Segunda prueba
Trabajo de investigación

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Creación de subconjuntos de grafos de conocimiento mediante Shape Expressions

Jose Emilio Labra Gayo

WESO

Razones para elección del tema

- Continúa investigación sobre *Shape Expressions* y sus aplicaciones
- Resolver problema práctico, propuesto por la comunidad
- Participación en biohackathones con esa temática
  - Virtual Biohackathon 2020
  - SWAT4(HC)LS Hackathon 2021
- Adopción de *Shape Expressions* por Wikidata
- Contrato "*Robustifying Scholia*", Univ. Virginia, *Sloan Foundation*
- Interés de Andra Waagmeester y proyecto GeneWiki
- Parte de entregable proyecto ANGLIRU
- Avance en la disciplina: Mejorar/facilitar consumo de datos semánticos

Principales resultados del artículo

- Definición formal de grafos RDF, *property graphs* y *wikbase graphs*
- Extensión de ShEx para *property graphs* (PShEx)
- Extensión de ShEx para *wikibase graphs* (WShEx)
- Definición de 5 técnicas de generación de subconjuntos
  - Entity-matching
  - Simple matching
  - ShEx-based matching
  - Shex+Slurp
  - ShEx+Pregel
- Definición e implementación algoritmo validación a gran escala sobre Spark GraphX

Formato del trabajo

Artículo científico en inglés
- La convocatoria no concreta la obligatoriedad de hacerlo en castellano
- El inglés permitirá su posible presentación en revista/congreso

Publicado en abierto como preprint en Arxiv
- ...

Objetivo a corto plazo:
- Terminar experimentos y enviar a publicación tras concurso

Creating Knowledge Graphs subsets using Shape Expressions

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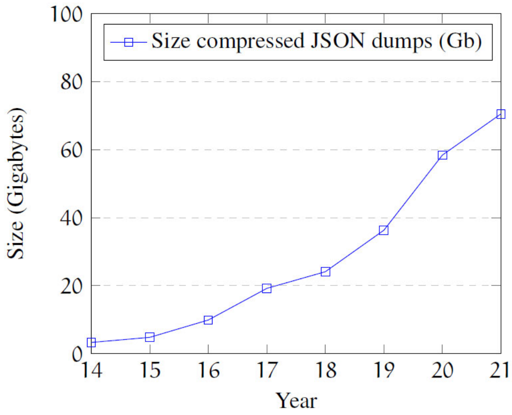
Motivation and main idea (1)

- Since its proposal in 2012, KGs are very successful
- Different kinds of KGs
  - Free/open and collaborative like Wikidata
  - Enterprise/proprietary and owned by companies: Google, Amazon, eBay, Facebook,Microsoft,...
- Size of their contents is continually growing
- Problem: KGs victims of their own success?
- Example: size of Wikidata dumps almost doubling
  - 30GB (2014 - uncompressed)
  - 1.256GB (2021 - uncompressed)
- Difficult for produce/consume/handle KGs



Idea 1: create subset of KGs for some domain

Motivation and main idea (2)

- Shape Expressions: language to describe and validate RDF
  - Concise and human-friendly
  - Automatically procesable
- Several tools already exist around ShEx
- Target audience: domain data experts
- Already adopted by Wikidata to validate RDF serialization of Wikibase entities

```
<Researcher> {
  :name        xsd:string ;
  :birthDate   xsd:date ? ;
  :birthPlace  @<Place> ? ;
  :knows       @<Researcher> *
}
<Place> {
  :name        xsd:string ;
  :country     @<Country>
}
<Country> {
  :name        xsd:string ;
}
```

Example of a ShEx schema

Idea 2: use Shape expressions to define those subsets

Structure of the presentation

3 main types of Knowledge graphs
- RDF graphs
- Property graphs
- Wikibase graphs

ShEx for those types of Knowledge Graphs
- ShEx
- PShEx
- WShEx

Review and propose approaches to generate subsets:
- Entity matching
- Simple matching
- ShEx−based matching
- ShEx+Slurp
- ShEx+Pregel

RDF graphs

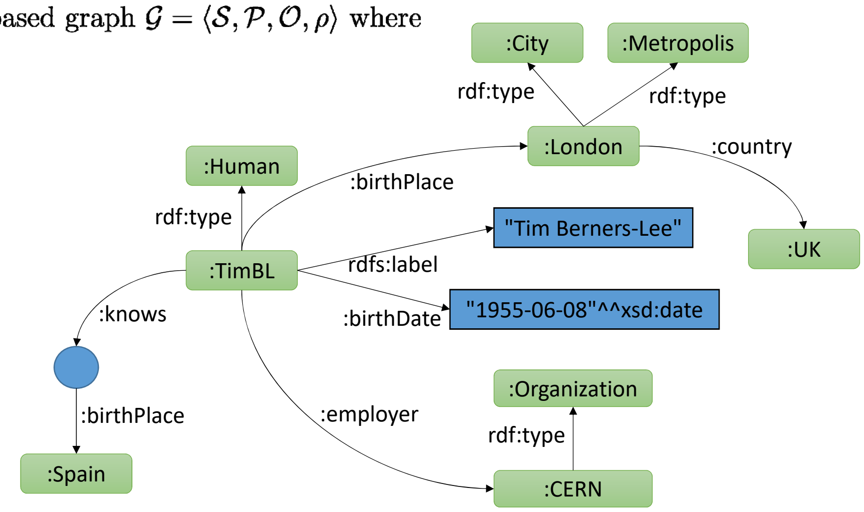
Given a set of IRIs $\mathcal{I}$, a set of blank nodes $\mathcal{B}$ and a set of literals *Lit* an *RDF graph* is a triple based graph $\mathcal{G} = \langle \mathcal{S}, \mathcal{P}, \mathcal{O}, \rho \rangle$ where

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

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

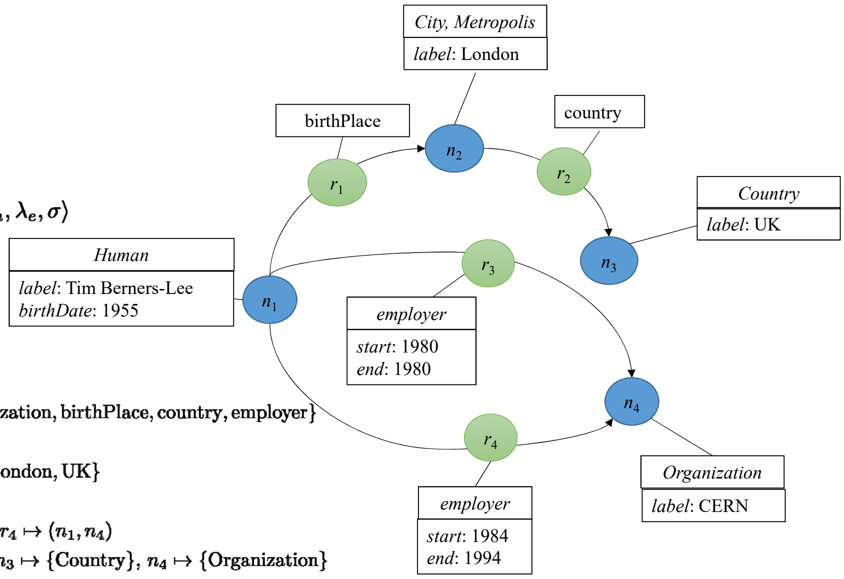
$\mathcal{O} = \mathcal{I} \cup \mathcal{B} \cup Lit$

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



Property graphs

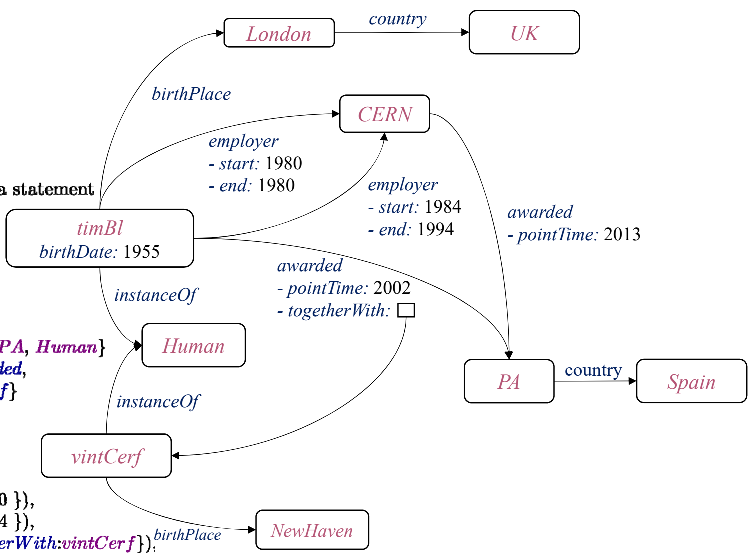
Given a set of types $\mathcal{T}$,
a set of properties $\mathcal{P}$,
and a set of values $\mathcal{V}$,
a *property graph* $\mathcal{G}$ is a tuple $\langle \mathcal{N}, \mathcal{E}, \rho, \lambda_n, \lambda_e, \sigma \rangle$
where $\mathcal{N} \cap \mathcal{E} = \emptyset$,
$\rho : \mathcal{E} \mapsto \mathcal{N} \times \mathcal{N}$ is a total function
$\lambda_n : \mathcal{N} \mapsto \mathit{FinSet}(\mathcal{T})$
$\lambda_e : \mathcal{E} \mapsto \mathcal{T}$
$\sigma : \mathcal{N} \cup \mathcal{E} \times \mathcal{P} \mapsto \mathit{FinSet}(\mathcal{V})$



$\mathcal{T} = \{\text{Human}, \text{City}, \text{Metropolis}, \text{Country}, \text{Organization}, \text{birthPlace}, \text{country}, \text{employer}\}$
$\mathcal{P} = \{\text{label}, \text{birthDate}, \text{start}, \text{end}\}$
$\mathcal{V} = \{\text{Tim Berners-Lee}, 1955, 1980, 1984, 1994, \text{London}, \text{UK}\}$
$\mathcal{N} = \{n_1, n_2, n_3, n_4\} \qquad \mathcal{E} = \{r_1, r_2, r_3, r_4\}$
$\rho = r_1 \mapsto (n_1, n_2), r_2 \mapsto (n_2, n_3), r_3 \mapsto (n_1, n_4), r_4 \mapsto (n_1, n_4)$
$\lambda_n = n_1 \mapsto \{\text{Human}\},\ n_2 \mapsto \{\text{City,Metropolis}\},\ n_3 \mapsto \{\text{Country}\},\ n_4 \mapsto \{\text{Organization}\}$
$\lambda_e = r_1 \mapsto \text{birthPlace}, r_2 \mapsto \text{country}, r_3 \mapsto \text{employer}, r_4 \mapsto \text{employer}$
$\sigma = (n_1, \mathit{label}) \mapsto \text{Tim Berners-Lee},\ (n_1, \mathit{birthDate}) \mapsto 1955$
$(n_2, \text{label}) \mapsto \text{London}\},\ (n_3, \text{label}) \mapsto UK,\ (n_4, \text{label}) \mapsto \text{CERN}$
$(r_3, \text{start}) \mapsto 1980,\ (r_3, \text{end}) \mapsto 1980,\ (r_4, \text{start}) \mapsto 1984,\ (r_4, \text{end}) \mapsto 1994$

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
$\rho \subseteq \mathcal{E} \times \mathcal{P} \times \mathcal{V} \times \mathit{FinSet}(\mathcal{P} \times \mathcal{V})$ 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.

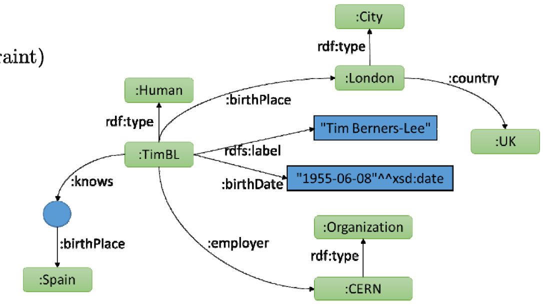


$\mathcal{Q} = \{\ \mathit{timBl}, \mathit{vintCerf}, \mathit{London}, \mathit{CERN}, \mathit{UK}, \mathit{Spain}, \mathit{PA}, \mathit{Human}\}$
$\mathcal{P} = \{\ \mathit{birthDate}, \mathit{birthPlace}, \mathit{country}, \mathit{employer}, \mathit{awarded},$
$\mathit{start}, \mathit{end}, \mathit{pointTime},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

ShEx for RDF

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

se	::=	cond	Basic boolean condition on nodes (node constraint)
	|	s	Shape
	|	se_1 AND se_2	Conjunction
	|	se_1 OR se_2	Disjunction
	|	NOT se	Negation
	|	$@l$	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
	|	$\_ \xrightarrow{p} @l$	Triple constraint with predicate p



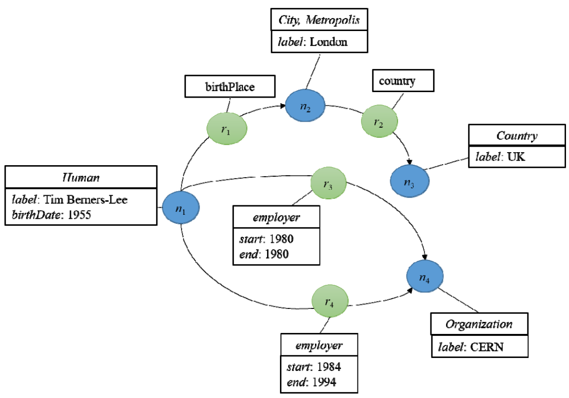
$$
\begin{array}{lcl}
\mathcal{L} & = & \{\ Person, Place, Country, Organization, Date\} \\
\delta(Person) & = & \{\ \_ \xrightarrow{birthDate} @Date;\ \_ \xrightarrow{birthPlace} @Place; \\
& & \quad \_ \xrightarrow{employer} @Organization*\ \} \\
\delta(Place) & = & \{\ \_ \xrightarrow{country} @Country\}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

PShEx for property graphs

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

se	::=	$cond_{t_s}$	Basic boolean condition on set of types $t_s \subseteq \mathcal{T}$
	|	s	Shape
	|	se_1 AND se_2	Conjunction
	|	se_1 OR se_2	Disjunction
	|	NOT se	Negation
	|	$@l$	Shape label reference for $l \in \mathcal{L}$
	|	qs	Qualifiers of that 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
	|	$\_ \xrightarrow{p} @l\ qs$	Triple constraint with property type p whose nodes satisfy the shape l and qualifiers qs
qs	::=	$\lfloor ps \rfloor$	Open qualifier specifiers ps
	|	$\lceil ps \rceil$	Closed qualifier 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 $v_s \subseteq \mathcal{V}$

