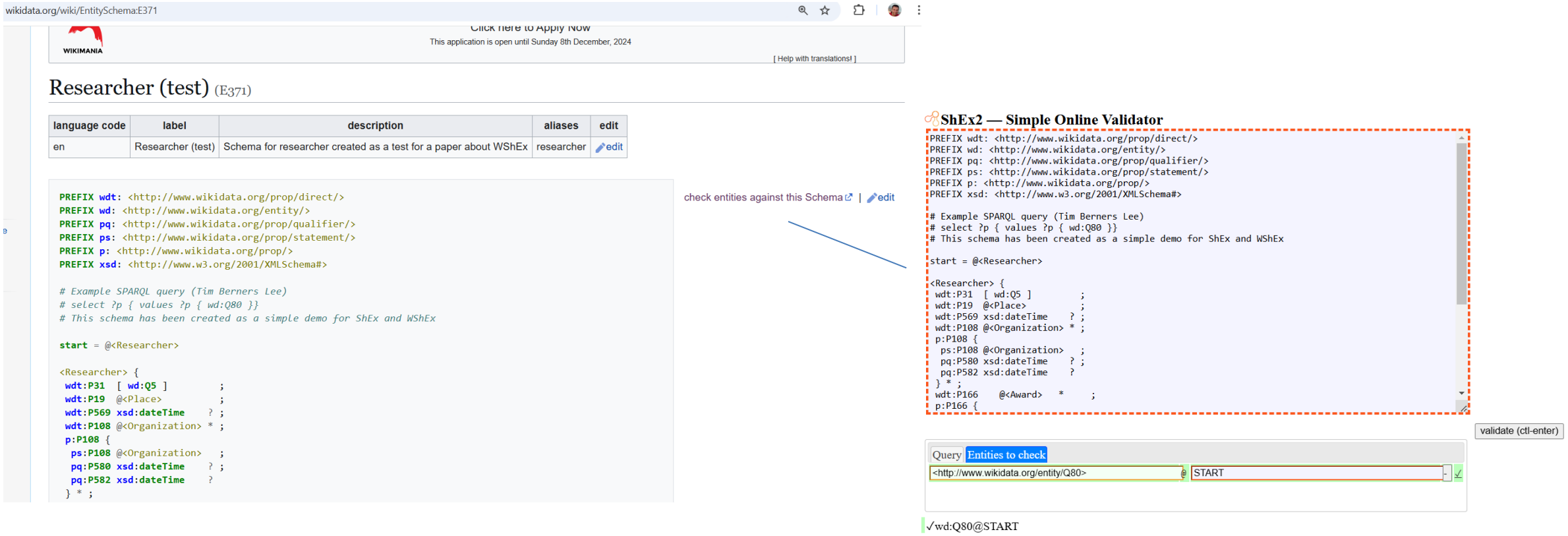
Entity-schema - ShEx

```
PREFIX pq: <.../prop/qualifier/>
PREFIX ps: <.../prop/statement/>
PREFIX p: <.../prop/>
PREFIX wdt: <.../prop/direct/>
PREFIX wd: <.../entity/>
PREFIX xsd: <...XMLSchema#>

<Researcher> {
 wdt:P31  [ wd:Q5 ]          ;
 wdt:P19  @<Place>           ;
 wdt:P569 xsd:dateTime       ;
 wdt:P108 @<Employer>      * ;
 p:P108 { ps:P108 @<Employer>     ;
          pq:P580 xsd:dateTime  ? ;
          pq:P582 xsd:dateTime  *
 } *
}
<Place> { }
<Employer> { }
```

Using Entity Schemas for validation

Example: https://www.wikidata.org/wiki/EntitySchema:E371



Wikibase also has property constraints for validation

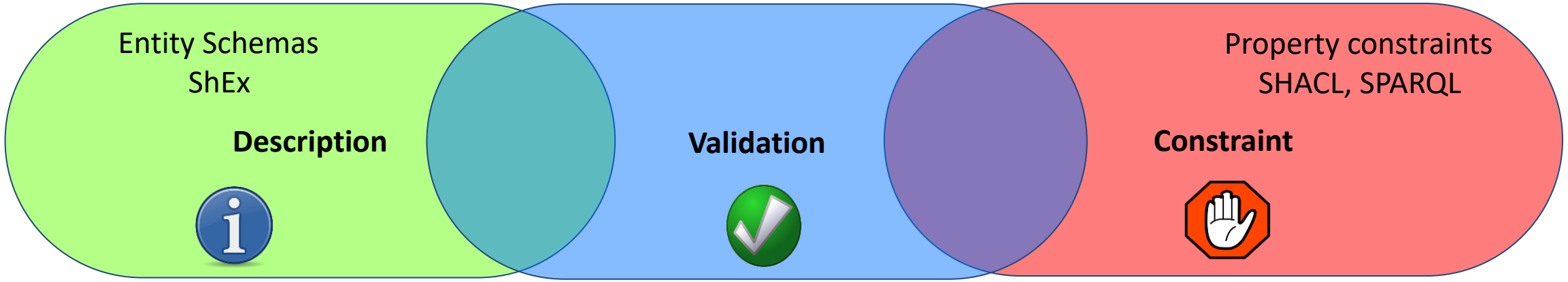
- Property constraints: rules on properties
  - Specify how the properties should be used
    - https://www.wikidata.org/wiki/Help:Property_constraints_portal
  - Constraints are hints, not firm restrictions (help or guidance to the editor)
- Example: single value constraint (Q19474404)
  - P19 (birth_place) in general is expected to conform to SingleValueConstraint
  - Example failing constraint (Noam Chomsky) and example with exception (Louis Seel)
- Property constraints definition/implementation is part of Wikibase

Entity schemas vs property constraints

Entity schemas contain descriptions of sets of ítems

- Easy to create a new entity schemas: Overlapping entity schemas for different purposes
- Entity schemas ecosystem

