Enabling Completeness-aware Querying in SPARQL

Luis Galárraga, Katja Hose, Simon Razniewski

May 14th, 2017

WebDB, Chicago

Outline

- Completeness in RDF knowledge bases
- Completeness oracles
- Our vision
  - Representations for completeness oracles
  - Reasoning with completeness oracles
  - Enabling completeness in SPARQL
- Summary & conclusions

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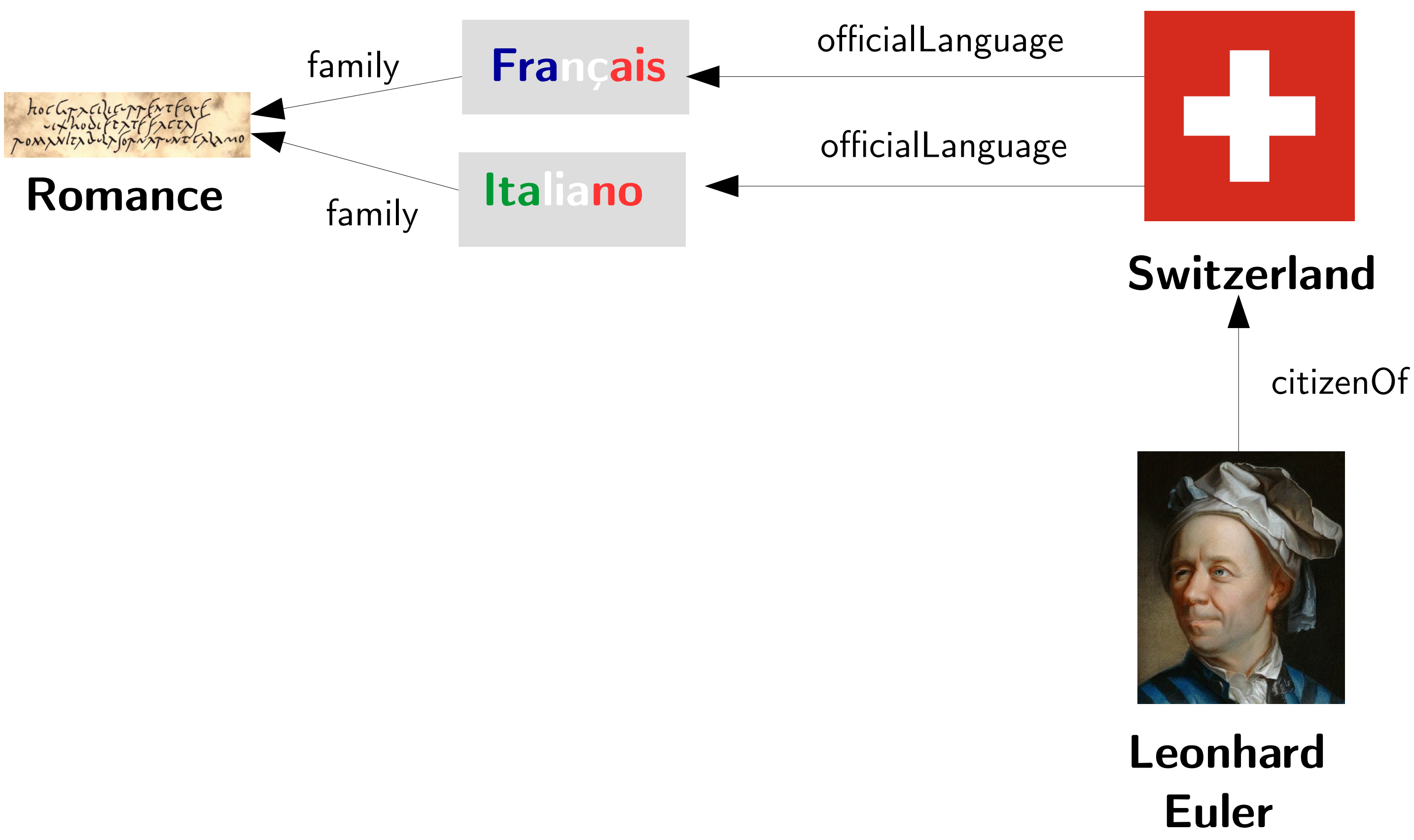
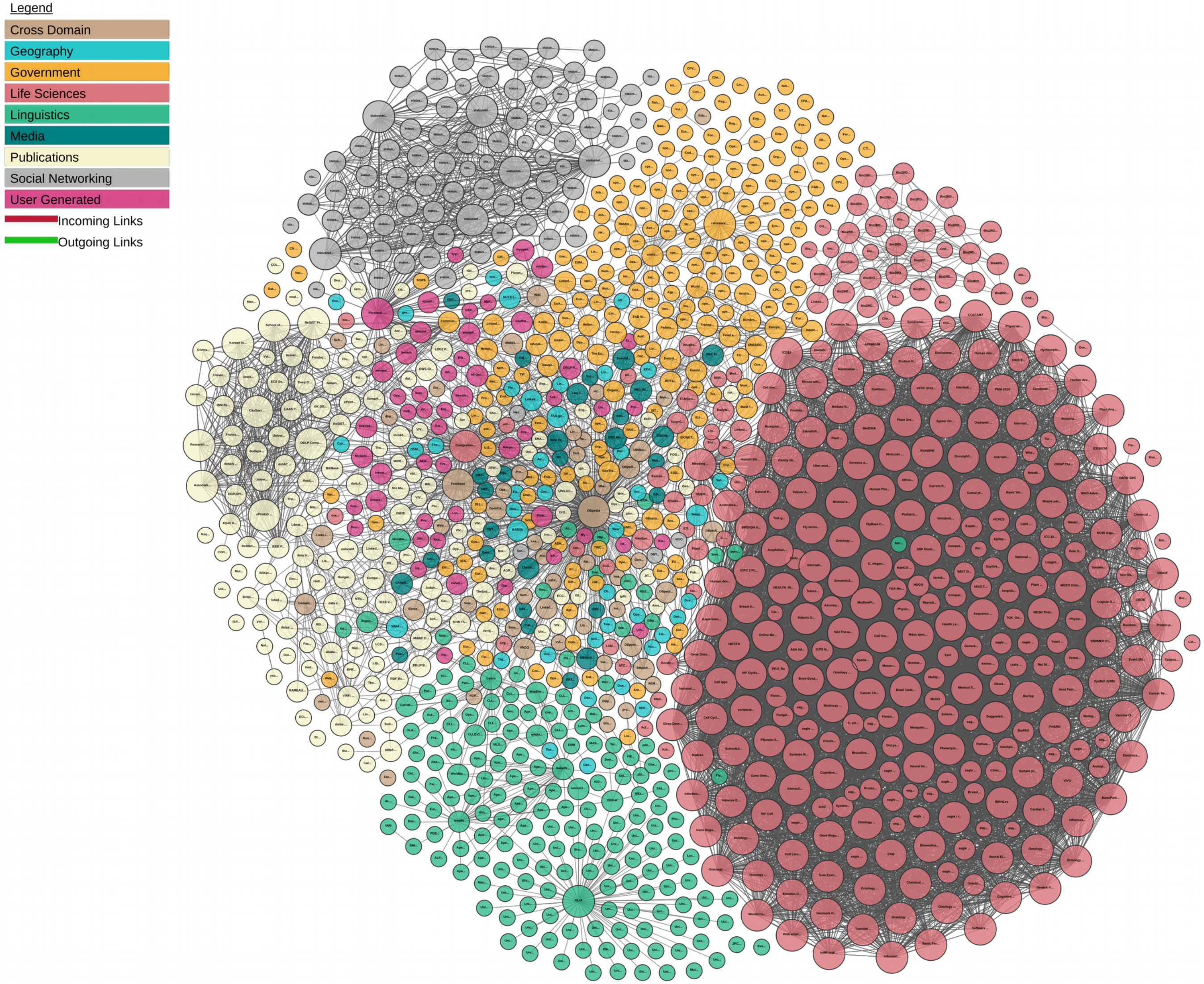
RDF Knowledge Bases (KBs)

Collection of structured knowledge



Plenty of KBs out there!



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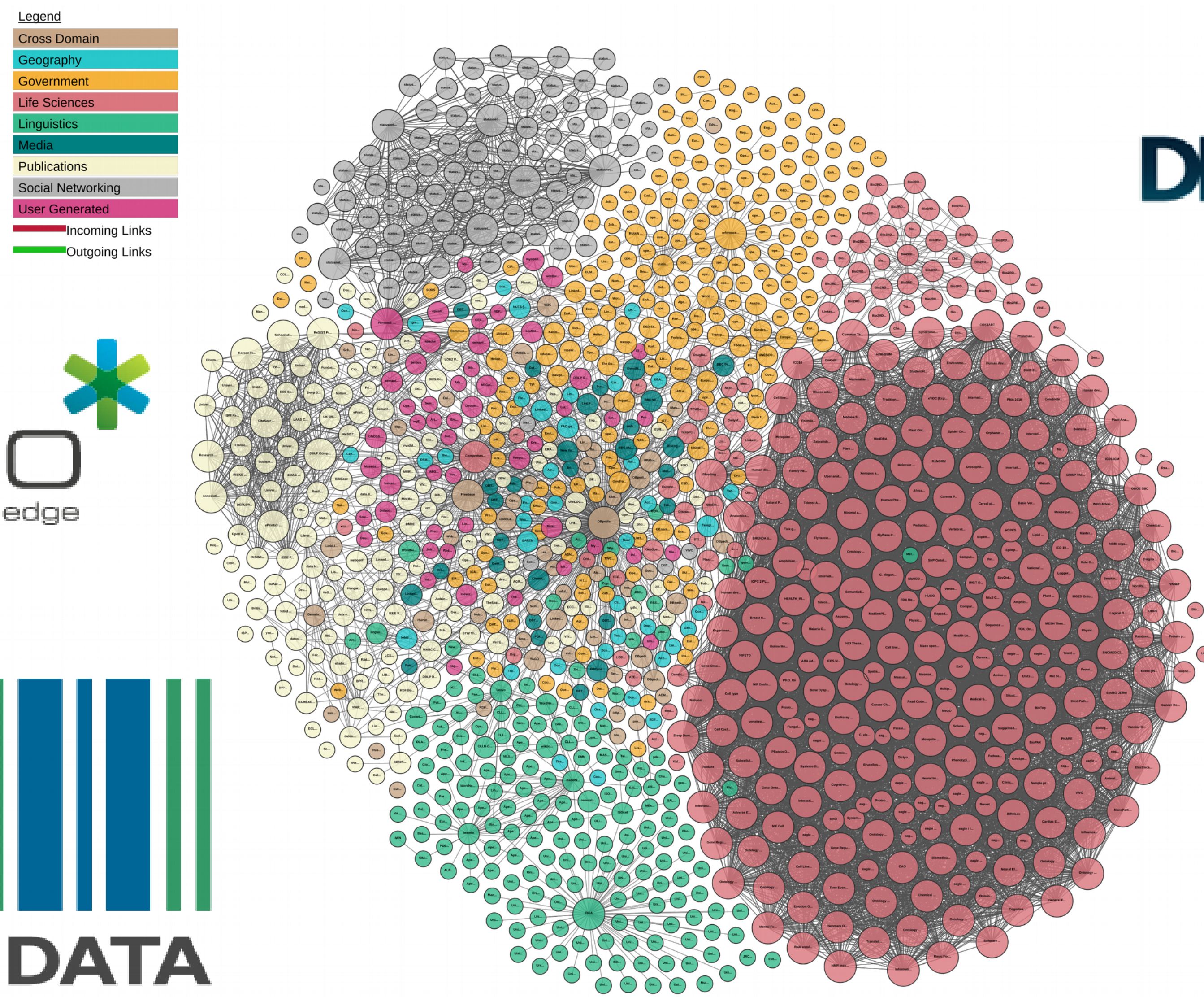
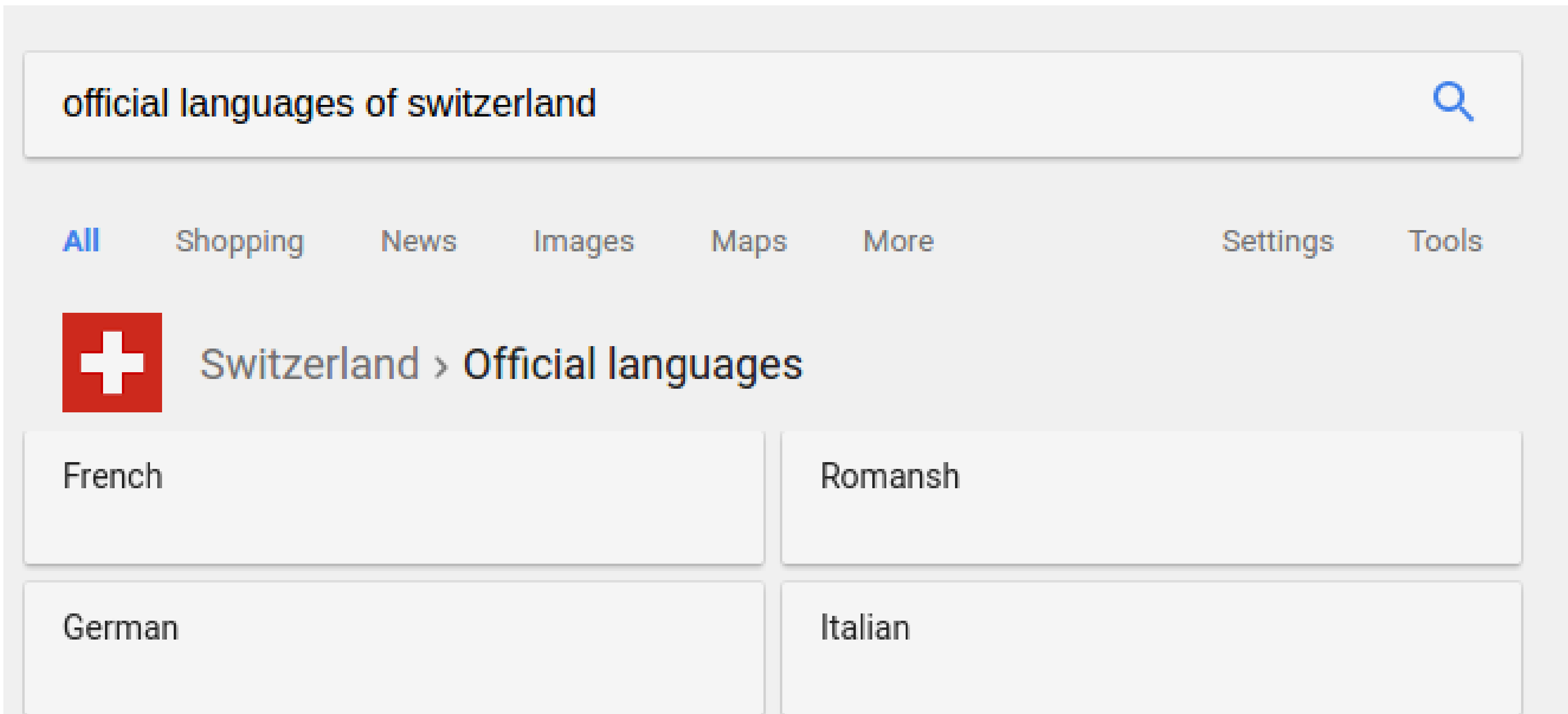