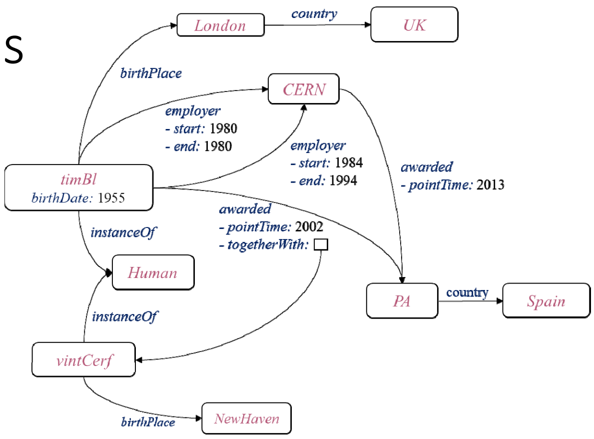


$$
\begin{array}{lcl}
\mathcal{L} & = & \{\ Person, Place, Country, Org\} \\
\delta(\text{Person}) & = & hasType_{Human}\ \text{AND}\ \lfloor label : String, birthDate : Date \rfloor\ \text{AND}\ \{ \\
& & \quad \_ \xrightarrow{birthPlace} @Place; \\
& & \quad \_ \xrightarrow{employer} @Org\ \lfloor start : Date, end : Date \rfloor * \\
& & \} \\
\delta(\text{Place}) & = & \lfloor label : String \rfloor\ \text{AND}\ \{ \\
& & \quad \_ \xrightarrow{country} @Country \\
& & \} \\
\delta(\text{Country}) & = & hasType_{Country}\ \text{AND}\ \lfloor label : String \rfloor\ \{\} \\
\delta(\text{Org}) & = & hasType_{Organization}\ \text{AND}\ \lfloor label : String \rfloor\ \{\}
\end{array}
$$

WShEx for Wikibase graphs

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

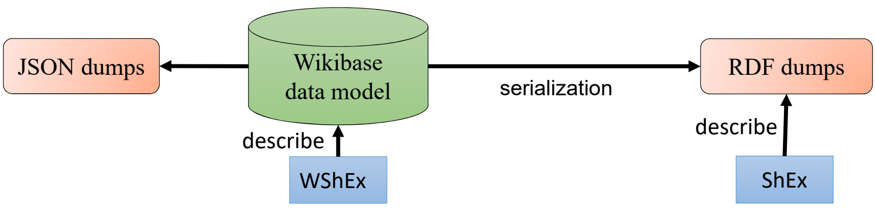
se	::=	cond	Basic boolean condition on nodes (node constraint)
	|	s	Shape
	|	se_1 AND se_2	Conjunction
	|	se_1 OR se_2	Disjunction
	|	NOT se	Negation
	|	$@l$	Shape label reference for $l \in \mathcal{L}$
s	::=	CLOSED s'	Closed shape
	|	s'	Open shape
s'	::=	{ te }	Shape definition
te	::=	$te_1 ; te_2$	Each of te_1 and te_2
	|	$te_1 \mid te_2$	Some of te_1 or te_2
	|	$te*$	Zero or more te
	|	$\_ \xrightarrow{p} @l\ qs$	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



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

What's the role of WShEx

- WShEx schemas describe Wikibase data model
  - Closer to JSON dumps
- ShEx (entity schemas) describe RDF serializacion of Wikibase data model

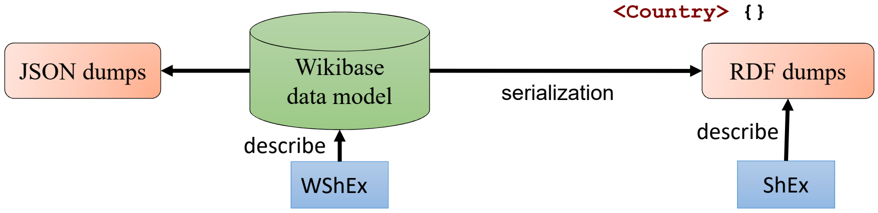


WShEx

```
<Researcher> {
 <birthPlace>         @<Place> ;
 <awarded>            @<Award> {{
    <togetherWith> @<Researcher> *
  }} *
}
<Place> {
 <country>            @<Country>
}
<Country> {}
```

ShEx

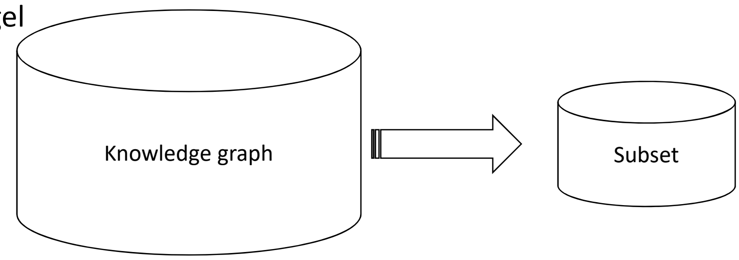
```
<Researcher> {
 wdt:birthPlace @<Place> ;
 p:birthPlace    {
    ps:birthPlace    @<Place>
 } ;
 wdt:awarded         @<Awarded> ;
 p:awarded {
   ps:awarded        @<Awarded> ;
   pq:togetherWith @<Researcher> *;
 } *
}
<Place> {
 wdt:country         @<Country> ;
 p:country {
  ps:country         @<Country> }
}
<Country> {}
```



Knowledge graphs subsets

Different approaches

- Entity-matching
- Simple-matching
- ShEx-based matching
- ShEx+Slurp
- ShEx+Pregel

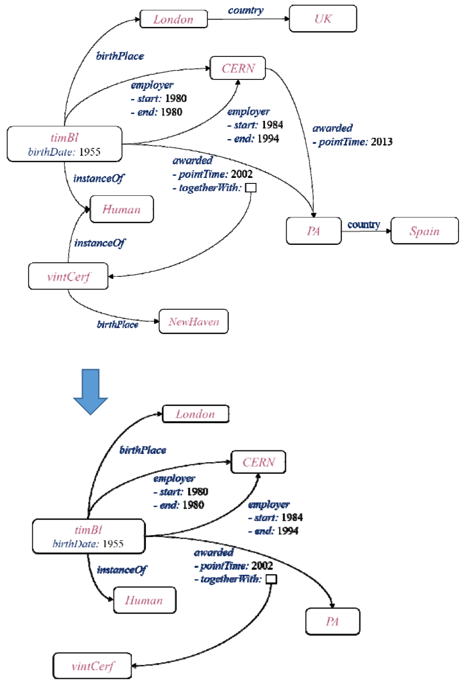


Entity-matching

Directly matches an entity like an ítem, property, etc.

Example: $\mathcal{Q}_s = \{timBl\}$

$\mathcal{Q}' = \{timBl, CERN, vintCerf, PA\}$
$\mathcal{P}' = \{birthDate, birthPlace, employer, awarded,$
$start, end, togetherWith\}$
$\mathcal{D}' = \{1984, 1994, 1980, 1955\}$
$\mathcal{S}' = \{(timBl, birthDate, 1955, \{\}),$
$(timBl, birthPlace, London, \{\}),$
$(timBl, employer, CERN, \{start : 1980, end : 1980\}),$
$(timBl, employer, CERN, \{start : 1984, end : 1994\}),$
$(timBl, awarded, PA, \{togetherWith : vintCerf\}),$
$(vintCerf, awarded, PA, \{togetherWith : timBl\})\}$



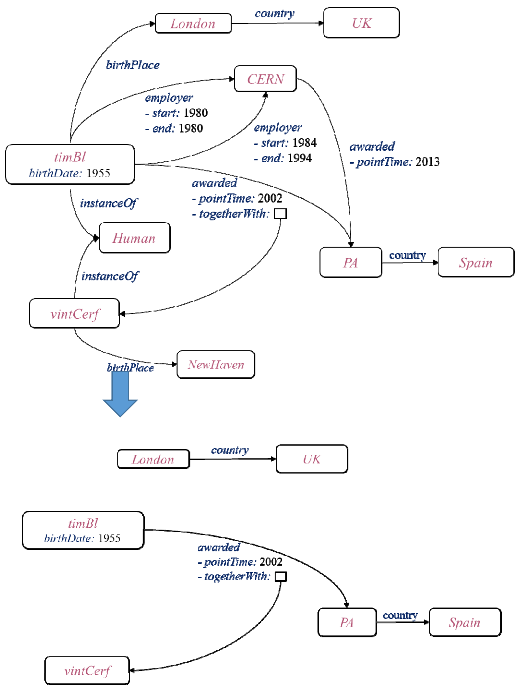
Simple matching

Defines a matching language:

m	::=	subject(e)	Subject $e \in \mathcal{E}$
	|	property(p)	Property $p \in \mathcal{P}$
	|	value(v)	Value $v \in \mathcal{V}$
	|	qualifier(p,v)	Qualifier with property $p \in \mathcal{P}$ and value $v \in \mathcal{V}$
	|	qualifiedProp(p)	Qualifier with property $p \in \mathcal{P}$
	|	qualifiedValue(v)	Qualifier with value $v \in \mathcal{V}$

Example: $M_s = \{\text{property(country)}, \text{qualifiedProp(togetherWith)}\}$

$\mathcal{Q}' = \{PA, Spain, London, UK, timBl, vintCerf\}$
$\mathcal{P}' = \{country, awarded, togetherWith\}$
$\mathcal{D}' = \{\}$
$\mathcal{S}' = \{(timBl, awarded, PA, \{togetherWith : vintCerf\}),$
$(PA, country, Spain, \{\})$
$(London, country, UK, \{\})\}$



ShEx-based matching

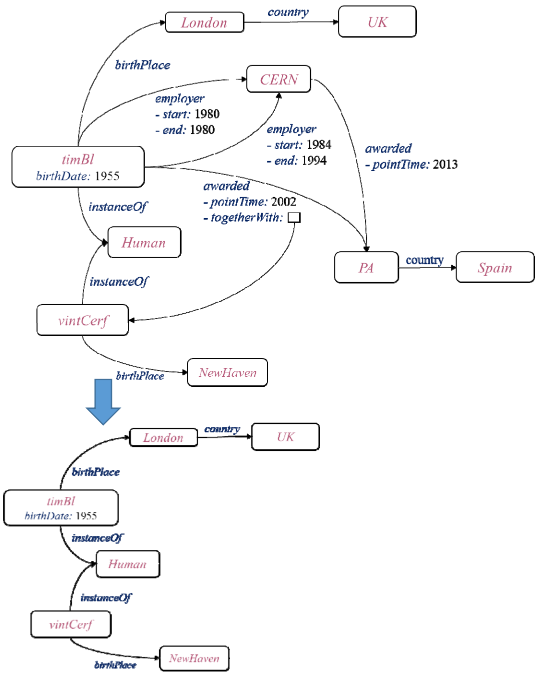
Uses ShEx definitions to match entities

Replaces shape references by *true*

Doesn't require graph traversal

$$
\begin{array}{lcl}
\mathcal{L} & = & \{\ Researcher, Place, Country, Date, Human\} \\
\delta(Researcher) & = & \{\ \text{␣} \xrightarrow{instanceOf} \text{@Human;} \\
 & & \quad \text{␣} \xrightarrow{birthDate} \text{@Date?;} \\
 & & \quad \text{␣} \xrightarrow{birthPlace} \text{@Place} \\
 & & \} \\
\delta(Place) & = & \{\ \text{␣} \xrightarrow{country} \text{@Country}\} \\
\delta(Date) & = & \in xsd:date \\
\delta(Human) & = & \in \{Human\}
\end{array}
$$

$$
\begin{array}{ll}
\mathcal{S} = \{ & (timBl, instanceOf, Human], \{\}), \\
 & (timBl, birthDate, 1955, \{\}), \\
 & (timBl, birthPlace, London, \{\}), \\
 & (London, country, UK, \{\}), \\
 & (vintCerf, instanceOf, Human], \{\}) \\
 & (vintCerf, birthPlace, newHaven, \{\}) \\
\} &
\end{array}
$$



ShEx-based matching

Can be implemented replacing shape references by *true*

$$
\begin{array}{lcl}
\delta(Researcher) & = & \{\ \text{␣} \xrightarrow{instanceOf} \text{@Human;} \\
 & & \quad \text{␣} \xrightarrow{birthDate} \text{@Date?;} \\
 & & \quad \text{␣} \xrightarrow{birthPlace} \text{@Place} \\
 & & \} \\
\delta(Place) & = & \{\ \text{␣} \xrightarrow{country} \text{@Country}\} \\
\delta(Date) & = & \in xsd:date \\
\delta(Human) & = & \in \{Human\}
\end{array}
$$

$$
\begin{array}{lcl}
\delta(Researcher) & = & \{\ \text{␣} \xrightarrow{instanceOf} \texttt{true;} \\
 & & \quad \text{␣} \xrightarrow{birthDate} \texttt{true?;} \\
 & & \quad \text{␣} \xrightarrow{birthPlace} \texttt{true} \\
 & & \} \\
\delta(Place) & = & \{\ \text{␣} \xrightarrow{country} \texttt{true}\}
\end{array}
$$

ShEx-based matching has been implemented in WDSub

It allows sequential processing of the dump

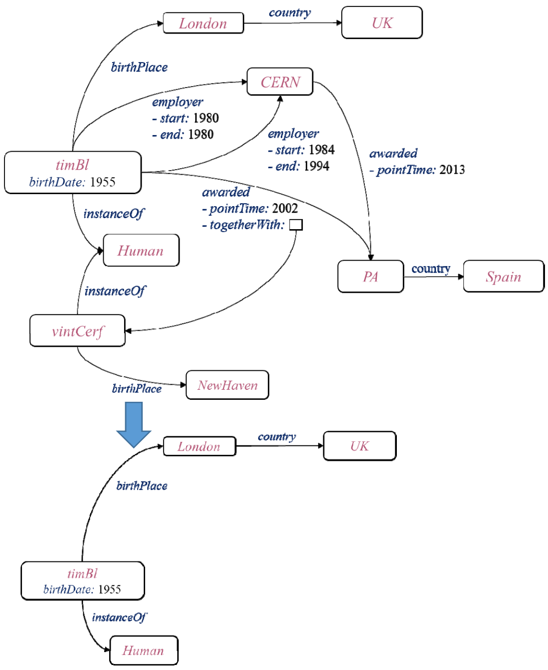
It can process the latest Wikidata dump in 5h 15'

