Semantic Understanding Of Tables (Symbolic)

Pedro Szekely

USC Information Sciences Institute

Outline

Introduction to semantic modeling

Semantic modeling languages

Interactive system for semantic modeling (Karma)

Automated system for semantic modeling

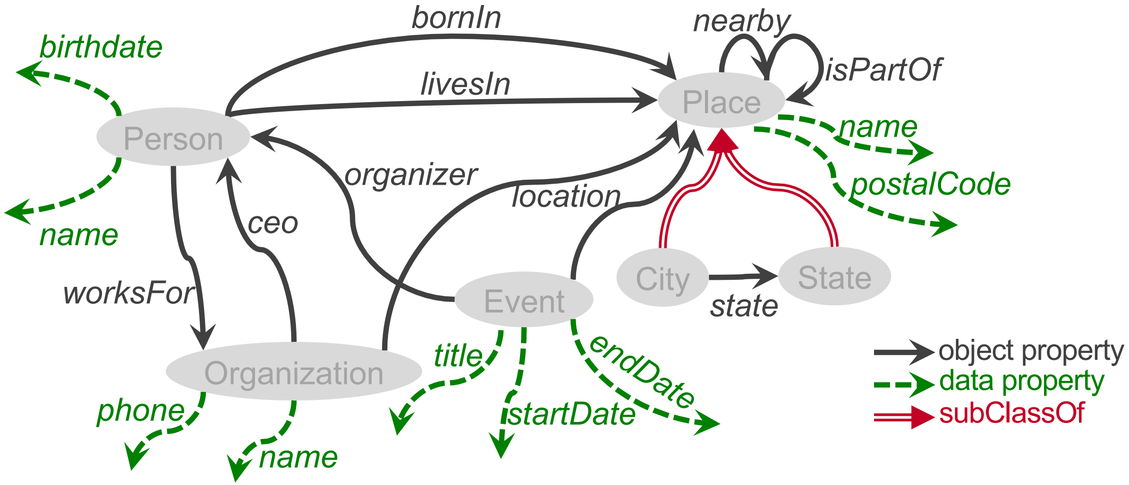
Entity linking for tables and related tasks

Semantic Modeling

Problem definition

Inputs: Table and Ontologies

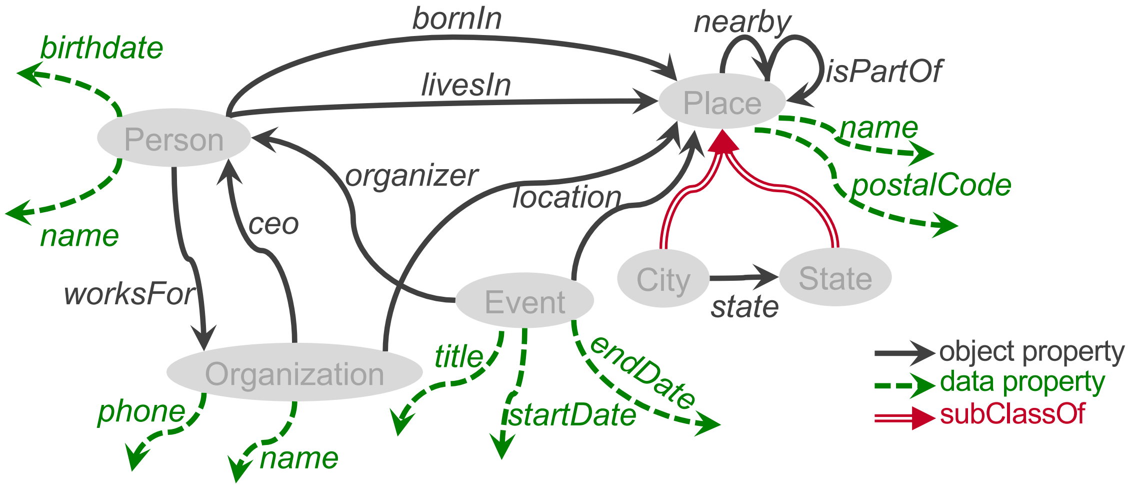
Domain Ontology



Table

Column 1	Column 2	Column 3	Column 4	Column 5
Bill Gates	Oct 1955	Microsoft	Seattle	WA
Mark Zuckerberg	May 1984	Facebook	White Plains	NY
Larry Page	Mar 1973	Google	East Lansing	MI

Domain Ontology



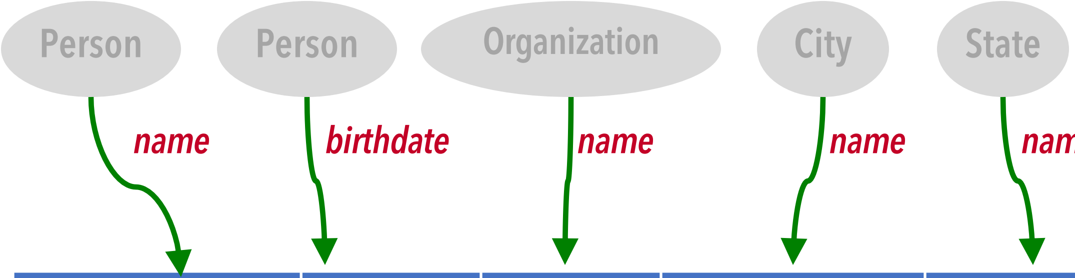
Semantic Model: maps table to domain ontology

Table

Column 1	Column 2	Column 3	Column 4	Column 5
Bill Gates	Oct 1955	Microsoft	Seattle	WA
Mark Zuckerberg	May 1984	Facebook	White Plains	NY
Larry Page	Mar 1973	Google	East Lansing	MI

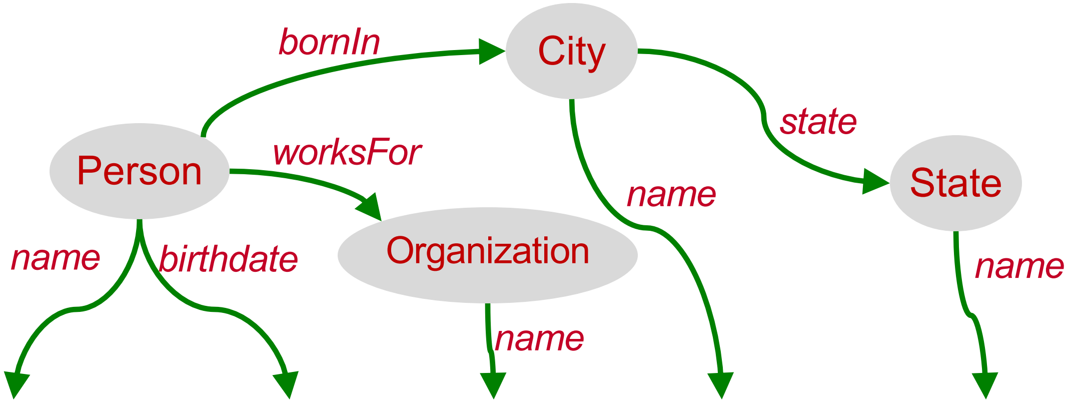
Semantic Model = Semantic Types + Relationships

Semantic Types



Column 1	Column 2	Column 3	Column 4	Column 5
Bill Gates	Oct 1955	Microsoft	Seattle	WA
Mark Zuckerberg	May 1984	Facebook	White Plains	NY
Larry Page	Mar 1973	Google	East Lansing	MI

Relationships



Column 1	Column 2	Column 3	Column 4	Column 5
Bill Gates	Oct 1955	Microsoft	Seattle	WA
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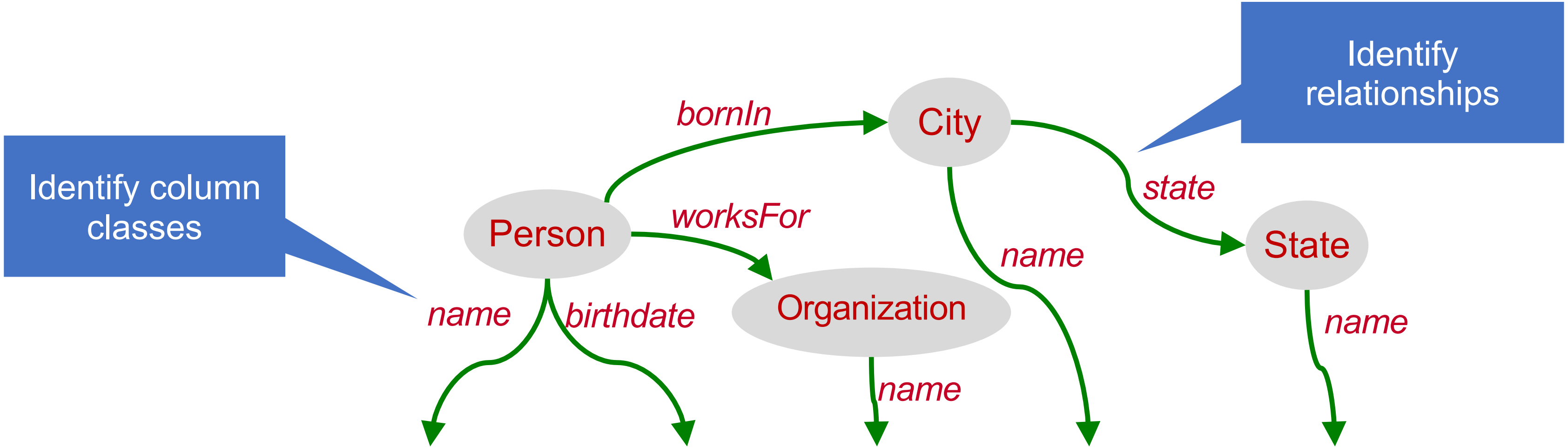
Subtasks of semantic modeling



Column 1	Column 2	Column 3	Column 4	Column 5
Bill Gates	Oct 1955	Microsoft	Seattle	WA
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Larry Page	Mar 1973	Google	East Lansing	MI

Entity link cell values

Semantic Modeling Languages

Relational to RDF Mapping Language: https://www.w3.org/TR/r2rml/

RDF Mapping Language: https://rml.io/specs/rml/

Languages to specify semantic models

R2RML

a language for expressing customized mappings from relational databases to RDF datasets (2012)

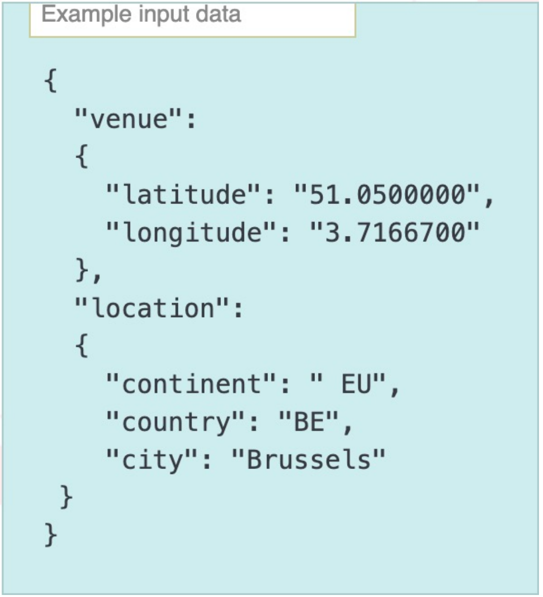
https://www.w3.org/TR/r2rml/

RML

a generic mapping language, based on and extending R2RML … adding support for data in other structured formats (2020)

https://rml.io/specs/rml/

RML Example



Example input data

```
{
  "venue":
  {
    "latitude": "51.0500000",
    "longitude": "3.7166700"
  },
  "location":
  {
    "continent": " EU",
    "country": "BE",
    "city": "Brussels"
 }
}
```

RML specification written in RDF (turtle)