Property constraints are rules that can be used to validate or recommend



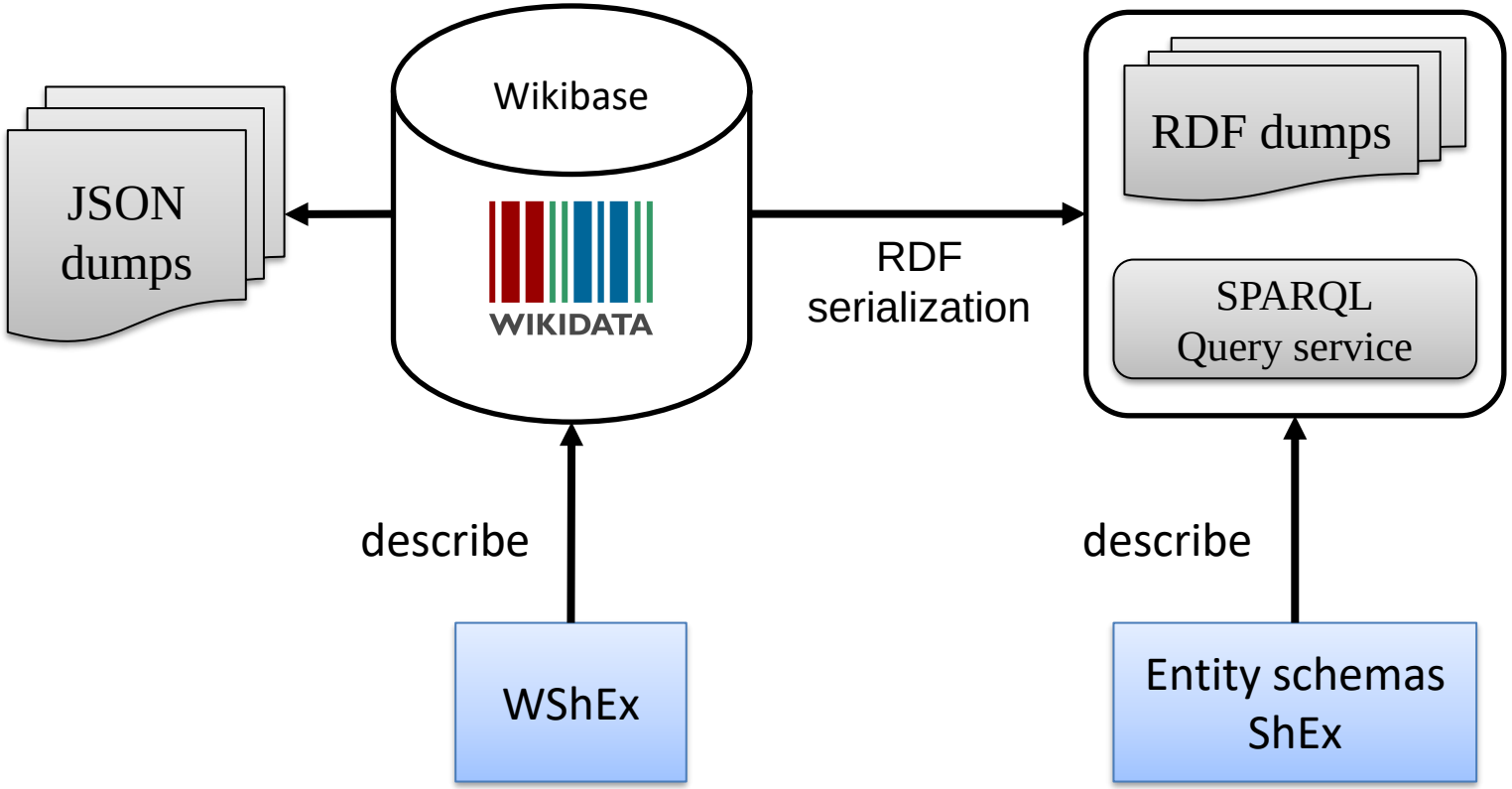
Tutorial Wiwi at ISWC'24

Paper about the relationship between property constraints and SHACL, SPARQL:
Ferranti, Nicolas et al. 'Formalizing and Validating Wikidata's Property Constraints Using SHACL and SPARQL'. 1 Jan. 2024 : 1 – 48.

WShEx

Although Entity Schemas and ShEx just work, they are indirectly describing Wikibase

WShEx has been proposed as a language to describe the Wikibase data model?



https://www.weso.es/WShEx/

Wikibase RDF representation

RDF

```
wd:Q80       wdt:P166  wd:Q3320352  ;
             p:P166    s:PQ80-494FA .

s:PQ80-494FA ps:P166   wd:Q3320352 ;
             pq:P585   2002        ;
             pq:P1706  wd:Q62843, wd:Q92935, wd:Q92743.
```

Could be represented as

```
:Q80 :P166  :Q3320352 {|
        :P585  2002;
        :P1796 :Q62843, :Q92935, :Q92743
   |}
```

Inspired by RDF-Star annotated triples syntax

WShEx: A language to describe and validate Wikibase entities

Jose Emilio Labra Gayo

Entity-schema - ShEx

```
PREFIX pq: <.../prop/qualifier/>
PREFIX ps: <.../prop/statement/>
PREFIX p: <.../prop/>
PREFIX wdt: <.../prop/direct/>
PREFIX wd: <.../entity/>
PREFIX xsd: <...XMLSchema#>

<Researcher> {
 wdt:P31   [ wd:Q5 ]          ;
 wdt:P166  @<Award>           * ;
 p:P166 {| ps:P166  @<Award>          ;
           pq:P585  xsd:dateTime    ? ;
           pq:P1706 @<Researcher>   *
 |} *
}
<Award> { wdt:P17 @<Country> ? }
<Country> {}
```

WShEx

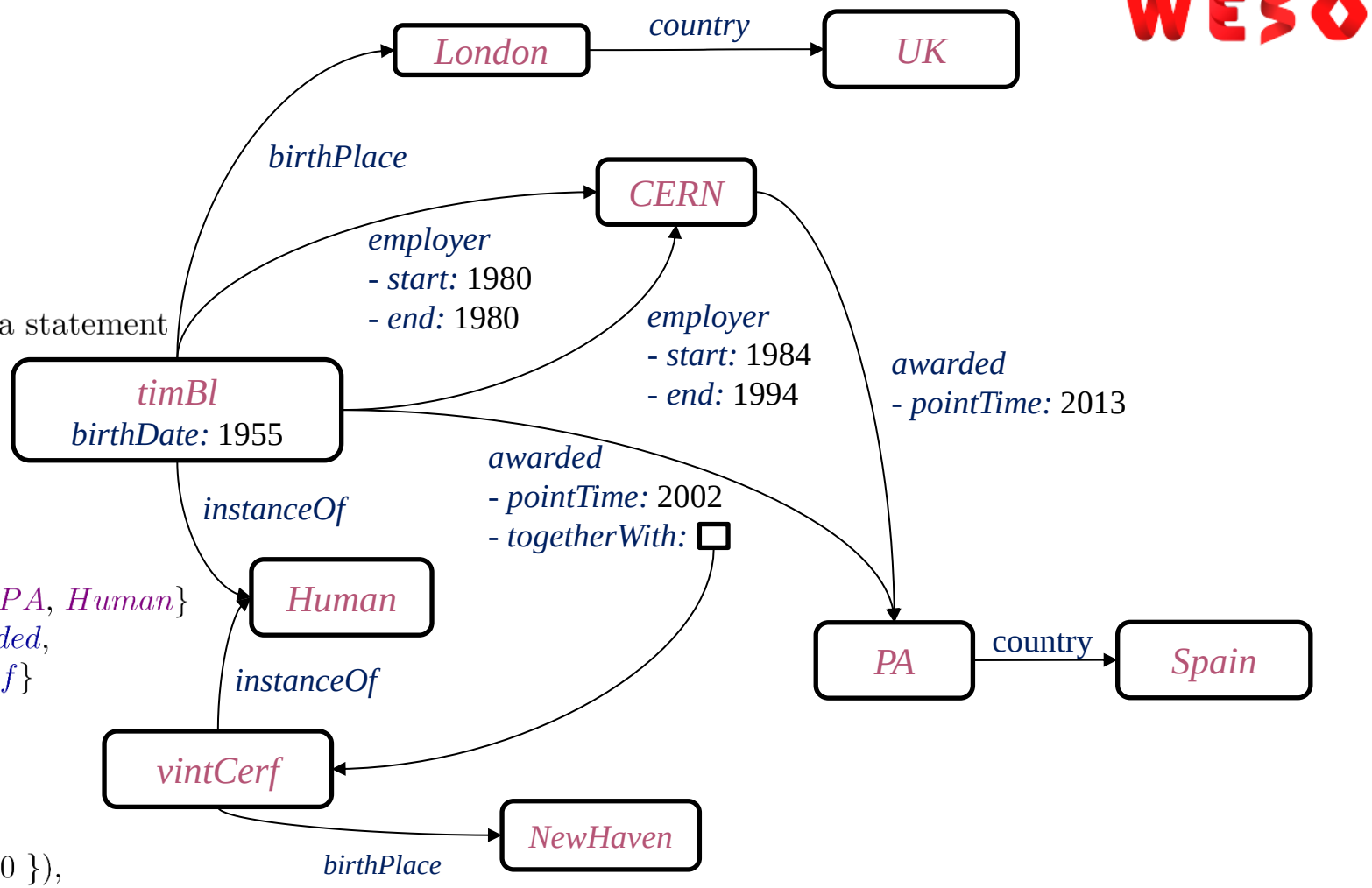
```
PREFIX : <.../entity/>

<Researcher> {
 :P31   [ :Q5 ]     ;
 :P166  @<Award> {| :P585  Time ? ,
                    :P1706 @<Researcher> ?
                 |} *
}
<Award> { :P17 @<Country> }
<Country> {}
```

https://arxiv.org/abs/2208.02697

Wikibase graphs

Given a mutually disjoint set of items $\mathcal{Q}$,
a set of properties $\mathcal{P}$ and
a set of data values $\mathcal{D}$,
a *Wikibase graph* is a tuple $\langle \mathcal{Q}, \mathcal{P}, \mathcal{D}, \rho \rangle$ such that
$\rho \subseteq \mathcal{E} \times \mathcal{P} \times \mathcal{V} \times FinSet(\mathcal{P} \times \mathcal{V})$ where
$\mathcal{E} = \mathcal{Q} \cup \mathcal{P}$ is the set of entities which can be subjects of a statement
$\mathcal{V} = \mathcal{E} \cup \mathcal{D}$ is the set of possible values of a property.