KBs in action



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- We do not know where the incompleteness lies
  - A single person in the KB could be actually single or the KB may be incomplete
- Problems for data producers and consumers
  - Consumers: no completeness guarantees for queries.
  - Producers: which parts of the KB need to be populated?

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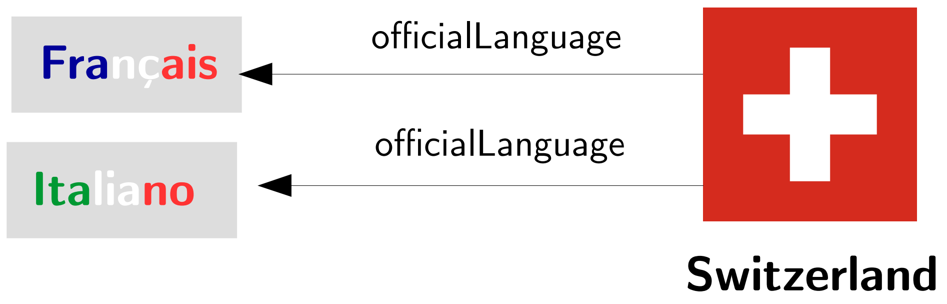

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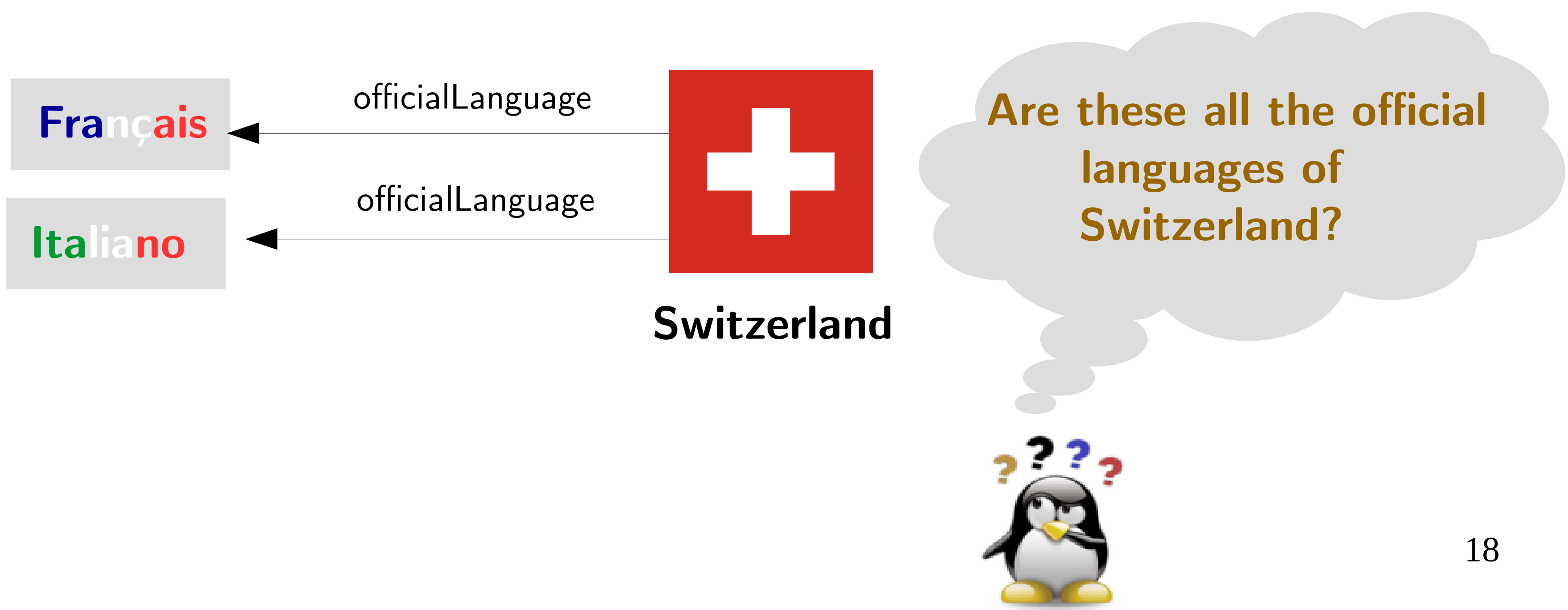

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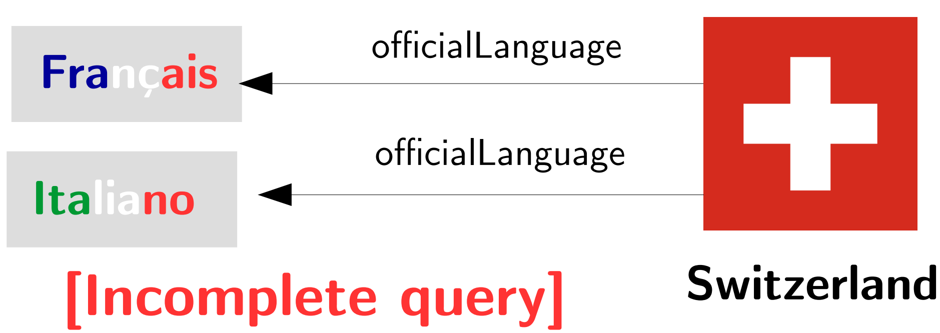

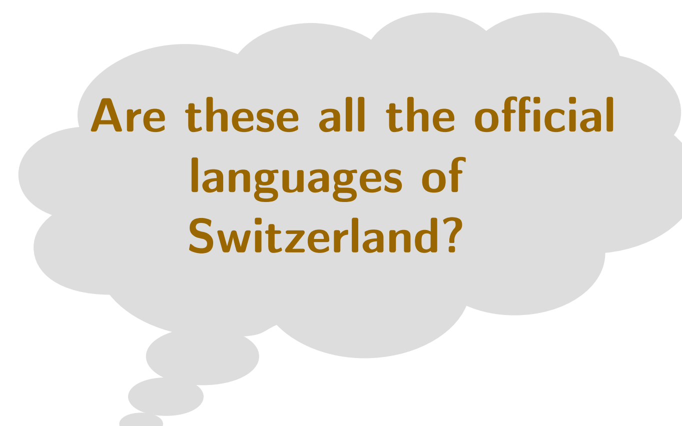

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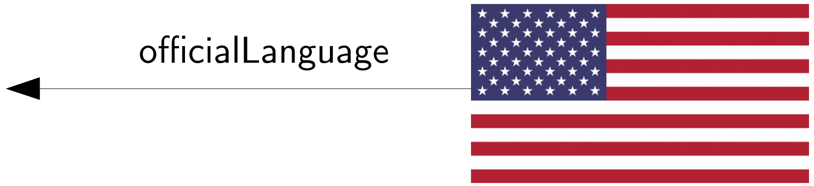

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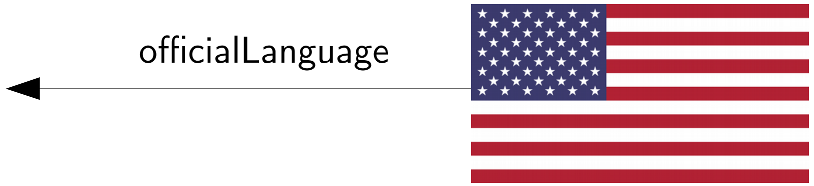

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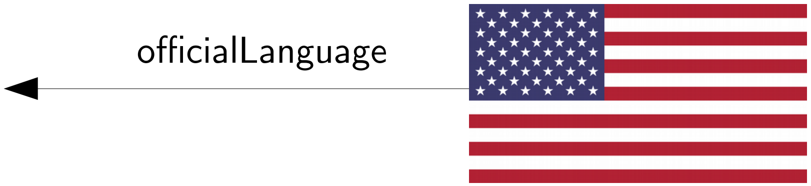

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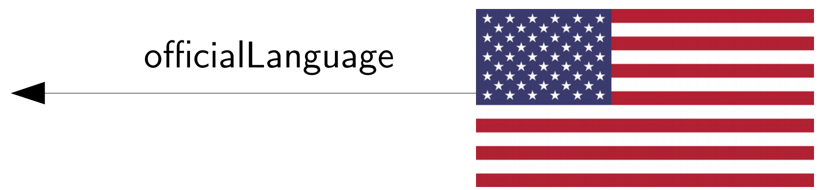

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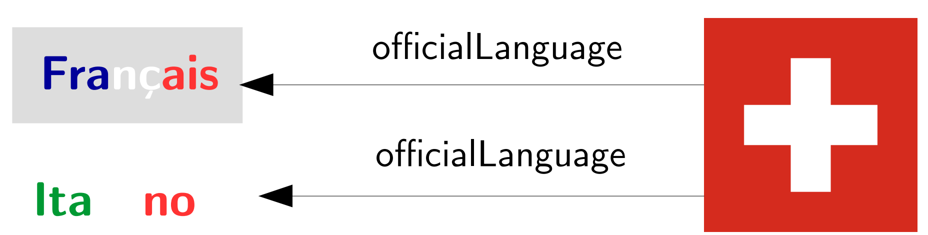

Switzerland

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Completeness oracle

- Boolean function $\boldsymbol{\omega}(\mathbf{q}, \mathbf{K})$ that guesses the completeness of a query q in a KB K.