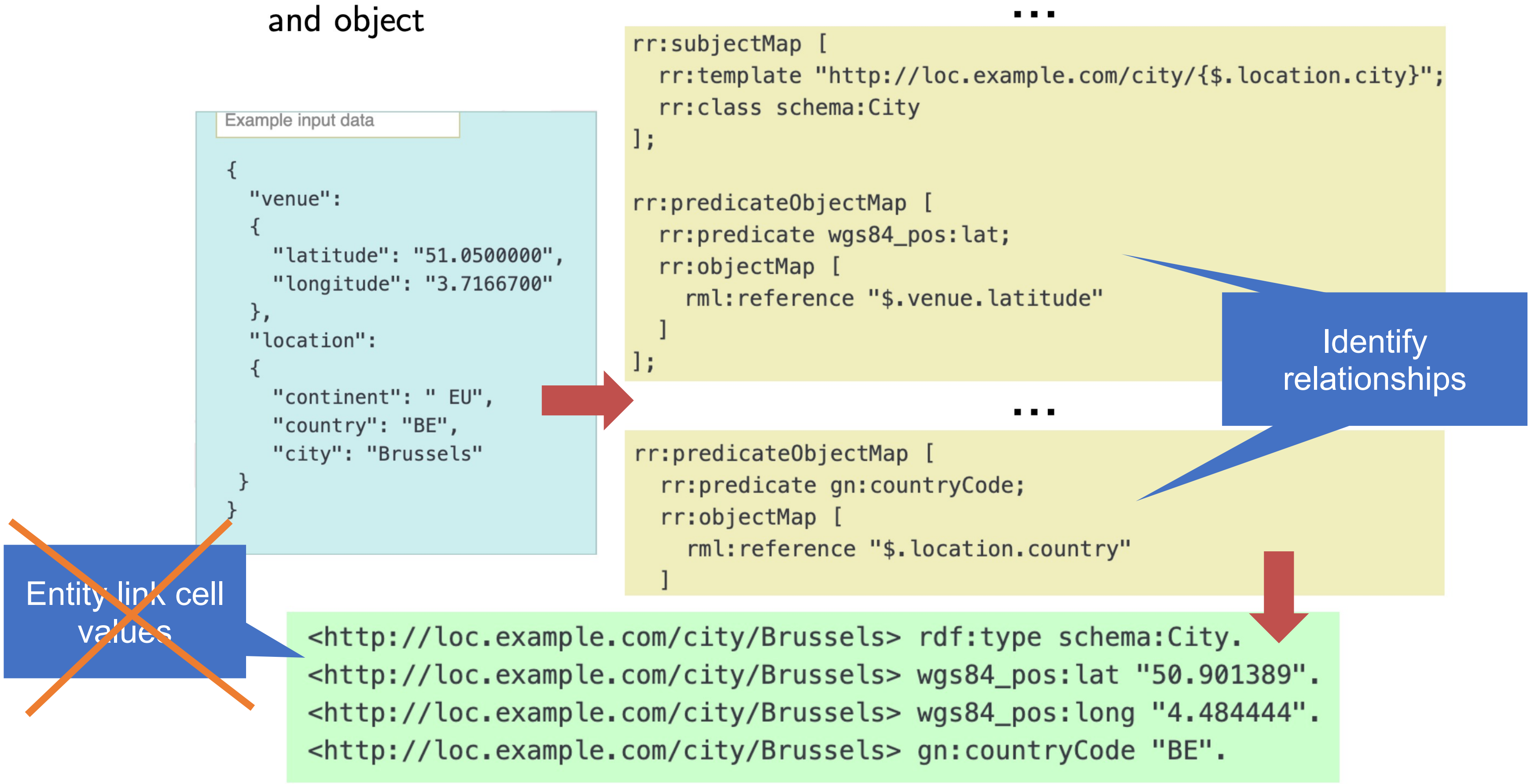
```
<#VenueMapping>
  rml:logicalSource [
    rml:source "http://www.example.com/files/Venue.json";
    rml:referenceFormulation ql:JSONPath;
    rml:iterator "$"
  ];

  rr:subjectMap [
    rr:template "http://loc.example.com/city/{$.location.city}";
    rr:class schema:City
  ];
```

Identify column classes

```
<http://loc.example.com/city/Brussels> rdf:type schema:City.
<http://loc.example.com/city/Brussels> wgs84_pos:lat "50.901389".
<http://loc.example.com/city/Brussels> wgs84_pos:long "4.484444".
<http://loc.example.com/city/Brussels> gn:countryCode "BE".
```

RML relationship mapping example

- subjectMap, predicateObjectMap: rules to get values for subject, predicate and object



Example input data

```
{
  "venue":
  {
    "latitude": "51.0500000",
    "longitude": "3.7166700"
  },
  "location":
  {
    "continent": " EU",
    "country": "BE",
    "city": "Brussels"
  }
}
```

```
...
rr:subjectMap [
  rr:template "http://loc.example.com/city/{$.location.city}";
  rr:class schema:City
];

rr:predicateObjectMap [
  rr:predicate wgs84_pos:lat;
  rr:objectMap [
    rml:reference "$.venue.latitude"
  ]
];
...
```

```
rr:predicateObjectMap [
  rr:predicate gn:countryCode;
  rr:objectMap [
    rml:reference "$.location.country"
  ]
```

```
<http://loc.example.com/city/Brussels> rdf:type schema:City.
<http://loc.example.com/city/Brussels> wgs84_pos:lat "50.901389".
<http://loc.example.com/city/Brussels> wgs84_pos:long "4.484444".
<http://loc.example.com/city/Brussels> gn:countryCode "BE".
```

Karma

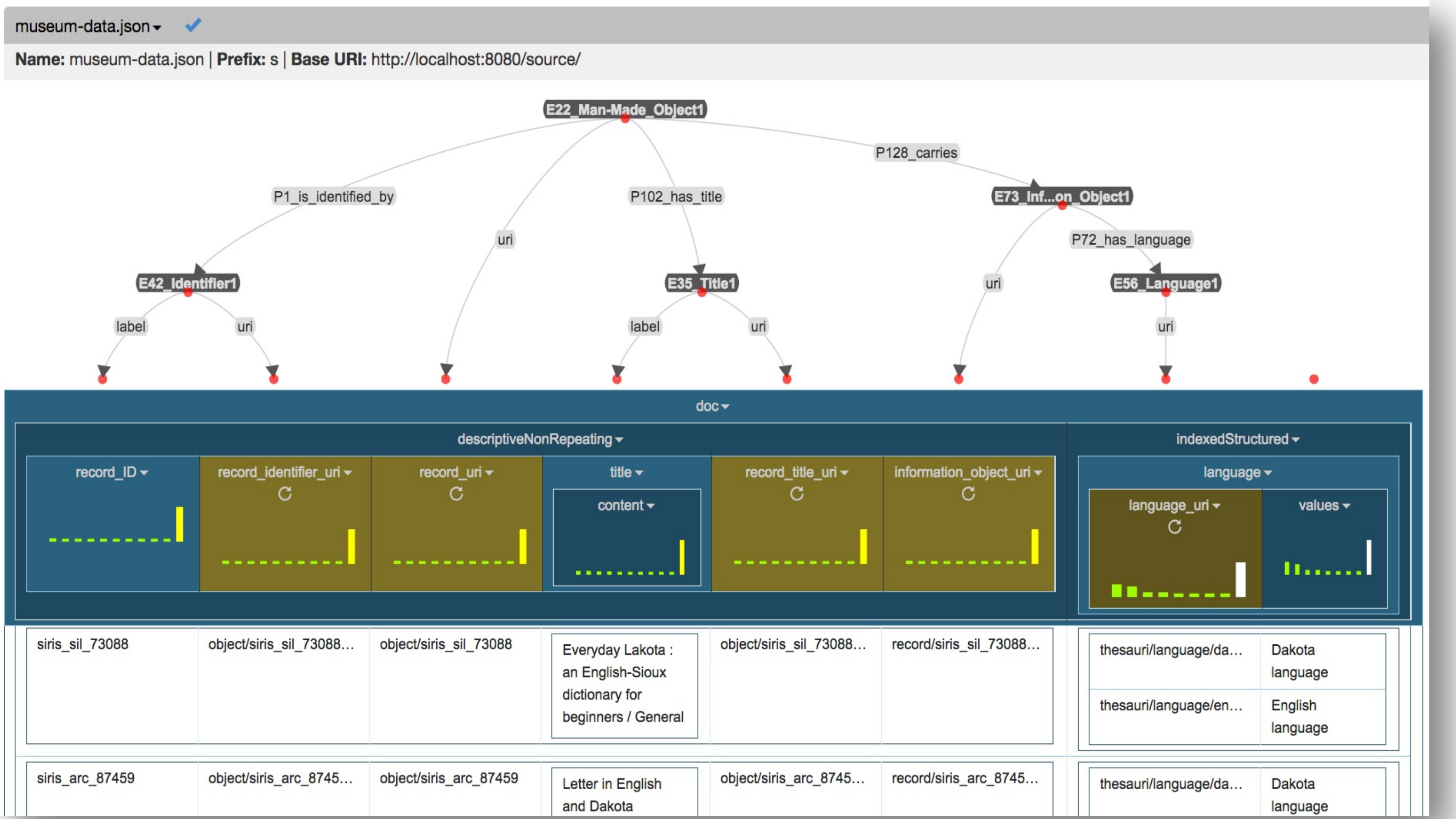
Interactive system for semantic modeling

Szekely P. et al. (2013) Connecting the Smithsonian American Art Museum to the Linked Data Cloud. In: The Semantic Web: Semantics and Big Data. ESWC 2013. Lecture Notes in Computer Science, vol 7882. Springer, Berlin, Heidelberg.

Taheriyan M., Knoblock C.A., Szekely P., Ambite J.L. (2012) Rapidly Integrating Services into the Linked Data Cloud. In: Cudré-Mauroux P. et al. (eds) The Semantic Web – ISWC 2012. ISWC 2012. Lecture Notes in Computer Science, vol 7649. Springer, Berlin, Heidelberg.

https://github.com/usc-isi-i2/Web-Karma

Interactive semantic modeling



museum-data.json ▾ ✓

Name: museum-data.json | **Prefix:** s | **Base URI:** http://localhost:8080/source/

doc ▾							
descriptiveNonRepeating ▾						indexedStructured ▾	
						language ▾	
record_ID ▾	record_identifier_uri ▾	record_uri ▾	title ▾	record_title_uri ▾	information_object_uri ▾	language_uri ▾	values ▾
			content ▾				
siris_sil_73088	object/siris_sil_73088…	object/siris_sil_73088	Everyday Lakota : an English-Sioux dictionary for beginners / General	object/siris_sil_73088…	record/siris_sil_73088…	thesauri/language/da… thesauri/language/en…	Dakota language English language
siris_arc_87459	object/siris_arc_8745…	object/siris_arc_87459	Letter in English and Dakota	object/siris_arc_8745…	record/siris_arc_8745…	thesauri/language/da…	Dakota language

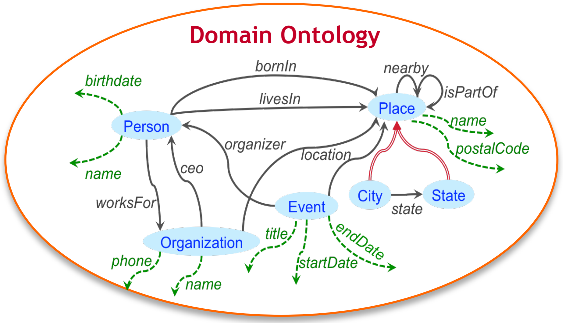
Learning Semantic Types

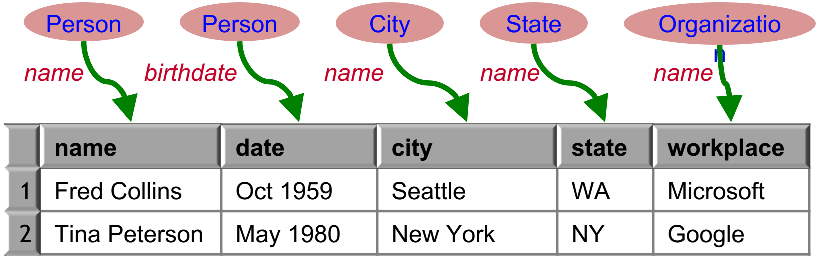
Requirements:

Learn from a small number of examples

Distinguish string and numeric values

Scale to many semantic types





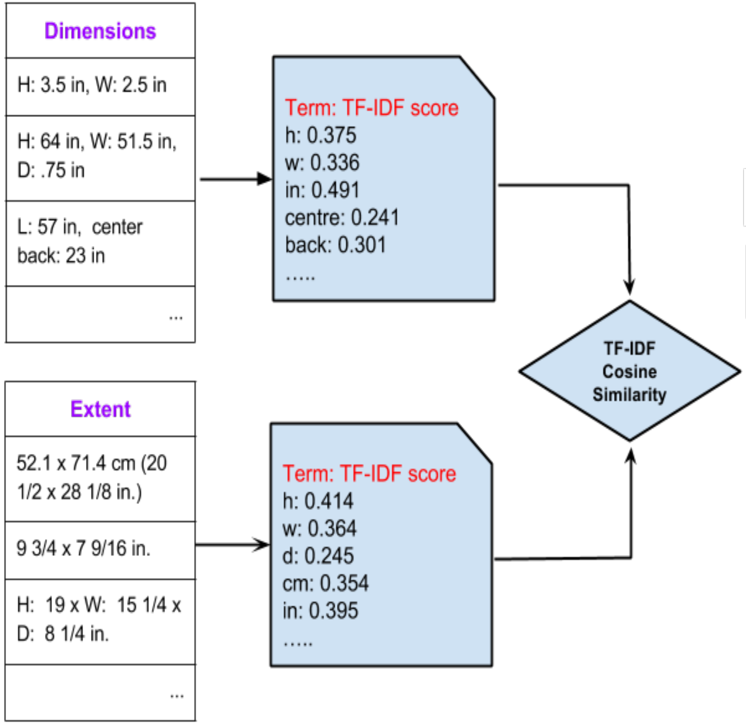
	name	date	city	state	workplace
1	Fred Collins	Oct 1959	Seattle	WA	Microsoft
2	Tina Peterson	May 1980	New York	NY	Google

Learning Semantic Types For Text

Textual Data

Treat each column of data as a document

Apply TF-IDF Cosine Similarity



Dimensions
H: 3.5 in, W: 2.5 in
H: 64 in, W: 51.5 in, D: .75 in
L: 57 in, center back: 23 in
...