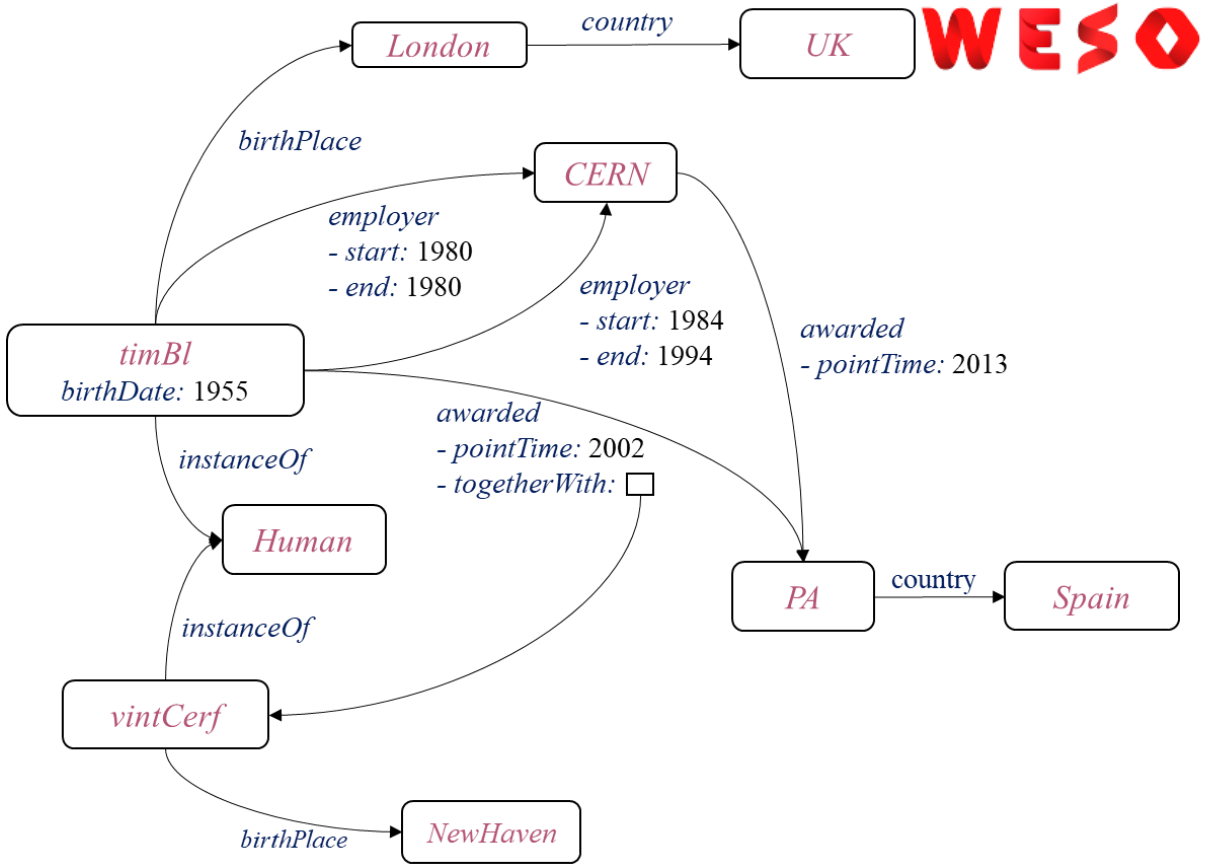


$$
\begin{aligned}
\mathcal{Q} &= \{ \; timBl, vintCerf, London, CERN, UK, Spain, PA, Human\} \\
\mathcal{P} &= \{ \; birthDate, birthPlace, country, employer, awarded, \\
&\quad\; start, end, pointTime, togetherWith, instanceOf\} \\
\mathcal{D} &= \{ \; 1984{,}1994{,}1980{,}1955\} \\
\rho &= \{ \; (timBl, instanceOf, Human, \{\}), \\
&\quad\; (timBl, birthDate, 1955, \{\}), \\
&\quad\; (timBl, birthPlace, London, \{\}), \\
&\quad\; (timBl, employer, CERN, \{\ start{:}1980, end{:}1980\ \}), \\
&\quad\; (timBl, employer, CERN, \{\ start{:}1984, end{:}1994\ \}), \\
&\quad\; (timBl, awarded, PA, \{pointTime{:}\ 2002, togetherWith{:}vintCerf\}), \\
&\quad\; (London, country, UK, \{\}), \\
&\quad\; (vintCerf, instanceOf, Human, \{\}) \\
&\quad\; (vintCerf, birthPlace, NewHaven, \{\}) \\
&\quad\; (CERN, awarded, PA, \{\ pointTime{:}\ 2013\ \}) \\
&\quad\; (PA, country, Spain, \{\ \}) \; \}
\end{aligned}
$$

WShEx for Wikibase graphs

A WShEx Schema is a tuple $\langle \mathcal{L}, \delta \rangle$ where
$\mathcal{L}$ set of shape labels
$\delta : \mathcal{L} \rightarrow se$

se	::=	cond	Basic boolean condition on nodes (node constraint)
	|	s	Shape
	|	se_1 `AND` se_2	Conjunction
	|	$@l$	Shape label reference for $l \in \mathcal{L}$
s	::=	`CLOSED` s'	Closed shape
	|	s'	Open shape
s'	::=	{ te }	Shape definition
te	::=	$te_1; te_2$	Each of te_1 and te_2
	|	$te_1 \mid te_2$	Some of te_1 or te_2
	|	$te*$	Zero or more te
	|	$\llcorner \xrightarrow{p} @l\ qs$	Triple constraint with predicate p value conforming to l and qualifier specifier qs
	|	ϵ	Empty triple expression
qs	::=	$\lfloor ps \rfloor$	Open property specifier
	|	$\lceil ps \rceil$	Closed property specifier
ps	::=	ps , ps	*EachOf* property specifiers
	|	$ps \mid ps$	*OneOf* property specifiers
	|	ps*	zero of more property specifiers
	|	ϵ	Empty property specifier
	|	p:@l	Property p with value conforming to shape l



$$
\begin{array}{rcl}
\mathcal{L} & = & \{ \ Person, Place, Country, Organization, Date, \ Award\} \\
\delta(Person) & = & \{ \ \llcorner \xrightarrow{birthDate} @Date; \ \llcorner \xrightarrow{birthPlace} @Place; \\
 & & \llcorner \xrightarrow{employer} @Organization \ \lfloor start : @Date \, , \, end : @Date \rfloor * \\
 & & \llcorner \xrightarrow{awarded} @Award \ \lfloor pointTime : @Date \, , \, togetherWith : @Person \rfloor * \\
 & & \} \\
\delta(Place) & = & \{ \ \llcorner \xrightarrow{country} @Country\} \\
\delta(Country) & = & \{ \ \} \\
\delta(Award) & = & \{ \ \llcorner \xrightarrow{country} @Country\} \\
\delta(Organization) & = & \{ \ \} \\
\delta(\text{Date}) & = & \in xsd : date
\end{array}
$$

Use cases

- Wikidata subsetting: Describe directly JSON dumps
- Entity schemas linter
  - Entity Schemas can be parsed to WShEx detecting inconsistencies
- Wikibase validation
  - Improve validation quality and messages
- Using WShEx ideas for Querying
  - Concise syntax and ability to handle dumps

Further information:

WShEx Specification:
https://www.weso.es/WShEx/

Future work

- Complete WShEx specification
  - Semantic specification including other features: references, labels,...
  - Compact syntax grammar
- Converter Entity Schemas (ShEx) ↔ WShEx
- WShEx tooling: validation, editors, etc.