SR completeness oracle

- Function $\boldsymbol{\varpi}$ that guesses the completeness of queries of the form [Galárraga et. al, 2017]:

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  - Query is **complete** in KB if at least one answer is known

Evaluating SR oracles

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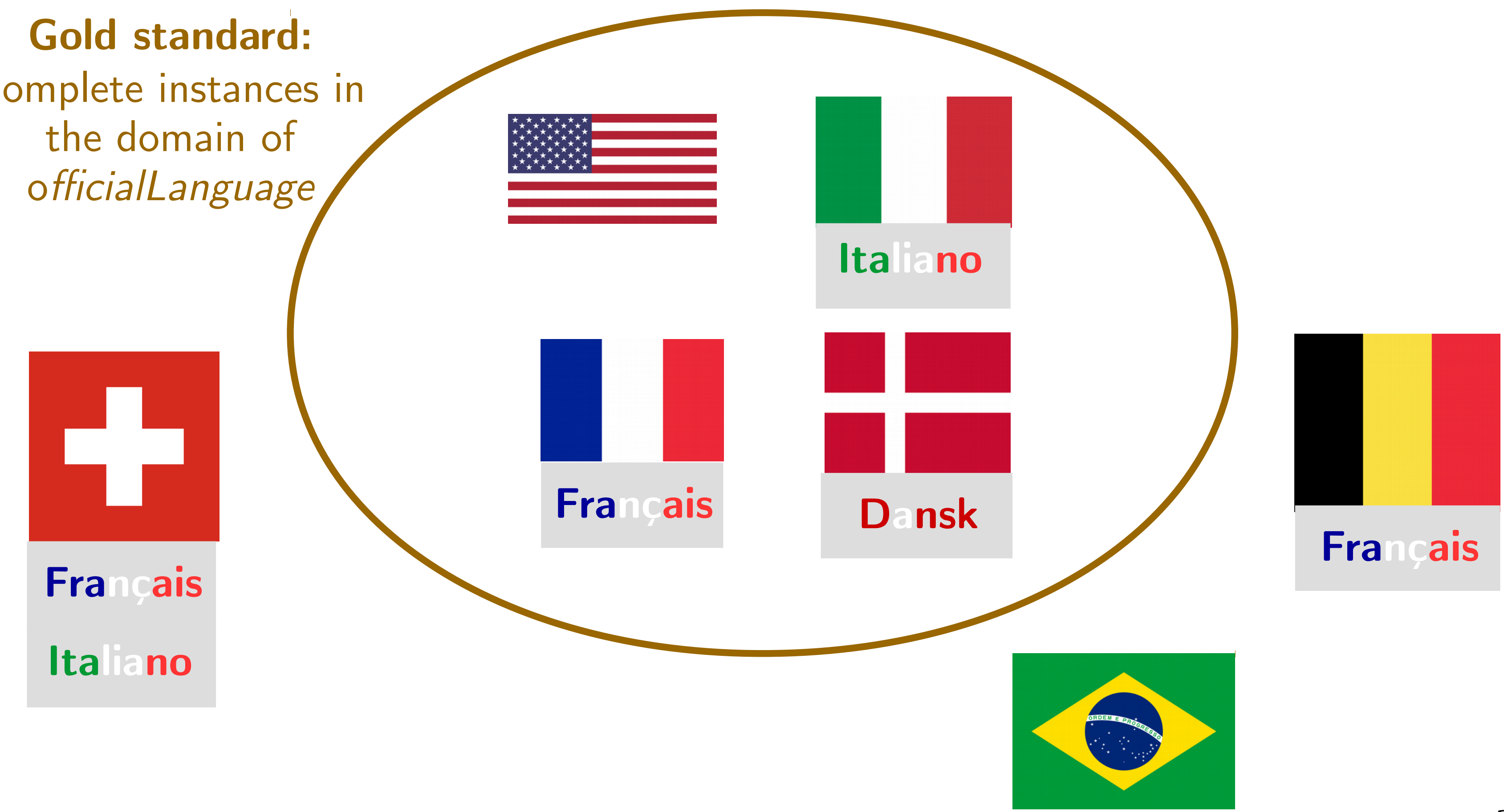

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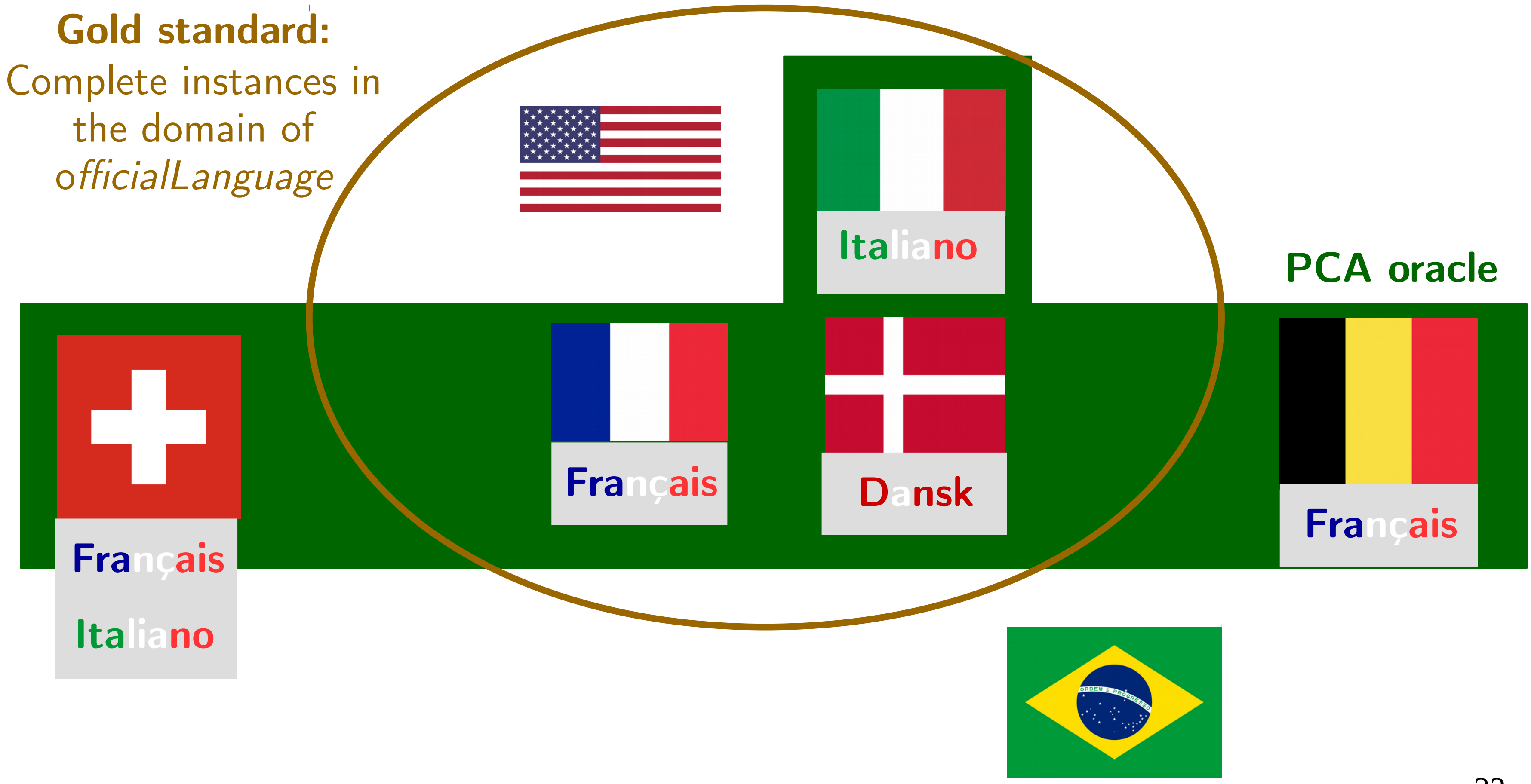
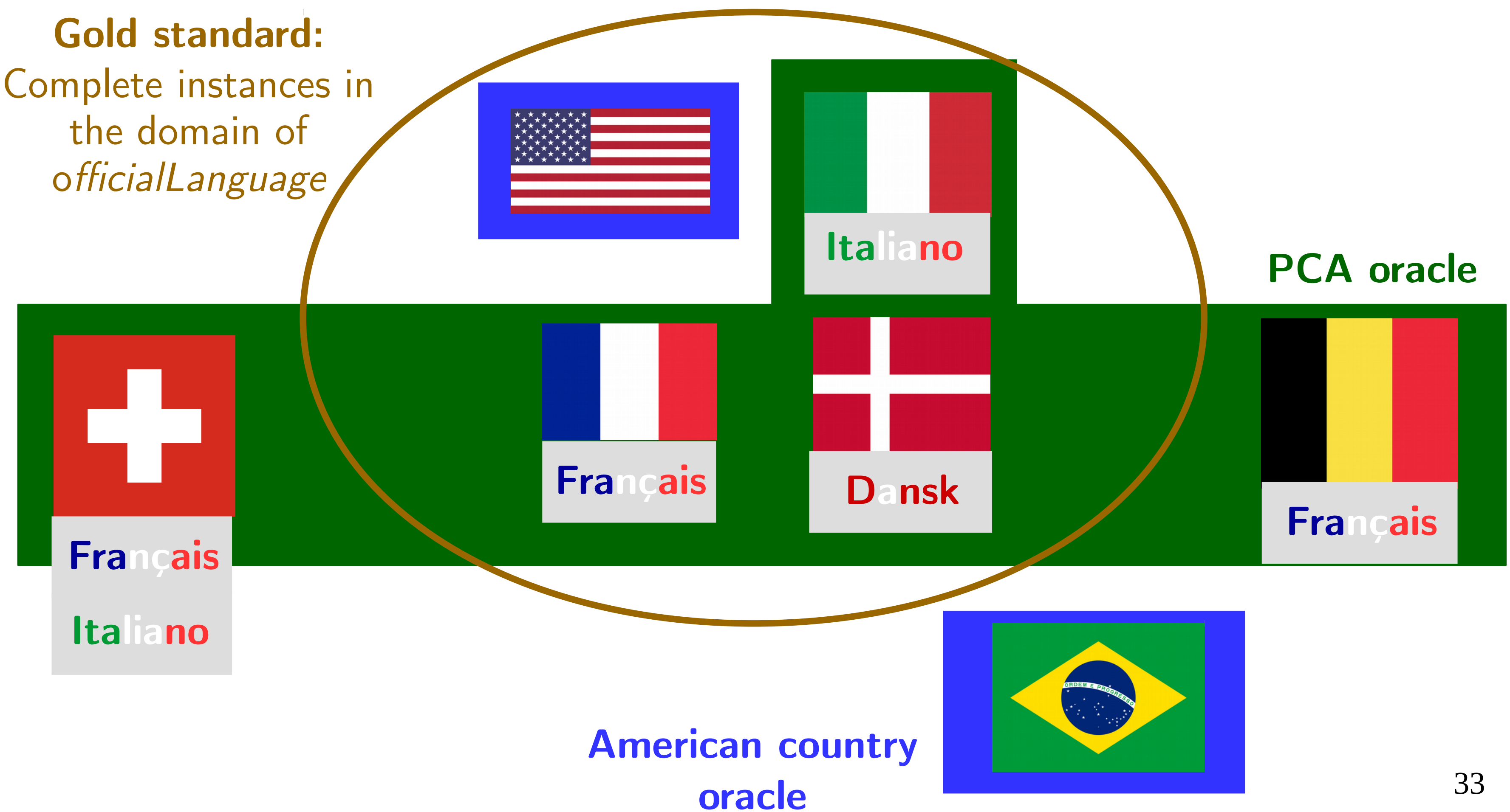