ShEx+slurp

Slurp = Shex option that collects nodes/triples while validating

Example:

$$
\begin{array}{lcl}
\mathcal{L} & = & \{ \; Researcher, Place, Country, Date, Human\} \\
\delta(Researcher) & = & \{ \; \_ \xrightarrow{instanceOf} @\text{Human}; \\
 & & \quad \_ \xrightarrow{birthDate} @\text{Date}; \\
 & & \quad \_ \xrightarrow{birthPlace} @\text{Place} \\
 & & \} \\
\delta(Place) & = & \{ \; \_ \xrightarrow{country} @\text{Country}\} \\
\delta(Country) & = & \{ \; \} \\
\delta(Date) & = & \in xsd:date \\
\delta(Human) & = & \in \{Human\}
\end{array}
$$



ShEx+Slurp

Formal definition generalizes ShEx semantics

New conformance relation:

$$\mathcal{G}, n, \tau \vDash se \leadsto \mathcal{G}'$$

$$Cond\,\frac{cond(n) = true}{\mathcal{G}, n, \tau \vDash cond \leadsto \langle \{n\}, \{\} \rangle} \qquad AND\,\frac{\mathcal{G}, n, \tau \vDash se_1 \leadsto \mathcal{G}_1 \quad \mathcal{G}, n, \tau \vDash se_2 \leadsto \mathcal{G}_2}{\mathcal{G}, n, \tau \vDash se_1 \texttt{ AND } se_2 \leadsto \mathcal{G}_1 \cup \mathcal{G}_2}$$

$$ClosedShape\,\frac{neighs(n, \mathcal{G}) = ts \quad \mathcal{G}, ts, \tau \Vdash s' \leadsto \mathcal{G}'}{\mathcal{G}, n, \tau \vDash_{\texttt{CLOSED}} s' \leadsto \mathcal{G}'}$$

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

$$OpenQs\,\frac{s' = \{(p, v) \in s | p \in preds(ps)\} \quad \mathcal{G}, s', \tau \vdash ps \leadsto (qs, \mathcal{G}')}{\mathcal{G}, s, \tau \vdash \lfloor ps \rfloor \leadsto (qs, \mathcal{G}')}$$

$$CloseQs\,\frac{\mathcal{G}, s, \tau \vdash ps \leadsto (qs, \mathcal{G}')}{\mathcal{G}, s, \tau \vdash \lceil ps \rceil \leadsto (qs, \mathcal{G}')}$$

$$EachOf\,\frac{(ts_1, ts_2) \in part(ts) \quad \mathcal{G}, ts_1, \tau \Vdash te_1 \leadsto \mathcal{G}_1 \quad \mathcal{G}, ts_2, \tau \Vdash te_2 \leadsto \mathcal{G}_2}{\mathcal{G}, ts, \tau \Vdash te_1; te_2 \leadsto \mathcal{G}_1 \cup \mathcal{G}_2}$$

$$EachOfQs\,\frac{\mathcal{G}, s, \tau \vdash ps_1 \leadsto (qs_1, \mathcal{G}_1) \quad \mathcal{G}, s, \tau \vdash ps_2 \leadsto (qs_2, \mathcal{G}_2)}{\mathcal{G}, s, \tau \vdash ps_1 \,,\, ps_2 \leadsto (qs_1 \cup_2, \mathcal{G}_1 \cup \mathcal{G}_2)}$$

$$OneOf_1\,\frac{\mathcal{G}, ts, \tau \Vdash te_1 \leadsto \mathcal{G}_1}{\mathcal{G}, ts, \tau \Vdash te_1 \mid te_2 \leadsto \mathcal{G}_1} \qquad OneOf_2\,\frac{\mathcal{G}, ts, \tau \Vdash te_2 \leadsto \mathcal{G}_2}{\mathcal{G}, ts, \tau \Vdash te_1 \mid te_2 \leadsto \mathcal{G}_2}$$

$$OneOfQs_1\,\frac{\mathcal{G}, s, \tau \vdash ps_1 \leadsto (qs_1, \mathcal{G}_1)}{\mathcal{G}, s, \tau \vdash ps_1 \mid ps_2 \leadsto (qs_1, \mathcal{G}_1)} \qquad OneOfQs_2\,\frac{\mathcal{G}, s, \tau \vdash ps_2 \leadsto (qs_2, \mathcal{G}_2)}{\mathcal{G}, s, \tau \vdash ps_1 \mid ps_2 \leadsto (qs_2, \mathcal{G}_2)}$$

$$Star_1\,\frac{}{\mathcal{G}, \emptyset, \tau \Vdash te* \leadsto \emptyset} \qquad StarQs_1\,\frac{}{\mathcal{G}, \emptyset, \tau \vdash ps* \leadsto (\{\}, \emptyset)}$$

$$Star_2\,\frac{(ts_1, ts_2) \in part(ts) \quad \mathcal{G}, ts_1, \tau \Vdash te \leadsto \mathcal{G}_1 \quad \mathcal{G}, ts_2, \tau \Vdash te* \leadsto \mathcal{G}_2}{\mathcal{G}, ts, \tau \Vdash te* \leadsto \mathcal{G}_1 \cup \mathcal{G}_2}$$

$$StarQs_2\,\frac{(s_1, s_2) \in part(s) \quad \mathcal{G}, s_1, \tau \vdash ps \leadsto (qs_1, \mathcal{G}_1) \quad \mathcal{G}, s_2, \tau \vdash ps* \leadsto qs_2, \mathcal{G}_2}{\mathcal{G}, s, \tau \vdash ps* \leadsto (qs_1 \cup qs_2, \mathcal{G}_1 \cup \mathcal{G}_2)}$$

$$TripleConstraint\,\frac{ts = \{\langle x, p, y, s\rangle\} \quad \mathcal{G}, y, \tau \vDash @l \leadsto \langle \mathcal{V}, \mathcal{E}\rangle \quad \mathcal{G}, s, \tau \vdash qs \leadsto (qs', \mathcal{G}_{qs})}{\mathcal{G}, ts, \tau \Vdash \_ \xrightarrow{p} @l\ qs \leadsto \langle \mathcal{V} \cup \{x\} \cup \{y\}, \mathcal{E} \cup (x, p, y, qs')\rangle \cup \mathcal{G}_{qs}}$$

$$EmptyQs\,\frac{}{\mathcal{G}, \emptyset, \tau \vdash \epsilon \leadsto (\{\}, \emptyset)} \qquad PropertyQs\,\frac{s = \{(p, v)\} \quad \mathcal{G}, v, \tau \vDash @l \leadsto \mathcal{G}'}{\mathcal{G}, s, \tau \vdash p : @l \leadsto (\{p : v\}, \mathcal{G}')}$$

ShEx+Slurp

- Implemented by shex.js and pyshex
  - Only for ShEx, not for PShEx or WShEx
- It does graph traversal while validating
  - Difficult to use for processing Wikidata dumps
- Subsets include only valid data according to the ShEx
- Problems:
  - Difficult to run behind SPARQL endpoint
  - Naïve implementation generates too many requests
  - Optimizations to improve number of SPARQL queries can generate timeouts

ShEx+Pregel

- Large scale validation
- Based on Pregel algorithm
  - Developed by Google 2010
- Based on Bulk Synchronous Parallel model
  - Supersteps = units of parallel computation
  - Communication through messages
- Implemented using Apache Spark GraphX library

Think like a vertex

- Vertex-centric approach
- Each vertice has an id and a state
- All vertexes receive an initial message
- While messages received do
  - Run vProg to update vertex state according to messages received
  - Run sendMsg for each triplet to generate messages
  - Merge messages by Vertex

GraphX

- Graph API from Apache Spark
  - RDD (Resilient distributed datasets)
  - MapReduce in memory

$Graph[\mathcal{V},\mathcal{E}]$ = graph with vertices $\mathcal{V}$ and edges $\mathcal{E}$

- Vertices are represented as $RDD[(Id,\mathcal{V})]$ where $Id = Long$
- Edges are represented as $RDD[(Id,Id,\mathcal{E})]$
- *triplets* view represents edges as collections $RDD[(\mathcal{V},\mathcal{E},\mathcal{V})]$.

Several built-in operators:

- `mapVertices`(`g`: `Graph`$[\mathcal{V},\mathcal{E}]$, `f`: $(\texttt{Id},\mathcal{V}) \to \mathcal{V}$): `Graph`$[\mathcal{V},\mathcal{E}]$
- `mapReduceTriples`(`g`:`Graph`$[\mathcal{V},\mathcal{E}]$, `m`: $(\mathcal{V},\mathcal{E},\mathcal{V}) \to [(\texttt{Id},\mathcal{M})]$, `r`:$(\mathcal{M},\mathcal{M}) \to \mathcal{M}$):`RDD`$[(\mathrm{Id},\mathcal{M})]$
- `joinVertices`(`g`:`Graph`$[\mathcal{V},\mathcal{E}]$, `msgs`:`RDD`$[(\texttt{Id}, \mathcal{M})]$, `f`:$(\texttt{Id}, \mathcal{V},\mathcal{M}) \to \mathcal{V}$): `Graph`$[\mathcal{V},\mathcal{E}]$
- pregel (see next slide)
- ...

GraphX Pregel pseudo-code

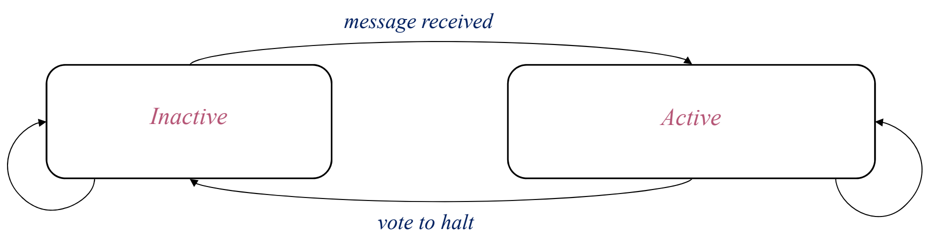
Algorithm 1: Pregel algorithm pseudocode as implemented in GraphX

Input parameters:
- g: Graph$[\mathcal{V},\mathcal{E}]$
- initialMsg: $\mathcal{M}$
- vProg: $(\mathtt{Id},\mathcal{V},\mathcal{M})\rightarrow\mathcal{V}$
- sendMsg: Triplet$\rightarrow[(\mathtt{Id},\mathcal{M})]$
- mergeMsg: $(\mathcal{M},\mathcal{M})\rightarrow\mathcal{M}$

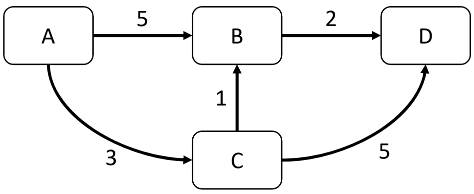
Output: g:Graph$[\mathcal{V},\mathcal{E}]$

```
g = mapVertices(g,λ(id,v)→vProg(id,v,initialMsg))
msgs = mapReduceTriples(g,sendMsg,mergeMsg)
while size(msgs) > 0 do
    g = joinVertices(g,msgs,vProg)
    msgs = mapReduceTriples(g,sendMsg,mergeMsg)
return g
```

Pregel's vertex state diagram



Shortest path to a node




```
val initialGraph = graph.mapVertices(
 (id, _) => if (id == source) 0 else ∞
)

initialMsg = ∞

def vProg(id: VertexId, dist: Int, msg: Int) =
  min(dist, msg)

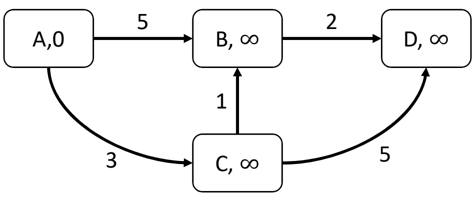
def sendMsg(t: Triplet) = {
  if (t.srcAttr + t.attr < t.dstAttr) {
    (t.dstId, t.srcAttr + t.attr)
  }
  else { }

def mergMsg(a: Int, b: Int) = min(a, b)

initialGraph.pregel(initialMsg)
                   (vProg,sendMsg,mergeMsg)
```

Shortest path to a node

initialGraph

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val initialGraph = graph.mapVertices(
 (id, _) => if (id == source) 0 else ∞
)

initialMsg = ∞

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  }
  else { }

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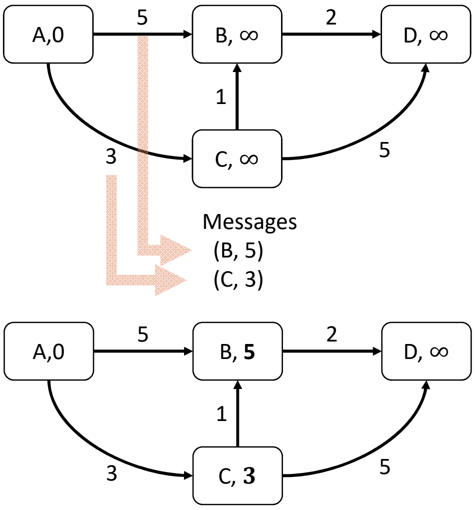
initialGraph.pregel(initialMsg)
                   (vProg,sendMsg,mergeMsg)
```

Shortest path to a node




```
val initialGraph = graph.mapVertices(
 (id, _) => if (id == source) 0 else ∞
)

initialMsg = ∞

def vProg(id: VertexId, dist: Int, msg: Int) =
  min(dist, msg)

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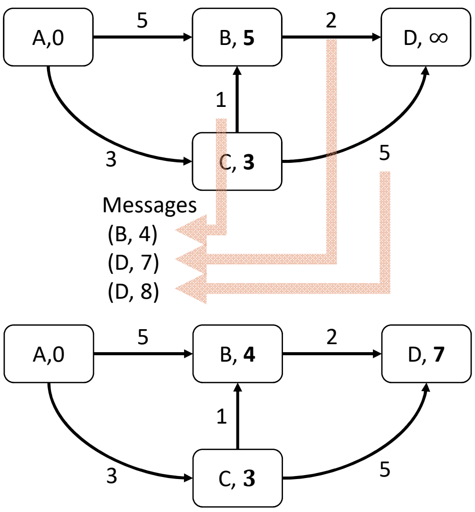
  if (t.srcAttr + t.attr < t.dstAttr) {
    (t.dstId, t.srcAttr + t.attr)
  }
  else { }

def mergMsg(a: Int, b: Int) = min(a, b)

initialGraph.pregel(initialMsg)
                   (vProg,sendMsg,mergeMsg)
```

Shortest path to a node




