

# **Data Mining and Information Extraction Methods for Large-Scale High Quality Representations of Scientific Publications**

**Dissertation Defense**

Tarek Saier | 22. April 2024



Data Mining and Information Extraction Methods  
for Large-Scale High Quality  
**Representations of Scientific Publications**

**Data Mining and Information Extraction Methods  
for Large-Scale High Quality  
Scholarly Data**

## Scholarly Data

## ■ Usage

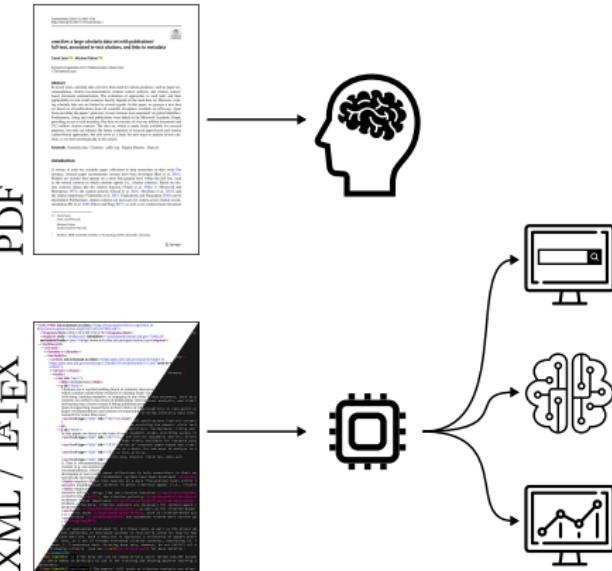
- **Services** (search, recommendation, statistics)
  - **ML models** (LLMs, summarization, recommender systems)
  - **Analyses** (temporal, geographic, institutional)

## ■ Flavors

- **Metadata** (MAG, OpenAlex, ORKG, crossref)
  - **Documents** (Core, arXMLiv, PMC)
  - **Linked Documents** (unarXive, S2ORC)

## ■ Data Sources

- PDF (Core, ACL Anthology)
  - XML (PubMed, PLOS, publisher internal)
  - LaTeX (arXiv)



## Motivation

## Background

## Outline

Corpus  
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## Citations & Non-English ooo

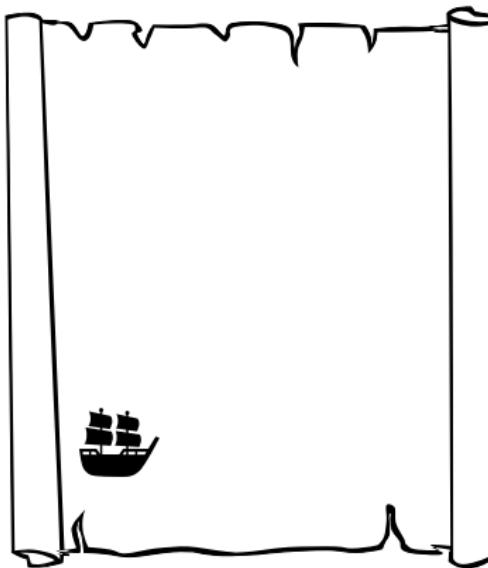
## Artifact Parameters

## Conclusion

## References

# Analogy

# Maps of the Sea



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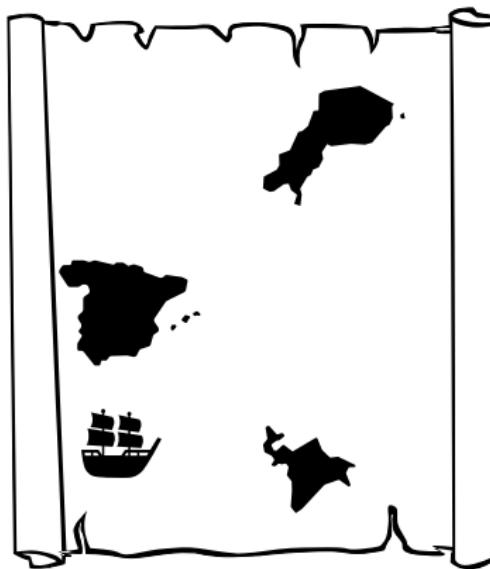
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# Maps of the Sea



## Motivation



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## Citations & Non-English ooo

