RECA: Related Tables Enhanced Column Semantic Type Annotation Framework

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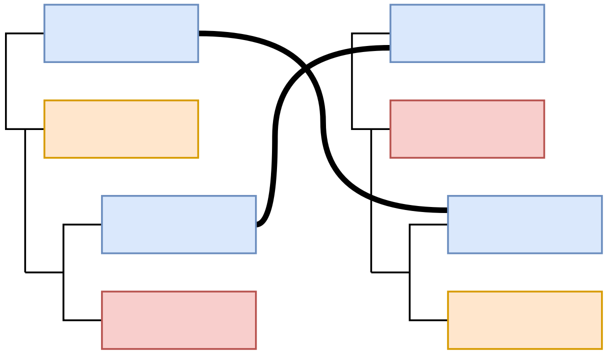
Outline

- Background and Motivation
- Definitions
- Methodology
- Experiments
- Summary

1. Background and Motivation

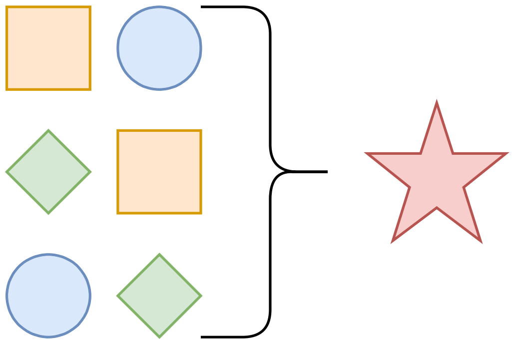
- Accurate column semantic type annotation is important for various applications:
  - schema matching, data cleaning, data integration, etc.



schema matching

Title 1	Title 2	Title 3
Value 1	Value 2	Value 3
Value 4	? ? ?	Value 6
Value 7	Value 8	Value 9
Value 10	Value 11	Value 12

data cleaning



data integration

1. Background and Motivation

- Two challenges exist:
  - The proper handle of wide tables
  - The utilization of inter-table context

?	?	?	?	?	...	?
Albania	27,398	$11,800	$2,949.57	2,994,667	…	Parliamentary Democracy
Algeria	2,381,740	$159,000	$3,948.01	34,994,937	…	Republic
Angola	1,246,700	$85,810	$5,003.43	13,338,541	…	Republic; Multiparty Presidential Regime
...	…	…	…	…	…	…

?	?	?	?	?	...	?
Bahamas	10,070	$7,538	$21,547.17	313,312	…	Constitutional Monarchy with a parliamentary system of government
Bangladesh	133,910	$100,100	$481.36	158,570,535	…	Parliame
Belgium	30,278	$461,300	$43,648.01	10,431,477	…	Federal F
...	…	…	…	…	…	…

?	?	?	?	?	...	?
Canada	9,984,670	$1,334,140	$40,457	34,733,000	…	Federal Parliamentary Democracy
Chile	748,800	$199,200	$10,058.50	16,888,760	…	republic
China	9,326,410	$5,745,000	$2,459.43	1,336,718,015	…	Communist State
...	…	…	…	…	…	…

1. Background and Motivation

- Two challenges exist:
  - The proper handle of wide tables
  - The utilization of inter-table context

?	?	?	?
Amorcito corazón	L. Suárez	D. Olivera	2012-06-10
A Nero Wolfe Mystery	S. M. Kaminsky	M. Chaykin	2002-08-18

WPPD

?	?	?	?
Chōriki Sentai Ohranger	T. Inoue	T. Satō	1996-02-23
Chōjin Sentai Jetman	T. Inoue	T. Wakamatsu	1992-02-14
Brewster Place	M. Angelou	O. Winfrey	1990-05-30
Anne of Green Gables: The Continuing Story	K. Sullivan	J. Crombie	2000-07-30
Angry Boys	C. Lilley	C. Lilley	2011-07-27
Alex Haley's Queen	A. Haley	Ann-Margret	1993-02-18
...	...	...	...

WPPD

1. Background and Motivation

- Tables with the same/similar named entity schemata tend to be from the same/similar data source and thus tend to have the same/similar column semantic types.

?	?	?	?
Amorcito corazón	L. Suárez	D. Olivera	2012-06-10
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WPPD

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...	...	...	...

WPPD

?	?	?	?
Donkey Kong Country	Nintendo	2006-12-08	2006
F-Zero	Nintendo	2006-12-08	2006
SimCity	Nintendo	2006-12-29	2006
Super Castlevania IV	Konami	2006-12-29	2006
Street Fighter II: The World Warrior	Capcom	2007-01-19	2007
...	...	...	...