```
val initialGraph = graph.mapVertices(
 (id, _) => if (id == source) 0 else ∞
)

initialMsg = ∞

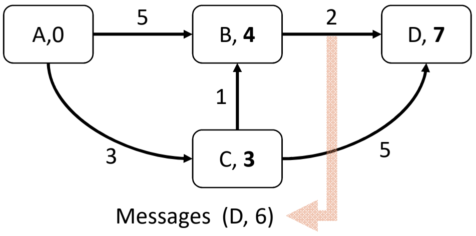
def vProg(id: VertexId, dist: Int, msg: Int) =
  min(dist, msg)

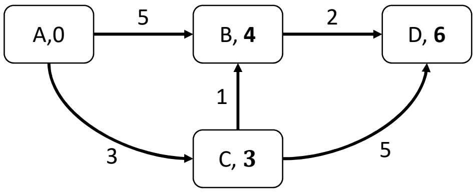
def sendMsg(t: Triplet) = {
  if (t.srcAttr + t.attr < t.dstAttr) {
    (t.dstId, t.srcAttr + t.attr)
  }
  else { }

def mergMsg(a: Int, b: Int) = min(a, b)

initialGraph.pregel(initialMsg)
                   (vProg,sendMsg,mergeMsg)
```

Shortest path to a node






```
val initialGraph = graph.mapVertices(
 (id, _) => if (id == source) 0 else ∞
)

initialMsg = ∞

def vProg(id: VertexId, dist: Int, msg: Int) =
  min(dist, msg)

def sendMsg(t: Triplet) = {
  if (t.srcAttr + t.attr < t.dstAttr) {
    (t.dstId, t.srcAttr + t.attr)
  }
  else { }

def mergMsg(a: Int, b: Int) = min(a, b)