Term: TF-IDF score
h: 0.375
w: 0.336
in: 0.491
centre: 0.241
back: 0.301
.....

Extent
52.1 x 71.4 cm (20 1/2 x 28 1/8 in.)
9 3/4 x 7 9/16 in.
H: 19 x W: 15 1/4 x D: 8 1/4 in.
...

Term: TF-IDF score
h: 0.414
w: 0.364
d: 0.245
cm: 0.354
in: 0.395
.....

$$tf(t,d) = frequency^{1/2}$$

$$idf(t) = 1 + log(\frac{numDocs}{docFreq + 1})$$

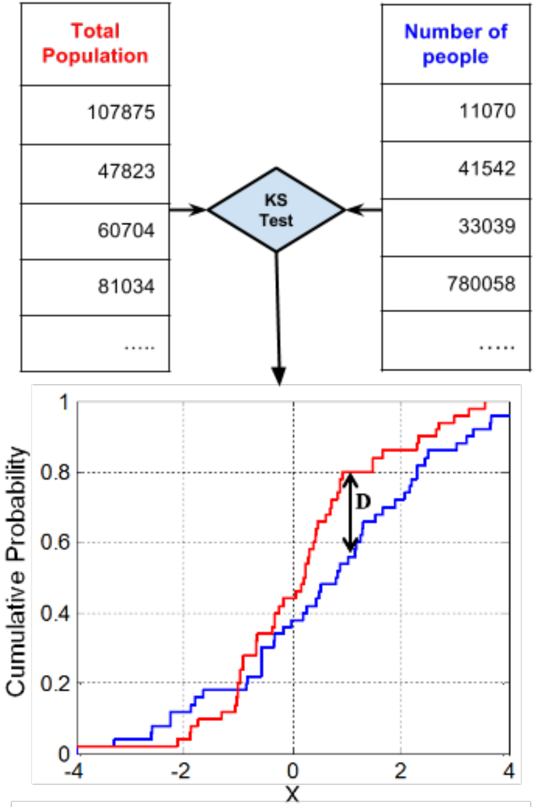
$$sim(q,d) = \frac{V(q).V(d)}{|V(q)|.|V(d)|}$$

Learning Numeric Semantic Types

Numeric Data

Apply statistical hypothesis testing to determine which distribution fits best

Apply Kolmogorov-Smirnov Test

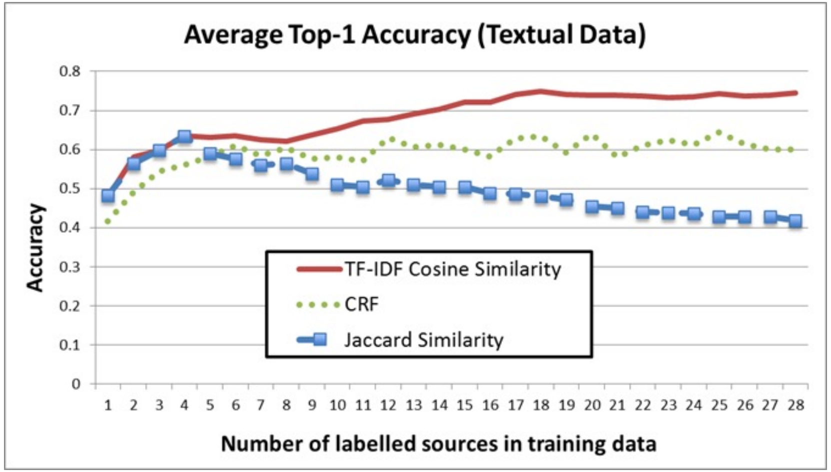


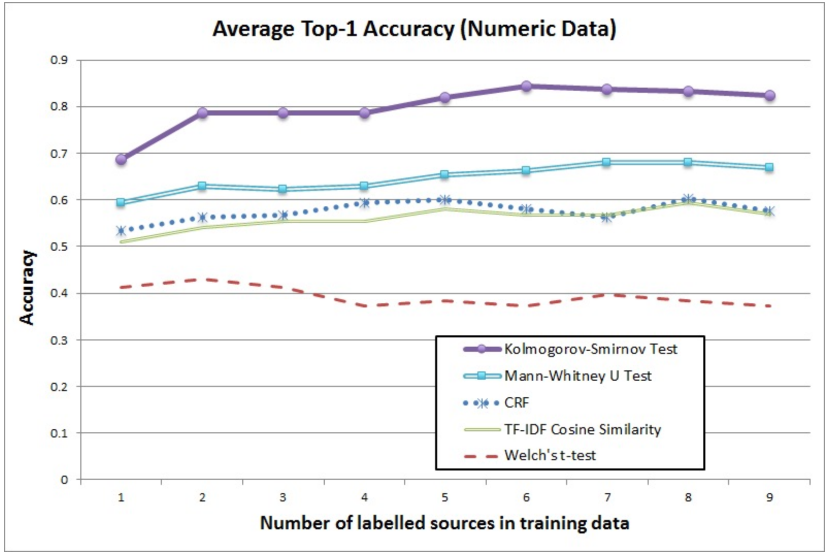
Total Population
107875
47823
60704
81034
.....

Number of people
11070
41542
33039
780058
.....

$$D_{N_1,N_2} = \sup_x |F_{1,N_1}(x) - F_{2,N_2}(x)|$$

Evaluation





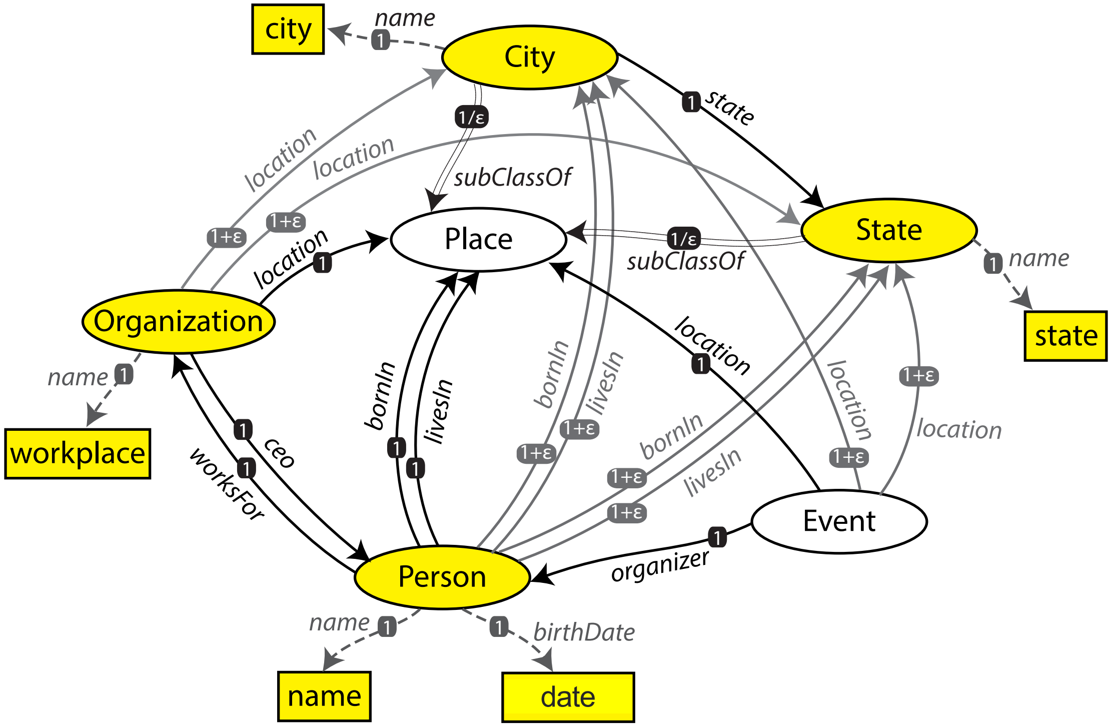
Combined approach achieves 97% accuracy on the top-4 accuracy

Suggestions shown in KARMA GUI

Determining relationships

after semantic types are defined

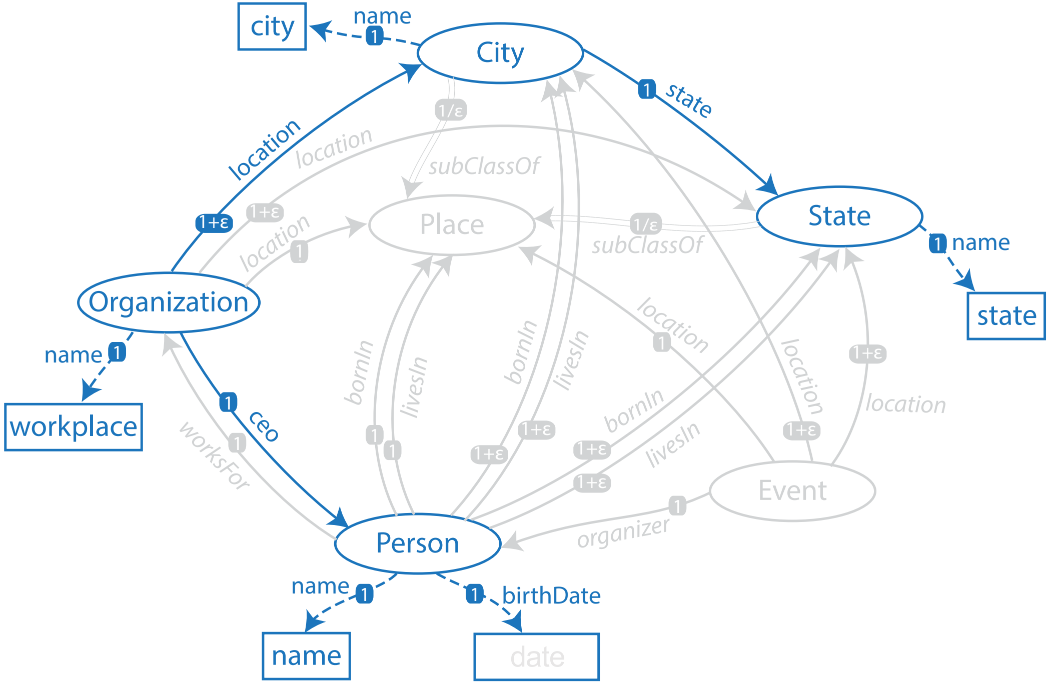
Construct a graph from semantic types and ontology



Determining relationships

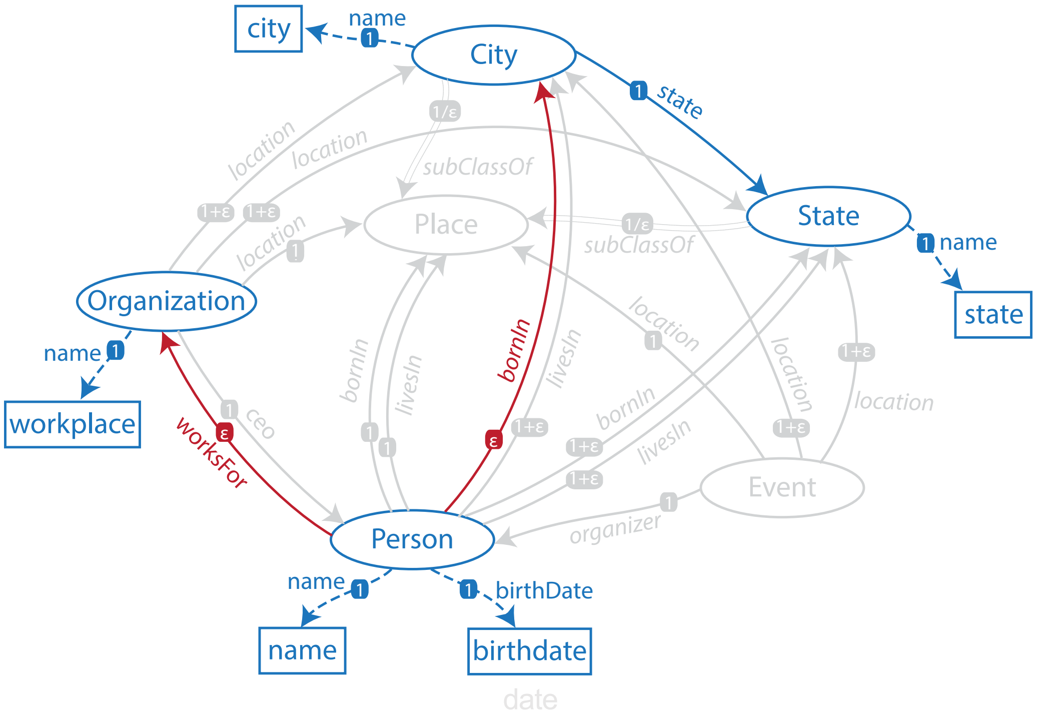
Select minimal tree that connects all semantic types