WODD

- W: Work of art; P: Person; D: Date; O: Organization

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2. Definitions - Concepts

- Named Entity Schema: Named Entity Schema is the table schema generated based on the most frequent named entity type extracted from each column.
- Related Tables: The tables that share the same named entity schema and are similar in content (Jaccard Similarity $> \delta$) with the original table.
- Sub-related Tables: The tables that share a similar named entity schema (the edit distance between their named entity schemata is less than a threshold) and are similar in content (Jaccard Similarity $> \delta$) with the original table.

2. Definitions - Problem

- (Column semantic type annotation): Given a web table T (without table headers) from the dataset D, denote the target column as C_t in T. The column semantic type annotation model W annotates C_t with a semantic type $\bar{y}_t$ = W (C_t, T, D), such that $\bar{y}_t$ best fits the semantics of C_t.

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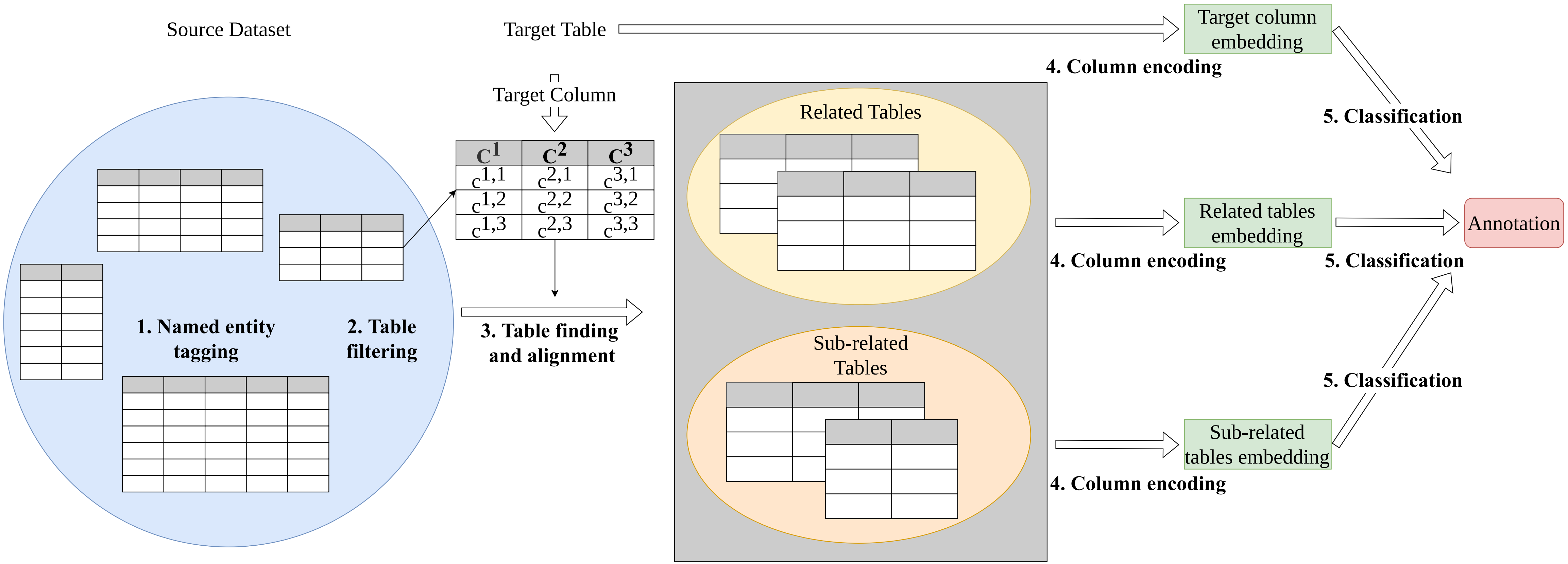
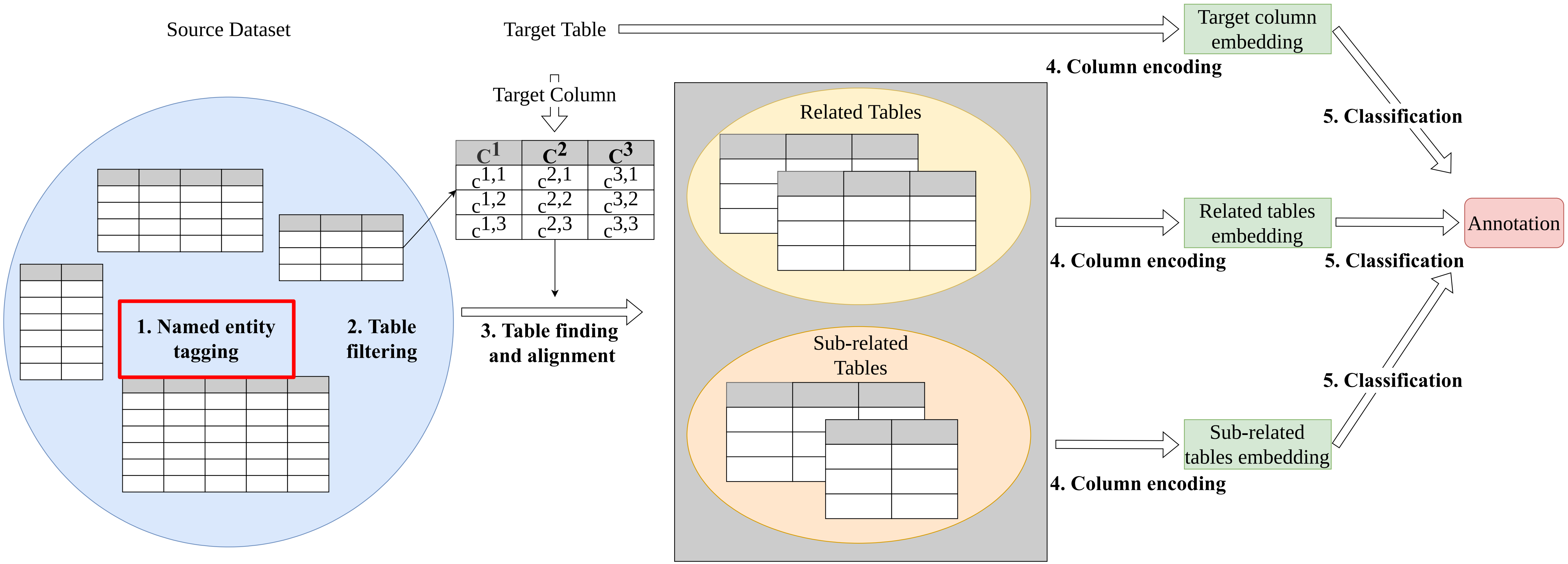
3. Methodology