Evaluating SR oracles

$$\varpi = \textit{american-country-oracle}(s, r)$$



Evaluating SR oracles

PCA oracle

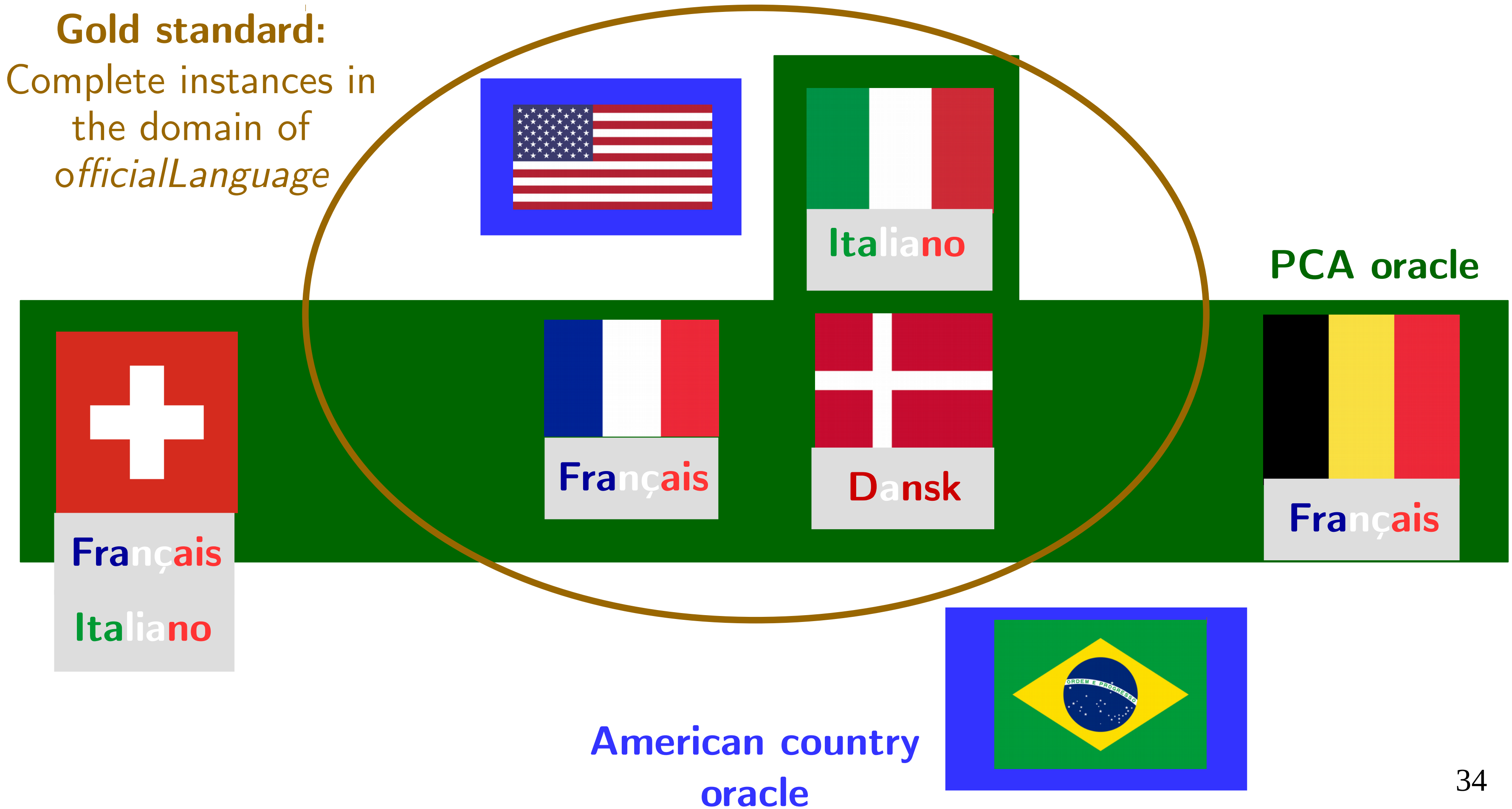
Precision = 3/5

Recall = 3/4

American country oracle

Precision = 1/2

Recall = 1/4



SR completeness oracles

- Closed World Assumption: $cwa(s, r) = true$
- PCA: $pca(s, r) = \exists\ o : r(s, o)$
- Cardinality: $card(s, r) = \#(o : r(s, o)) \geq k$
- Popular entities: $popularity_{pop}(s, r) = pop(s)$
- No-chg over time: $nochange_{chg}(s, r) = \sim chg(s, r)$
- Star : $star_{r_1,..,r_n}(s, r) = \forall\ i \in \{1,..,n\} : \exists\ o : r_i(s, o)$
- Class: $class_c(s, r) = type(s, c)$
- Rule mining oracle

Rule mining SR oracle

- Based on completeness rules

notype(x, Adult), type(x, Person) ⇒ complete(x, hasChild)

dateOfDeath(x, y), lessThan_1(x, placeOfDeath)⇒ incomplete(x, placeOfDeath)

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  - 100% F1-measure for functional relations, quite good for relations *hasChild*, *graduatedFrom*

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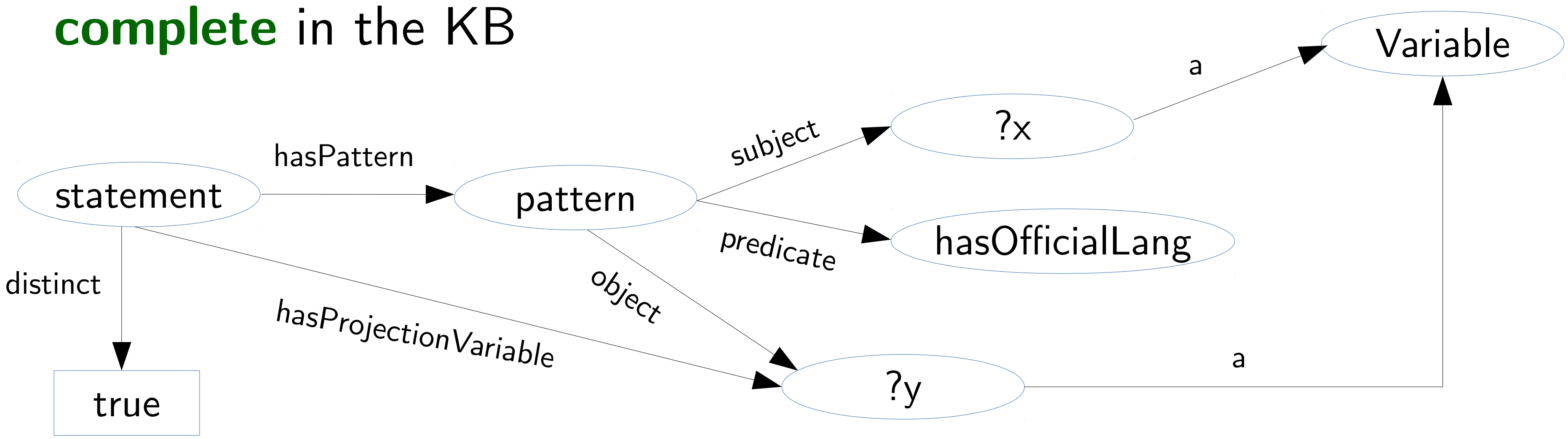

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  - A call to the oracle asks for the existence of the query in the graph

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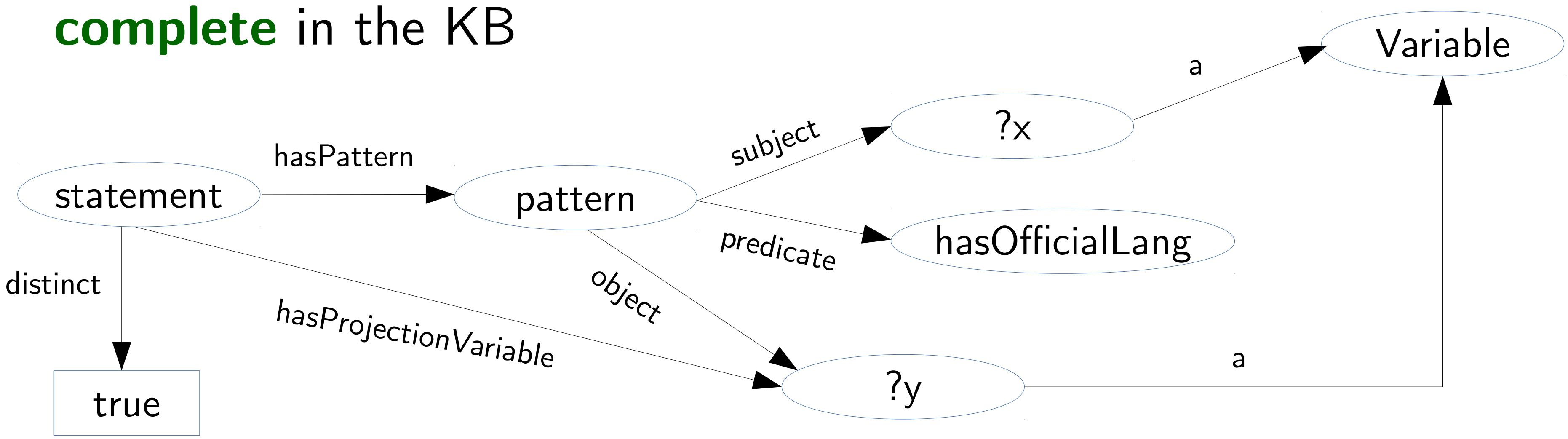

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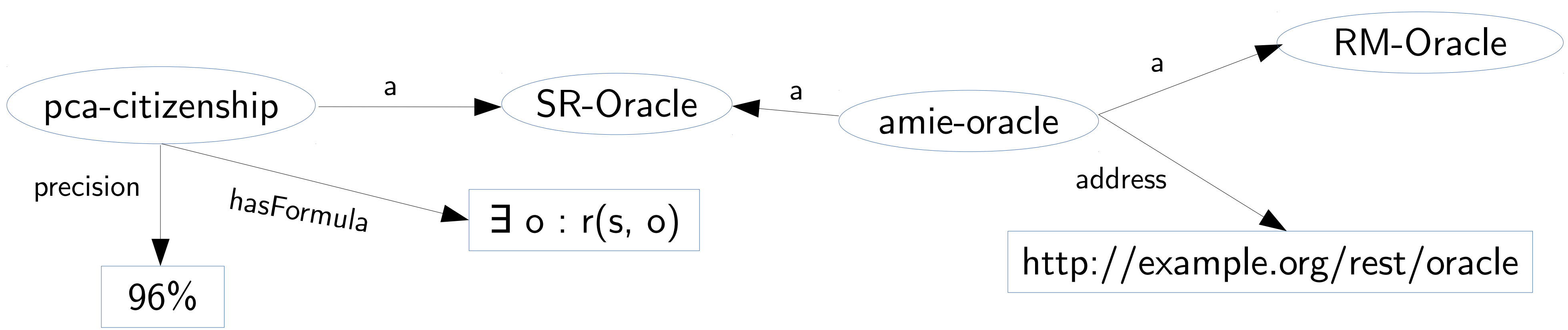
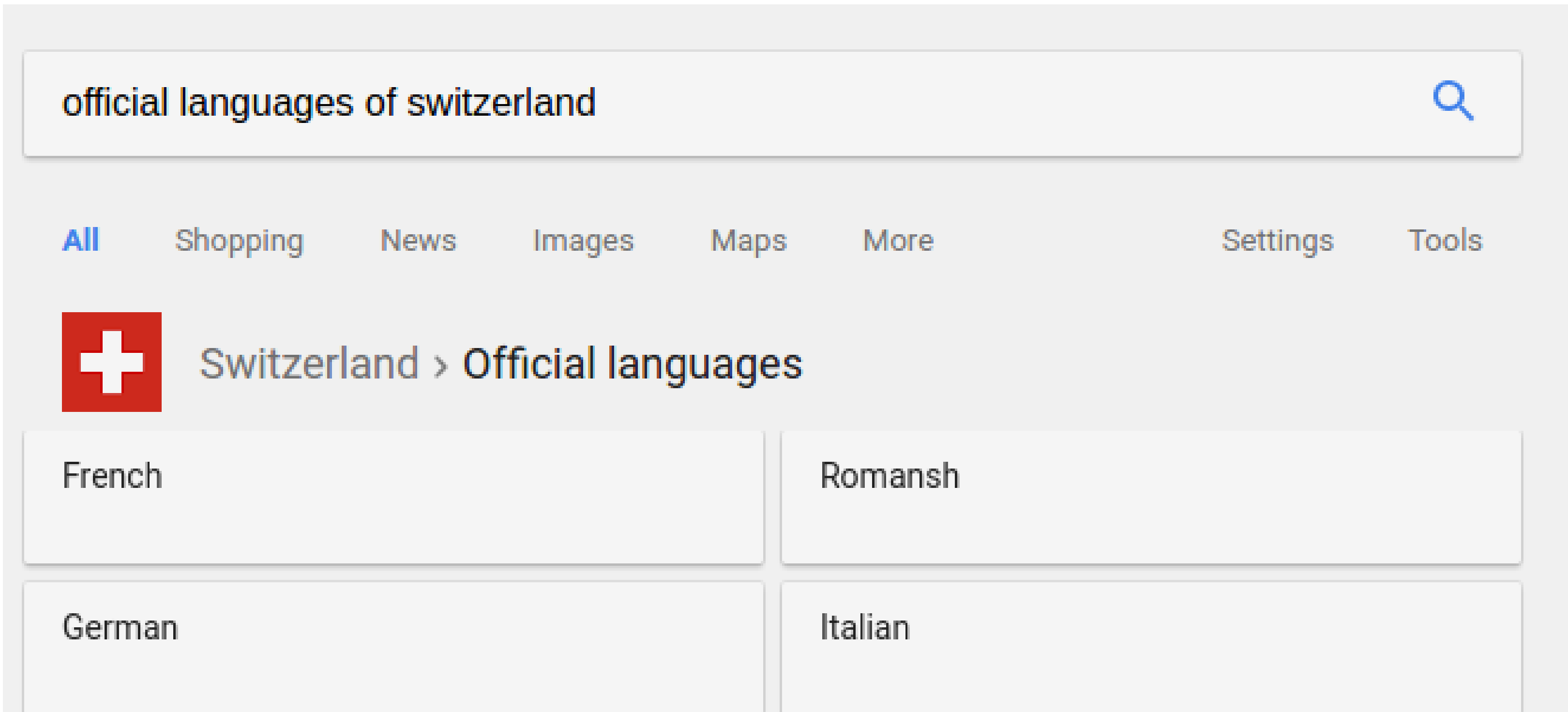