A customized **Steiner tree algorithm** [Kou & Markowsky, 1981]



Refining the semantic model

Use the GUI to impose constraints on Steiner Tree Algorithm



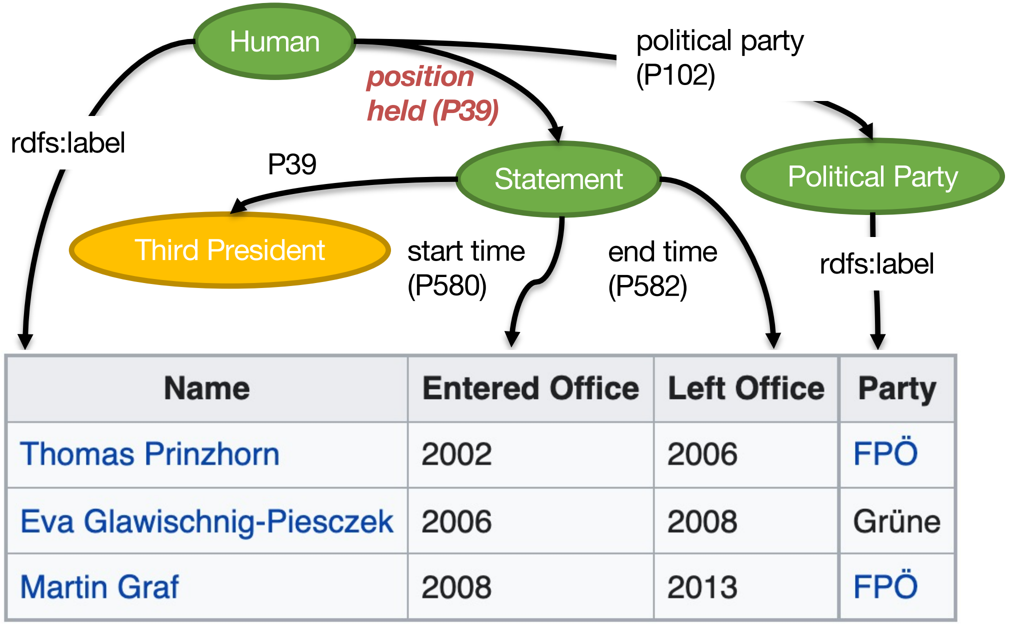
GRAMS

Inferring Semantic Descriptions of Wikipedia Tables

Binh Vu, Craig A. Knoblock, Pedro Szekely, Minh Pham, & Jay Pujara (2021). A Graph-based Approach for Inferring Semantic Descriptions of Wikipedia Tables. In ISWC 2021 - 20th International Semantic Web Conference.

Challenges in Modeling Web Tables

- semantic model includes information not in the table
  - *Third President* is in the table context
- n-ary relationships
  - *position held P39*



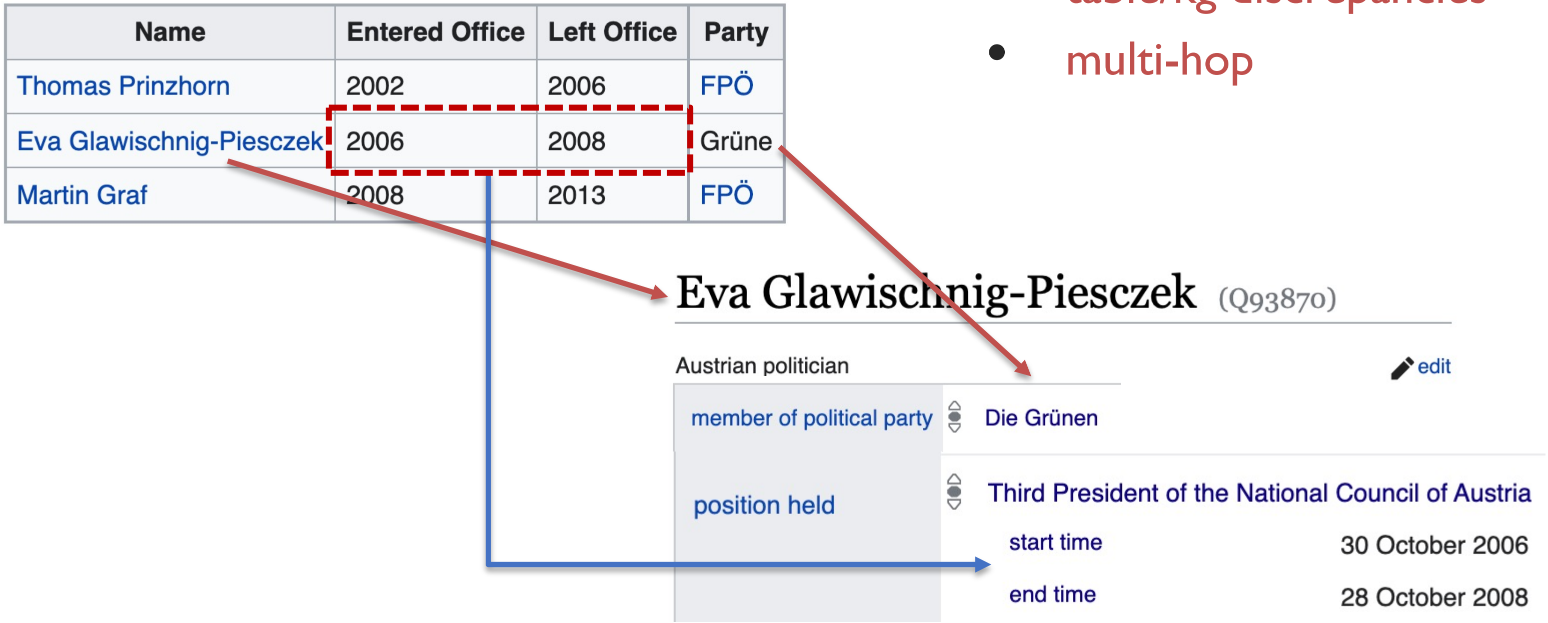
Name	Entered Office	Left Office	Party
Thomas Prinzhorn	2002	2006	FPÖ
Eva Glawischnig-Piesczek	2006	2008	Grüne
Martin Graf	2008	2013	FPÖ

Third Presidents of National Council (Austria)

Main idea: entity linking

Challenges

- incomplete KG
- table/kg discrepancies
- multi-hop



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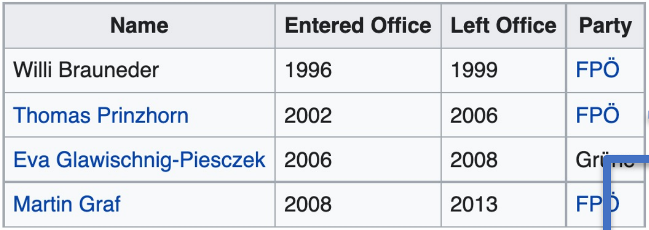
Eva Glawischnig-Piesczek (Q93870)

Austrian politician

member of political party	Die Grünen
position held	Third President of the National Council of Austria start time 30 October 2006 end time 28 October 2008

Approach

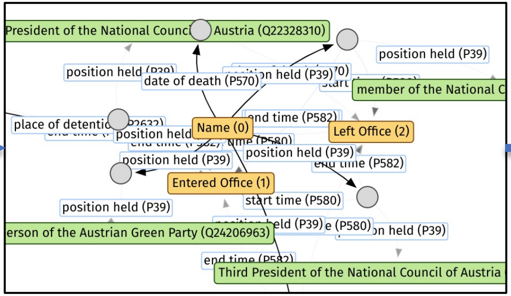
WIKIDATA



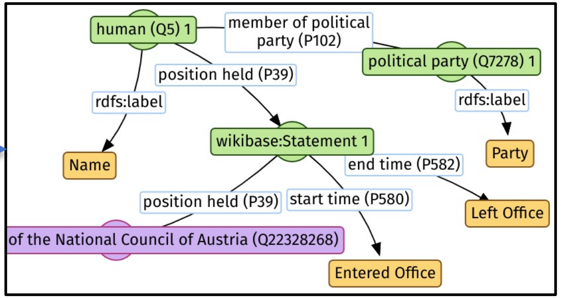
Name	Entered Office	Left Office	Party
Willi Brauneder	1996	1999	FPÖ
Thomas Prinzhorn	2002	2006	FPÖ
Eva Glawischnig-Piesczek	2006	2008	Grüne
Martin Graf	2008	2013	FPÖ

Linked table

Contextual values

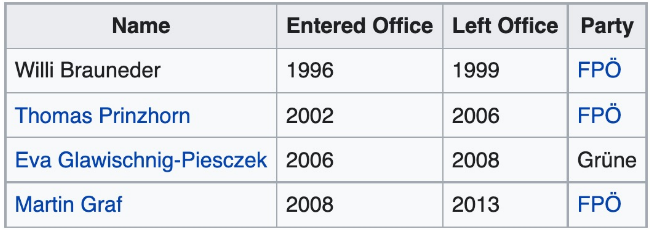


Candidate Graph



Semantic Description

Create a graph of cells and context



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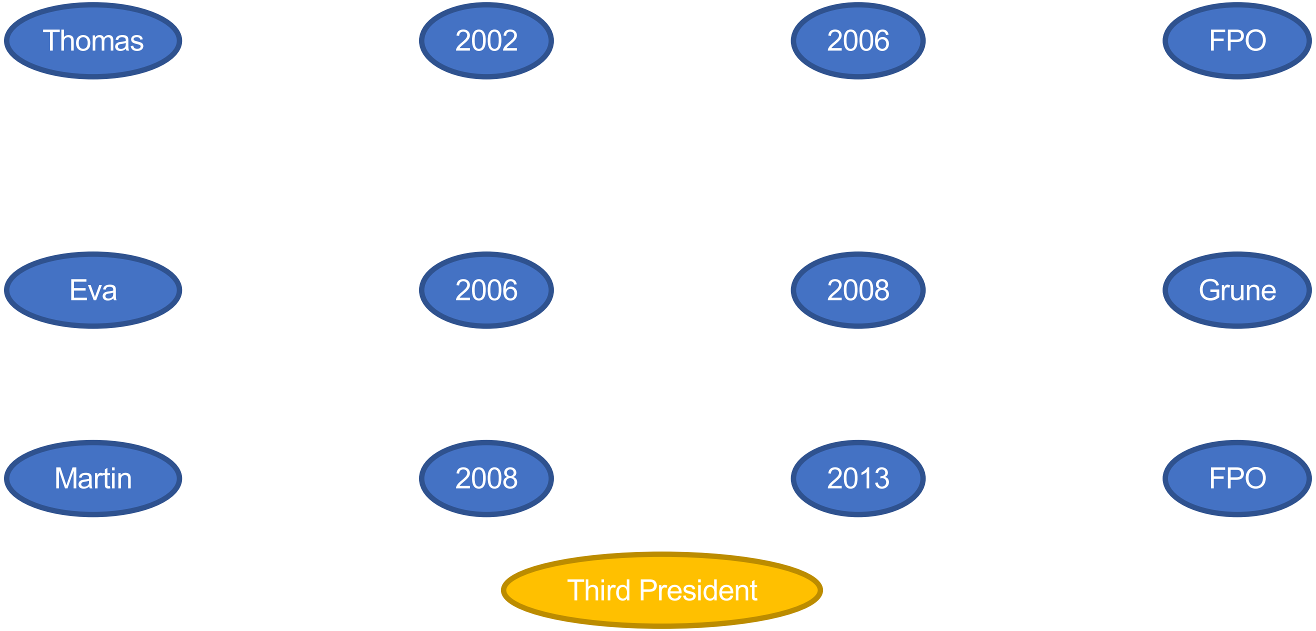