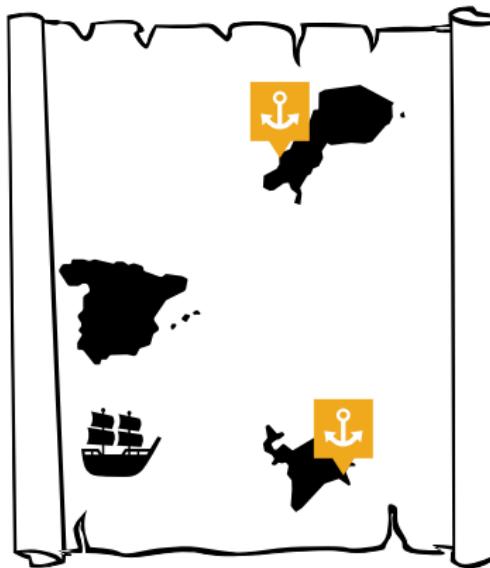
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# Maps of the Sea



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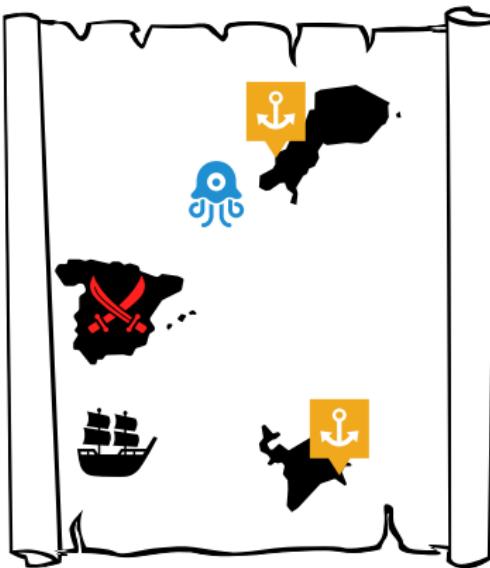
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# Maps of the Sea



## Motivation



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## Citations & Non-English ooo

## Artifact Parameters

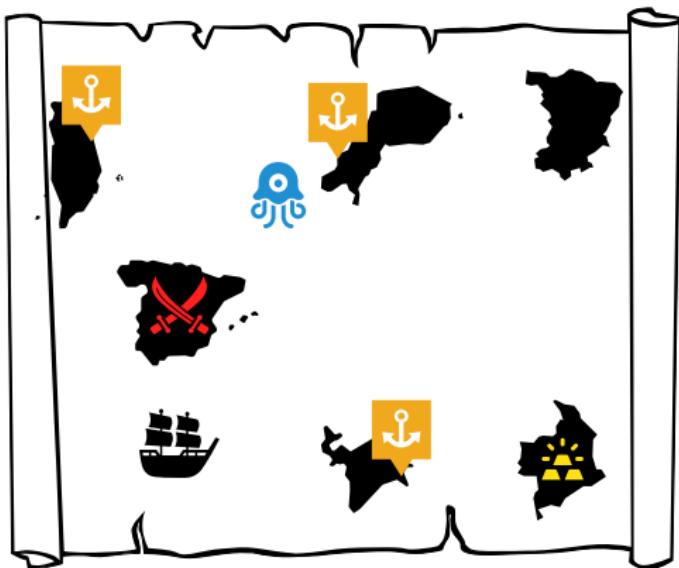


## Conclusion

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## References

# Maps of the Sea



## Motivation



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## Citations & Non-English ooo

## Artifact Parameters



## Conclusion

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## References

# Maps of the Sea / Maps of Science

## The Sailor looks for

- Port to trade
- Island to explore

## The Scientist looks for

- Paper to read
- Venue to publish at
- Research idea to explore

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# Maps of the Sea / Maps of Science

## The Trade Company looks for

- Routes to expand
- Ports to build
- Sailor to hire

## The University/Funding Body looks for

- Research to fund
- Researcher to hire
- Policy to establish

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# Maps of the Sea / Maps of Science

**The Trade Company** looks for

- Routes to expand
- Ports to build
- Sailor to hire

**The University/Funding Body** looks for

- Research to fund
- Researcher to hire
- Policy to establish

**better maps ⇒ better decisions**

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**The Trade Company** looks for

- Routes to expand
- Ports to build
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**The University/Funding Body** looks for

- Research to fund
- Researcher to hire
- Policy to establish

**false maps ⇒ misleading/false analyses, models, etc.**

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# Maps of the Sea / Maps of Science

**The Trade Company** looks for

- Routes to expand
- Ports to build
- Sailor to hire

**The University/Funding Body** looks for

- Research to fund
- Researcher to hire
- Policy to establish

**our maps of science are insufficient**

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# Maps of the Sea / Maps of Science

**The Trade Company** looks for

- Routes to expand
- Ports to build
- Sailor to hire

**The University/Funding Body** looks for

- Research to fund
- Researcher to hire
- Policy to establish



## Research Objective

Develop methods for generating large-scale, high quality scholarly data.