Further information:

WShEx Specification:
https://www.weso.es/WShEx/

Contents

Property graphs

- Popular model in industry
  - Neo4j, Amazon Neptune, Oracle, etc
- GQL has been published in 2024
  - Recent publication of ISO/IEC FDIS 39075
  - Developed by ISO/IEC JTC1 SC32 WG3: the “SQL” committee
  - Influenced by Cypher, PGQL, etc.
  - Specification behind a paywall*
    - But some open source tools: https://ldbcouncil.org
    - and public documents

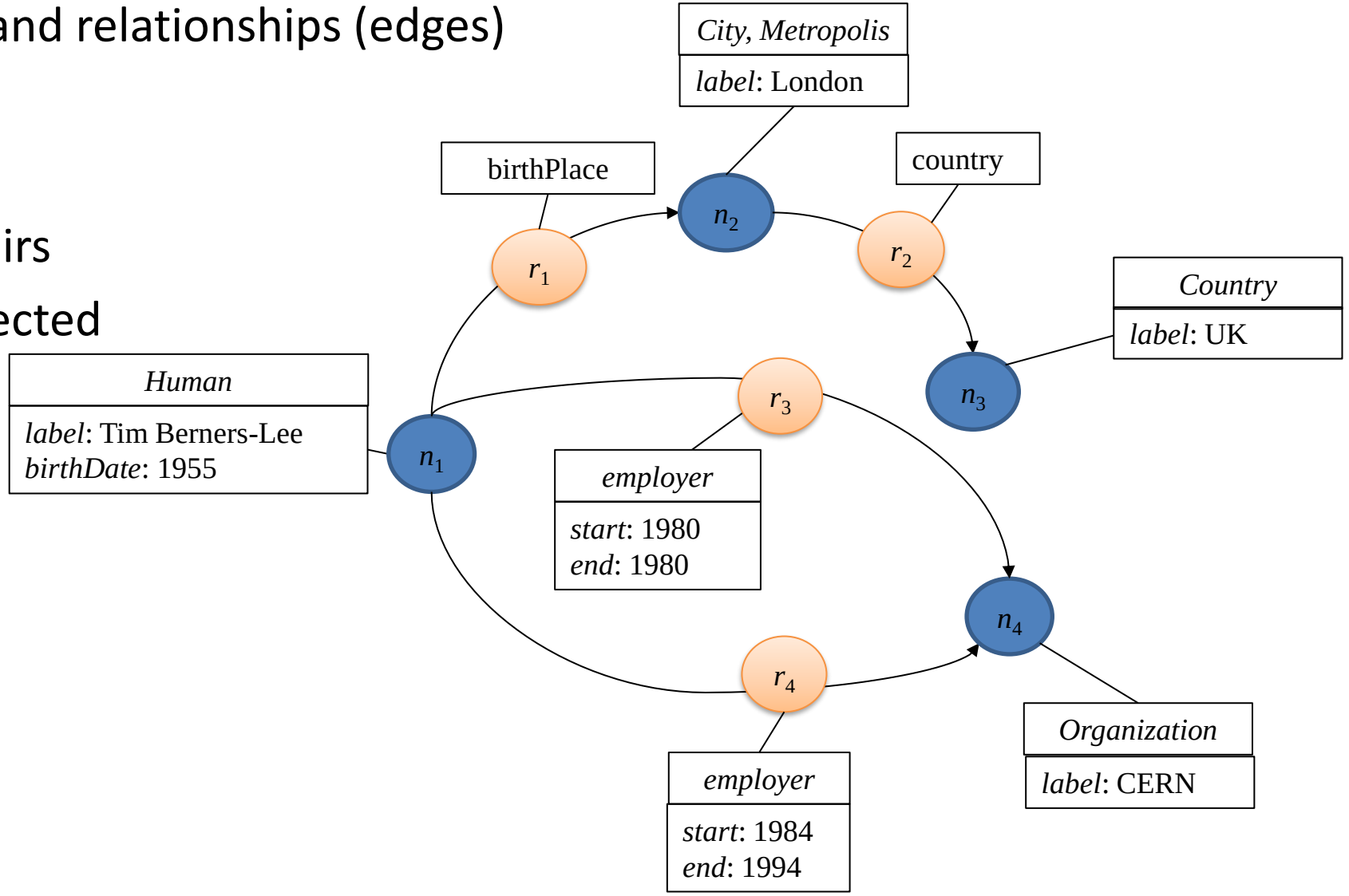
Property graphs

Graph structure with nodes and relationships (edges)

Nodes and edges can have:

- Labels
- A set of property-value pairs

Edges can be directed/undirected



Shaping Property graphs with GQL

GQL defines the concept of Graph Types

- It describes the graph in terms of restrictions on labels, properties, nodes, edges and topology
- Graph types constrain the set of nodes that can be contained in a graph

Multiple graphs can refer to the same graph type

Graph types can be created independently:

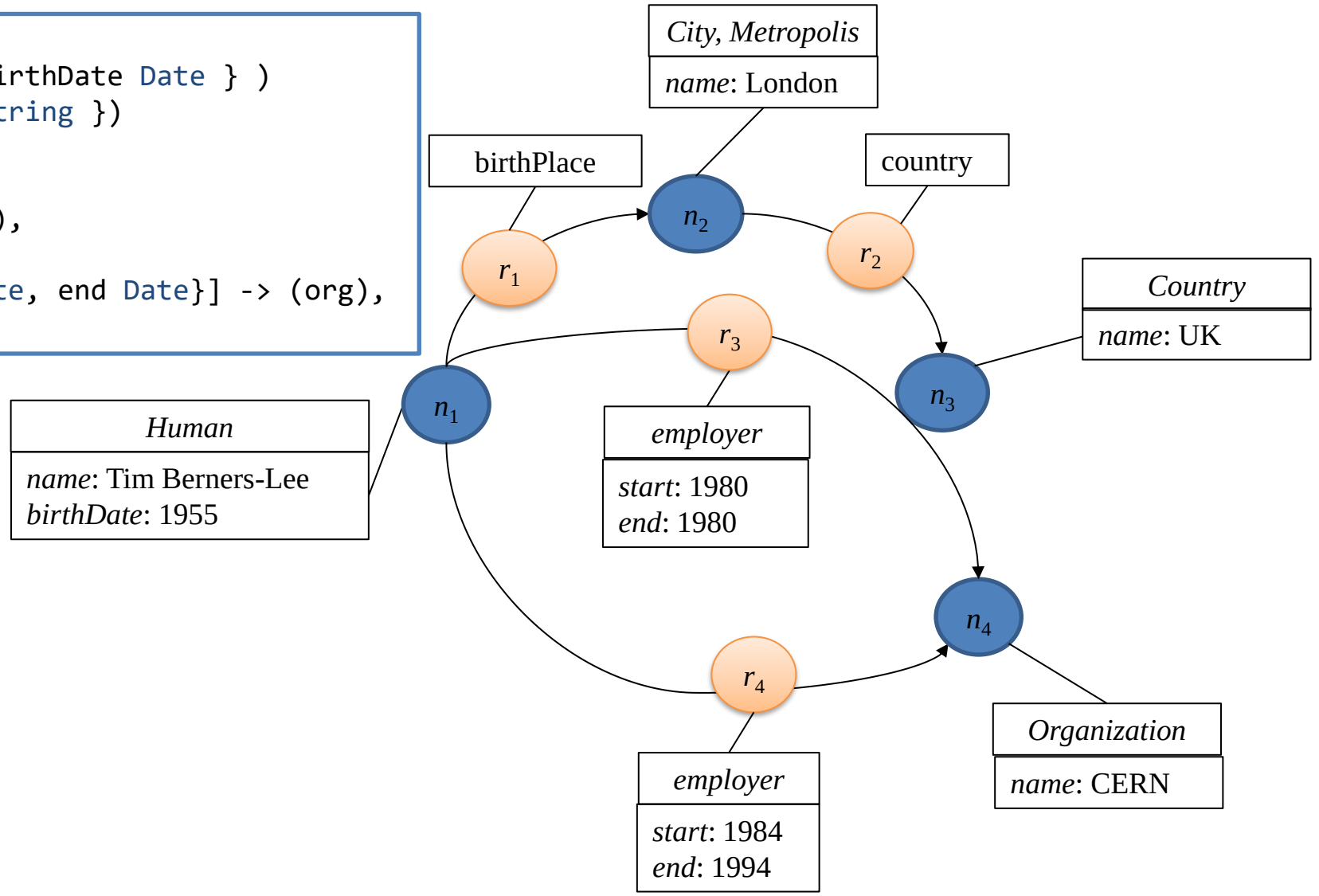
```
CREATE GRAPH TYPE name { graph type spec }
```