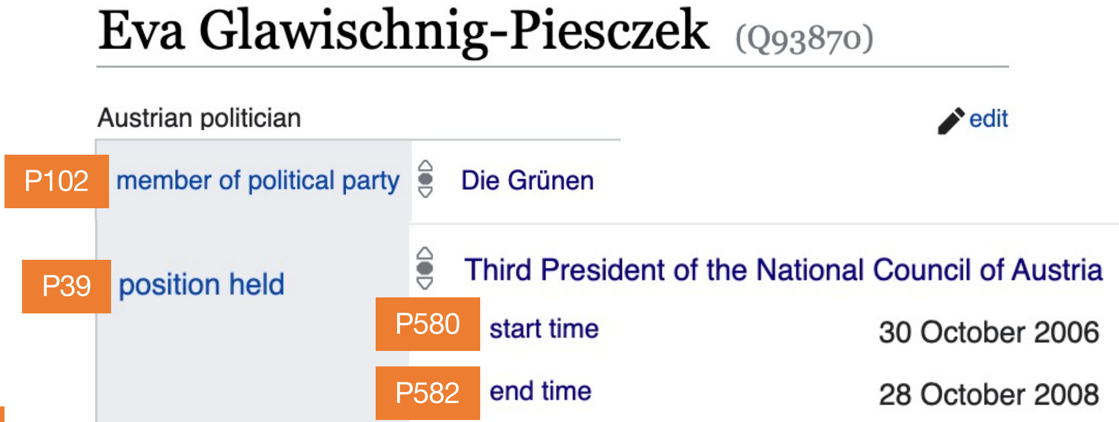
Thomas 2002 2006 FPO

Eva 2006 2008 Grune

Martin 2008 2013 FPO

Third President

Construct Candidate Graph: Discover Links

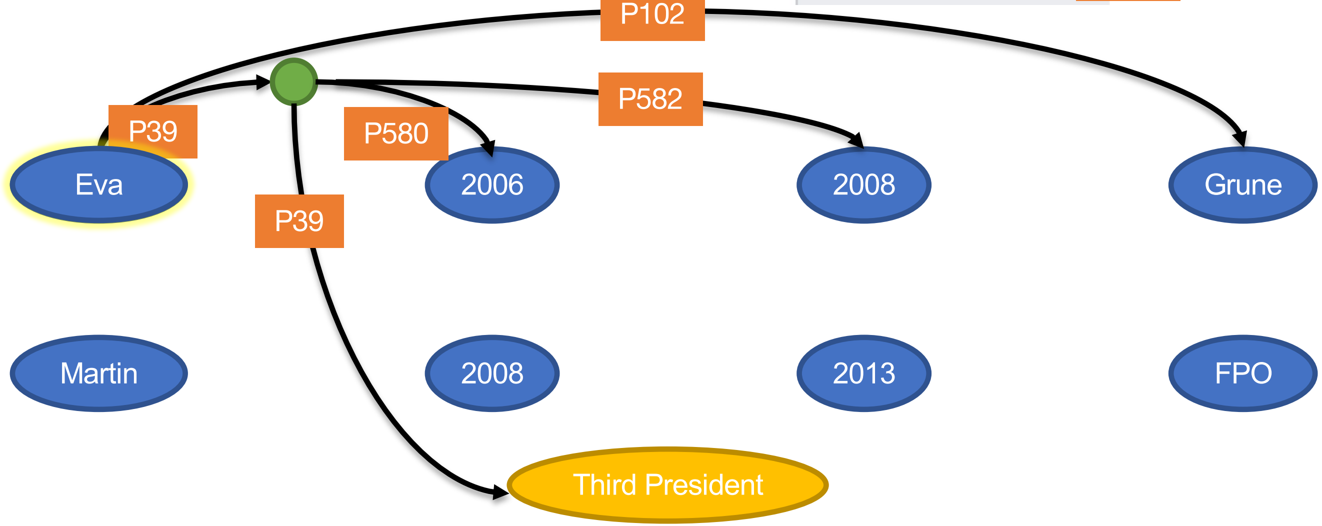


Eva Glawischnig-Piesczek (Q93870)

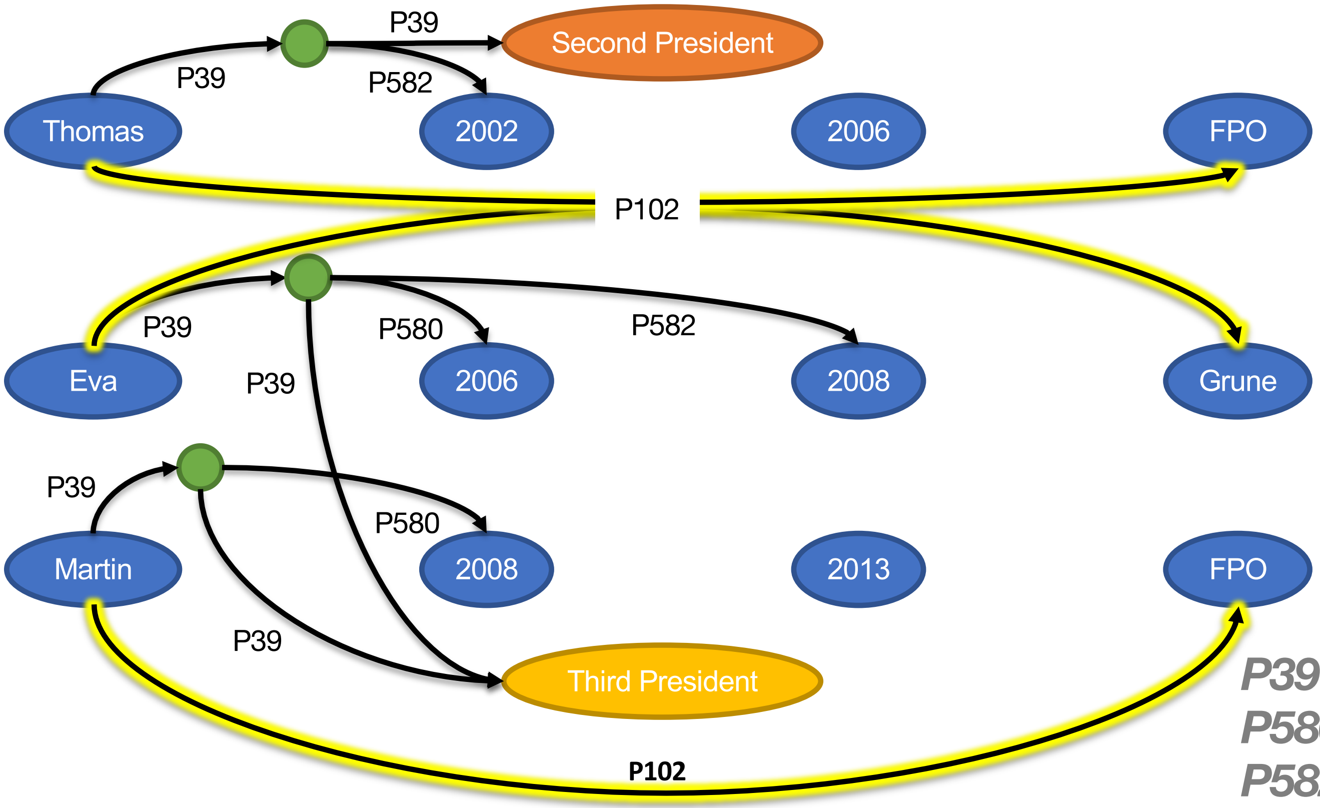
Austrian politician

edit

P102 member of political party	Die Grünen	
P39 position held	Third President of the National Council of Austria	
	P580 start time	30 October 2006
	P582 end time	28 October 2008

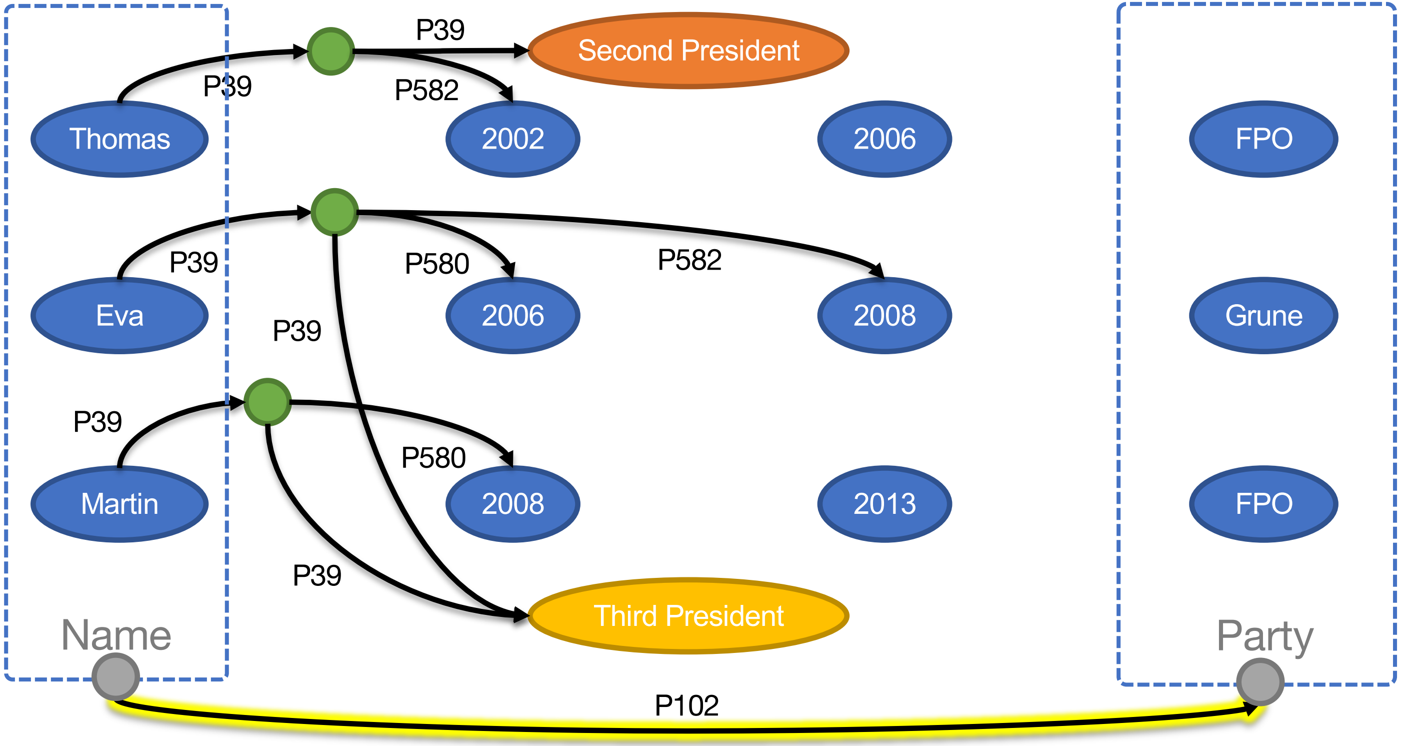


Group links from same source & target columns



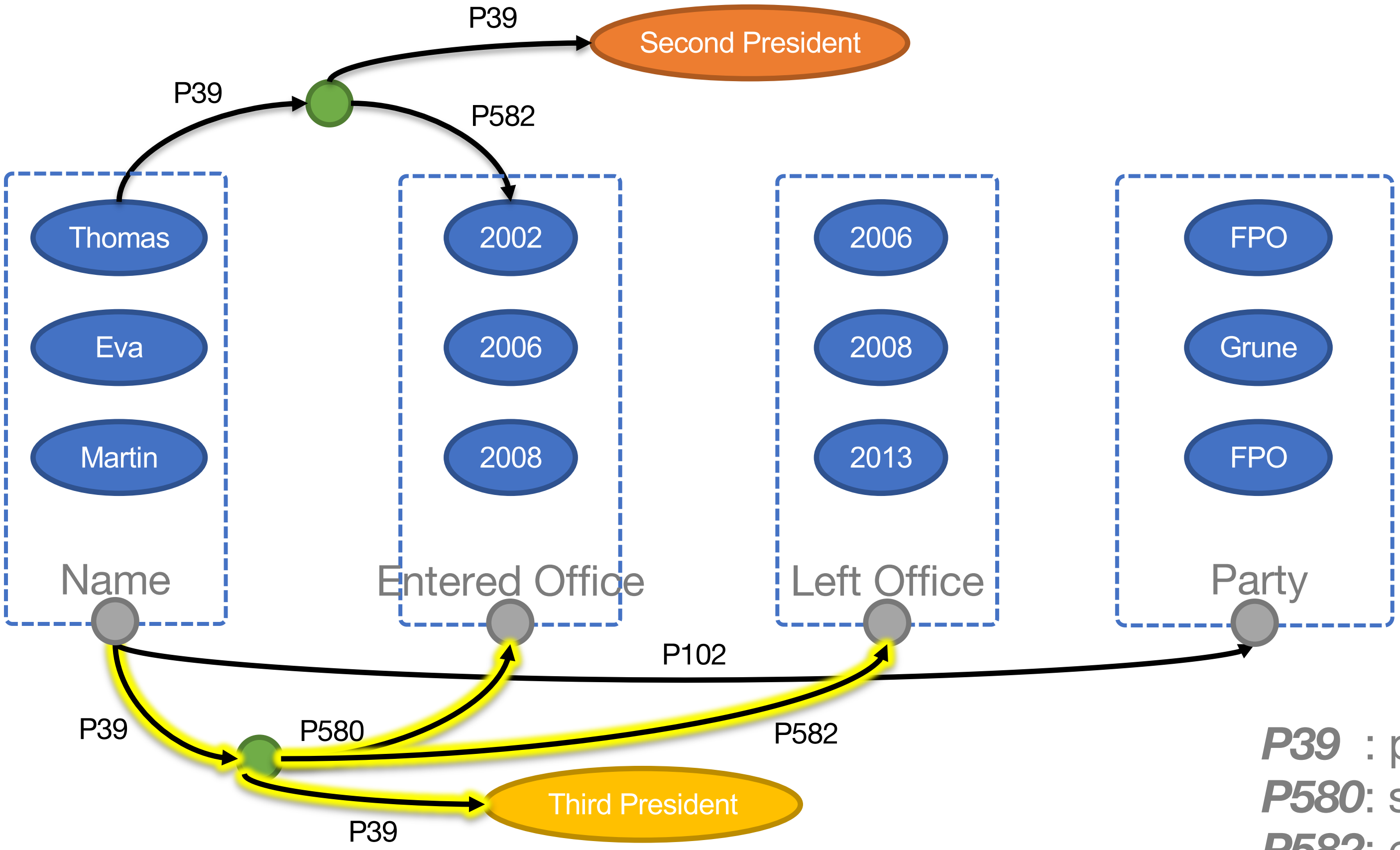
P39 : position held
P580: start time
P582: end time