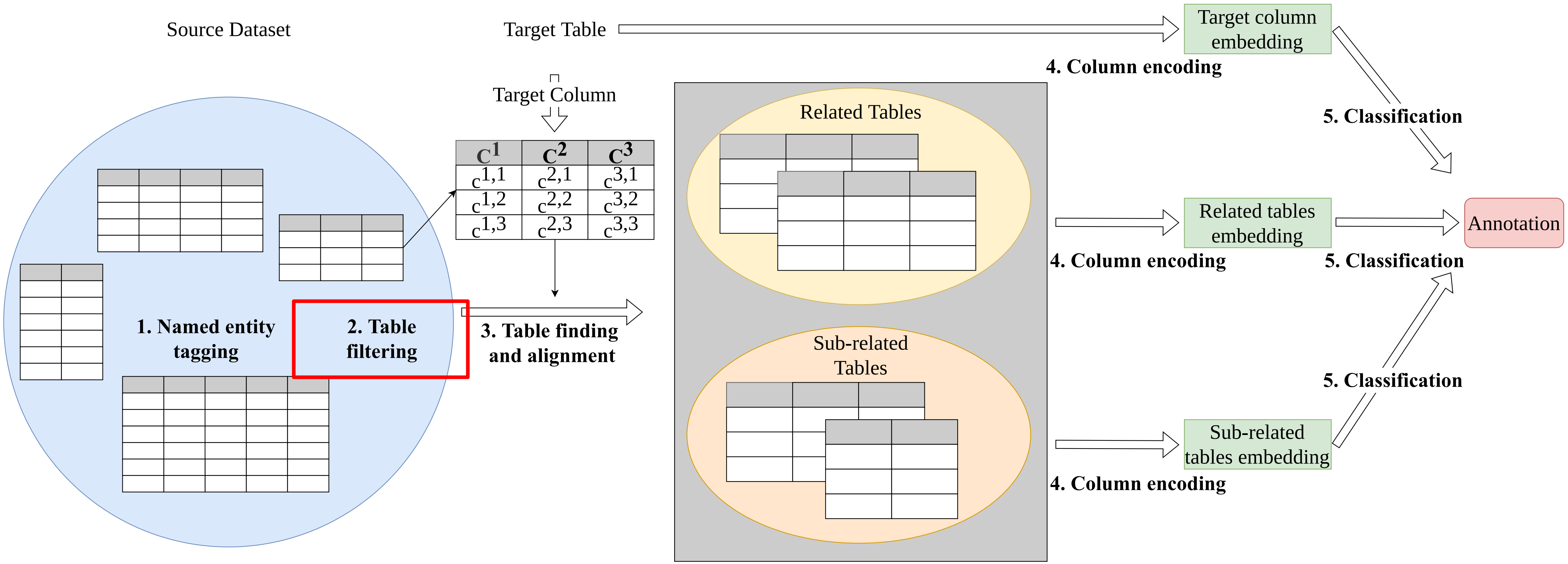
3. Methodology



3. Methodology - Named Entity Tagging

- Given a table T with M columns and N rows, we use the spaCy tagging tool to identify the named entities in each column and tag them.
- We further classify the DATE and PERSON types based on the data format.
  - E.g. DD-MM-YYYY; YYYY; January 16^{th} 2022; 2023
  - E.g. J. K. Rowling; Anna
- We include an additional EMPTY type.
- The most frequent named entity type in each column forms the named entity schema.

3. Methodology



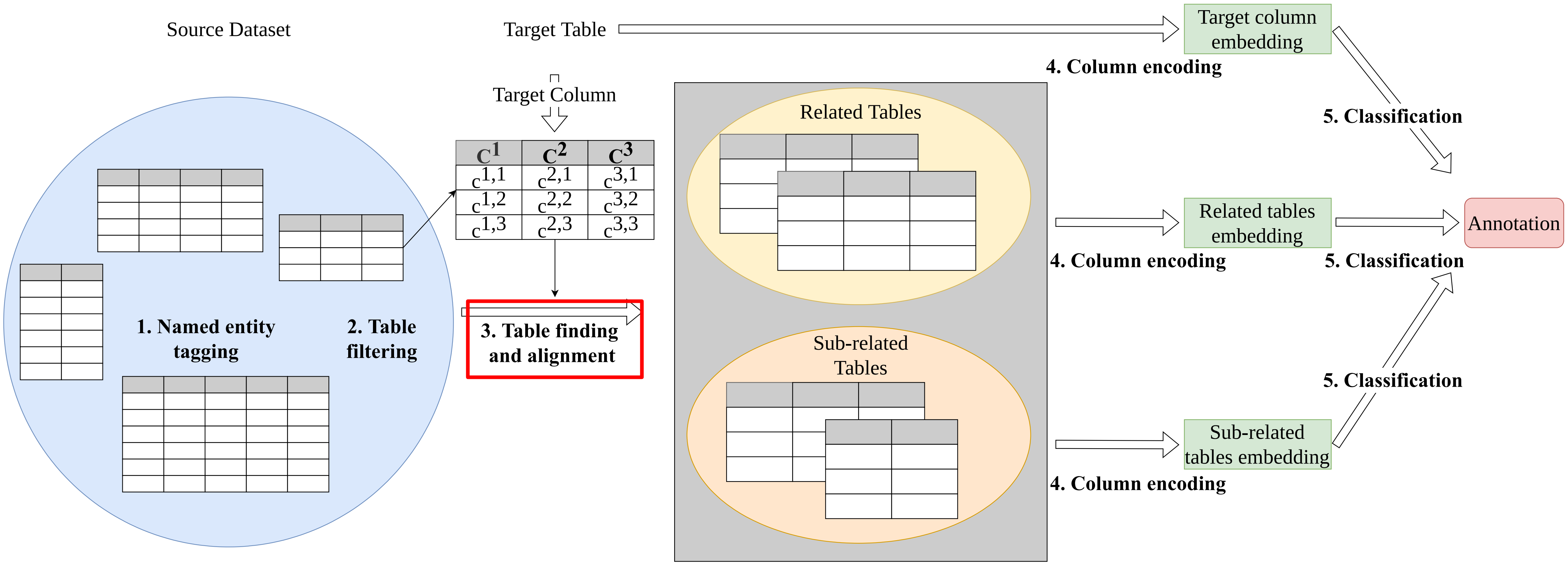
3. Methodology - Table Filtering

- To filter out tables that are irrelevant in content, we compute the Jaccard similarity between the set of words for each table pair.

$$\text{Jaccard}(A_i, A_j) = \frac{|A_i \cap A_j|}{|A_i \cup A_j|}$$

- If $\text{Jaccard}(A_i, A_j) > \delta$, include T_j as a candidate table of T_i.