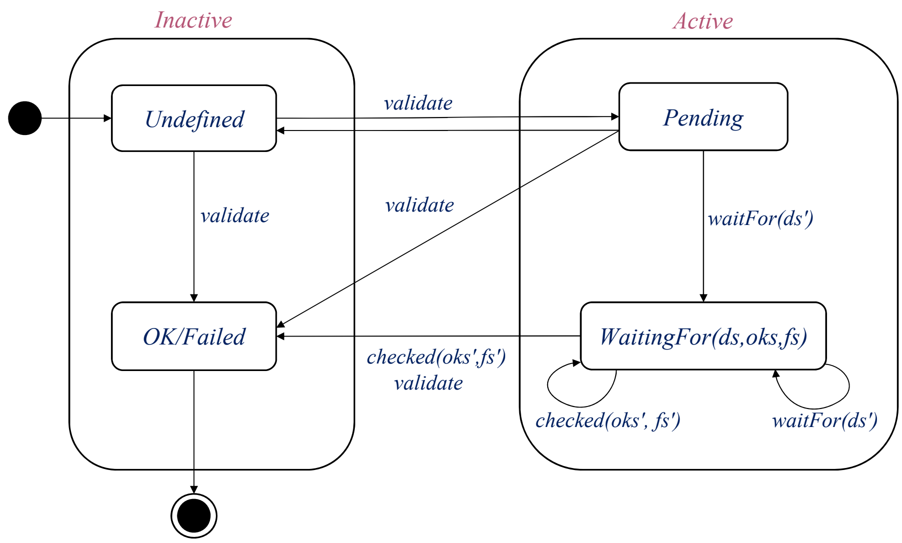
initialGraph.pregel(initialMsg)
                   (vProg,sendMsg,mergeMsg)
```

Idea: Validate graphs using Pregel?

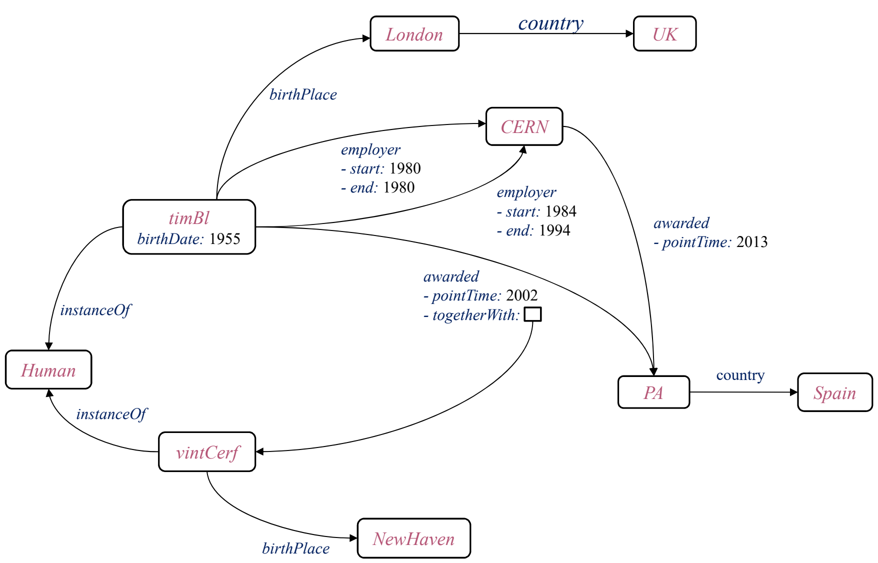
Associate each node with a status map

- Status map contains information about node conformance to shapes
- Messages =
  - Requests to validate
  - Request to wait for neighbours
  - Information about validated/failed neighbours
- Initial message = request to validate `start` shape
- In each iteration we collect information from neighbours conformance
- We provide 3 parameters
  - checkLocal: tries to check conformance of a node locally or return pending neighbours
  - checkNeighs: checks neighbours with regular expression defined by a shape
  - tripleConstraints: return the triple constraints associated with a shape label

State diagram

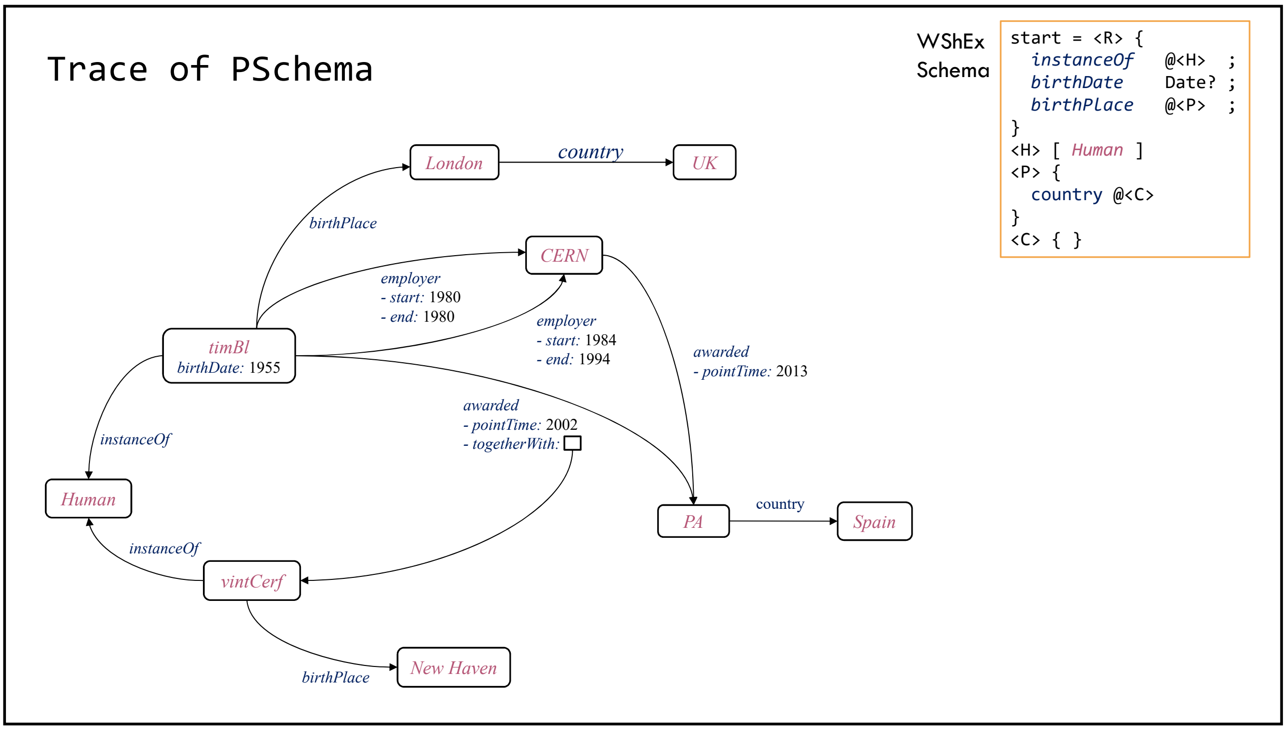


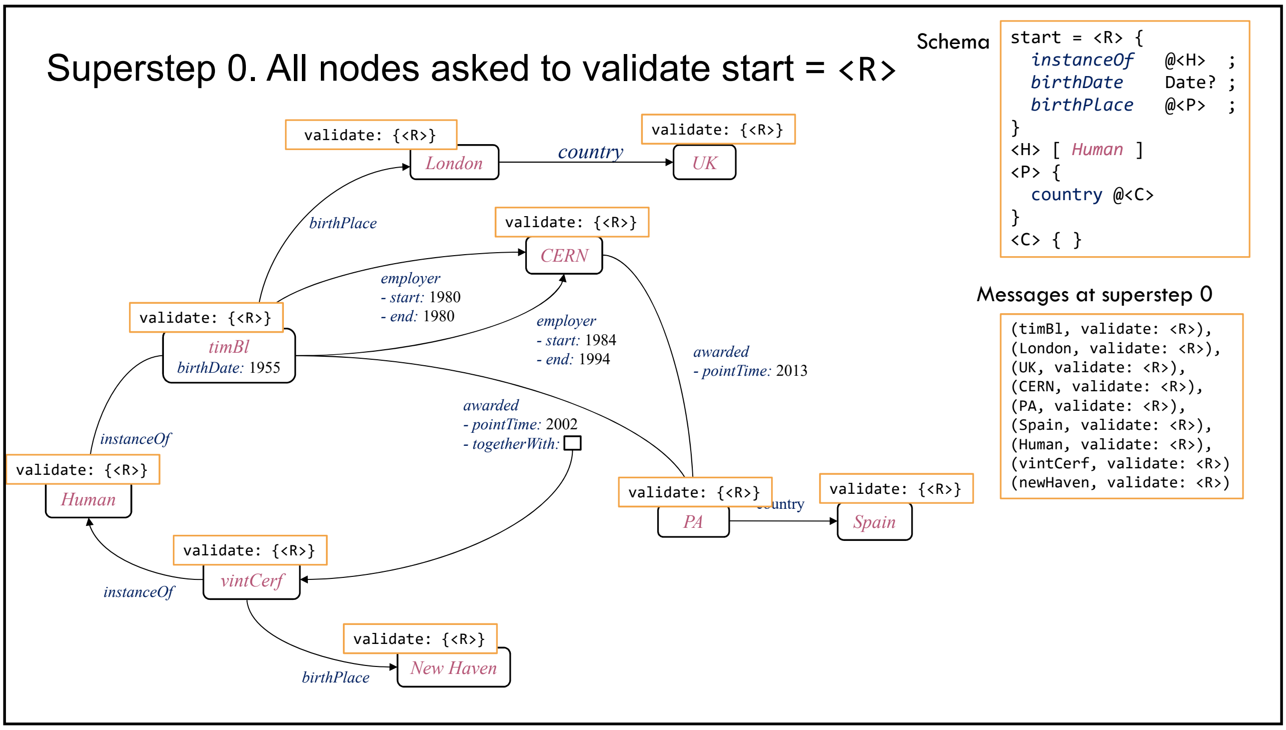
Trace of PSchema

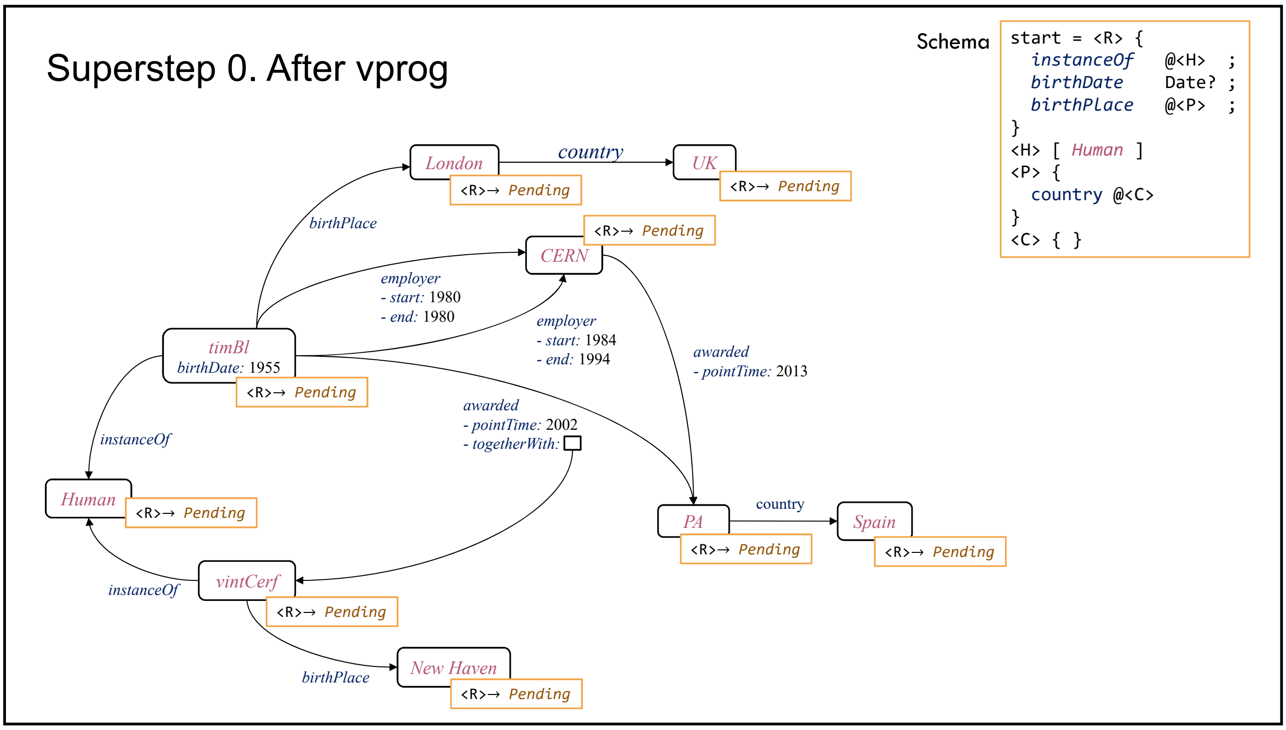


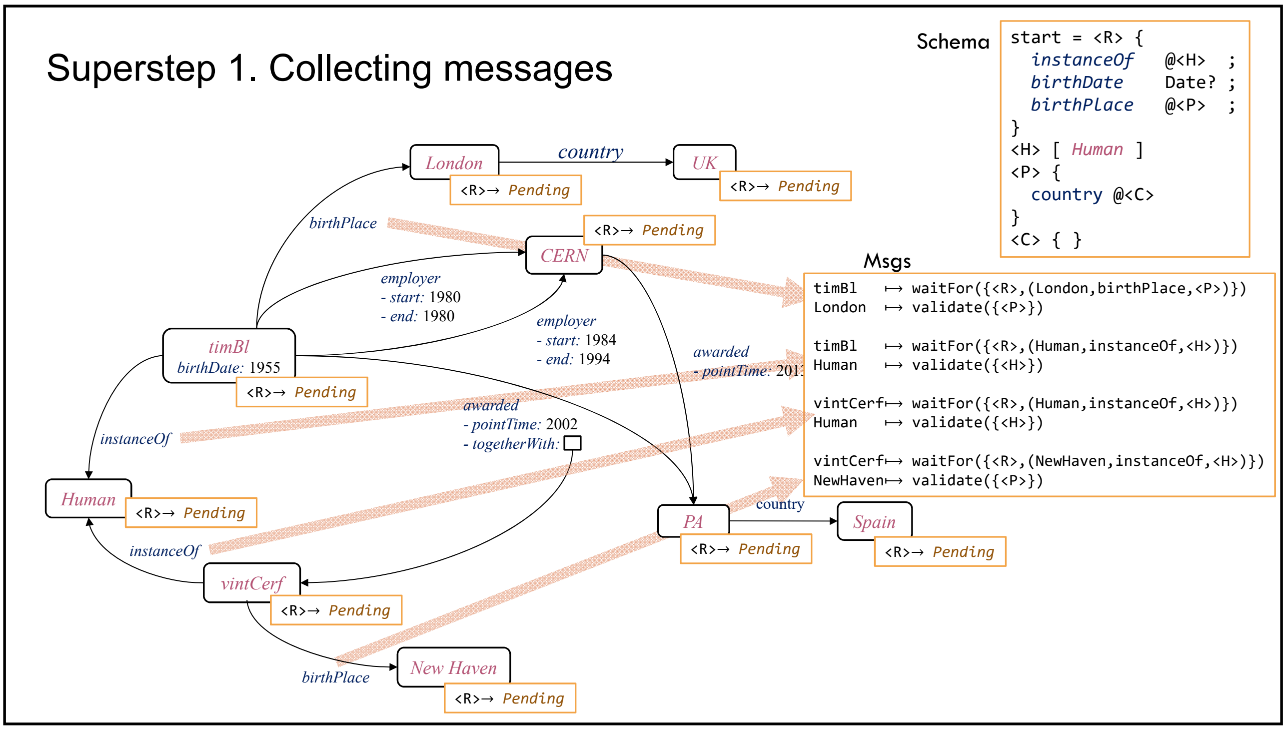
WShEx Schema

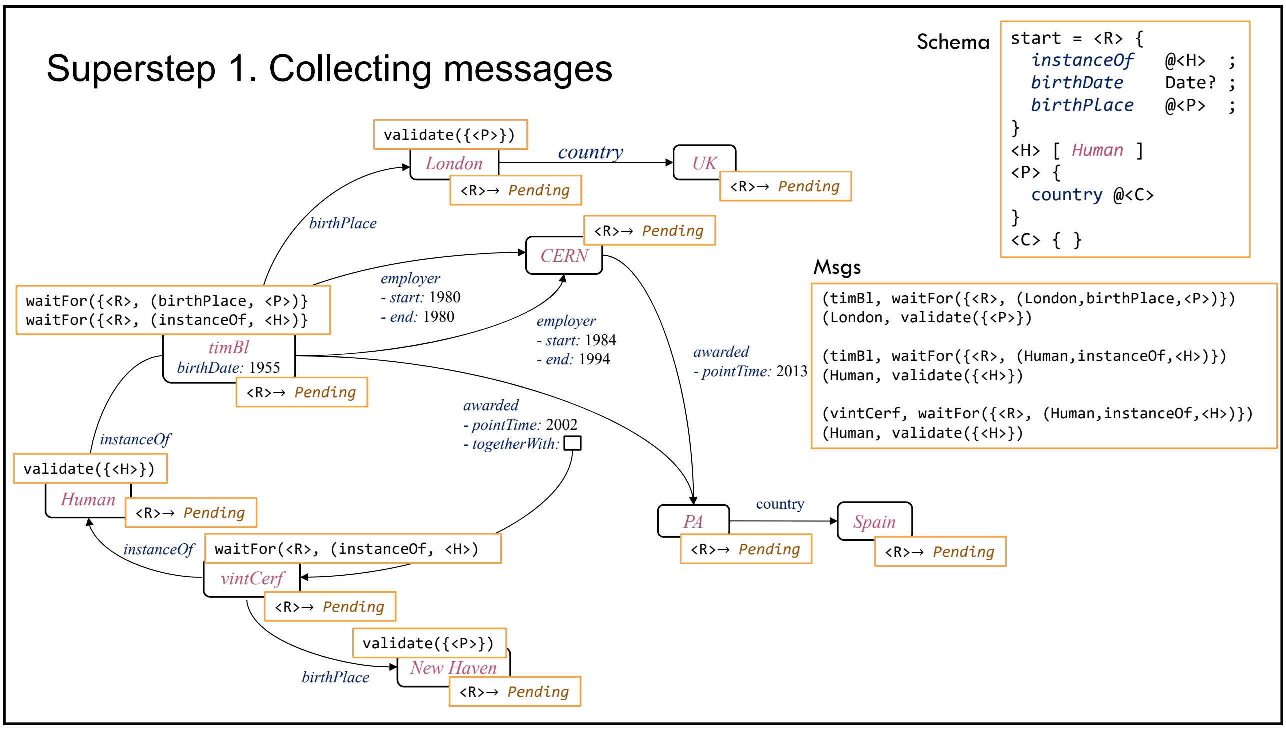
```
start = <Researcher> {
  instanceOf    @<Human>   ;
  birthDate     Date? ;
  birthPlace    @<Place>   ;
}
<Human> [ Human ]
<Place> {
  country @<Country>
}
<Country> { }
```

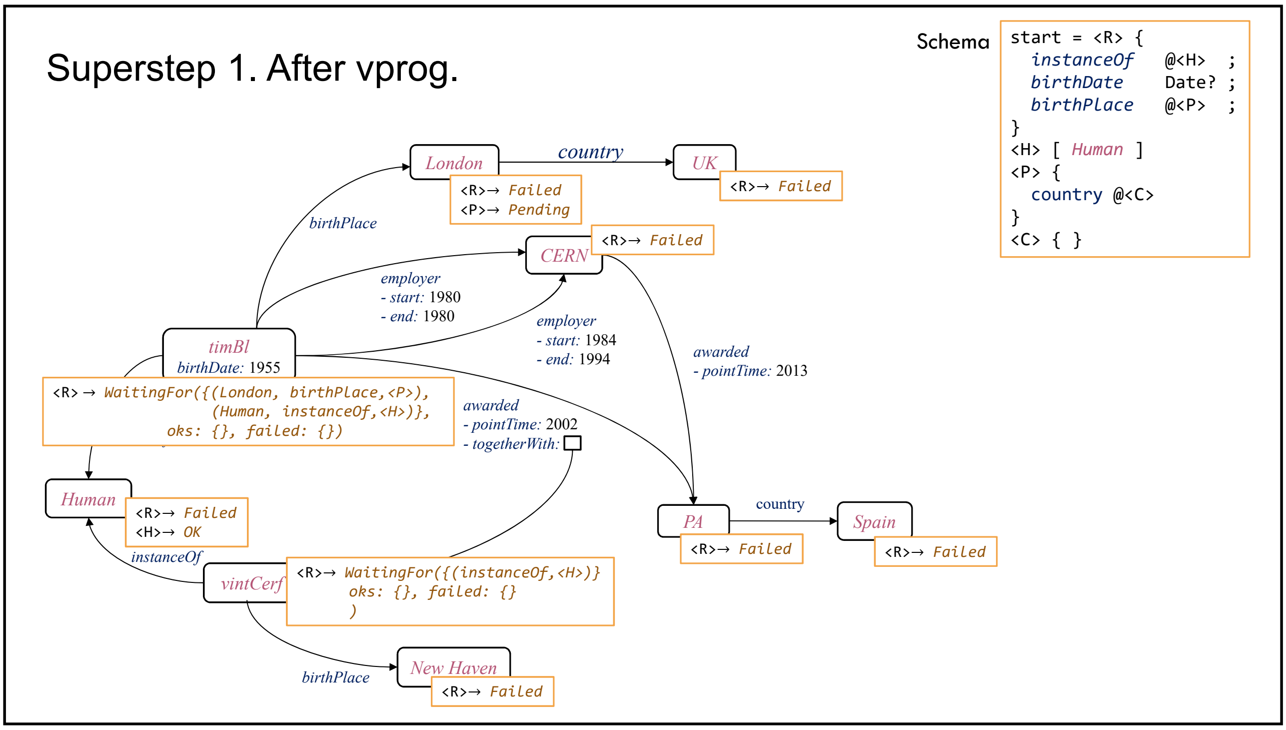

Trace of PSchema
WShEx Schema
start = <R> {
instanceOf @<H> ;
birthDate Date? ;
birthPlace @<P> ;
}
<H> [Human]
<P> {
country @<C>
}
<C> { }
London
country
UK
birthPlace
CERN
employer
- start: 1980
- end: 1980
employer
- start: 1984
- end: 1994
awarded
- pointTime: 2013
timBl
birthDate: 1955
awarded
- pointTime: 2002
- togetherWith:
instanceOf
Human
PA
country
Spain
instanceOf
vintCerf
birthPlace
New Haven

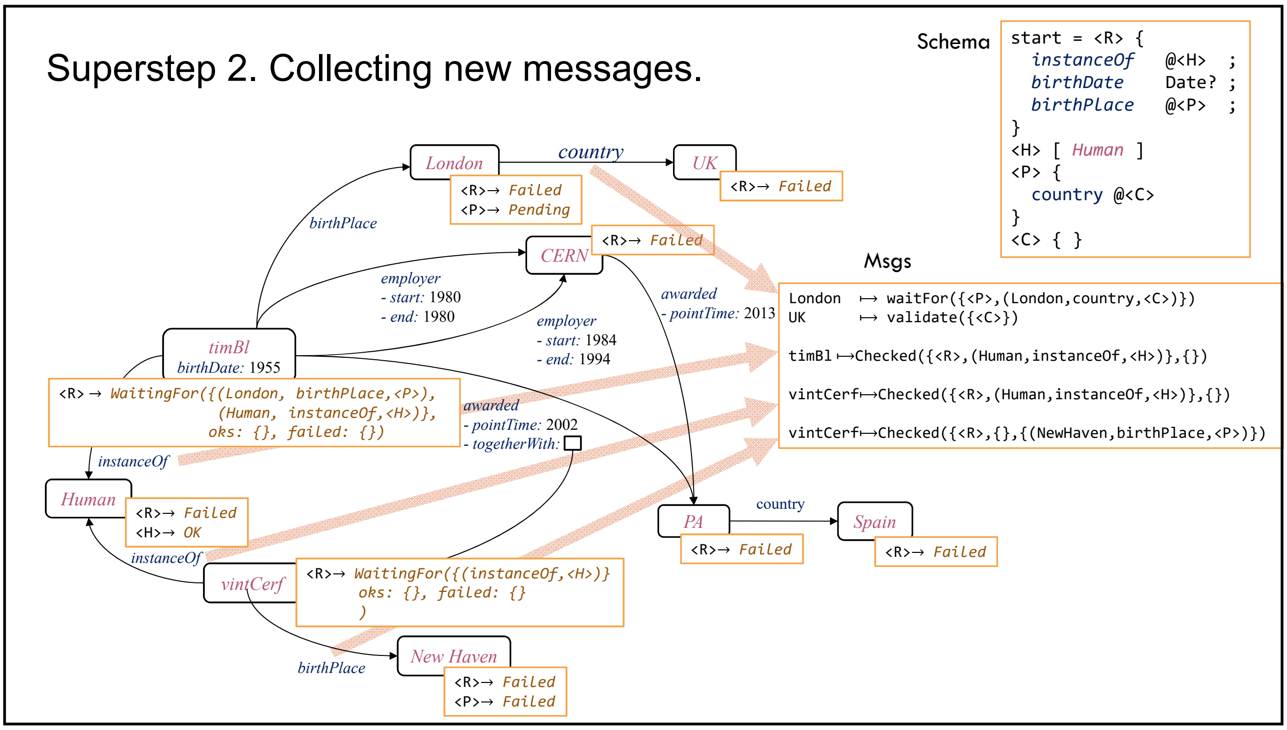

Superstep 0. All nodes asked to validate start = <R>
Schema
start = <R> {
instanceOf @<H> ;
birthDate Date? ;
birthPlace @<P> ;
}
<H> [Human]
<P> {
country @<C>
}
<C> { }
Messages at superstep 0
(timBl, validate: <R>),
(London, validate: <R>),
(UK, validate: <R>),
(CERN, validate: <R>),
(PA, validate: <R>),
(Spain, validate: <R>),
(Human, validate: <R>),
(vintCerf, validate: <R>)
(newHaven, validate: <R>)
validate: {<R>}
London
country
UK
birthPlace
CERN
employer
- start: 1980
- end: 1980
employer
- start: 1984
- end: 1994
awarded
- pointTime: 2013
timBl
birthDate: 1955
awarded
- pointTime: 2002
- togetherWith:
instanceOf
Human
PA
Spain
vintCerf
instanceOf
birthPlace
New Haven

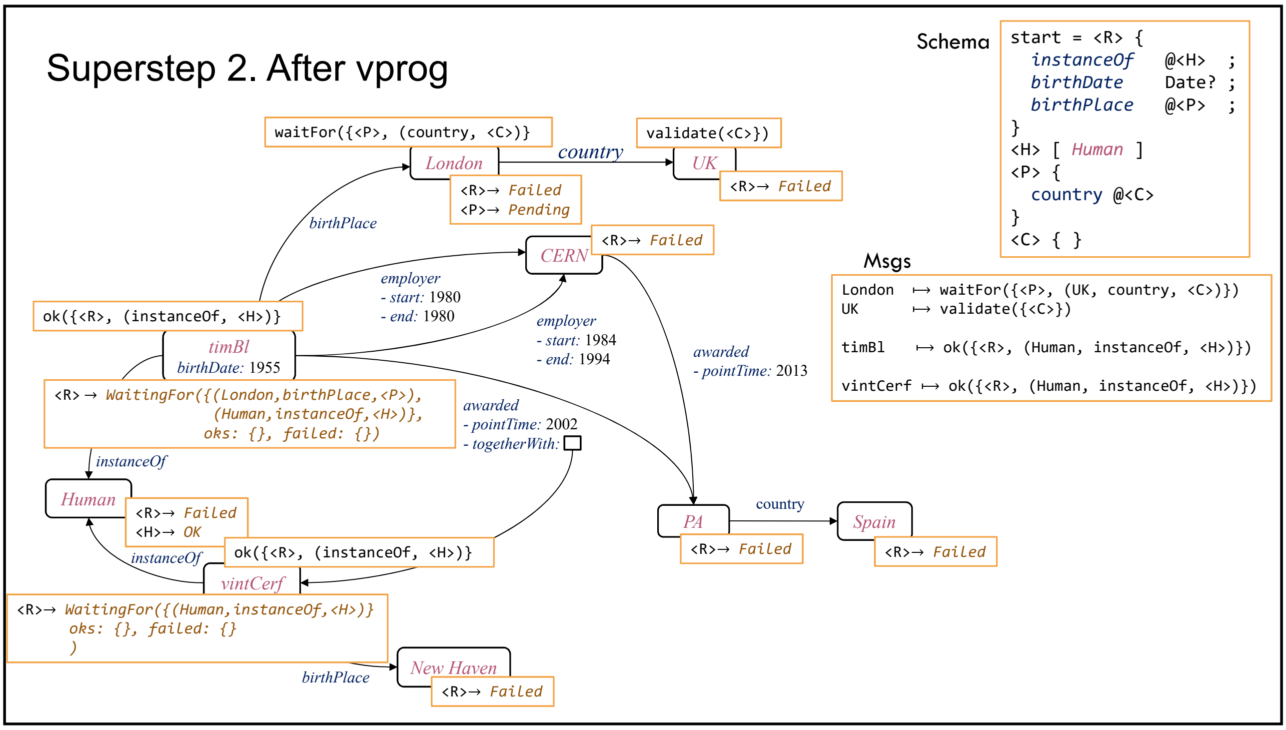

Superstep 0. After vprog
Schema
start = <R> {
instanceOf @<H> ;
birthDate Date? ;
birthPlace @<P> ;
}
<H> [Human]
<P> {
country @<C>
}
<C> { }
London
country
UK
<R>→ Pending
birthPlace
CERN
employer
- start: 1980
- end: 1980
employer
- start: 1984
- end: 1994
awarded
- pointTime: 2013
timBl
birthDate: 1955
awarded
- pointTime: 2002
- togetherWith:
instanceOf
Human
PA
country
Spain
vintCerf
instanceOf
birthPlace
New Haven

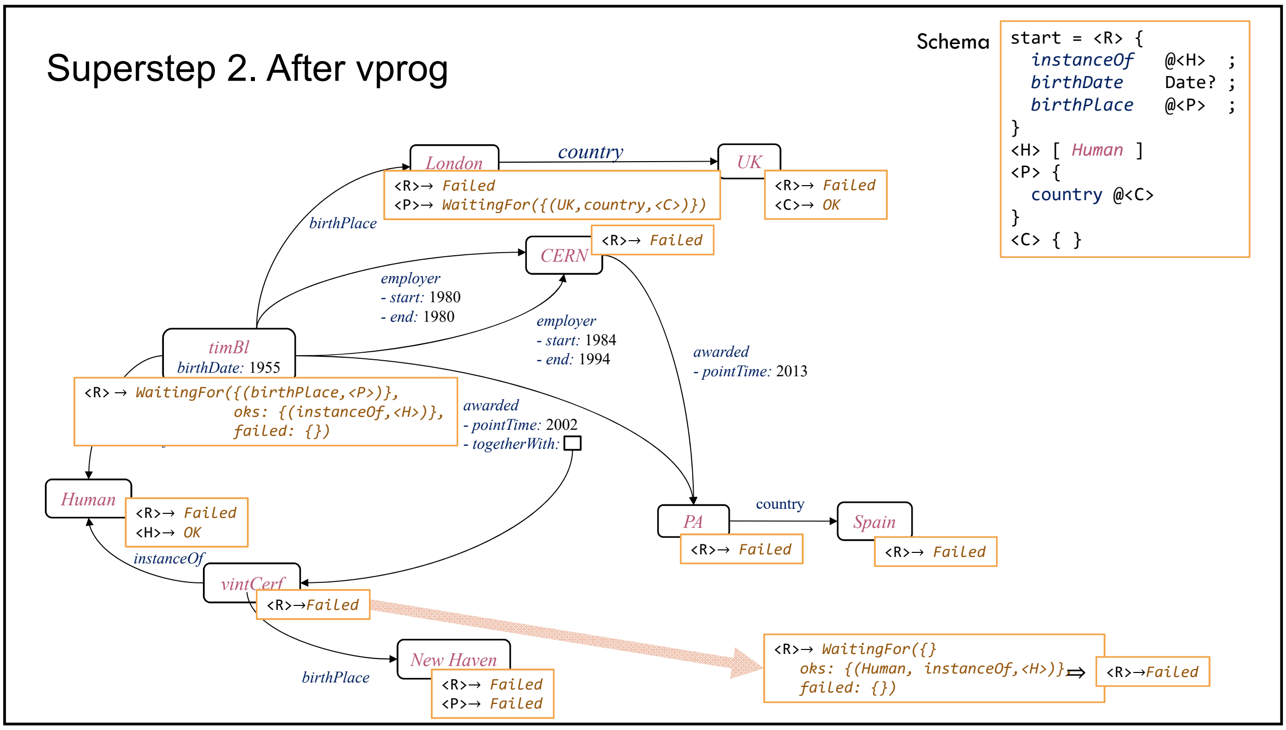

Superstep 1. Collecting messages
Schema
start = <R> {
instanceOf @<H> ;
birthDate Date? ;
birthPlace @<P> ;
}
<H> [Human]
<P> {
country @<C>
}
<C> { }
Msgs
timBl ⟼ waitFor({<R>,(London,birthPlace,<P>)})
London ⟼ validate({<P>})
timBl ⟼ waitFor({<R>,(Human,instanceOf,<H>)})
Human ⟼ validate({<H>})
vintCerf⟼ waitFor({<R>,(Human,instanceOf,<H>)})
Human ⟼ validate({<H>})
vintCerf⟼ waitFor({<R>,(NewHaven,instanceOf,<H>)})
NewHaven⟼ validate({<P>})
London
country
UK
<R>→ Pending
birthPlace
CERN
employer
- start: 1980
- end: 1980
employer
- start: 1984
- end: 1994
awarded
timBl
birthDate: 1955
awarded
- pointTime: 2002
- togetherWith:
instanceOf
Human
PA
country
Spain
vintCerf
instanceOf
birthPlace
New Haven

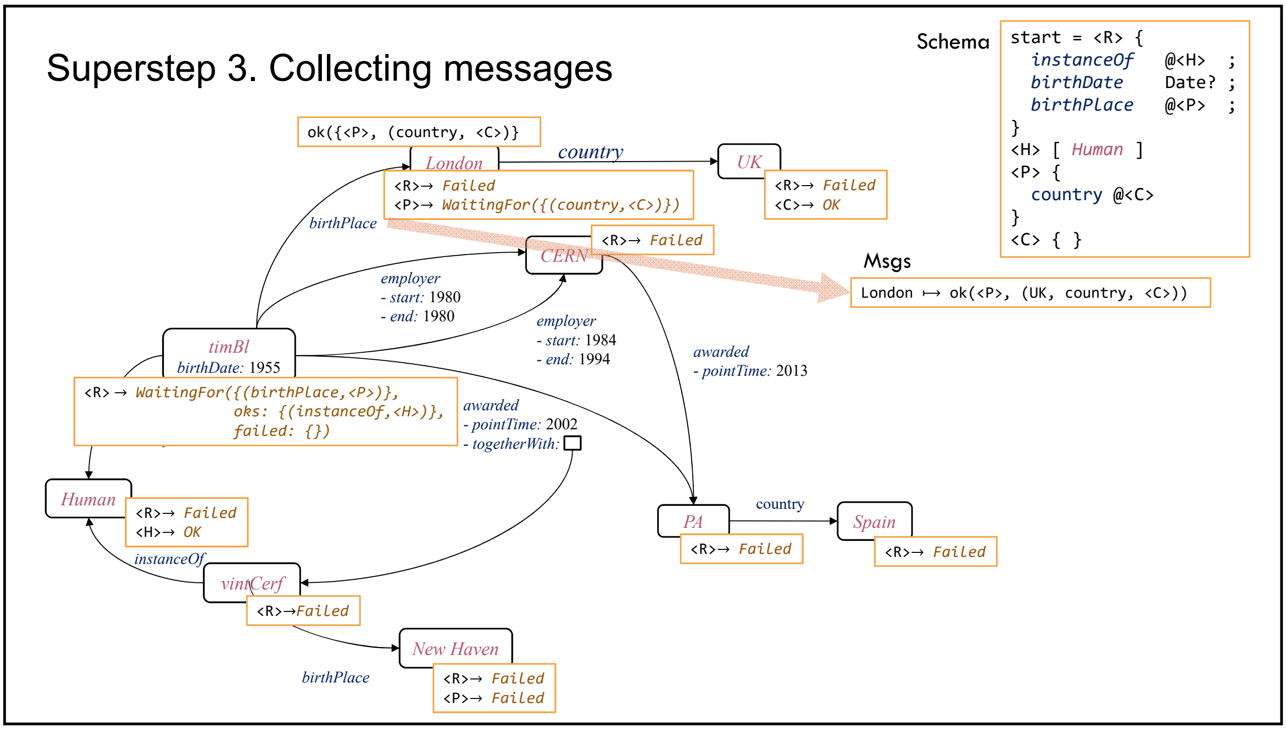

Superstep 1. Collecting messages
Schema
start = <R> {
instanceOf @<H> ;
birthDate Date? ;
birthPlace @<P> ;
}
<H> [Human]
<P> {
country @<C>
}
<C> { }
Msgs
(timBl, waitFor({<R>, (London,birthPlace,<P>)})
(London, validate({<P>})
(timBl, waitFor({<R>, (Human,instanceOf,<H>)})
(Human, validate({<H>})
(vintCerf, waitFor({<R>, (Human,instanceOf,<H>)})
(Human, validate({<H>})
validate({<P>})
London
country
UK
<R>→ Pending
<R>→ Pending
birthPlace
<R>→ Pending
CERN
waitFor({<R>, (birthPlace, <P>)}
waitFor({<R>, (instanceOf, <H>)}
employer
- start: 1980
- end: 1980
employer
- start: 1984
- end: 1994
awarded
- pointTime: 2013
timBl
birthDate: 1955
<R>→ Pending
awarded
- pointTime: 2002
- togetherWith:
instanceOf
validate({<H>})
Human
<R>→ Pending
PA
country
Spain
<R>→ Pending
<R>→ Pending
instanceOf
waitFor(<R>, (instanceOf, <H>)
vintCerf
<R>→ Pending
validate({<P>})
birthPlace
New Haven
<R>→ Pending


Superstep 1. After vprog.
Schema
start = <R> {