Construct Candidate Graph: Summarization



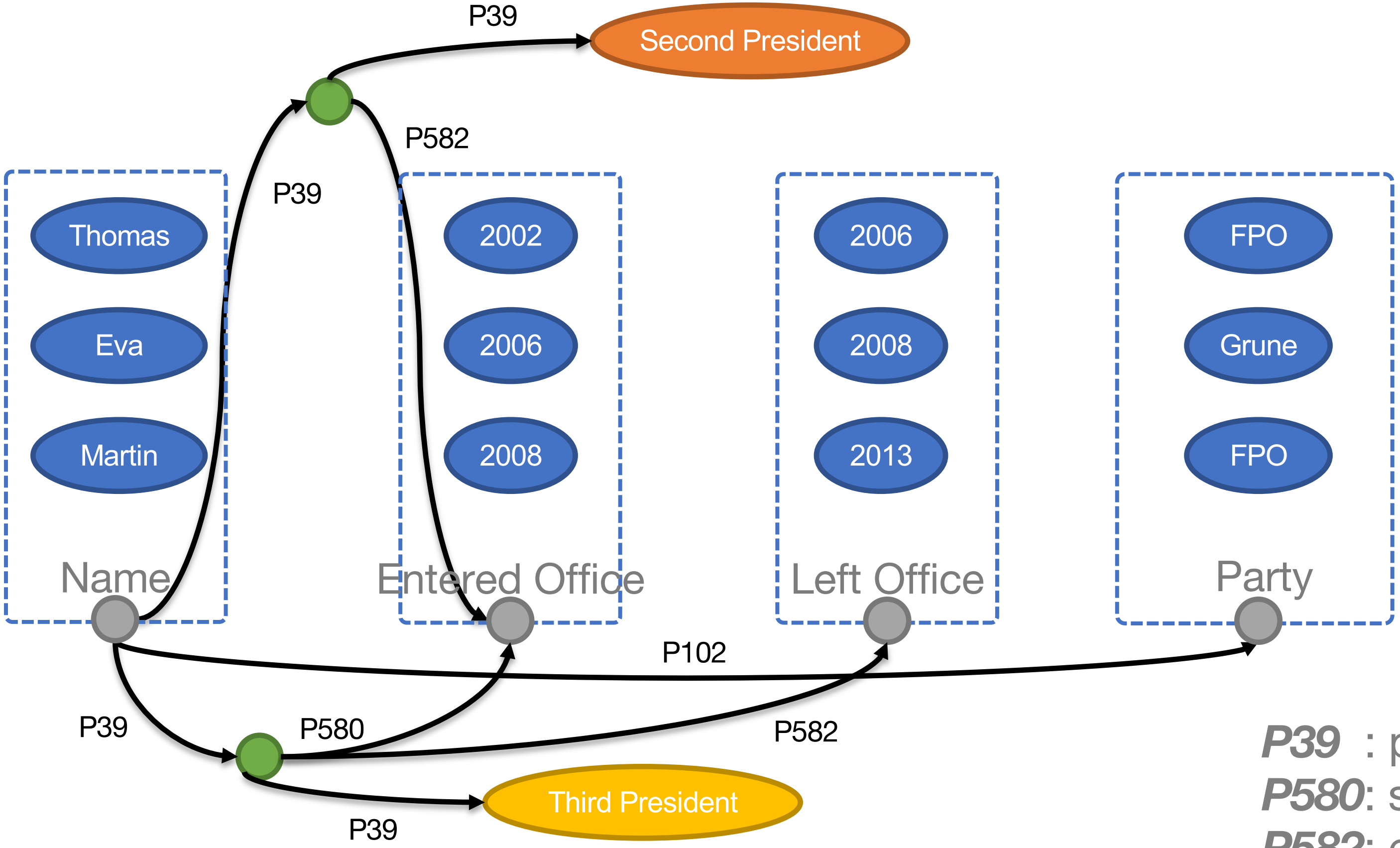
P39 : position held
P580: start time
P582: end time

Construct Candidate Graph: Summarization



P39 : position held
P580: start time
P582: end time

Construct Candidate Graph: Summarization

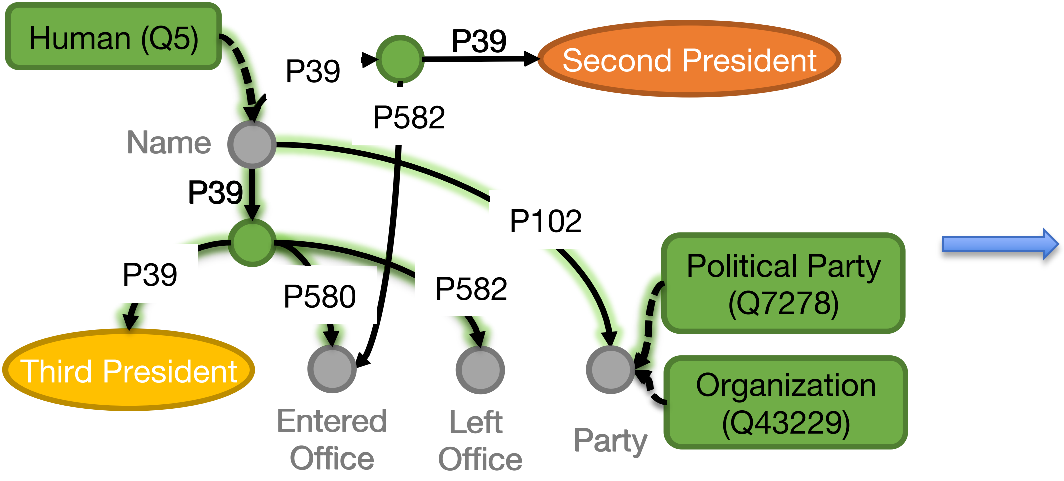


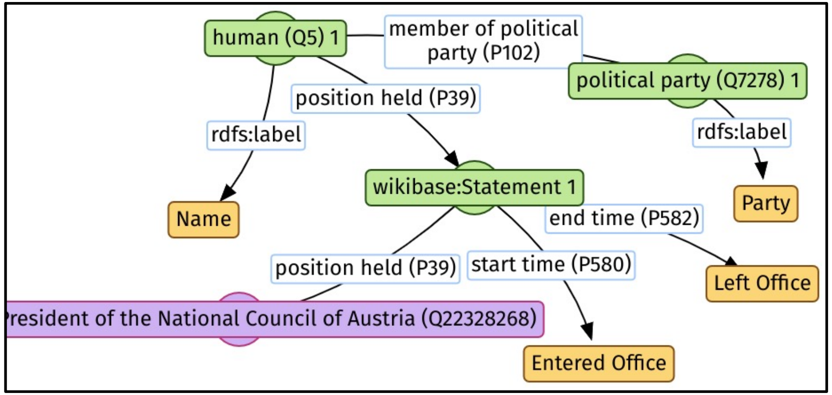
P39 : position held
P580: start time
P582: end time

Building semantic models from candidate graphs

- Candidate (n-ary) relationships *from the candidate graph*
- Candidate columns' types *from entities in table columns*

⟹ Need to select the most appropriate relationships and types.





Semantic Graph

Collective reasoning problem

- Probabilistic Soft Logic (PSL)

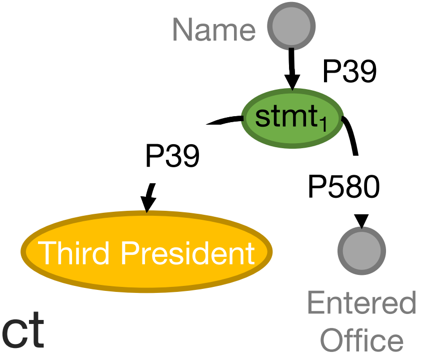
- Define predicates

- Define rules

PSL Predicates (examples)

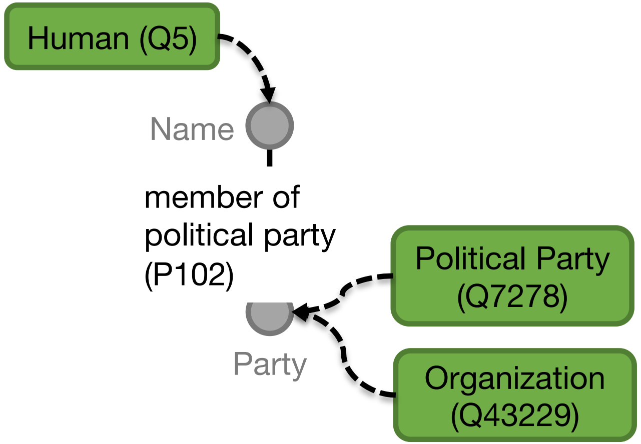
CorrectRel(N_1, N_2, P): if a relationship is correct

- CorrectRel(Name, stmt$_1$, P39)
- CorrectRel(stmt$_1$, Third President, P39)
- CorrectRel(stmt$_1$, Entered Office, P580)



CorrectType(N_1, T): if a column type assignment is correct

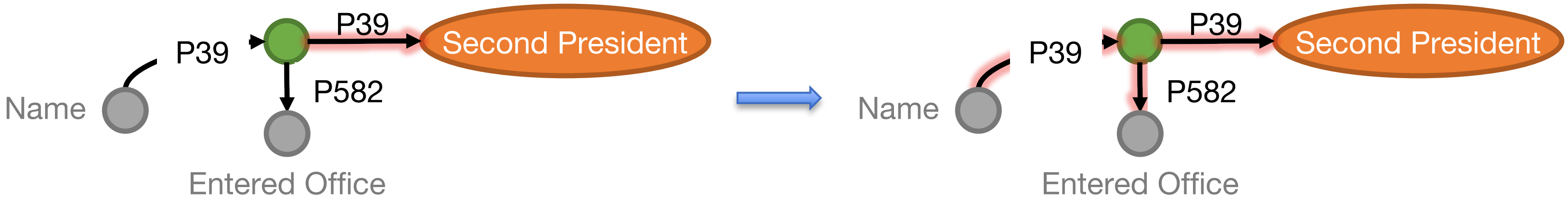
- CorrectType(Name, Human)
- CorrectType(Party, Organization)
- CorrectType(Party, Political Party)



P39 : position held ***P580***: start time ***P582***: end time

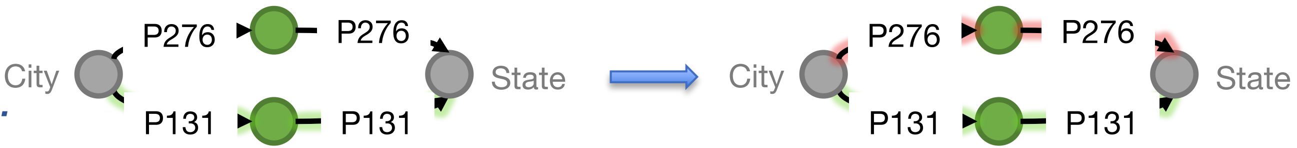
PSL Rules (examples)

If a statement value is incorrect, then the statement's qualifiers are also incorrect