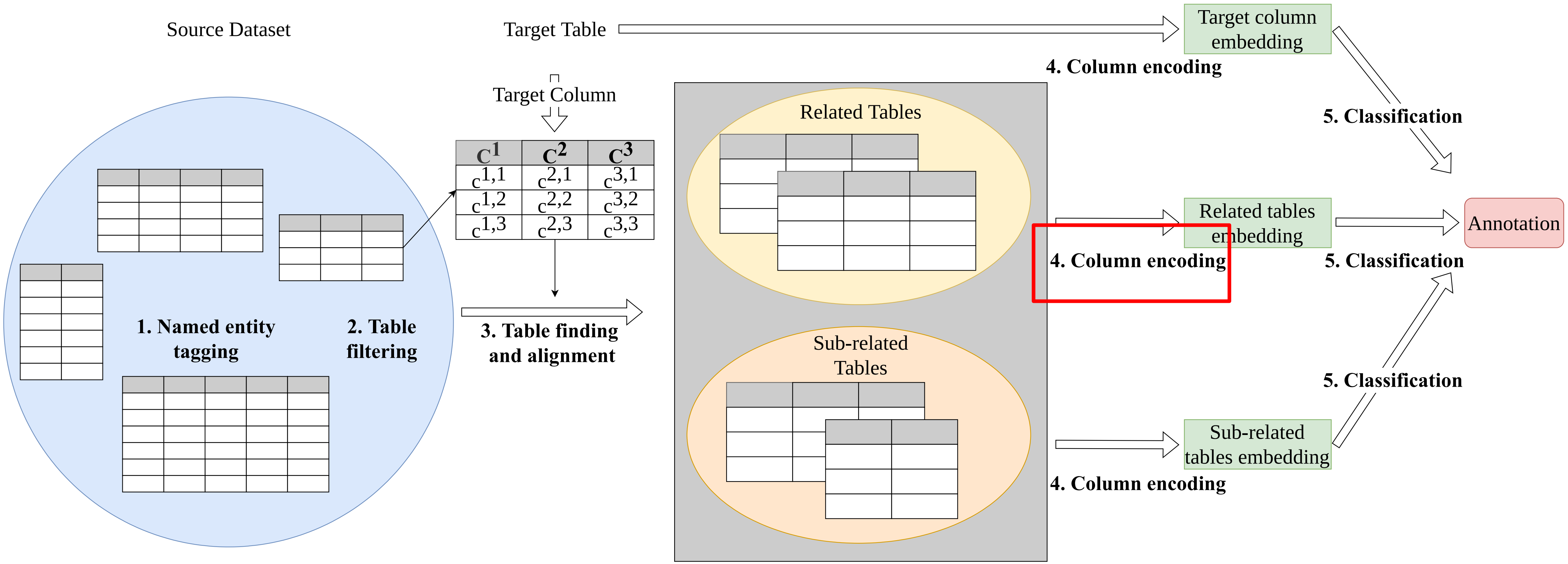
3. Methodology



3. Methodology - Table Finding and Alignment

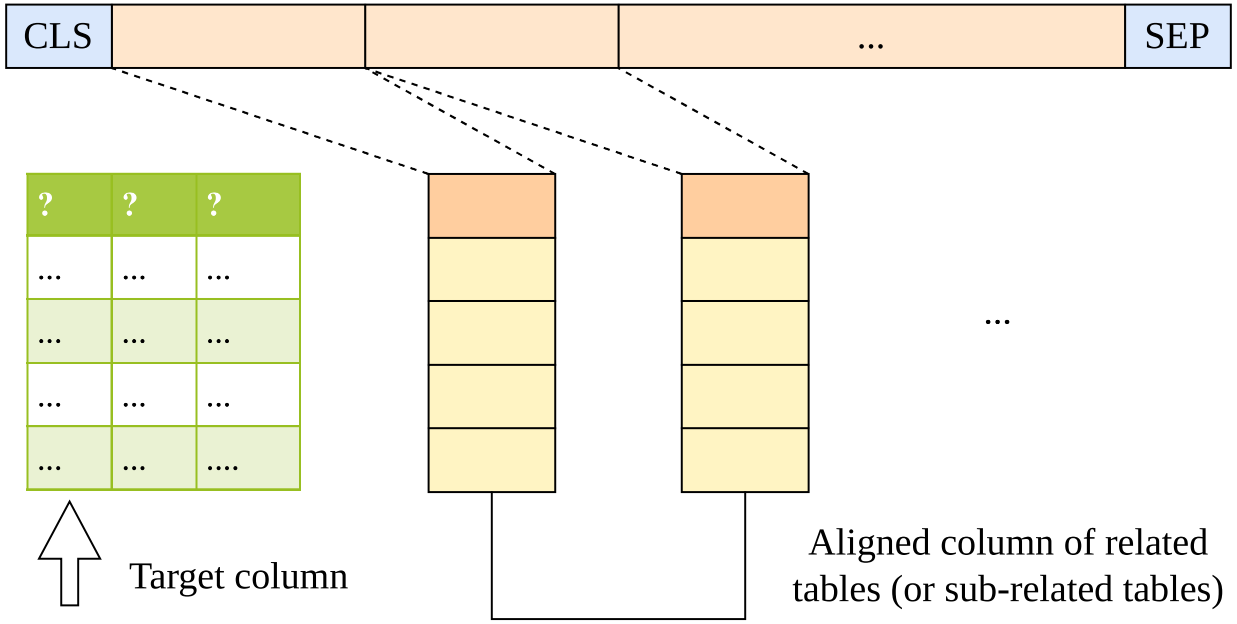
- Related tables: candidate tables T_j that share the same named entity schema as T_i.
- Sub-related tables: we consider the following two requirements:
  - Schema similarity: the named entity schemata should not be very different (edit distance less than a threshold).