instanceOf @<H> ;
birthDate Date? ;
birthPlace @<P> ;
}
<H> [Human]
<P> {
country @<C>
}
<C> { }
London
country
UK
<R>→ Failed
<P>→ Pending
<R>→ Failed
birthPlace
<R>→ Failed
CERN
employer
- start: 1980
- end: 1980
employer
- start: 1984
- end: 1994
awarded
- pointTime: 2013
timBl
birthDate: 1955
<R> → WaitingFor({(London, birthPlace,<P>),
(Human, instanceOf,<H>)},
oks: {}, failed: {})
awarded
- pointTime: 2002
- togetherWith:
Human
<R>→ Failed
<H>→ OK
PA
country
Spain
<R>→ Failed
<R>→ Failed
instanceOf
vintCerf
<R>→ WaitingFor({(instanceOf,<H>)}
oks: {}, failed: {}
)
birthPlace
New Haven
<R>→ Failed


Superstep 2. Collecting new messages.
Schema
start = <R> {
instanceOf @<H> ;
birthDate Date? ;
birthPlace @<P> ;
}
<H> [Human]
<P> {
country @<C>
}
<C> { }
Msgs
London ↦ waitFor({<P>,(London,country,<C>)})
UK ↦ validate({<C>})
timBl ↦Checked({<R>,(Human,instanceOf,<H>)},{})
vintCerf↦Checked({<R>,(Human,instanceOf,<H>)},{})
vintCerf↦Checked({<R>,{},{(NewHaven,birthPlace,<P>)})
London
<R>→ Failed
<P>→ Pending
country
UK
<R>→ Failed
birthPlace
CERN
<R>→ Failed
employer
- start: 1980
- end: 1980
employer
- start: 1984
- end: 1994
awarded
- pointTime: 2013
timBl
birthDate: 1955
<R> → WaitingFor({(London, birthPlace,<P>),
(Human, instanceOf,<H>)},
oks: {}, failed: {})
awarded
- pointTime: 2002
- togetherWith:
instanceOf
Human
<R>→ Failed
<H>→ OK
instanceOf
vintCerf
<R>→ WaitingFor({(instanceOf,<H>)}
oks: {}, failed: {}
)
PA
<R>→ Failed
country
Spain
<R>→ Failed
New Haven
<R>→ Failed
<P>→ Failed
birthPlace


Superstep 2. After vprog
Schema
start = <R> {
instanceOf @<H> ;
birthDate Date? ;
birthPlace @<P> ;
}
<H> [Human]
<P> {
country @<C>
}
<C> { }
Msgs
London ↦ waitFor({<P>, (UK, country, <C>)})
UK ↦ validate({<C>})
timBl ↦ ok({<R>, (Human, instanceOf, <H>)})
vintCerf ↦ ok({<R>, (Human, instanceOf, <H>)})
waitFor({<P>, (country, <C>)}
validate(<C>})
London
<R>→ Failed
<P>→ Pending
country
UK
<R>→ Failed
birthPlace
CERN
<R>→ Failed
employer
- start: 1980
- end: 1980
employer
- start: 1984
- end: 1994
awarded
- pointTime: 2013
ok({<R>, (instanceOf, <H>)}
timBl
birthDate: 1955
<R> → WaitingFor({(London,birthPlace,<P>),
(Human,instanceOf,<H>)},
oks: {}, failed: {})
awarded
- pointTime: 2002
- togetherWith:
instanceOf
Human
<R>→ Failed
<H>→ OK
instanceOf
ok({<R>, (instanceOf, <H>)}
vintCerf
<R>→ WaitingFor({(Human,instanceOf,<H>)}
oks: {}, failed: {}
)
PA
<R>→ Failed
country
Spain
<R>→ Failed
New Haven
<R>→ Failed
birthPlace

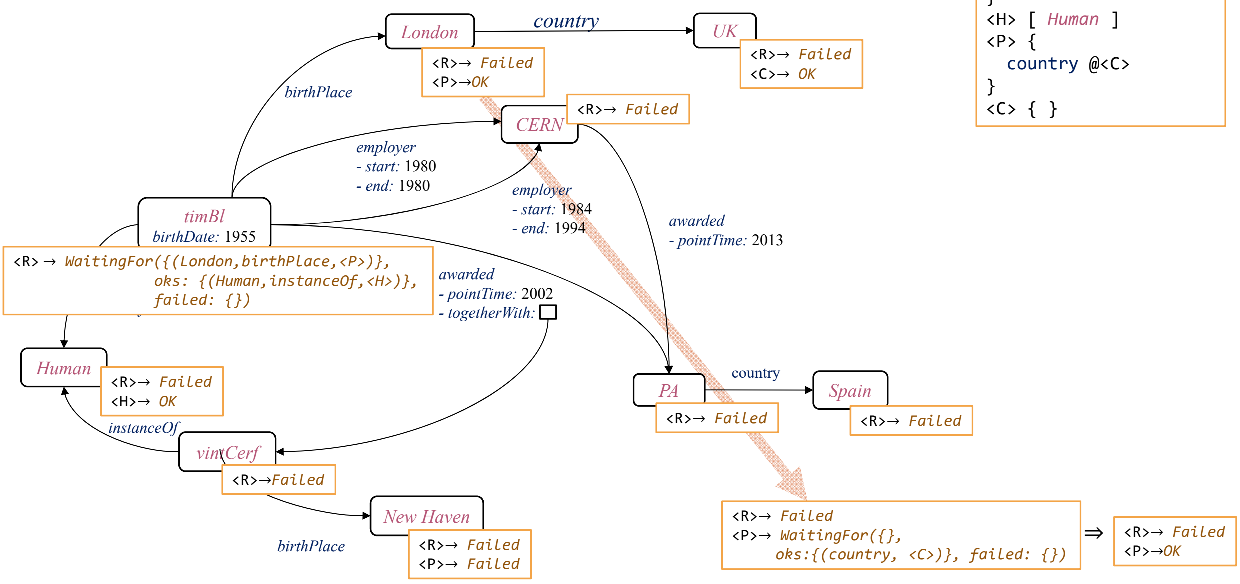

Superstep 2. After vprog
Schema
start = <R> {
instanceOf @<H> ;
birthDate Date? ;
birthPlace @<P> ;
}
<H> [Human]
<P> {
country @<C>
}
<C> { }
London
country
UK
<R>→ Failed
<P>→ WaitingFor({(UK,country,<C>)})
<R>→ Failed
<C>→ OK
birthPlace
CERN
<R>→ Failed
employer
- start: 1980
- end: 1980
employer
- start: 1984
- end: 1994
awarded
- pointTime: 2013
timBl
birthDate: 1955
<R> → WaitingFor({(birthPlace,<P>)},
oks: {(instanceOf,<H>)},
failed: {})
awarded
- pointTime: 2002
- togetherWith:
Human
<R>→ Failed
<H>→ OK
instanceOf
PA
country
Spain
<R>→ Failed
<R>→ Failed
vintCerf
<R>→Failed
<R>→ WaitingFor({}
oks: {(Human, instanceOf,<H>)}
failed: {})
⇒
<R>→Failed
New Haven
birthPlace
<R>→ Failed
<P>→ Failed


Superstep 3. Collecting messages
Schema
start = <R> {
instanceOf @<H> ;
birthDate Date? ;
birthPlace @<P> ;
}
<H> [Human]
<P> {
country @<C>
}
<C> { }
ok({<P>, (country, <C>)}
London
country
UK
<R>→ Failed
<P>→ WaitingFor({(country,<C>)})
<R>→ Failed
<C>→ OK
birthPlace
CERN
<R>→ Failed
Msgs
London ↦ ok(<P>, (UK, country, <C>))
employer
- start: 1980
- end: 1980
employer
- start: 1984
- end: 1994
awarded
- pointTime: 2013
timBl
birthDate: 1955
<R> → WaitingFor({(birthPlace,<P>)},
oks: {(instanceOf,<H>)},
failed: {})
awarded
- pointTime: 2002
- togetherWith:
Human
<R>→ Failed
<H>→ OK
instanceOf
PA
country
Spain
<R>→ Failed
<R>→ Failed
vintCerf
<R>→Failed
New Haven
birthPlace
<R>→ Failed
<P>→ Failed

Superstep 3. After vprog

Schema

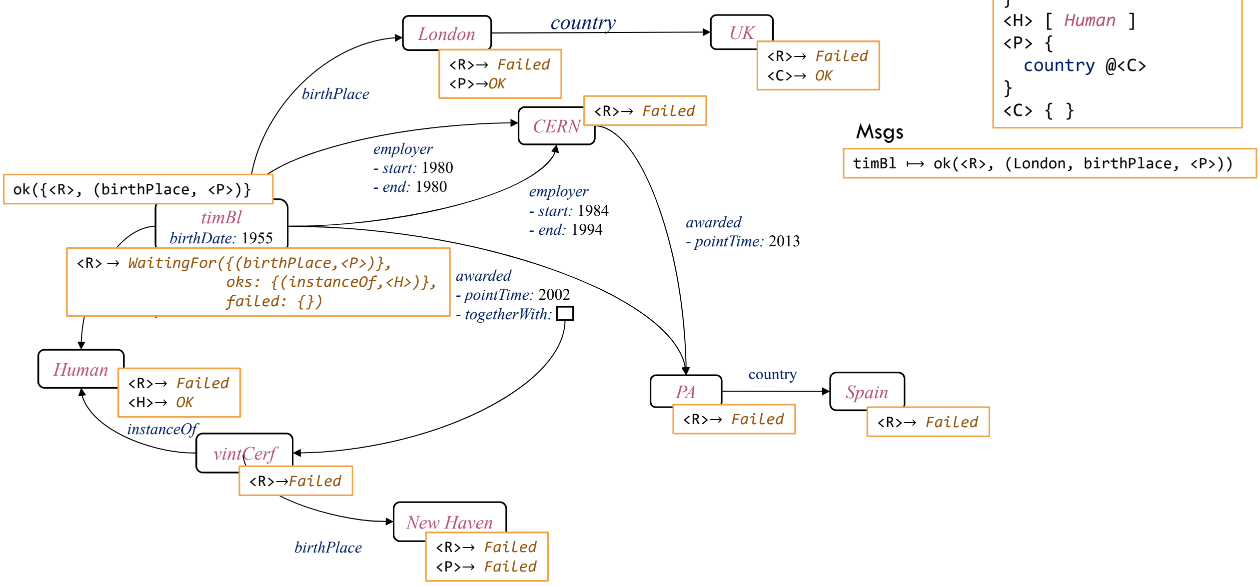
```
start = <R> {
  instanceOf    @<H>  ;
  birthDate     Date? ;
  birthPlace    @<P>  ;
}
<H> [ Human ]
<P> {
  country @<C>
}
<C> { }
```



Superstep 4. Collecting messages

Schema

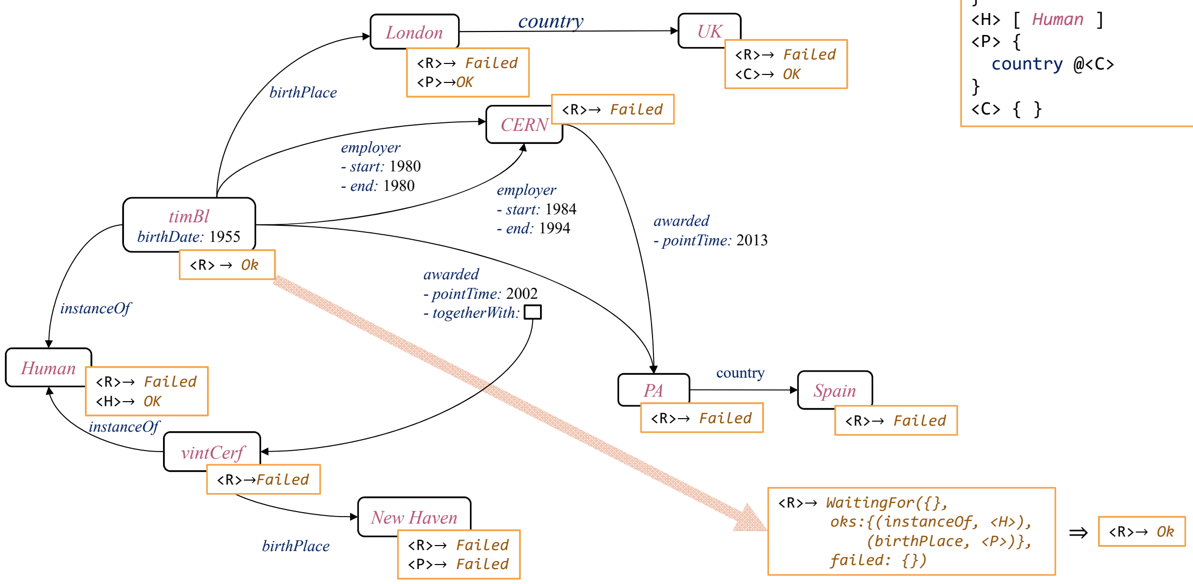
```
start = <R> {
  instanceOf    @<H>  ;
  birthDate     Date? ;
  birthPlace    @<P>  ;
}
<H> [ Human ]
<P> {
  country @<C>
}
<C> { }
```



Superstep 4. After vprog

Schema

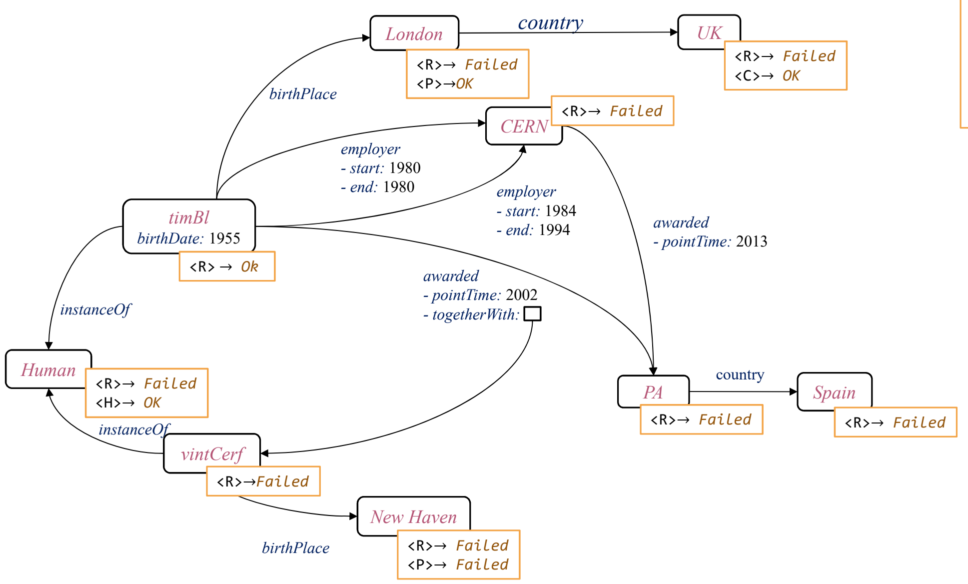
```
start = <R> {
  instanceOf   @<H>  ;
  birthDate    Date? ;
  birthPlace   @<P>  ;
}
<H> [ Human ]
<P> {
  country @<C>
}
<C> { }
```



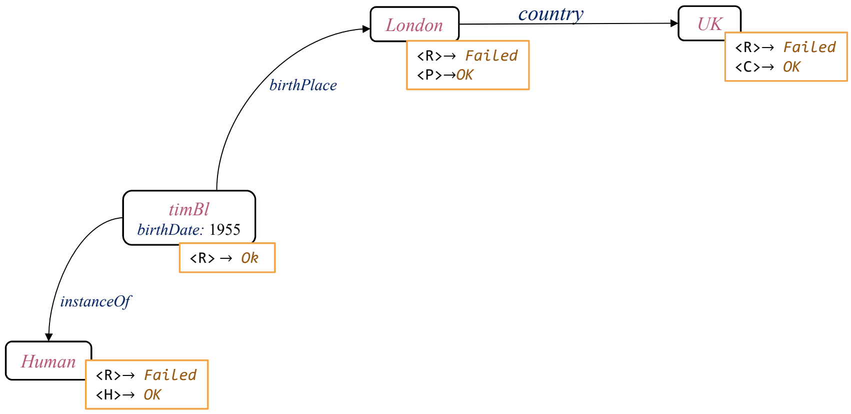
End state: All nodes inactive, no more messages

Schema