Or when creating the graph:

```
CREATE GRAPH …content… TYPED { graph type spec }
```

Shaping property graphs with GQL: Example

```
CREATE GRAPH TYPE example {
  (researcher :Human => { name String, birthDate Date } )
  (place :City & :Metropolis => { name String })
  (country :Country => { name String })
  (org :Organization => { name String })
  (researcher) -[ :birthPlace ]-> (place),
  (place) -[ :country ]-> (country),
  (researcher) -[:employer => { start Date, end Date}] -> (org),
}
```



Shaping Property graphs with GQL

Validating graphs with graph types

A graph is of a graph type if:

- Each of the nodes in the graph are of a node type specified in the graph type
- Each of the edges in the graph are of an Edge type in the graph

Inserting or updating nodes and edges in a graph that has a constraining graph type such that the graph would no longer be of that graph type causes an exception condition to be raised: **graph type violation**

Shaping property graphs with GQL

Graph types in GQL are closed

- No open/partial semantics

No Cardinality constraints about the topology of the graph?

Schema fixed vs schema-less

- It is also possible to have a schema-less graph as:

```
CREATE GRAPH … TYPED ANY
```

- Schema-less graphs are not restricted by a graph type, they may contain anything the property graph model allows.

Shaping property graphs: PG-Schema

PGSchema has been proposed as a joint effort of several researchers

- Open/Closed Record types
- Edge/Node types
- Labelling types
- Content types
- Constraints with PG-Keys
- No support for cardinality constraints on the graph topology

See also:

- Ora Lassila's presentation about a Common PG-Schema and SHACL
- Our recent work about a Common foundation for PGSchema, SHACL and ShEx

PShEx

Proposal to extend ShEx to handle property graphs

Similar to WShEx, but adapted for Property graphs

We add a new description level for property-value pairs (in nodes and edges)

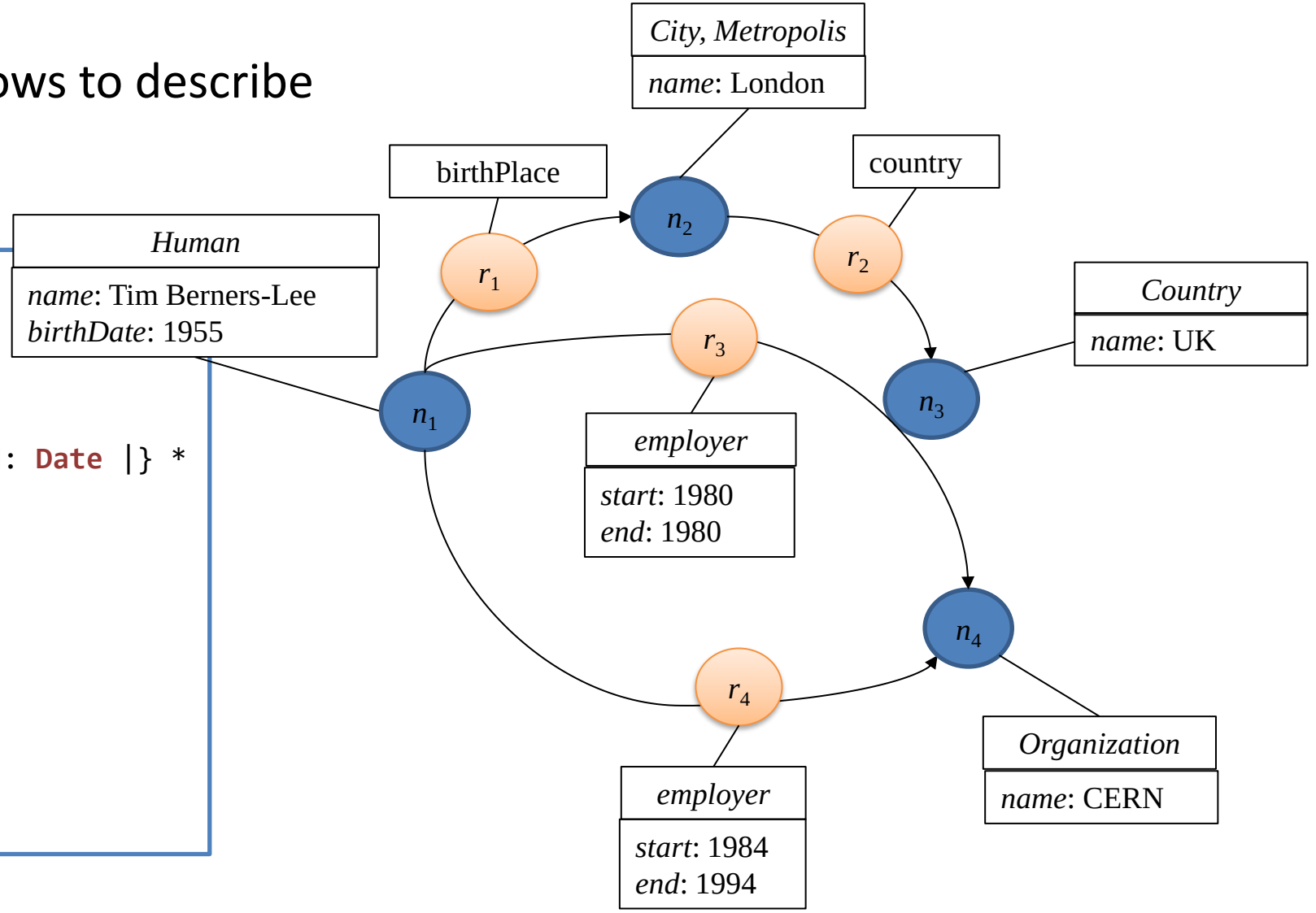
It allows to declare cardinality constraints on the topology of the graph

Extending Shape Expressions for different types of knowledge graphs , Jose Emilio Labra Gayo, In 1st Workshop on *Data Quality meets Machine Learning and Knowledge Graphs*, DQMLKG, part of *Extended Semantic Web Conference 2024*, ESWC24. - 2024, http://labra.weso.es/publication/2024_shex_extensions/

Shaping property graphs: PShEx

PShEx = ShEx extension that allows to describe property graphs

```
<Researcher> [( Human )] [|
  name:       String     ;
  birthDate:  Date     ?
|] AND {
  birthPlace: @<Place> ? ;
  employer:   @<Org> {| start: Date; end: Date |} *
}
<Place> [( City)]{
  country: @<Country>
}
<Country> {
  name: String
}
<Org> {
  name: String
}
```