Providing completeness guarantees



List of results is complete according to oracle ϖ with confidence X

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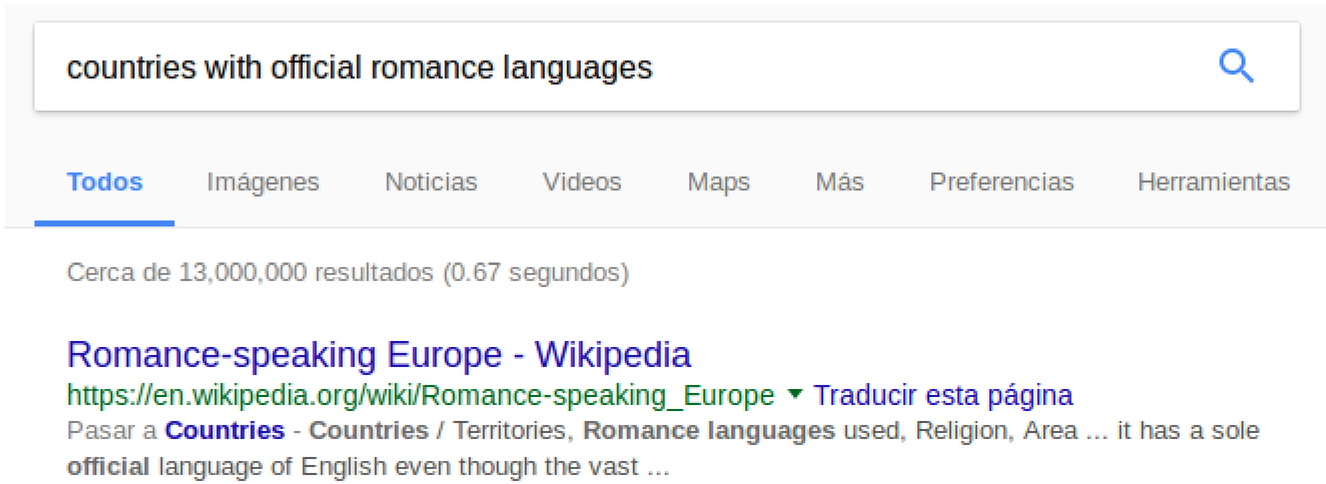

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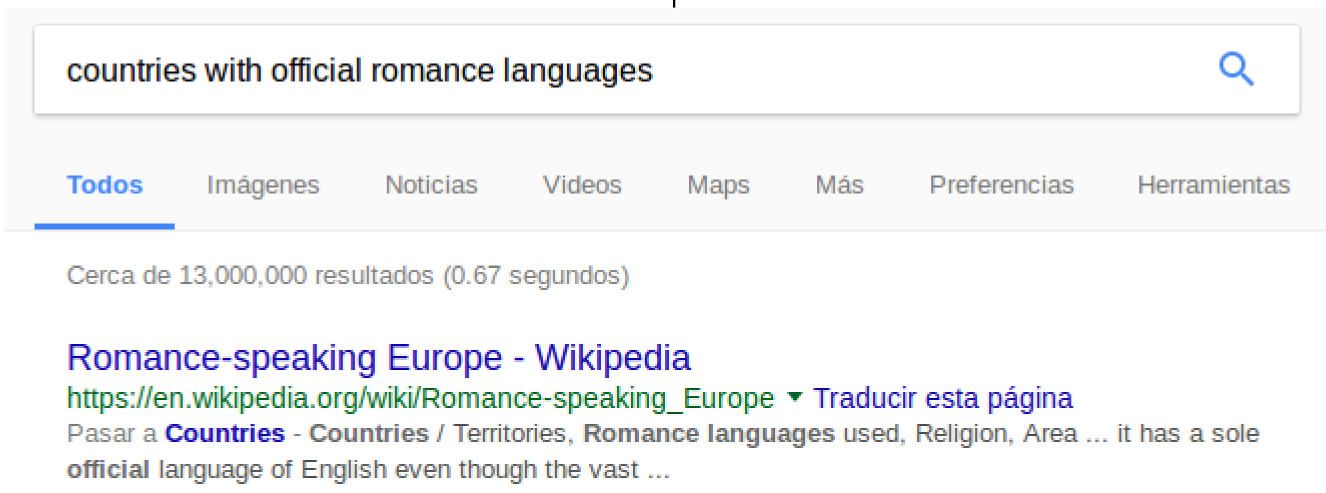


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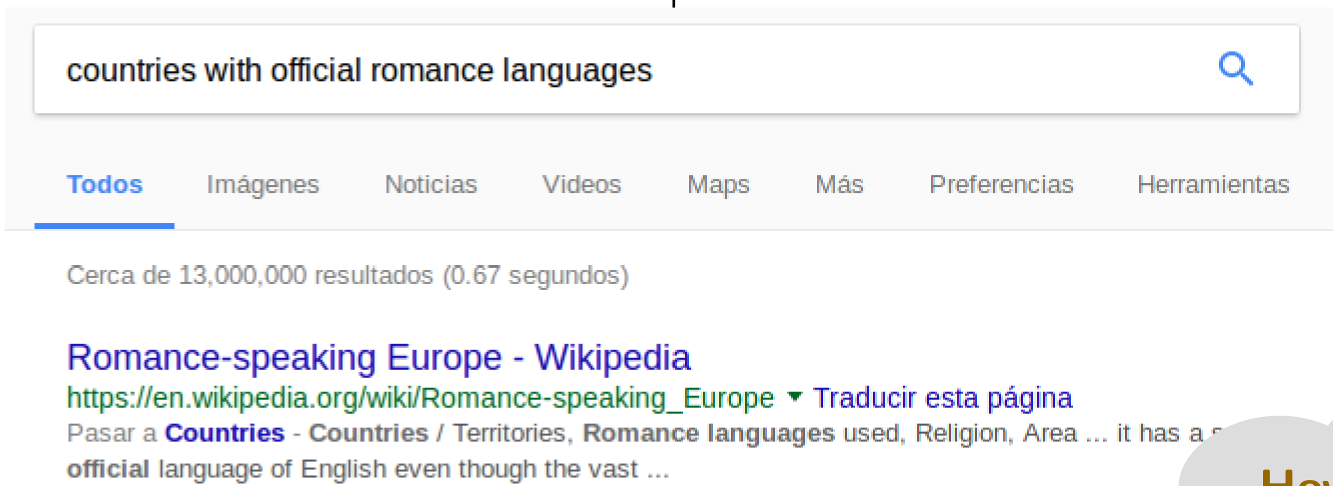


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How to provide completeness guarantees for arbitrary queries?

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- If $\boldsymbol{\omega}_{\mathbf{d}}$ returns true, $\boldsymbol{\omega}_{\mathbf{d}}$ states that the KB knows all languages that are official in some country

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It will generate false negatives

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If the KB misses Ligurian, this term returns false

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Even though this term does not care, because Ligurian is not official in any country

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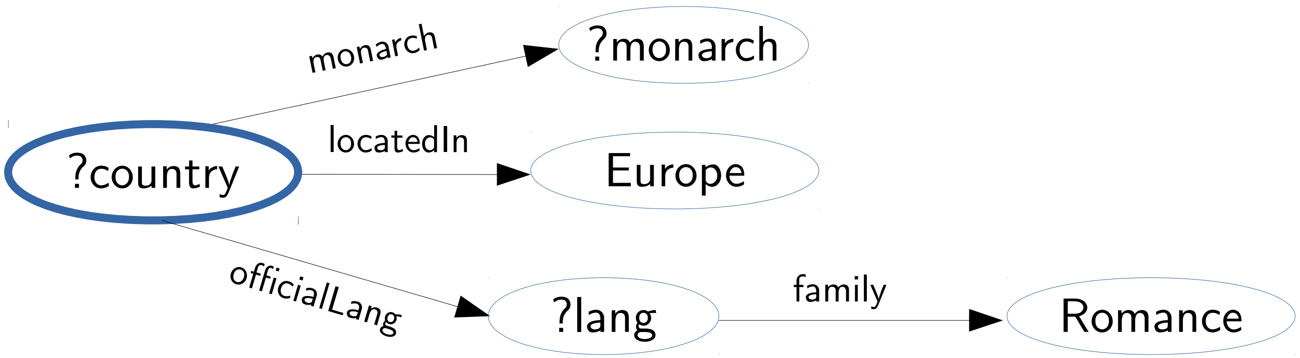
Automatic oracle composition

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SELECT ?country WHERE {
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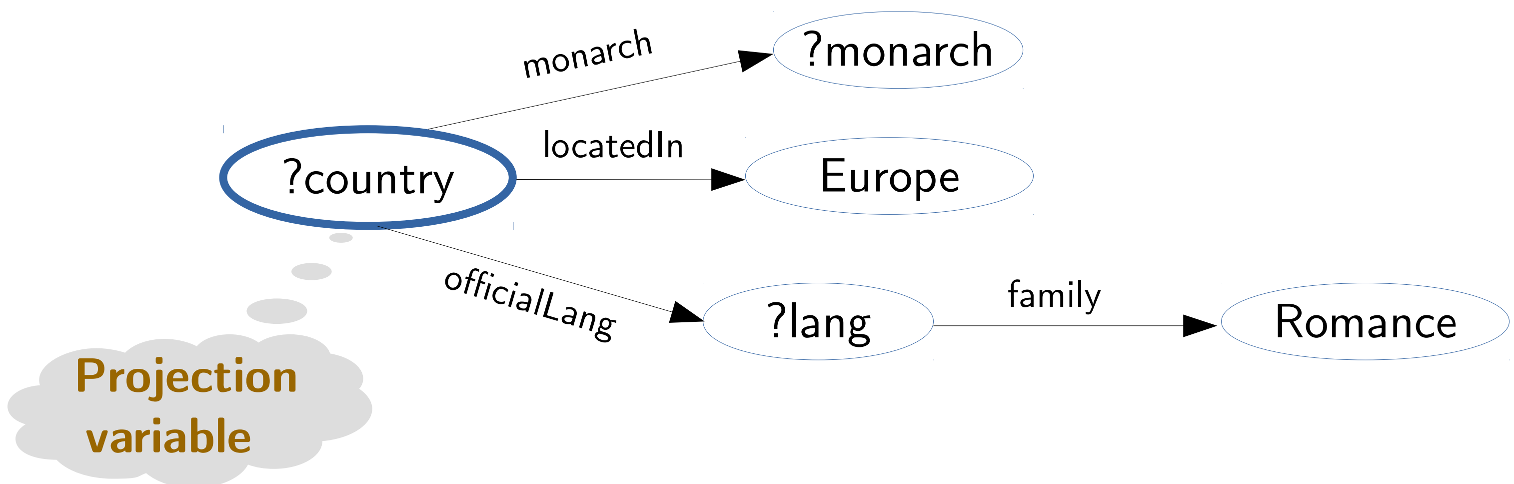