```
start = <R> {
  instanceOf   @<H>  ;
  birthDate    Date? ;
  birthPlace   @<P>  ;
}
<H> [ Human ]
<P> {
  country @<C>
}
<C> { }
```



Wikibase Subgraph: entities with some OK shape



Schema

```
start = <R> {
  instanceOf   @<H>  ;
  birthDate    Date? ;
  birthPlace   @<P>  ;
}
<H> [ Human ]
<P> {
  country @<C>
}
<C> { }
```

Status and Messages

Status	::=	$Undefined$	Default status
	|	Ok	Node conforms
	|	$Failed$	Node doesn't conform
	|	$Pending$	Requested to conform
	|	$WaitingFor(ds, oks, fs)$	Waiting for some neighbours ds = list dependants neighbours oks = list of conformant neighbours fs = list of non conformant neighbours where $ds, oks, failed \in \mathcal{V} \times \mathcal{P} \times \mathcal{L}$

Msg	::=	$Validate$	Request to validate
	|	$Checked(oks, fs)$	Some neighbours have been checked oks = neighbours that have been checked as conformant fs = neighbours that have been checked as non-conformant where $oks, fs \in \mathcal{V} \times \mathcal{P} \times \mathcal{L}$
	|	$WaitFor(ds)$	Request to wait for some neighbours where $ds \in \mathcal{V} \times \mathcal{P} \times \mathcal{L}$

Adapting Pregel to validate graphs using ShEx

Algorithm 1: Pregel-based ShEx validation pseudocode

Input parameters:
- `g`: `Graph`$[\mathcal{V}, \mathcal{E}]$
- `initialLabel`: $\mathcal{L}$
- `checkLocal`: $(\mathcal{L}, \mathcal{V}) \to Ok|\ Failed|\ Pending($`Set`$[\mathcal{L}])$
- `checkNeighs`: $(\mathcal{L},$ `Bag`$[(\mathcal{E}, \mathcal{L})]$, `Set`$[(\mathcal{E}, \mathcal{L})]) \to Ok|Failed$
- `tripleConstraints`: $\mathcal{L} \to$ `Set`$[(\mathcal{E}, \mathcal{L})]$

Output: `g:Graph`$[(\mathcal{V}, \mathcal{L} \mapsto \text{Status}), \mathcal{E}]$

gs = mapVertices(g, λ(id, v)→(id, (v, λv→*Undefined*)))
gs = pregel(*Validate*, gs, vProg, sendMsg, mergeMsg)
gs = mapVertices(gs, checkUnsolved)
return gs

def checkUnsolved(v,m) = (v,m') where

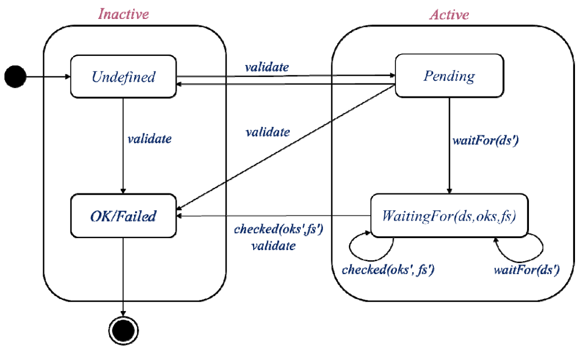
$$m'(l) = \begin{cases} \texttt{checkNeighs}(l, \emptyset, \emptyset) & \text{if } m(l) = Pending \\ \texttt{checkNeighs}(l, \text{oks}, \text{fs} \cup \text{ds}) & \text{if } m(l) = WaitingFor(ds, oks, fs)\} \\ m(l) & \text{otherwise} \end{cases}$$

Parameters

- InitialLabel, start label
- checkLocal, attempts to check if a node conforms locally. Possible results:
  - Ok
  - Failed
  - Pending(ls)
- checkNeighs, attempts to check the neighbourhood of a node. Result:
  - Ok
  - Failed
- tripleConstraints: set of constraints associated with a label

vProg definition

$\texttt{vProg}(id,(n,m), msg) = (n,m')$ where
$m'(l) = m(l)$
except for the cases indicated by the rules:



$$\frac{\begin{array}{c}(n,m), l \rightsquigarrow Validate \\ m(l) = s \in \{Undefined, Pending\}\end{array} \quad checkLocal(l,n) = r \in \{Ok, Failed\}}{m'(l) = r}$$

$$\frac{\begin{array}{c}(n,m), l \rightsquigarrow Validate \\ m(l) = r \in \{Undefined, Pending\}\end{array} \quad checkLocal(l,n) = Pending(ls)}{\begin{array}{c}m'(l) = Undefined \\ m'(l') = Pending\ \forall l' \in ls\end{array}}$$

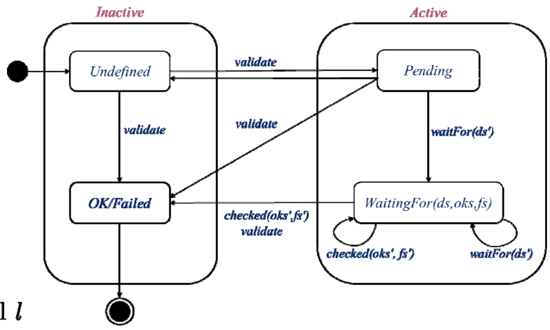
$$\frac{\begin{array}{c}(n,m), l \rightsquigarrow Validate \\ m(l) = r \in \{Ok, Failed\}\end{array}}{m'(l) = r}$$

$$\frac{\begin{array}{c}(n,m), l \rightsquigarrow Validate \\ m(l) = WaitingFor(ds, oks, fs)\end{array}}{m'(l) = Ok}$$

$$\frac{\begin{array}{c}(n,m), l \rightsquigarrow Checked(oks, fs) \\ m(l) = WaitingFor(ds, oks', fs')\end{array} \quad ds \setminus (oks \cup fs) \neq \emptyset}{m'(l) = WaitingFor(ds, oks \cup oks', fs \cup fs')}$$

$$\frac{\begin{array}{c}(n,m), l \rightsquigarrow Checked(oks, fs) \\ m(l) = WaitingFor(ds, oks', fs')\end{array} \quad ds \setminus (oks \cup fs) = \emptyset}{m'(l) = checkNeighs(l, oks \cup oks', fs \cup fs')}$$

sendMsg



$\langle (s, m_s), p, (o, m_o) \rangle =$
triplet view with
- subject (s, m_s)
- predicate p
- object (o, m_o)

$(x, m_x), l \rightsquigarrow Msg =$
message Msg sent to node x with status map m_x for label l

$$\frac{\langle (s,m_s),p,(o,m_o)\rangle \in \mathcal{G} \quad m_s(l) = Pending \quad tcs(l,\mathcal{S}) = \_ \xrightarrow{p} @l'}{\begin{array}{c}(s,m_s), l \rightsquigarrow WaitFor((o,p,l')) \\ (o,m_o), l \rightsquigarrow Validate\end{array}}$$

$$\frac{\langle (s,m_s),p,(o,m_o)\rangle \in \mathcal{G} \quad m_s(l) = WaitingFor(ds,oks,fs) \quad (o,p,l') \in ds \quad m_o(l') = Ok}{(s,m_s), l \rightsquigarrow Checked((o,p,l'),\emptyset)}$$

$$\frac{\langle (s,m_s),p,(o,m_o)\rangle \in \mathcal{G} \quad m_s(l) = WaitingFor(ds,oks,fs) \quad (o,p,l') \in ds \quad m_o(l') = Failed}{(s,m_s), l \rightsquigarrow Checked(\emptyset,(o,p,l'))}$$

mergeMsg

$$\texttt{mergeMsg}((n,m), l \rightsquigarrow msg_1, (n,m), l \rightsquigarrow msg_2) \quad = \quad (n,m), l \rightsquigarrow msg_1 \oplus msg_2$$

$$\begin{array}{rl}
Validate \oplus y & = y \\
Validate \oplus Checked(oks,fs) & = Checked(oks,fs) \\
Validate \oplus WaitFor(ds) & = WaitFor(ds) \\
Checked(oks,fs) \oplus Validate & = Checked(oks,fs) \\
Checked(oks,fs) \oplus Checked(oks',fs') & = Checked(oks \cup oks', fs \cup fs') \\
Checked(oks,fs) \oplus WaitFor(ds) & = Checked(oks \cup ds, fs \cup fs) \\
WaitFor(ds) \oplus Validate & = WaitFor(ds) \\
WaitFor(ds) \oplus Checked(oks,fs) & = Checked(oks \cup ds, fs) \\
WaitFor(ds) \oplus WaitFor(ds') & = WaitFor(ds \cup ds')
\end{array}$$

checkLocal

$$\texttt{checkLocal:}\ (\mathcal{L}, \mathcal{V}) \to Ok|\ Failed|\ Pending(\texttt{Set}[\mathcal{L}])$$

Checks if it is possible to validate a node locally

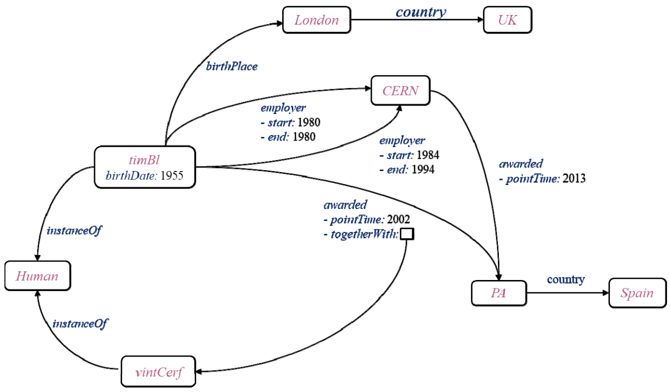
Returns

Ok: Node conforms

Failed: Node doesn't conform

Pending(ls) conformance depends on neighbours