Prefer fine-grained properties to high-level properties

location (P276) is parent of ***located in admin. area (P131)***



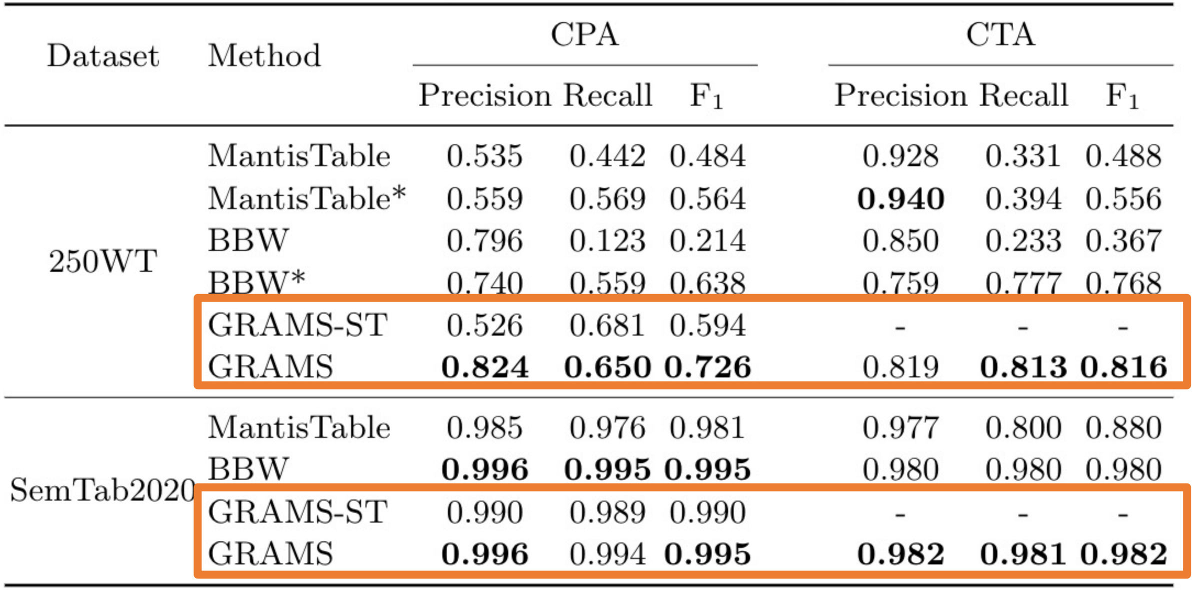
Evaluation of GRAM

Collective reasoning is beneficial

- Avoids cascading errors from subject column detection phase
- Handles columns with multiple entity types, and n-ary relationships

Wikipedia tables

Synthetic tables



Dataset	Method	CPA			CTA		
		Precision	Recall	F$_1$	Precision	Recall	F$_1$
250WT	MantisTable	0.535	0.442	0.484	0.928	0.331	0.488
	MantisTable*	0.559	0.569	0.564	**0.940**	0.394	0.556
	BBW	0.796	0.123	0.214	0.850	0.233	0.367
	BBW*	0.740	0.559	0.638	0.759	0.777	0.768
	GRAMS-ST	0.526	0.681	0.594	-	-	-
	GRAMS	**0.824**	**0.650**	**0.726**	0.819	**0.813**	**0.816**
SemTab2020	MantisTable	0.985	0.976	0.981	0.977	0.800	0.880
	BBW	**0.996**	**0.995**	**0.995**	0.980	0.980	0.980
	GRAMS-ST	0.990	0.989	0.990	-	-	-
	GRAMS	**0.996**	0.994	**0.995**	**0.982**	**0.981**	**0.982**

MantisTable* and BBW* are modified to retrieve correct subject column

Entity Linking For Tables

Nguyen, Phuc, et al. "MTab4Wikidata at SemTab 2020: Tabular Data Annotation with Wikidata." SemTab@ ISWC. 2020.

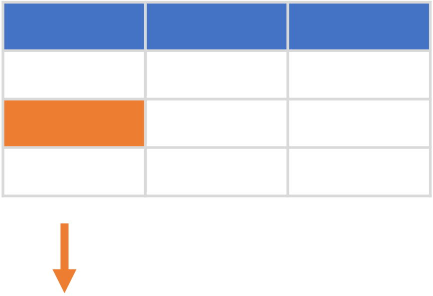
Huynh, Viet-Phi, et al. "DAGOBAH: Enhanced Scoring Algorithms for Scalable Annotations of Tabular Data." SemTab@ ISWC. 2020.

Abdelmageed, Nora, and Sirko Schindler. "JenTab: A Toolkit for Semantic Table Annotations." (2021).

Cremaschi, Marco, Roberto Avogadro, and David Chieregato. "MantisTable: an Automatic Approach for the Semantic Table Interpretation." SemTab@ ISWC 2019 (2019): 15-24.

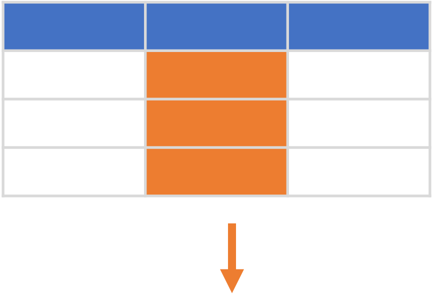
Task Definitions

Column Entity Annotation (CEA)



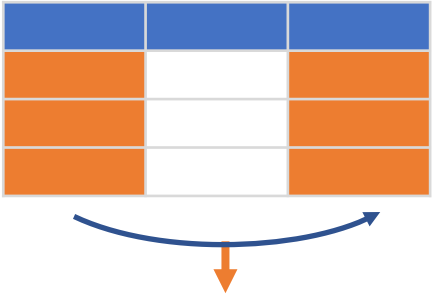
entity

Column Table Annotation (CTA)



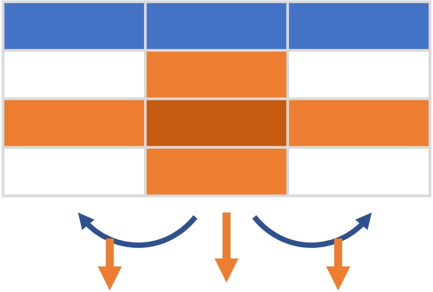
class

Column Property Annotation (CPA)

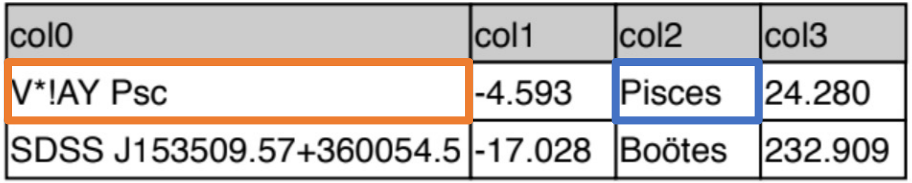


property

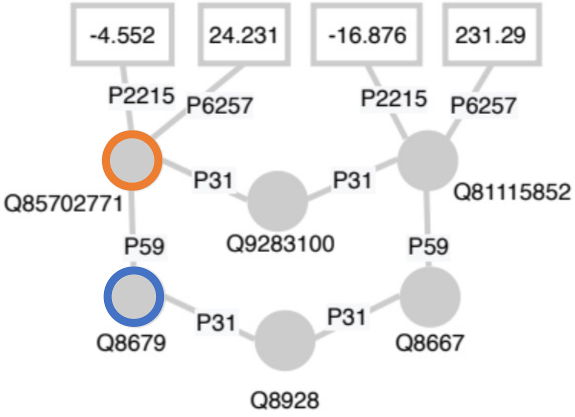
Usually solved together



property class property



col0	col1	col2	col3
V*!AY Psc	-4.593	Pisces	24.280
SDSS J153509.57+360054.5	-17.028	Boötes	232.909



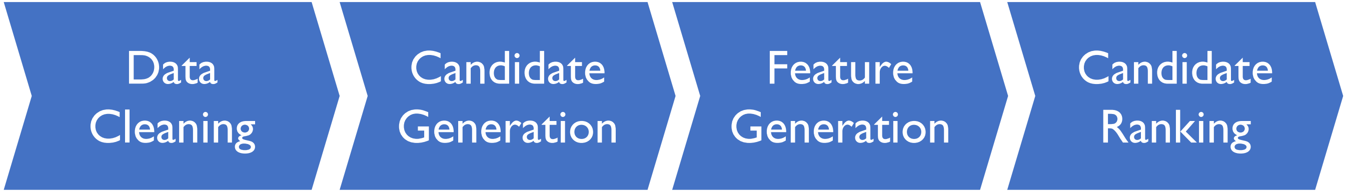
WIKIDATA

Entities labels:
- Q85702771: V* AY Psc
- Q81115852: SDSS J152509.57+360054.5
- Q8667: Boötes
- Q8679: Pisces

Type labels:
- Q9283100: nova-like stars
- Q8928: constellation

Property labels:
- P31: instance of
- P59: constellation
- P2215: proper motion
- P6257: right ascension

Typical CEA/CTA/CPA pipeline


Data Cleaning

Candidate Generation

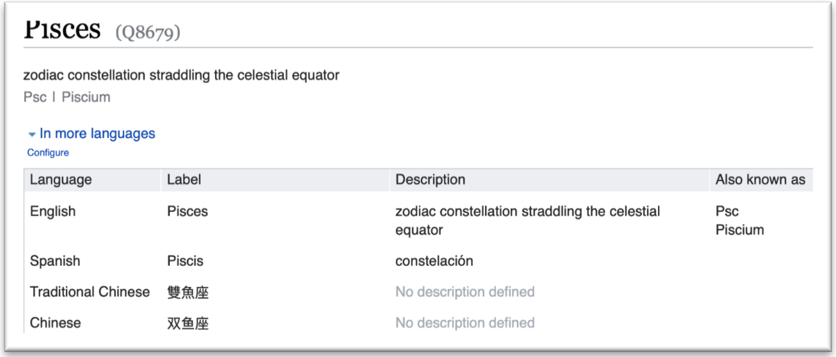
Feature Generation

Candidate Ranking

Data cleaning

- Fix broken unicode: https://ftfy.readthedocs.io/en/latest
- Remove text in parenthesis/brackets
- Expand abbreviations
- Isolate units of measure
- Identify syntactic types: string, numbers, dates, …
- Identify main entity

Candidate generation



Pisces (Q8679)

zodiac constellation straddling the celestial equator

Psc | Piscium

Language	Label	Description	Also known as
English	Pisces	zodiac constellation straddling the celestial equator	Psc Piscium
Spanish	Piscis	constelación	
Traditional Chinese	雙魚座	No description defined	
Chinese	双鱼座	No description defined	

Objective

- High recall

Lookup using multilingual labels/aliases

- Wikidata API: https://www.wikidata.org/w/api.php
- Wikipedia redirects and anchors
- Custom ElasticSearch index

Fuzzy query

- Progressive Levenshtein distance
- Two column indices [MTab4Wikidata]

Feature generation

Cell features

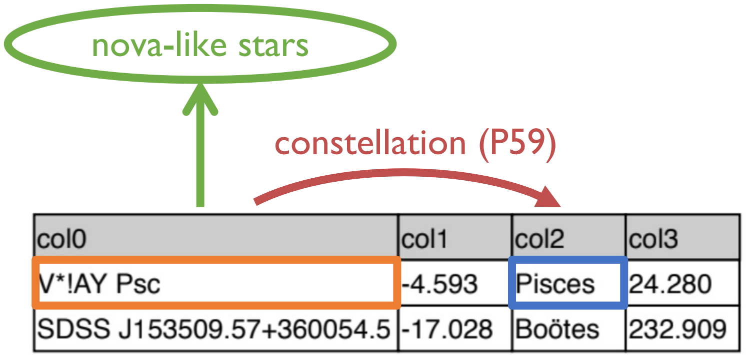
- String similarity
- popularity (pagerank, smallest Q-number)
- Wikidata embeddings

Row features (CPA)

- Candidates that respect properties are more likely to be correct

Column features (CTA)

- Instances of the column class are more likely to be correct



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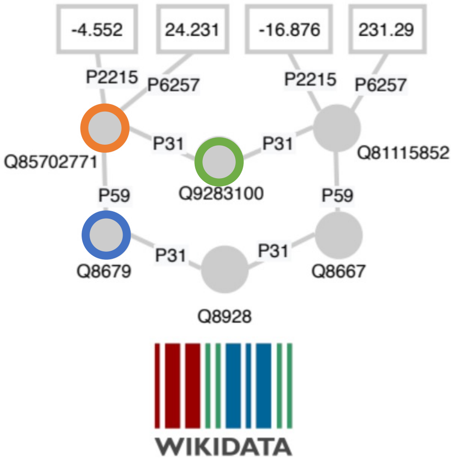