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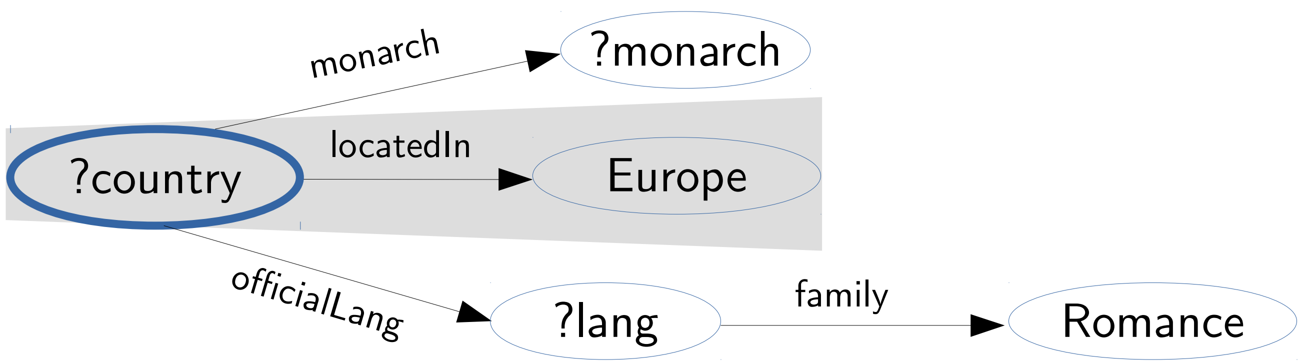

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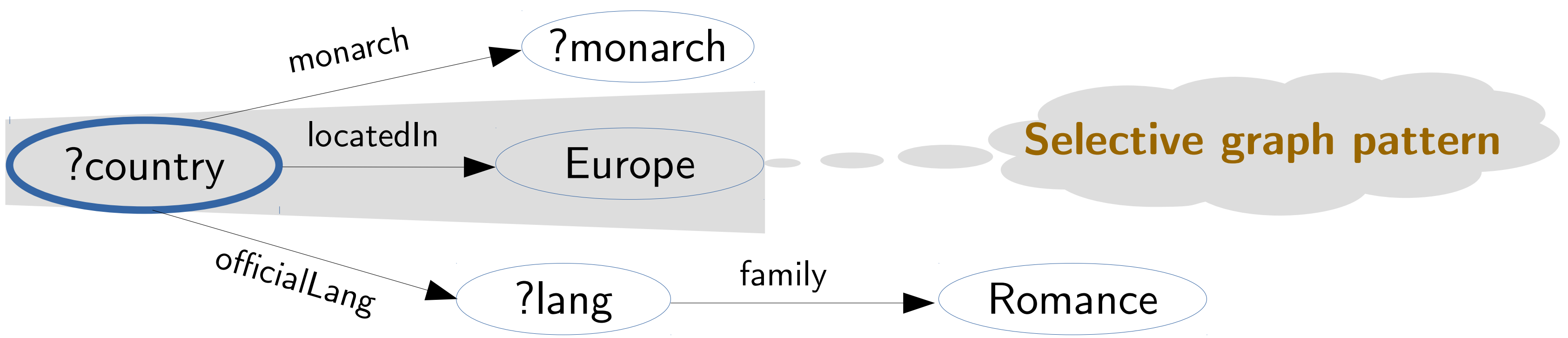

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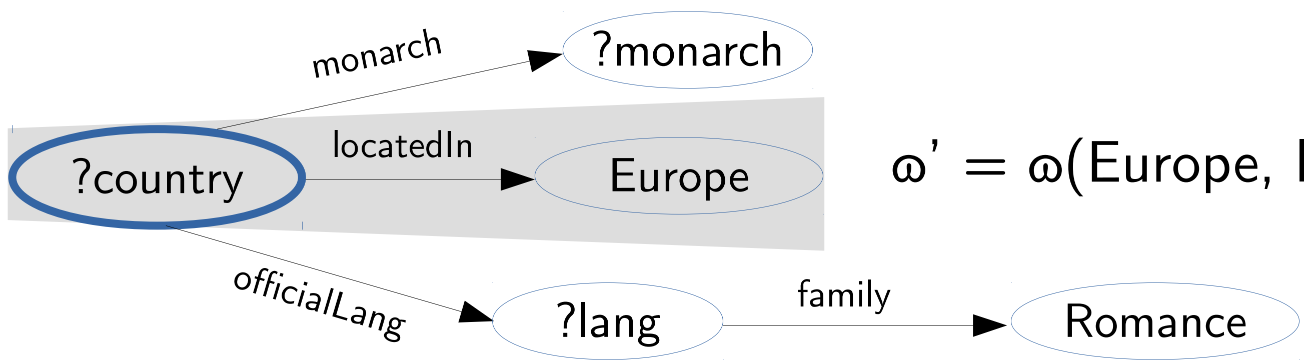

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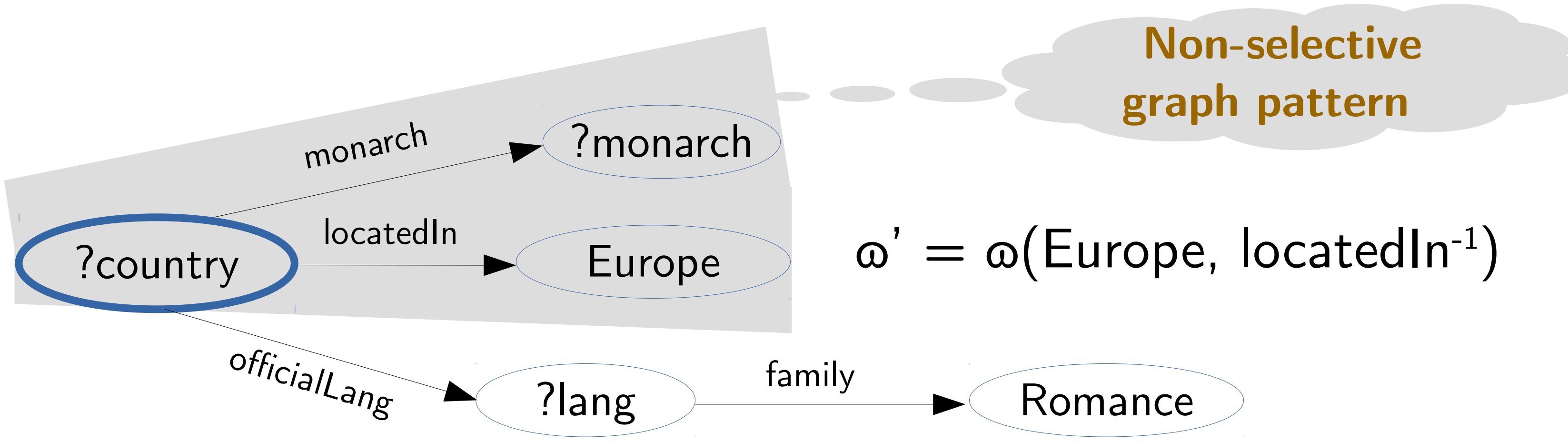

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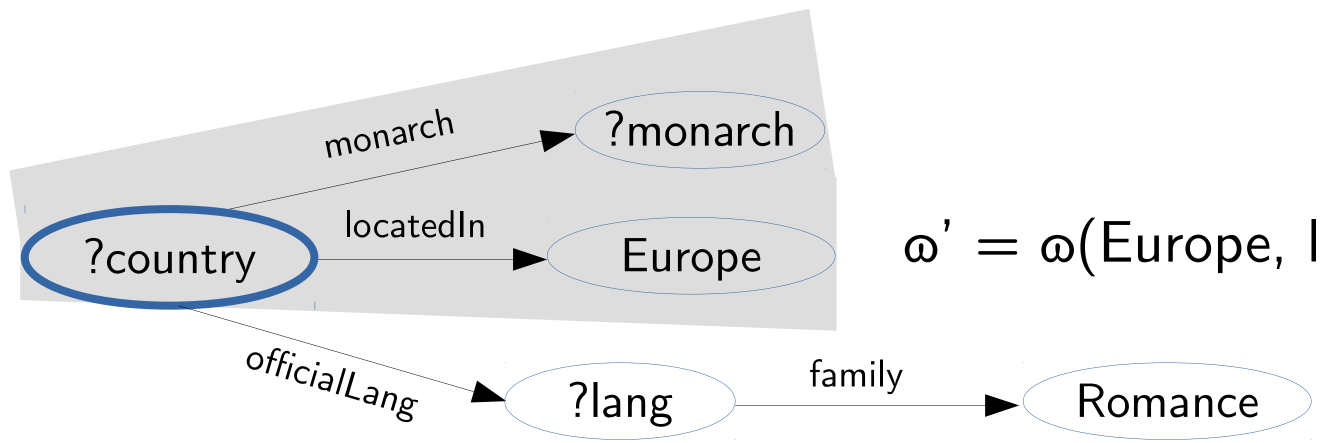

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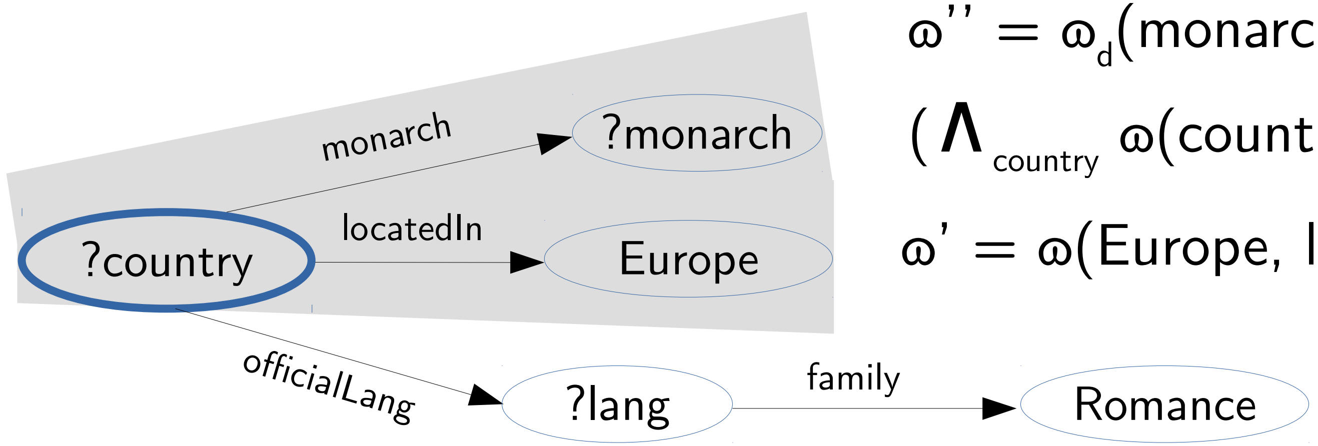

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$(\bigwedge_{\text{country}} \omega(\text{country, monarch}))$

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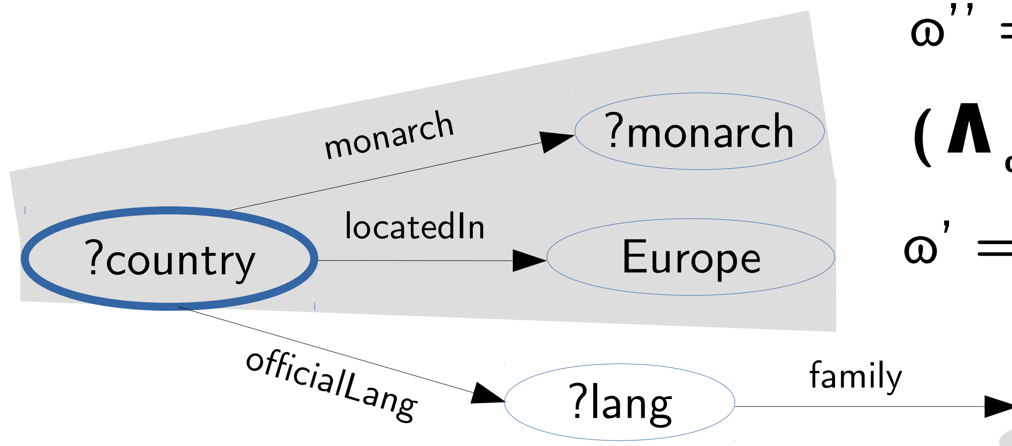