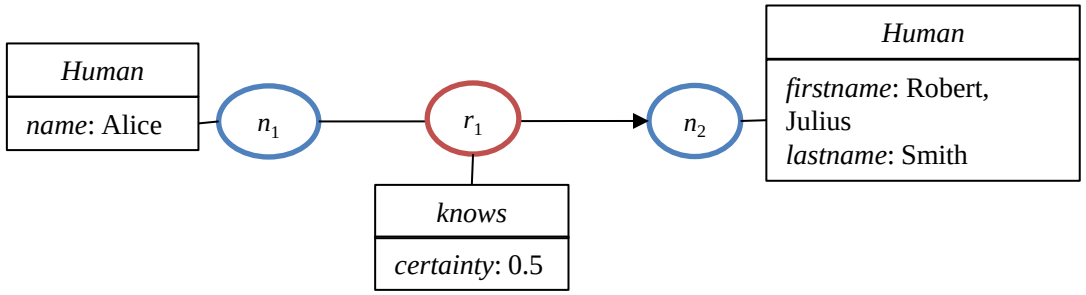


Shaping property graphs with PShEx

PShEx supports regular expressions to describe the graph content

Another example

```
<Person> [( Human )] AND
  [| name: String |
     firstname: String *,
     lastname: String
  |] AND {
     knows @<Person> {|
       certainty: Float
     |} *
  }
```



PShEx abstract syntax

PShEx adds property value specifiers (*pvs*) to nodes and edges

se	::=	$cond_{t_s}$	Basic boolean condition on set of types $t_s \subseteq T$
	|	s	Shape
	|	se_1 AND se_2	Conjunction
	|	$@l$	Shape label reference for $l \in L$
	|	pvs	Property-value specifiers of a node
s	::=	CLOSED $\{te\}$	Closed shape
	|	$\{te\}$	Open shape
te	::=	$te_1; te_2$	Each of te_1 and te_2
	|	$te_1 \mid te_2$	Some of te_1 or te_2
	|	$te*$	Zero or more te
	|	$\_ \xrightarrow{p} @l\ pvs$	Triple constraint with property type p whose nodes satisfy the shape l and property-values pvs
pvs	::=	$\lfloor ps \rfloor$	Open property-value specifiers ps
	|	$\lceil ps \rceil$	Closed property-value specifiers ps
ps	::=	$ps_1\ ,\ ps_2$	Each of ps_1 and ps_2
	|	$ps_1 \mid ps_2$	OneOf of ps_1 or ps_2
	|	$ps*$	zero of more ps
	|	$p : cond_v$	Property p with value conforming to $cond_v$ $cond_{v_s}$ is a boolean condition on sets of values $v_s \subseteq V$

```
<Person> [( Human )] AND
  [| name: String |
     firstname: String *,
     lastname: String
  |] AND {
     knows @<Person> {|
       certainty: Float
     |} *
  }
```

$$
\begin{aligned}
L &= \{\ Person\} \\
\delta(Person) &= hasType_{Human}\ \text{AND} \\
&\quad \lfloor name : String \mid firstname : String*\ , lastname : String \rfloor\ \text{AND} \\
&\quad \{\ \_ \xrightarrow{knows} @Person\ \lfloor certainty : Float \rfloor^*\ \}
\end{aligned}
$$

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- Applications:
  - Inferring shapes from data, Knowledge Graphs Subsets, etc.

RDF1.2 (RDF-Star)

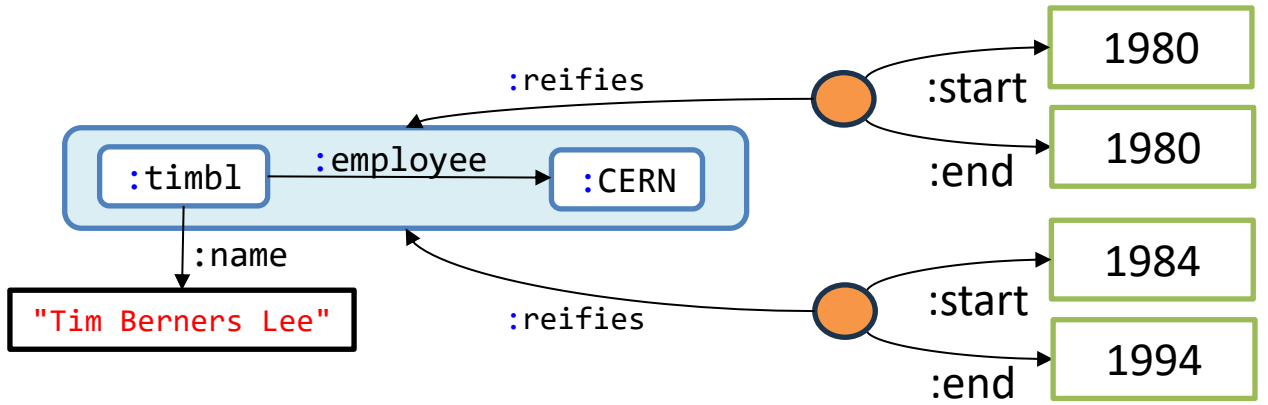
Currently under discussion (https://github.com/w3c/rdf-star-wg/wiki)

Add statements about triples

Reifiers

```
:timbl :name  "Tim Berners Lee“ ;
       :employer :CERN .
_:r1 rdf:reifies << :timbl :employer :CERN >> .
_:r1 :start 1980 ;
     :end   1980 .
```

```
_:r2 rdf:reifies << :timbl :employer :CERN >> .
_:r2 :start 1984 ;
     :end   1994 .
```



Alternative syntax

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

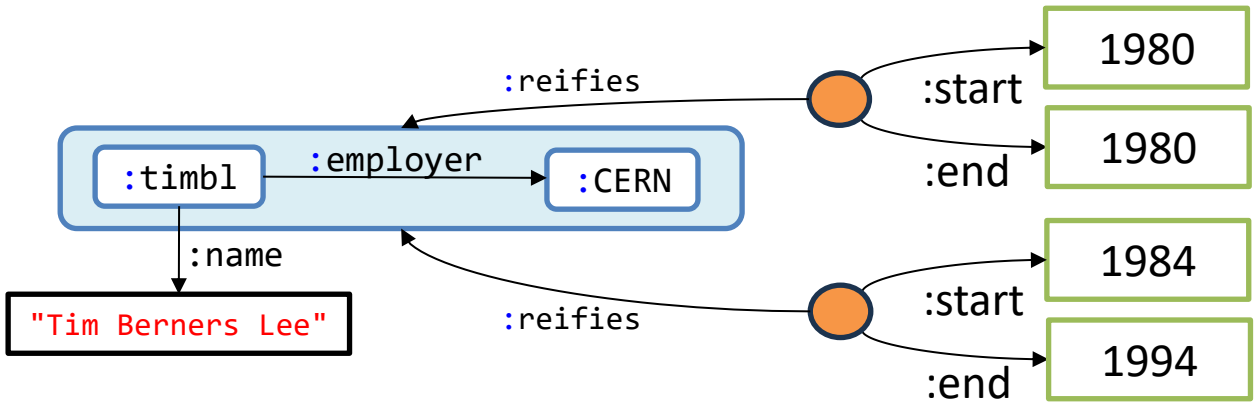
ShEx-Star

Example

```
<Person> {
    ( :name   xsd:string
    | :firstName xsd:string + ;
      :lastname xsd:string
    ) ;
   << :employee @<Org> >> {|
        :start xsd:date,
        :start xsd:date
   |} *
}
<Org> {}
```