  - Column location alignment: The named entity type of the target column matches with that of the column at the identical location in the sub-related table.

3. Methodology

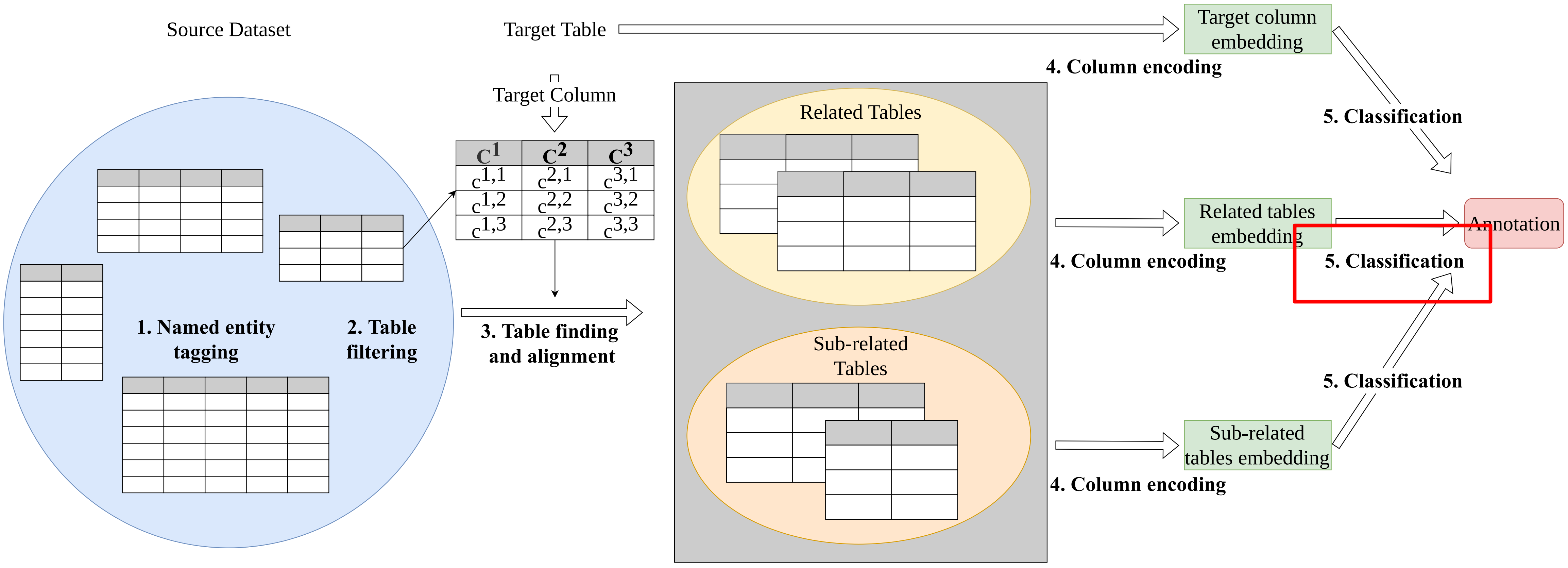


3. Methodology - Column Encoding

- The target column is encoded with BERT solely.
- The aligned columns in related tables and sub-related tables are encoded separately with BERT.
- The tokens are allocated fairly to each related table (or sub-related table).