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not needed in case of Set semantics

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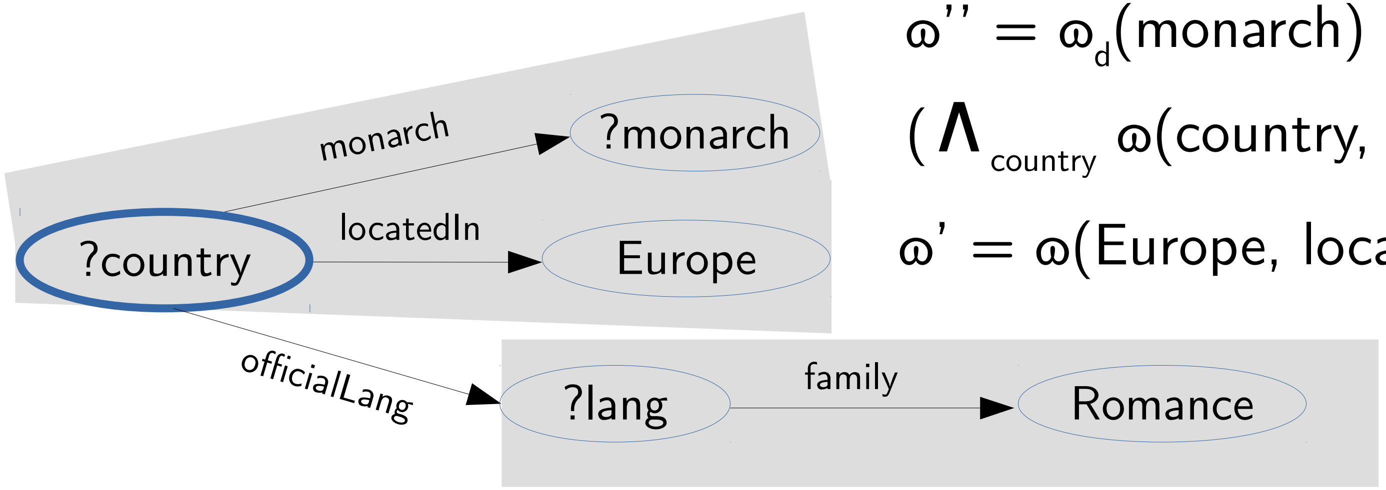