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

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



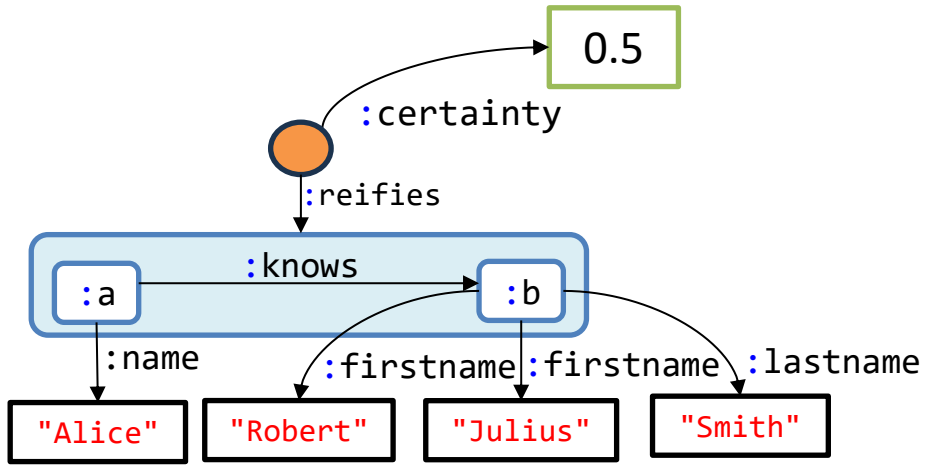
ShEx-Star

Example

```
<Person> {
    ( :name   xsd:string
    | :firstName xsd:string + ;
      :lastname xsd:string
    ) ;
   << :knwows @<Person> >> {| :certainty xsd:float |} *
}
```

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

:a :name  "Alice" .
<< :a :knows :b >> :certainty 0.5 .
:b :firstname "Robert", "Julius" ;
    :lastname  "Smith" .
```



ShEx-Star abstract syntax

ShEx-Star adds two new rules for triple expressions te

$$se \quad ::= \quad \ldots \text{same as in ShEx}$$

te	$::=$	$te_1; te_2$	Each of te_1 and te_2
	$\mid$	$te_1 \mid te_2$	Either te_1 or te_2
	$\mid$	$te*$	Zero or more te
	$\mid$	$\llcorner \xrightarrow{p} se$	Outgoing Triple with predicate p and object conforming to se
	$\mid$	$se \xrightarrow{p} \llcorner$	Incoming triple with predicate p and subject conforming to se
	$\mid$	ϵ	Empty triple expression
	$\mid$	$\ll \llcorner \xrightarrow{p} se \gg \{\mid te \mid\}$	Outgoing Triple term constraint with predicate p
	$\mid$	$\ll se \xrightarrow{p} \llcorner \gg \{\mid te \mid\}$	Incoming triple term constraint with predicate p

$$\delta(Person) = \{ \; (\llcorner \xrightarrow{name} String \mid \llcorner \xrightarrow{fistname} String*; \llcorner \xrightarrow{lastname} String); \; \ll \llcorner \xrightarrow{knows} @Person \gg \{\mid \llcorner \xrightarrow{certainty} Float \mid\}* \; \}$$

```
<Person> {
    ( :name   xsd:string
    | :firstName xsd:string + ;
      :lastname xsd:string
    ) ;
   << :knwows @<Person> >> {| :certainty xsd:float |} *
}
```

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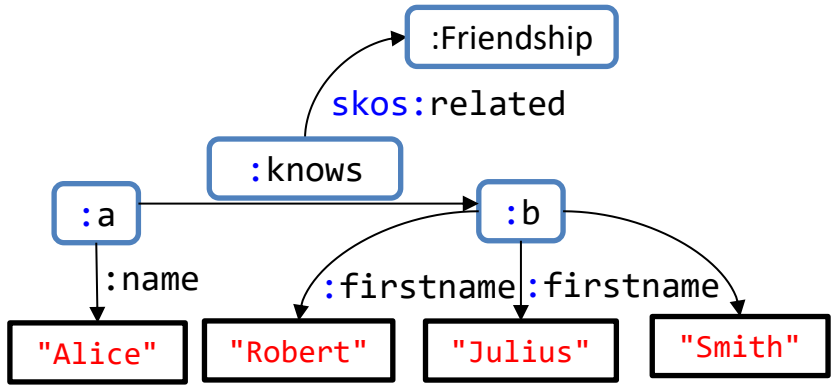
RDF with nodes as properties

In RDF Graphs, nodes can also be properties




```
prefix : <http://example.org/>
prefix skos: <http://.../skos/core#>

:a :name  "Alice" ;
    :knows :b .
:b :firstname "Robert", "Julius" ;
   :lastname  "Smith" .
:knows skos:related :Friendship .
```

ShEx-N

Example:

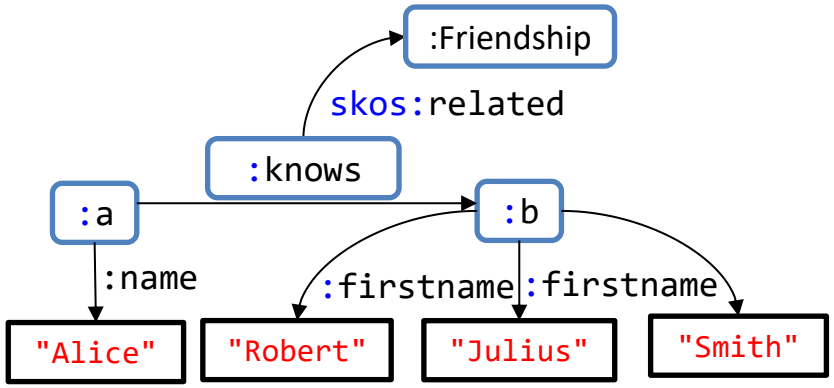
```
<FriendshipProperty> {
  skos:related [ :Friendship ] ;
  @<Person> >-< @<Person>
}
<Person> {
    ( :name   xsd:string
    | :firstName xsd:string + ;
      :lastname xsd:string
    ) ;
    :knows @<Person> *
}
```

$$\delta(FriendShipProperty) = \{ \; \_ \xrightarrow{skos:related} [: Friendship] \; ; \; @Person \rightleftharpoons @Person \; \}$$

$$\delta(Person) = \{ \; \_ \xrightarrow{:name} String \; | \; \_ \xrightarrow{:firstname} String* \; ; \; \_ \xrightarrow{:lastname} String \; ; \; \_ \xrightarrow{knows} @Person \; * \; \}$$