3. Methodology



3. Methodology - Classification

- The embeddings of the target column, related tables, and sub-related tables are passed to three corresponding classification modules.
- Each classification module contains two layers: dropout and linear layers.
- The generated output embeddings are combined with learnable weights:

$$a_i^t = \alpha * \hat{v}_i^t + \beta * \hat{r}_i^t + \gamma * \hat{x}_i^t$$

- We use the cross-entropy loss as the loss function.

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4. Experiments – Datasets and Metrics

- Datasets:

	WebTables	Semtab2019
# semantic types	78	275
# tables	32262	3045
# annotated columns	74141	7603
Avg. # rows	20.0	69.0
Avg. # columns	2.3	4.5
Avg. # annotated columns	2.3	2.5

- Metrics:
  - Support-weighted F1: weighted support of per type F1 scores
  - Macro average F1: average of per type F1 scores (emphasize on long-tail types)

4. Experiments – Main Results

- RECA outperforms all the state-of-the-arts in terms of the F1 scores.

	Semtab2019 dataset		WebTables dataset	
Model names	Support-weighted F1	Macro average F1	Support-weighted F1	Macro average F1
Sherlock [15]	0.646 ± 0.006	0.440 ± 0.009	0.844 ± 0.001	0.670 ± 0.010
TaBERT [35]	0.768 ± 0.011	0.413 ± 0.019	0.896 ± 0.005	0.650 ± 0.011
TABBIE [16]	0.799 ± 0.013	0.607 ± 0.011	0.929 ± 0.003	0.734 ± 0.019
DODUO [30]	0.820 ± 0.009	0.630 ± 0.015	0.928 ± 0.001	0.742 ± 0.012
RECA	**0.853** ± 0.005	**0.674** ± 0.007	**0.937** ± 0.002	**0.783** ± 0.014

4. Experiments – Ablation Study

- We conducted ablation study on RECA:
  - RECA target only: only encode the target column
  - RECA w/o re: encode both target column and aligned columns in sub-related tables
  - RECA w/o sub: encode both target column and aligned columns in related tables
- Performance drops on macro average F1 scores are greater than that on support-weighted F1 scores – incorporating inter-table context can improve the annotation quality on less-populated semantic types.

	Semtab2019 dataset		WebTables dataset	
Model names	Support-weighted F1	Macro average F1	Support-weighted F1	Macro average F1
RECA *target only*	0.808 ± 0.017	0.586 ± 0.039	0.911 ± 0.001	0.688 ± 0.014
RECA *w/o re*	0.836 ± 0.012	0.641 ± 0.037	0.927 ± 0.001	0.748 ± 0.024
RECA *w/o sub*	0.848 ± 0.009	0.650 ± 0.019	0.936 ± 0.002	0.774 ± 0.011
RECA	**0.853** ± 0.005	**0.674** ± 0.007	**0.937** ± 0.002	**0.783** ± 0.014

4. Experiments - Learning and Input Data Utilization

- RECA is efficient in utilizing the learning data and the input data.