```
checkLocal(<Human>, Human) = Ok
checkLocal(<Researcher>, Human) = Failed
checkLocal(<Researcher>, timBL) = Pending { <Human>, <Place> }
```




```
start = <Researcher>
<Researcher> {
  instanceOf    @<Human>  ;
  birthDate     Date? ;
  birthPlace    @<Place>  ;
}
<Human> [ Human ]
<Place> {
  country @<Country>
}
<Country> { }
```

checkNeighs

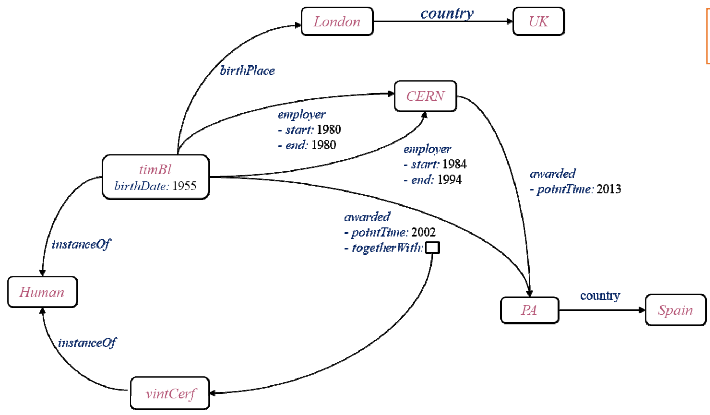
$$\texttt{checkNeighs:}\ (\mathcal{L}, \texttt{Bag}[(\mathcal{E}, \mathcal{L})], \texttt{Set}[(\mathcal{E}, \mathcal{L})]) \to Ok|Failed$$

Checks if the bag of neighbours of a node conform to the regular bag expression defined by a shape

Returns: ok (conforms), failed (doesn't)

```
checkNeighs(<Researcher>, {(instanceOf, <Human>), (birthPlace, <London>)}, {}) = Ok
checkNeighs(<Researcher>, {(instanceOf, <Human>) }, {}) = Failed
```

```
rbe(<Researcher>) = (instanceOf, <Human>);
                    (birthPlace, <Place>)
```




```
start = <Researcher>
<Researcher> {
  instanceOf    @<Human>  ;
  birthDate     Date? ;
  birthPlace    @<Place>  ;
}
<Human> [ Human ]
<Place> {
  country @<Country>
}
<Country> { }
```

tripleConstraints

$\texttt{tripleConstraints}\colon\ \mathcal{L} \rightarrow \texttt{Set}[(\mathcal{E},\ \mathcal{L})]$

Returns the triple constraints of a shape label

```
tripleConstraints(<Researcher>) = {(instanceOf, <Human>), (birthPlace, <Place>)}
tripleConstraints(<Human>) = {}
tripleConstraints(<Place>) = {(country, <Country>)}
tripleConstraints(<Country>) = {}
```

```
start = <Researcher>
<Researcher> {
  instanceOf   @<Human>  ;
  birthDate    Date? ;
  birthPlace   @<Place>  ;
}
<Human> [ Human ]
<Place> {
  country @<Country>
}
<Country> { }
```

Preliminary results

- Implemented in SparkWDSub using Apache Spark GraphX
  - No optimizations applied
- Latest Wikidata dumps on AWS can be processed on AWS
  - 512 cores, 3.904 Gb RAM, 121.600 Gb disk
  - For 2014 Wikidata dump (31.3 GB uncompressed) in 3 minutes
  - For 2021 Wikidata dump (1.256,55 Gb uncompressed) it took 36 minutes
  - Only for simple schemas yet

Conclusions

Formal definition of Knowledge graphs
- RDF graphs, property graphs, wikibase graphs

ShEx extension for property graphs/wikibase graphs

Formal definition of wikibase graphs subsets

Scalable approach to validate big knowledge graphs
- Inspired by Pregel algorithm (Spark GraphX)

Repaso de contribuciones

	Grafos RDF	*Property graphs*	Grafos Wikibase
Definición formal	Realizado previamente	Realizado previamente	**Presente trabajo**
Descripción grafos conocimiento	ShEx Realizado anteriormente	**PShEx** **Presente trabajo**	**WShEx** **Presente trabajo**
Entity-generated (definición)	-	-	**Presente trabajo**
Entity-generated (implementación)	-	-	WDumper
Simple matching (definición)	-	-	**Presente trabajo**
Simple matching (implementación)	-	-	Wdumper
ShEx-based matching (definición)	-	-	**Presente trabajo**
ShEx-based matching (implementación)	-	-	**WDSub**
ShEx+Slurp (definición)	-	-	**Presente trabajo**
ShEx+Slurp (implementación)	ShEx.js, pyShEx	-	-
ShEx+Pregel (definición)	-	-	**Presente trabajo**
ShEx+Pregel (implementación)	-	-	**SparkWDSub**

Fin presentación ejercicio 1

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