$\omega'' = \omega_d(\text{monarch}) \wedge$

$(\bigwedge_{\text{country}} \omega(\text{country, monarch}))$

$\omega' = \omega(\text{Europe, locatedIn}^{-1})$

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SELECT ?country WHERE {
    ?country monarch ?monarch .
    ?country locatedIn Europe .
    ?country officialLang ?lang .
    ?lang family Romance .
}
```

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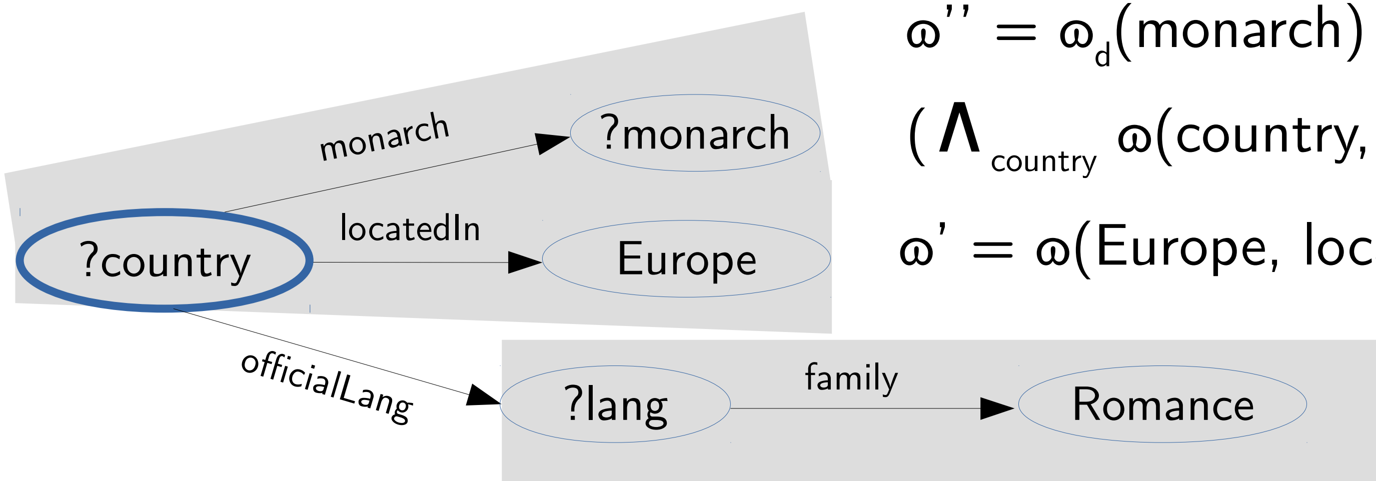

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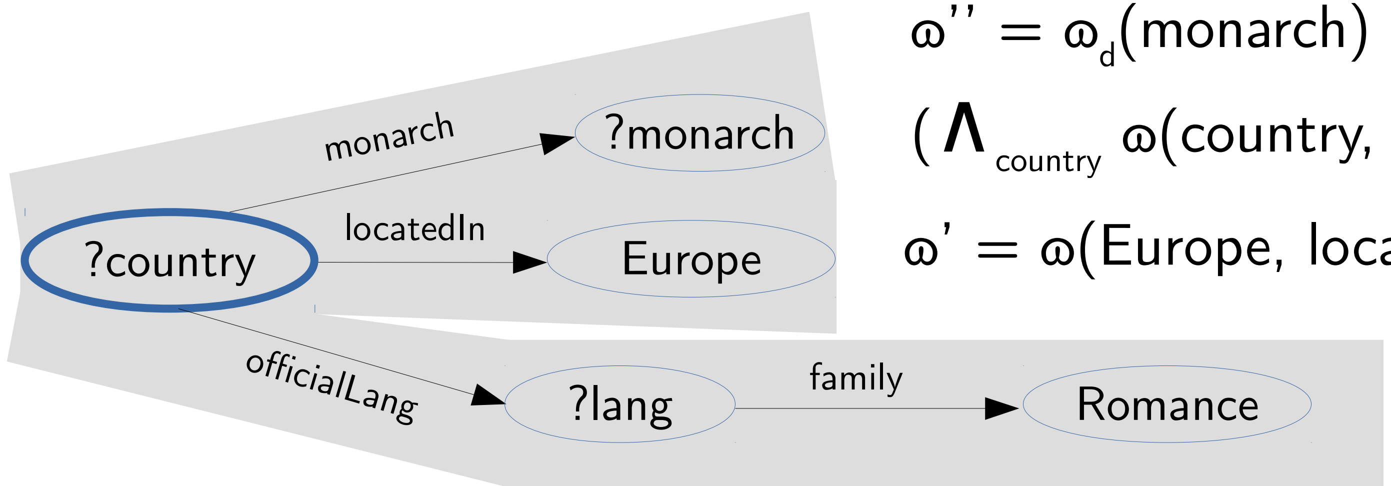

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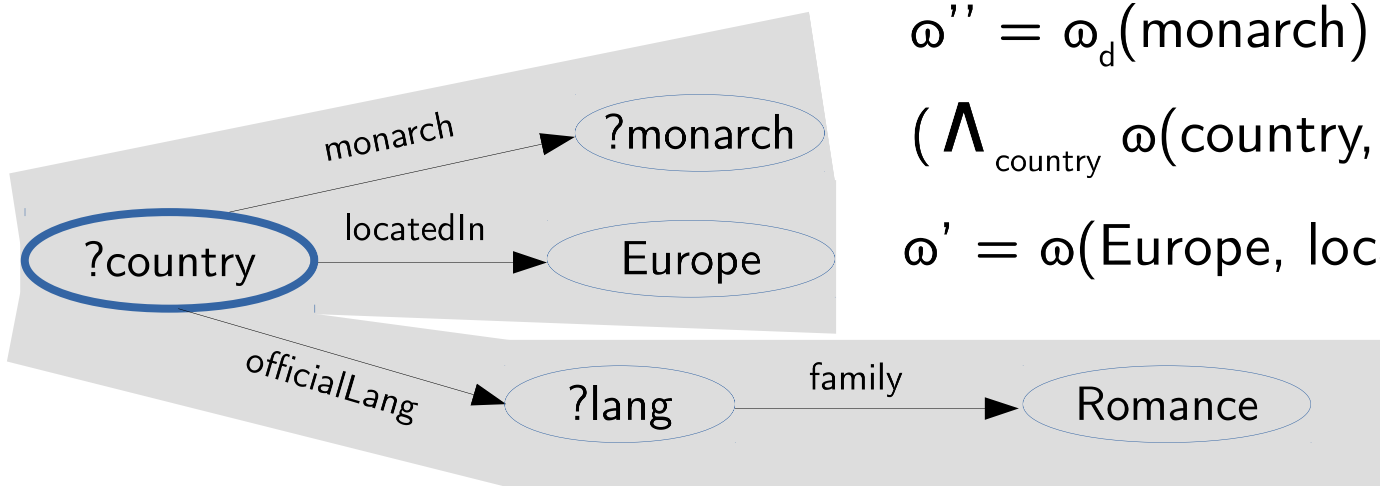

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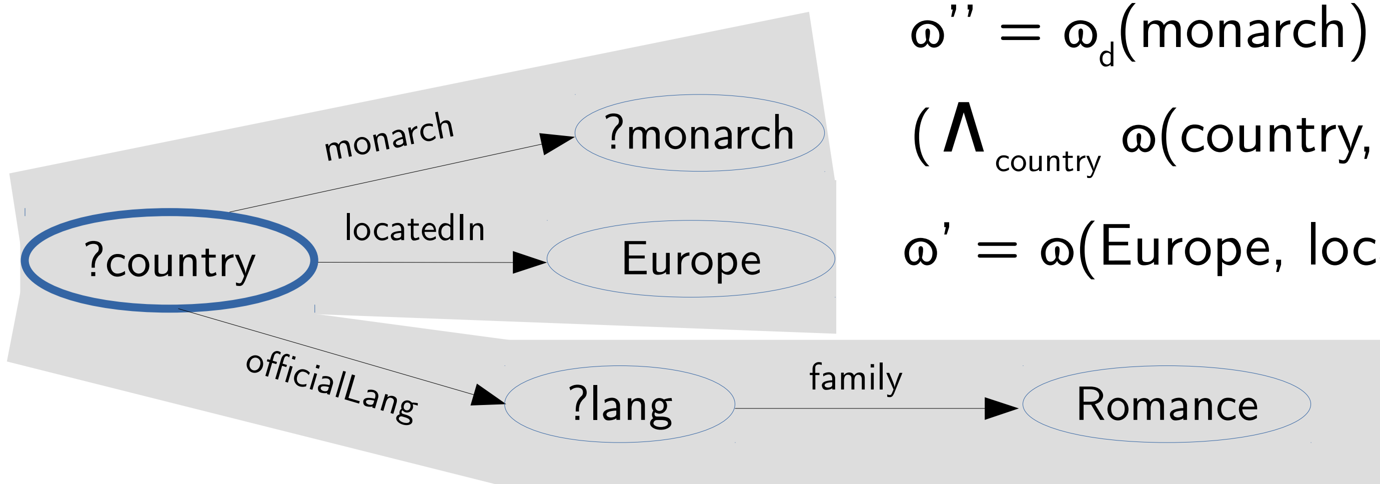

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Completeness veredict $= \varpi^{**} \wedge \varpi^{*} \wedge \varpi' \wedge \varpi''$

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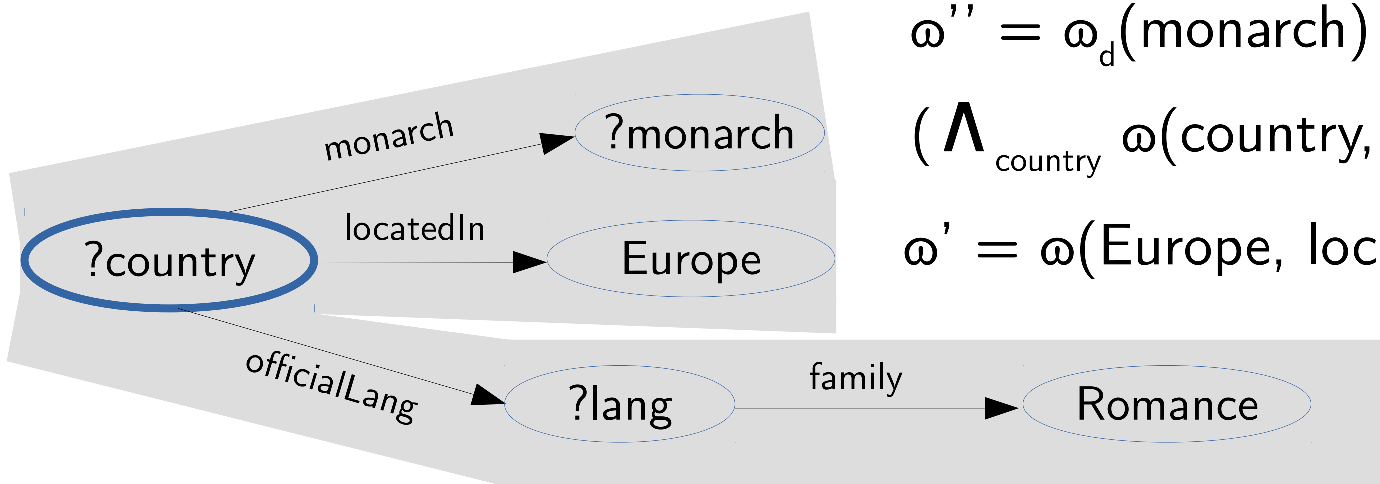

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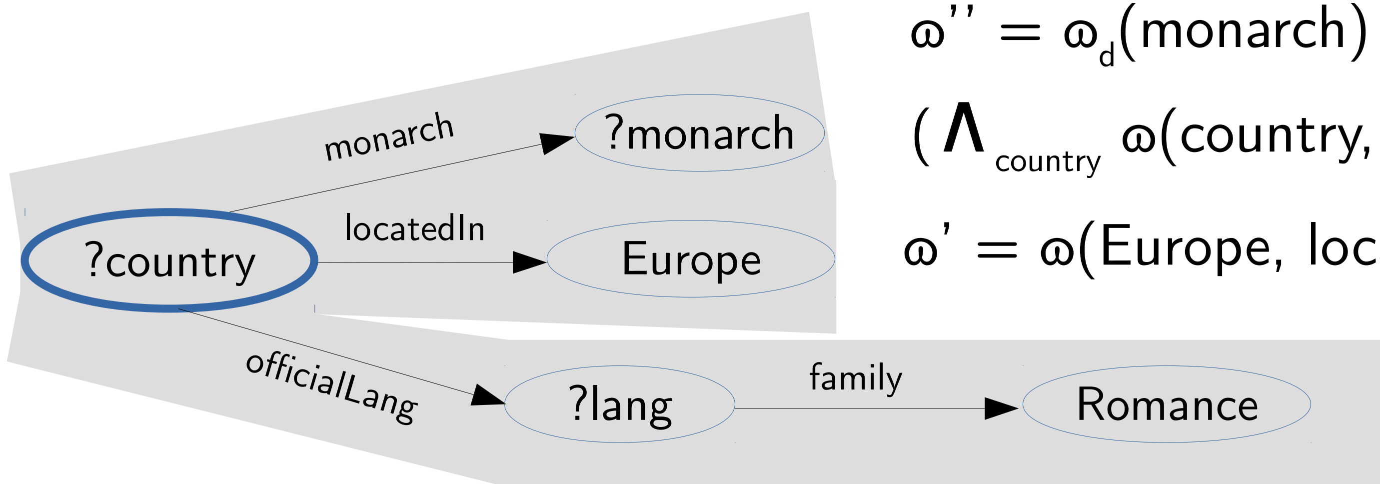
Automatic oracle composition



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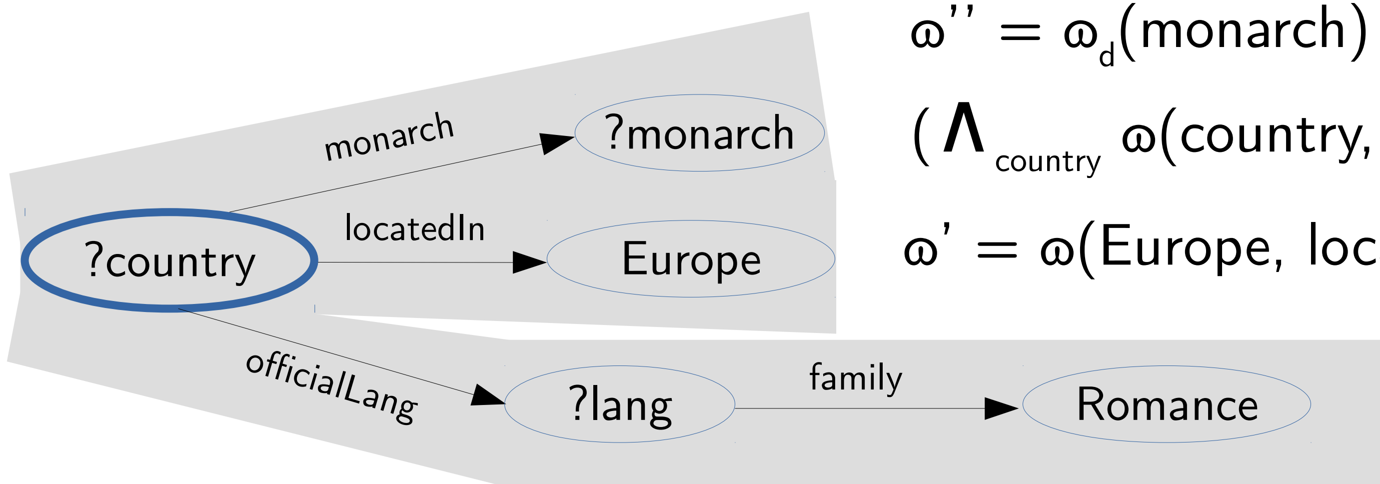
It could easily lead to false negatives

Completeness veredict = $\varpi^{**} \wedge \varpi^{*} \wedge \varpi' \wedge \varpi''$

Confidence = prec(ϖ^{**}) × prec(ϖ^{*}) × prec(ϖ') × prec(ϖ'')

Automatic oracle composition



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We would like to minimize the number of used oracles

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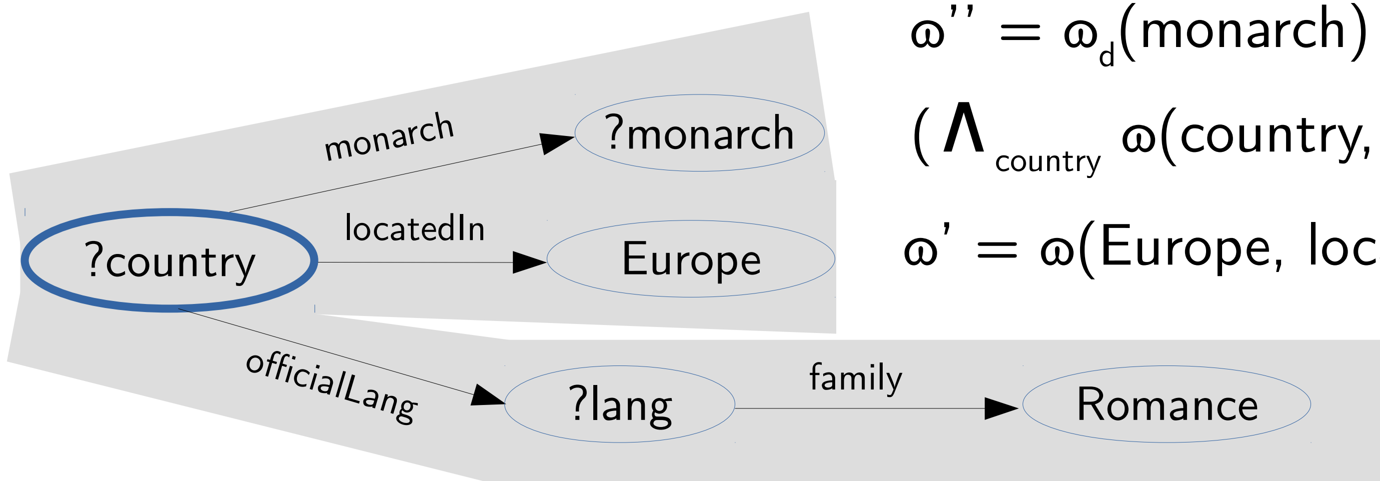

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Use more complex oracles that cover larger parts of the query graph at once

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Completeness veredict $= \varpi^{**} \wedge \varpi^{*} \wedge \varpi' \wedge \varpi''$

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Outline

- Completeness in RDF knowledge bases
- Completeness oracles
- Our vision
  - Representations for completeness oracles
  - Reasoning with completeness oracles
  - Enabling completeness in SPARQL
- Summary & conclusions

Enabling completeness in SPARQL

- Calls to completeness oracles could be embedded in the query language

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```
SELECT ?state sum(?nspeak) WHERE {
    ?county inState ?state .
    ?county spanishSpeakers ?nspeak .
} GROUP BY ?state HAVING (complete(?nspeak))
```

Enabling completeness in SPARQL

- Calls to completeness oracles could be embedded in the query language
  - Example: aggregated number of Spanish speakers in a county per state, only for *those states with complete information*

Boolean aggregation function on sets of bindings

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SELECT ?state sum(?nspeak) WHERE {
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} GROUP BY ?state HAVING (complete(?nspeak))
```
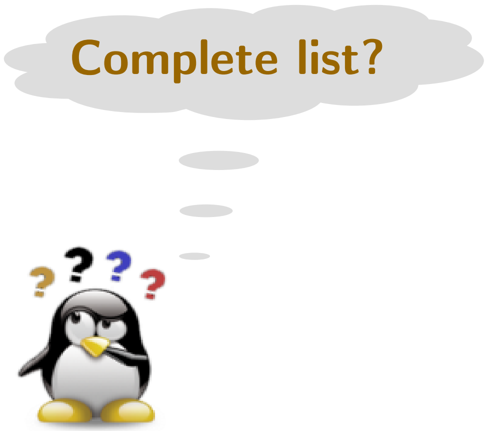

Enabling completeness in SPARQL

- For each value of *?state* check if the bindings for *?nspeak* are complete

?state	?county	?nspeak
Delaware	New Castle Kent Sussex	2000 4300 1200
Hawaii	Hawaii Kalawao	30000 1200



SELECT ?state sum(?nspeak) WHERE {
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Enabling completeness in SPARQL

- For each value of *?state* check if the bindings for *?nspeak* are complete

?state	?county	?nspeak
Delaware	New Castle	2000
	Kent	4300
	Sussex	1200
Hawaii	Hawaii	30000
	Kalawao	1200

SELECT **complete**(?nspeak) WHERE {
  ?county inState Delaware .
  ?county spanishSpeakers ?nspeak .
}

SELECT ?state sum(?nspeak) WHERE {
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Enabling completeness in SPARQL

- For each value of *?state* check if … for *?nspeak* are complete

Completeness oracles to the rescue!

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Summary

- Completeness is a dimension of data quality
  - It determines the value and reliability of the data
  - Existing work provides only completeness statements and oracles for simple queries
- Semantic Web is not completeness-aware
  - **Vision**
    - Use completeness oracles for simpler queries to infer completeness for arbitrary queries
    - Embed completeness in the SPARQL query language
  - **Goal:** Increase the value of the results delivered by queries

Future work

- Augment existing RDF data with completeness statements and oracles
- Implement reasoning with completeness oracles in SPARQL query engines
  - Extend the SPARQL query language to support the *complete* aggregation function