Learning data utilization

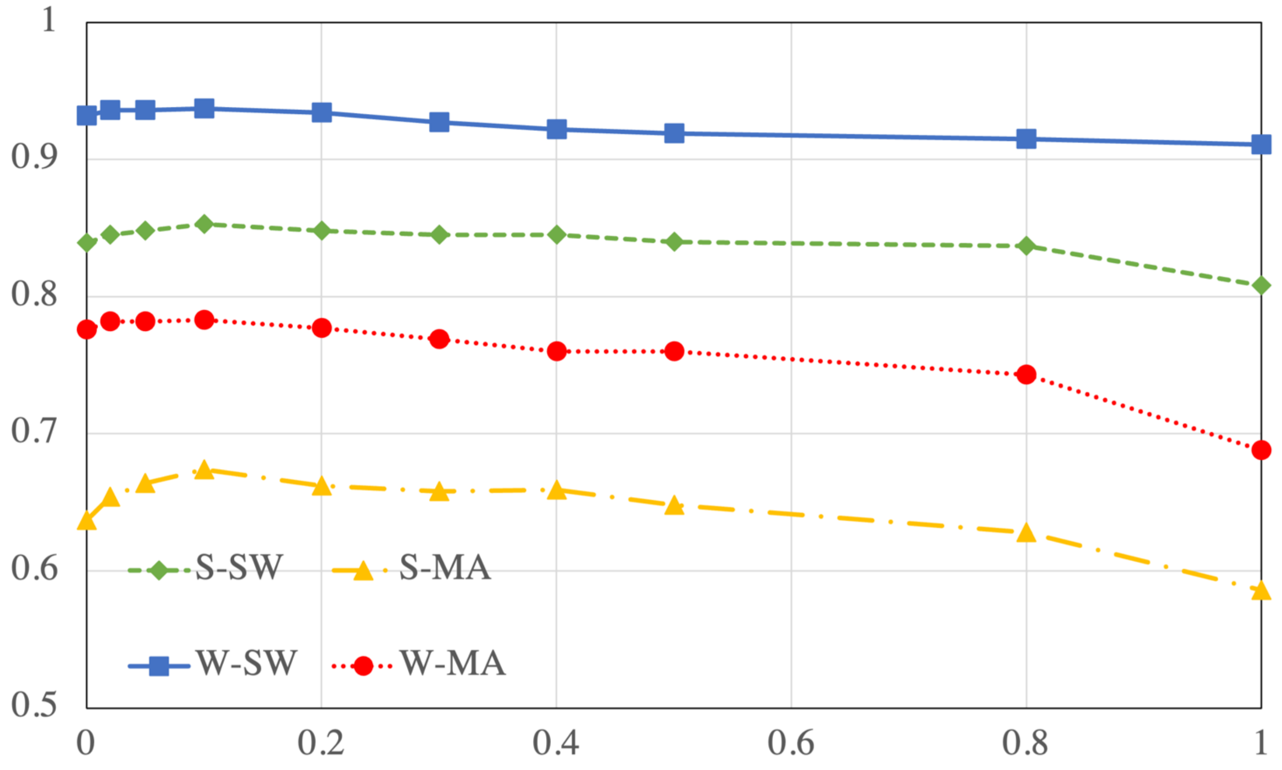
Datasets	[%]	Support-weighted F1	Macro average F1
Semtab2019	25	0.697 ± 0.041	0.442 ± 0.074
Semtab2019	50	0.792 ± 0.020	0.566 ± 0.045
Semtab2019	75	0.820 ± 0.021	0.631 ± 0.047
Semtab2019	100	**0.853** ± 0.005	**0.674** ± 0.007
WebTables	25	0.909 ± 0.002	0.680 ± 0.008
WebTables	50	0.924 ± 0.004	0.738 ± 0.019
WebTables	75	0.930 ± 0.002	0.772 ± 0.013
WebTables	100	**0.937** ± 0.002	**0.783** ± 0.014

Input data utilization

Datasets	Max	Support-weighted F1	Macro average F1
Semtab2019	8	0.540 ± 0.009	0.319 ± 0.010
Semtab2019	16	0.654 ± 0.013	0.436 ± 0.006
Semtab2019	32	0.728 ± 0.010	0.507 ± 0.020
Semtab2019	128	0.816 ± 0.017	0.620 ± 0.033
Semtab2019	256	0.851 ± 0.011	0.662 ± 0.024
Semtab2019	512	**0.853** ± 0.005	**0.674** ± 0.007
WebTables	8	0.907 ± 0.004	0.737 ± 0.011
WebTables	16	0.923 ± 0.002	0.762 ± 0.011
WebTables	32	0.931 ± 0.002	0.780 ± 0.010
WebTables	128	**0.937** ± 0.002	**0.783** ± 0.014
WebTables	256	0.936 ± 0.003	**0.783** ± 0.020
WebTables	512	0.936 ± 0.001	0.780 ± 0.011

4. Experiments – Parameter Sensitivity

- RECA achieves stable performance when the Jaccard threshold is in the range of [0, 0.3].



- S-SW and S-MA stand for the support-weighted and macro average F1 scores on the Semtab2019 dataset; W-SW and W-MA stand for the support-weighted and macro average F1 scores on the WebTables dataset.

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5. Summary

- We propose RECA for column semantic type annotation. RECA extracts and leverages inter-table context to enhance the annotation quality of the target column, thus resolving the wide table issue.
- We define a novel named entity schema for RECA to efficiently align related and sub-related tables, which resolves the difficulty of incorporating inter-table context.
- We conduct extensive experiments on two real-world web table datasets to show that RECA outperforms all the state-of-the-art methods. The result demonstrates the effectiveness of utilizing the inter-table context to annotate column semantic types accurately.
- We show that RECA is data efficient and learning efficient, since it requires shorter input token sequences and fewer training data to achieve high performance.