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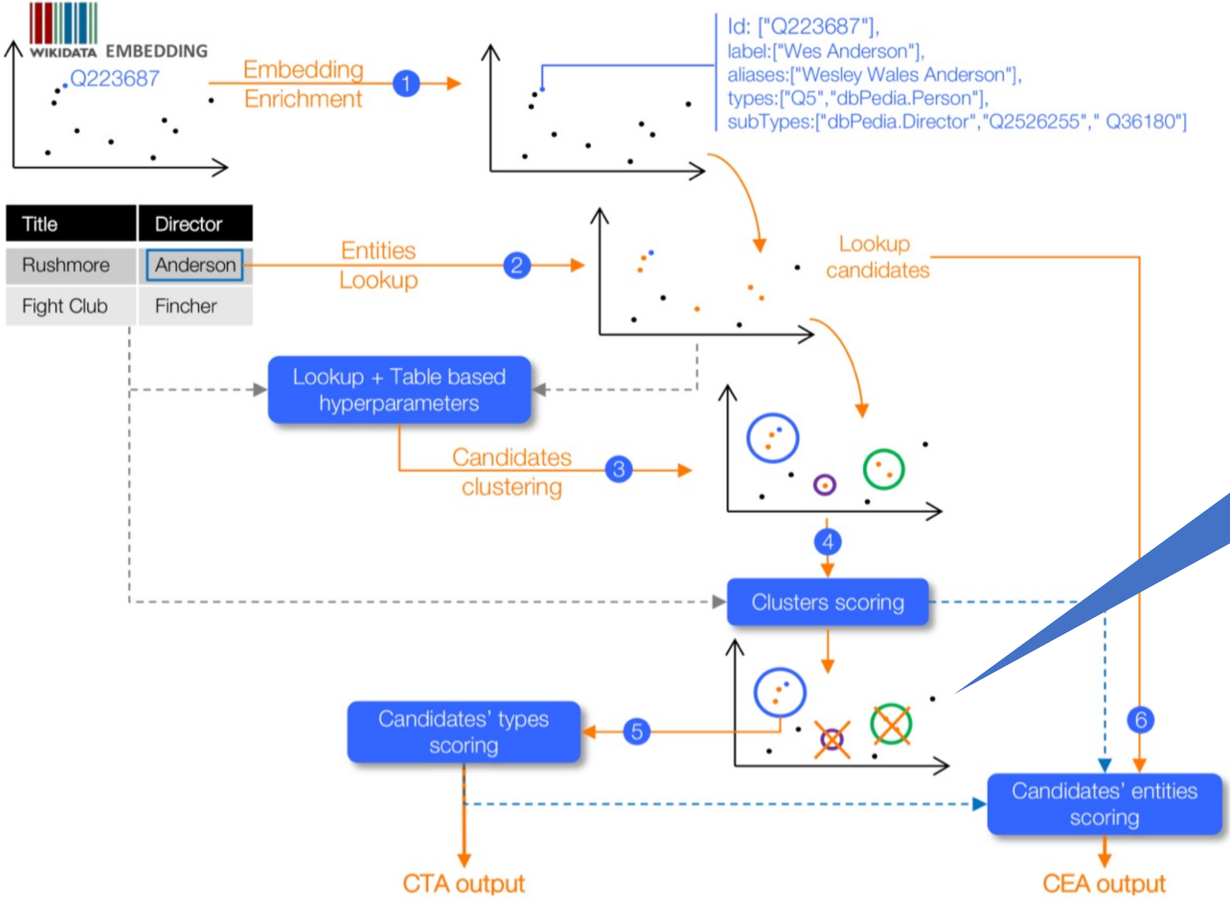
[MTab4Wikidata]

DAGOBAH: use embeddings as features



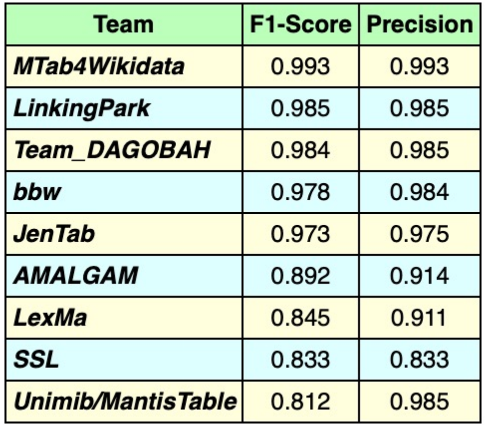
prefer clusters that contain candidates for more cells

SemTab 2020

Semantic Web Challenge on Tabular Data to Knowledge Graph Matching

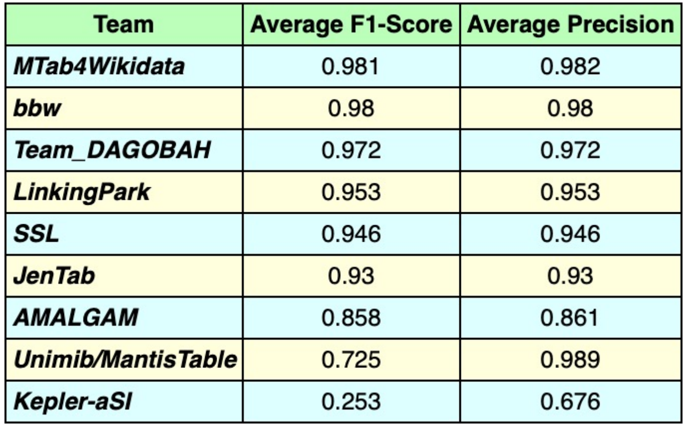
https://www.cs.ox.ac.uk/isg/challenges/sem-tab/2020/

Column Entity Annotation (CEA)



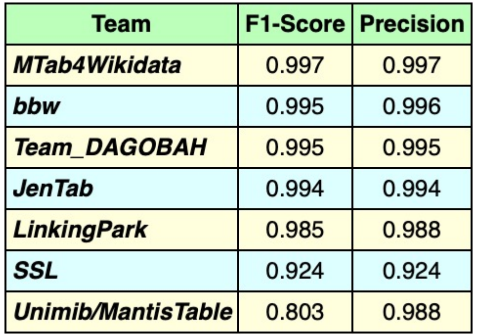
Team	F1-Score	Precision
MTab4Wikidata	0.993	0.993
LinkingPark	0.985	0.985
Team_DAGOBAH	0.984	0.985
bbw	0.978	0.984
JenTab	0.973	0.975
AMALGAM	0.892	0.914
LexMa	0.845	0.911
SSL	0.833	0.833
Unimib/MantisTable	0.812	0.985

Column Table Annotation (CTA)



Team	Average F1-Score	Average Precision
MTab4Wikidata	0.981	0.982
bbw	0.98	0.98
Team_DAGOBAH	0.972	0.972
LinkingPark	0.953	0.953
SSL	0.946	0.946
JenTab	0.93	0.93
AMALGAM	0.858	0.861
Unimib/MantisTable	0.725	0.989
Kepler-aSI	0.253	0.676

Column Property Annotation (CPA)



Team	F1-Score	Precision
MTab4Wikidata	0.997	0.997
bbw	0.995	0.996
Team_DAGOBAH	0.995	0.995
JenTab	0.994	0.994
LinkingPark	0.985	0.988
SSL	0.924	0.924
Unimib/MantisTable	0.803	0.988

- Top system has an almost perfect score
- Many systems perform well
- All systems are heuristic
- Tables are synthetic (generated from Wikidata)

CEA/CTA/CPA open problems

Tables contain new entities

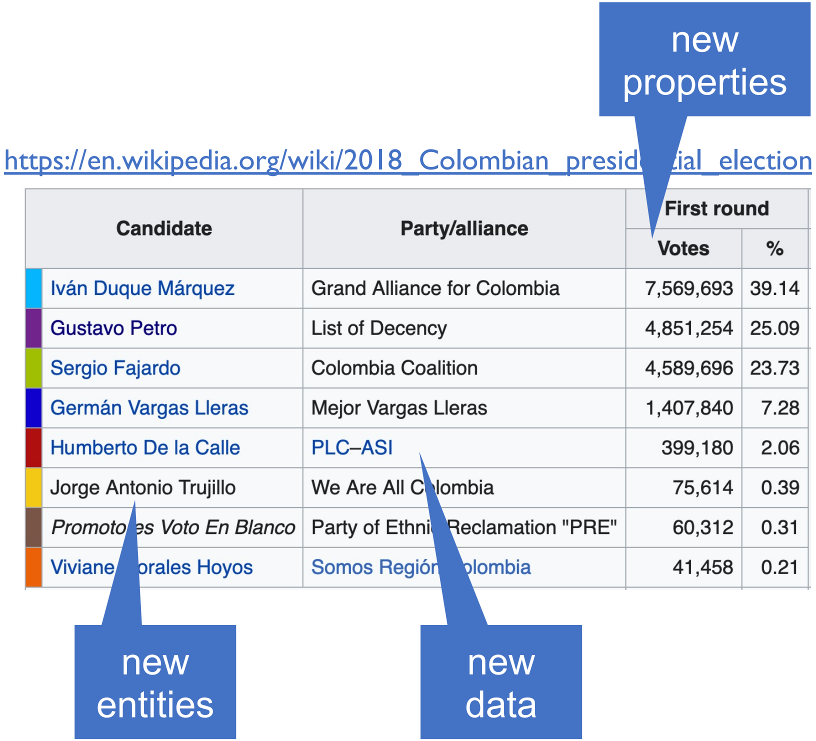
- NIL linking
- Suggest new entities

Tables contain new properties

- Suggest new properties

Table data more recent than KG, or table/KG contain errors

- Confuses identification of properties



https://en.wikipedia.org/wiki/2018_Colombian_presidential_election

Candidate	Party/alliance	First round	
		Votes	%
Iván Duque Márquez	Grand Alliance for Colombia	7,569,693	39.14
Gustavo Petro	List of Decency	4,851,254	25.09
Sergio Fajardo	Colombia Coalition	4,589,696	23.73
Germán Vargas Lleras	Mejor Vargas Lleras	1,407,840	7.28
Humberto De la Calle	PLC–ASI	399,180	2.06
Jorge Antonio Trujillo	We Are All Colombia	75,614	0.39
Promotores Voto En Blanco	Party of Ethnic Reclamation "PRE"	60,312	0.31
Viviane Morales Hoyos	Somos Región Colombia	41,458	0.21

Summary

Summary

Semantic modeling

- Identify classes and relationships to describe tables
- CTA and CPA are the simple cases
- Wikidata brings new challenges: n-ary relations, multi-hop properties
- Early work focused on custom ontologies
- Recent work focused on large public KGs (Wikidata, DBpedia)

Evaluation remains a challenge

- Benchmarks with real tables are small (T2DV2)
- Large benchmarks are synthetic and biased (SemTab 2020)
- Heuristic systems perform very well

Bibliography

Taheriyan, M., Craig A. Knoblock, Pedro A. Szekely and J. Ambite. “Rapidly Integrating Services into the Linked Data Cloud.” International Semantic Web Conference (2012).

Szekely, Pedro A., Craig A. Knoblock, Fengyu Yang, Xuming Zhu, E. Fink, Rachel Allen and Georgina Goodlander. “Connecting the Smithsonian American Art Museum to the Linked Data Cloud.” ESWC (2013).

Bhagavatula, Chandra Sekhar, Thanapon Noraset, and Doug Downey. "Tabel: Entity linking in web tables." *International Semantic Web Conference*. Springer, Cham, 2015.

Ritze, Dominique, and Christian Bizer. "Matching web tables to DBpedia-A feature utility study." *context* 42.41 (2017): 19-31.

Efthymiou, Vasilis, et al. "Matching web tables with knowledge base entities: from entity lookups to entity embeddings." *International Semantic Web Conference*. Springer, Cham, 2017.

Cremaschi, Marco, Roberto Avogadro, and David Chieregato. "MantisTable: an Automatic Approach for the Semantic Table Interpretation." *SemTab@ ISWC* 2019 (2019): 15-24.

Nguyen, P., N. Kertkeidkachorn, R. Ichise and Hideaki Takeda. “MTab: Matching Tabular Data to Knowledge Graph using Probability Models.” SemTab@ISWC (2019).

Chen, Shuang, Alperen Karaoglu, C. Negreanu, Tingting Ma, Jin-ge Yao, Jack Williams, A. D. Gordon and Chin-Yew Lin. “LinkingPark: An Integrated Approach for Semantic Table Interpretation.” SemTab@ISWC (2020).

Chabot, Yoan, Thomas Labbé, Jixiong Liu and Raphael Troncy. “DAGOBAH: An End-to-End Context-Free Tabular Data Semantic Annotation System.” SemTab@ISWC (2019).

Abdelmageed, Nora. “JenTab: A Toolkit for Semantic Table Annotations.” (2021).

Binh Vu, Craig A. Knoblock, Pedro Szekely, Minh Pham, & Jay Pujara (2021). A Graph-based Approach for Inferring Semantic Descriptions of Wikipedia Tables. In ISWC 2021 - 20th International Semantic Web Conference.