```
prefix : <http://example.org/>
prefix skos: <http://.../skos/core#>

:a :name  "Alice" ;
    :knows :b .
:b :firstname "Robert", "Julius" ;
   :lastname  "Smith" .
:knows skos:related :Friendship .
```



ShEx-N abstract syntax

We add a new rule for triple expressions *te*

se	::=	cond	Basic boolean condition on nodes (node constraint)
	|	s	Shape
	|	se_1 `AND` se_2	Conjunction of se_1 and se_2
	|	$@l$	Shape label reference for $l \in L$
	|	`CLOSED` $\{te\}$	Closed shape
	|	$\{te\}$	Open shape
te	::=	$te_1; te_2$	Each of te_1 and te_2
	|	$te_1 \mid te_2$	Either te_1 or te_2
	|	$te*$	Zero or more te
	|	$\_ \xrightarrow{p} se$	Outgoing Triple with predicate p and object conforming to se
	|	$se \xrightarrow{p} \_$	Incoming triple with predicate p and subject conforming to se
	|	ϵ	Empty triple expression
	|	$se_1 \xrightarrow{\_} se_2$	Triple constraint with focus node acting as predicate and subject conforming to se_1 and object conforming to se_2

Semantics of these extensions

We define the semantics using 2 conformance relationships and several inference rules

$$G, n, \tau \vDash se = \text{node } n \text{ in graph } G \text{ conforms to } se \text{ with assignment } \tau$$

$$G, ts, \tau \Vdash te = \text{neighborhood } ts \text{ of graph } G \text{ conform to } te \text{ with assignment } \tau$$

More details in the paper

Extending Shape Expressions for different types of knowledge graphs , Jose Emilio Labra Gayo, In 1st Workshop on *Data Quality meets Machine Learning and Knowledge Graphs*, DQMLKG, part of *Extended Semantic Web Conference 2024*, ESWC24. - 2024
http://labra.weso.es/publication/2024_shex_extensions/

ShEx semantics

Shape expressions *se*

$$Cond\frac{cond(n) = true}{G, n, \tau \vDash cond} \qquad AND\frac{G, n, \tau \vDash se_1 \quad G, n, \tau \vDash se_2}{G, n, \tau \vDash se_1 \texttt{ AND } se_2}$$

$$ShapeRef\frac{\delta(l) = se \quad G, n, \tau \vDash se}{G, n, \tau \vDash @l} \qquad ClosedShape\frac{neighs(n, G) = ts \quad G, ts, \tau \Vdash te}{G, n, \tau \vDash \texttt{CLOSED } \{te\}}$$

Triple expressions *te*

$$OpenShape\frac{ts = \{\langle x, p, y\rangle \in neighs(n, G) \mid p \in preds(te)\} \quad G, ts, \tau \Vdash te}{G, n, \tau \vDash \{te\}}$$

$$EachOf\frac{(ts_1, ts_2) \in part(ts) \quad G, ts_1, \tau \Vdash te_1 \quad G, ts_2, \tau \Vdash te_2}{G, ts, \tau \Vdash te_1; te_2}$$

$$OneOf_1\frac{G, ts, \tau \Vdash te_1}{G, ts, \tau \Vdash te_1 \mid te_2} \qquad OneOf_2\frac{G, ts, \tau \Vdash te_2}{G, ts, \tau \Vdash te_1 \mid te_2}$$

$$TC_1\frac{ts = \{\langle x, p, y\rangle\} \quad G, y, \tau \vDash @l}{G, ts, \tau \Vdash \_ \xrightarrow{p} @l} \qquad TC_2\frac{ts = \{\langle y, p, x\rangle\} \quad G, y, \tau \vDash @l}{G, ts, \tau \Vdash @l \xrightarrow{p} \_}$$

$$Star_2\frac{(ts_1, ts_2) \in part(ts) \quad G, ts_1, \tau \Vdash te \quad G, ts_2, \tau \Vdash te*}{G, ts, \tau \Vdash te*} \qquad Star_1\frac{}{G, \emptyset, \tau \Vdash te*}$$

ShEx-Star semantics

Same rules as for ShEx plus:

$$TTC_1 \frac{ts = \{\langle \ll t \gg, p, y \rangle\} \quad G, y, \tau \vDash se \quad neighs(\ll t \gg, G) = ts' \quad G, ts', \tau \Vdash te}{G, ts, \tau \Vdash \ll \_ \xrightarrow{p} se \gg \{|te|\}}$$

$$TTC_2 \frac{ts = \{\langle x, p, \ll t \gg \rangle\} \quad G, x, \tau \vDash se \quad neighs(\ll t \gg, G) = ts' \quad G, ts', \tau \Vdash te}{G, ts, \tau \Vdash \ll se \xrightarrow{p} \_ \gg \{|te|\}}$$

$$\begin{aligned} \delta(Person) \quad = \quad \{ \quad & (\_ \xrightarrow{name} String \mid \_ \xrightarrow{fistname} String^*; \_ \xrightarrow{lastname} String); \\ & \ll \_ \xrightarrow{knows} @Person \gg \{|\_ \xrightarrow{certainty} Float|\}^* \\ \} & \end{aligned}$$

ShEx-N semantics

Same rules as in ShEx plus:

$$NP_1 \frac{ts = \{\langle s, x, o\rangle\} \quad G, s, \tau \vDash se_1 \quad G, o, \tau \vDash se_2}{G, ts, \tau \Vdash se_1 \overset{\sqcup}{\rightarrow} se_2}$$

$$\begin{array}{rcll} \delta(FriendShipProperty) & = & \{ & \sqcup \xrightarrow{skos{:}related} [: Friendship] \ ; \\ & & & @Person \overset{\sqcup}{\rightarrow} @Person \\ & & \} & \\ \delta(Person) & = & \{ & \sqcup \xrightarrow{:name} String \\ & & | & \sqcup \xrightarrow{:firstname} String^* \ ; \sqcup \xrightarrow{:lastname} String \ ; \\ & & & \sqcup \xrightarrow{knows} @Person \ * \\ & & \} & \end{array}$$

PShEx semantics

Semantics of shape expressions *se* (similar to ShEx)

$$Cond_{ts}\ \frac{\lambda_n(n) = vs \qquad cond_{ts}(vs) = true}{G, n, \tau \vDash cond_{ts}} \qquad AND\ \frac{G, n, \tau \vDash se_1 \qquad G, n, \tau \vDash se_2}{G, n, \tau \vDash se_1\ \texttt{AND}\ se_2}$$

$$ClosedShape\ \frac{neighs(n, G) = ts \qquad G, ts, \tau \Vdash s'}{G, n, \tau \vDash \texttt{CLOSED}\ \{te\}}$$

$$OpenShape\ \frac{ts = \{\langle x, p, y\rangle \in neighs(n, G) \mid p \in preds(te)\} \qquad G, ts, \tau \Vdash te}{G, n, \tau \vDash \{te\}}$$

PShEx semantics

Semantics of property value specifiers *ps*

$$OpenPVs\frac{s' = \{(p,v) \in s | p \in props(ps)\} \quad G, s', \tau \vdash ps}{G, s, \tau \vdash \lfloor ps \rfloor} \qquad ClosePVs\frac{G, s, \tau \vdash ps}{G, s, \tau \vdash \lceil ps \rceil}$$

$$EachOfPs\frac{G, s, \tau \vdash ps_1 \quad G, s, \tau \vdash ps_2}{G, s, \tau \vdash ps_1\ ,\ ps_2}$$

$$OneOfPs_1\frac{G, s, \tau \vdash ps_1}{G, s, \tau \vdash ps_1 \mid ps_2} \qquad OneOfPs_2\frac{G, s, \tau \vdash ps_2}{G, s, \tau \vdash ps_1 \mid ps_2}$$

$$StarPs_1\frac{}{G, \emptyset, \tau \vdash ps*} \qquad StarPs_2\frac{(s_1, s_2) \in part(s) \quad G, s_1, \tau \vdash ps \quad G, s_2, \tau \vdash ps*}{G, s, \tau \vdash ps*}$$

$$PropertyValue\frac{s = \{(p,w)\} \quad conv_v(w) = \texttt{true}}{G, s, \tau \vdash p : cond_v}$$

PShEx semantics

Semantics of triple expressions *te* (similar to ShEx)

$$EachOf\ \frac{(ts_1, ts_2) \in part(ts) \quad G, ts_1, \tau \Vdash te_1 \quad G, ts_2, \tau \Vdash te_2}{G, ts, \tau \Vdash te_1; te_2}$$

$$OneOf_1\ \frac{G, ts, \tau \Vdash te_1}{G, ts, \tau \Vdash te_1 \mid te_2} \qquad OneOf_2\ \frac{G, ts, \tau \Vdash te_2}{G, ts, \tau \Vdash te_1 \mid te_2}$$

$$TripleConstraint\ \frac{ts = \{\langle x, p, y, s\rangle\} \quad G, y, \tau \vDash @l \quad G, s, \tau \vdash qs}{G, ts, \tau \Vdash \_ \xrightarrow{p} @l\ qs}$$

$$Star_1\ \frac{}{G, \emptyset, \tau \Vdash te*}$$

$$Star_2\ \frac{(ts_1, ts_2) \in part(ts) \quad G, ts_1, \tau \Vdash te \quad G, ts_2, \tau \Vdash te*}{G, ts, \tau \Vdash te*}$$

Conclusions

ShEx = similar to a Grammar for Knowledge graphs

It can be extended for other kinds of Knowledge Graphs

- Wikibase graphs: WShEx
- Property graphs: P-ShEx
- RDF-Star: ShEx-Star
- RDF with nodes as properrties: ShEx-N

Future work

- WShEx
  - Implement it in rudof
  - It was implementd in Scala (wdsub)
  - Very useful to créate Wikidata subsets
- PShEx
  - Define compact syntax and implement prototype
- ShEx-Star
  - Align with current work on RDF 1.2
  - Implement prototype
- ShEx-N
  - Define compact syntax and implement it
  - Identify use cases and expressiveness

Prioritize which of those lines to follow
Use cases and usability of tools are important

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