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Data Mining and Information Extraction Methods  
for **Large-Scale High Quality**  
Representations of Scientific Publications

# Maps of Science



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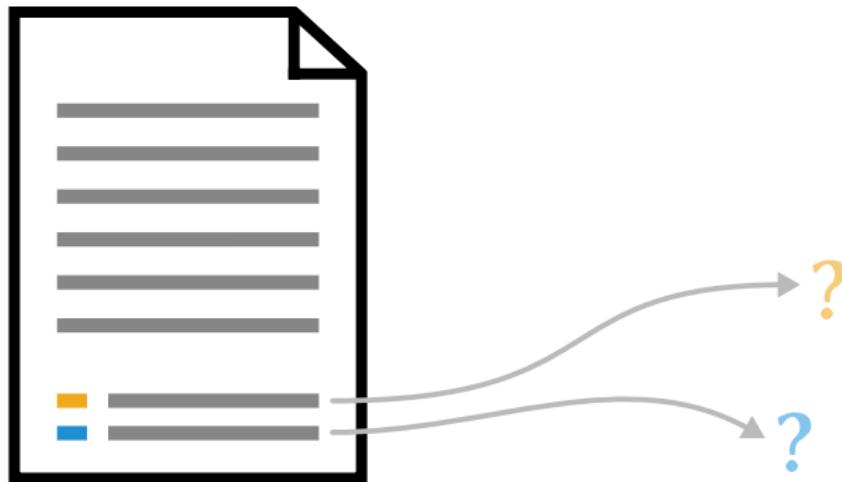
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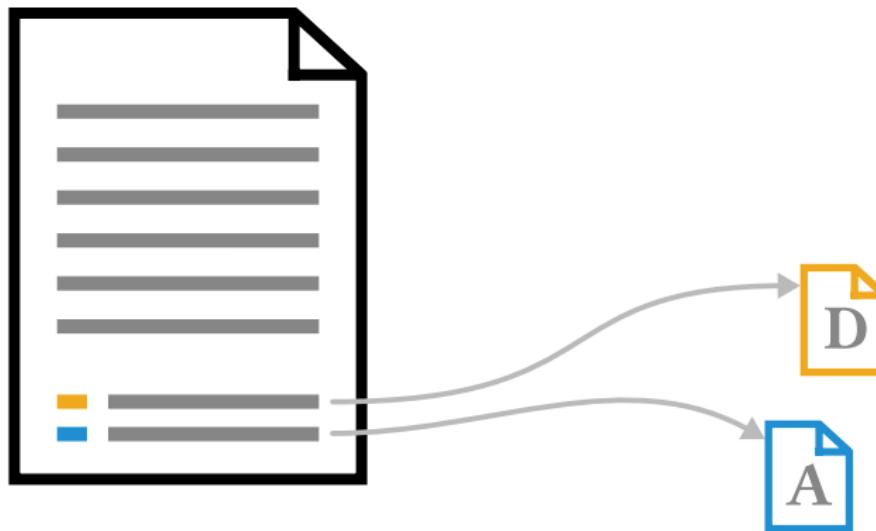
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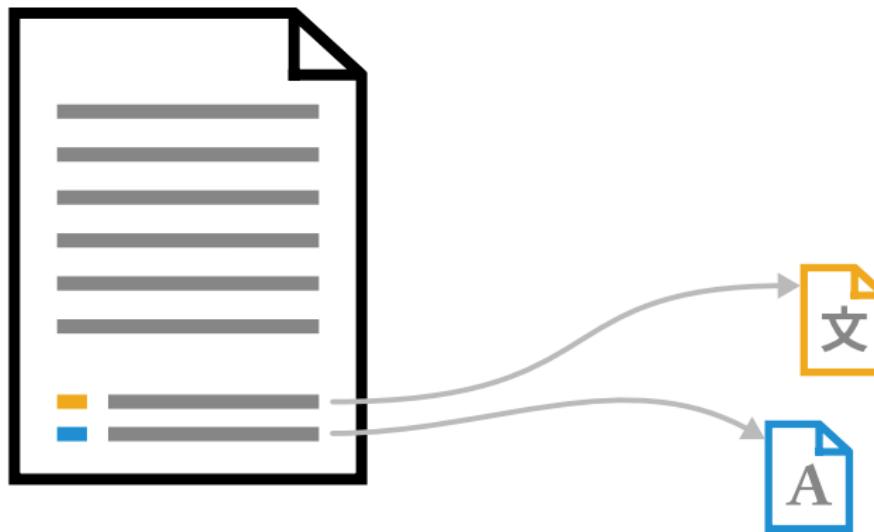
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# Maps of Science



use ABC [2] with  
 $\alpha$  set to  $1 \times 10^{-5}$  ...



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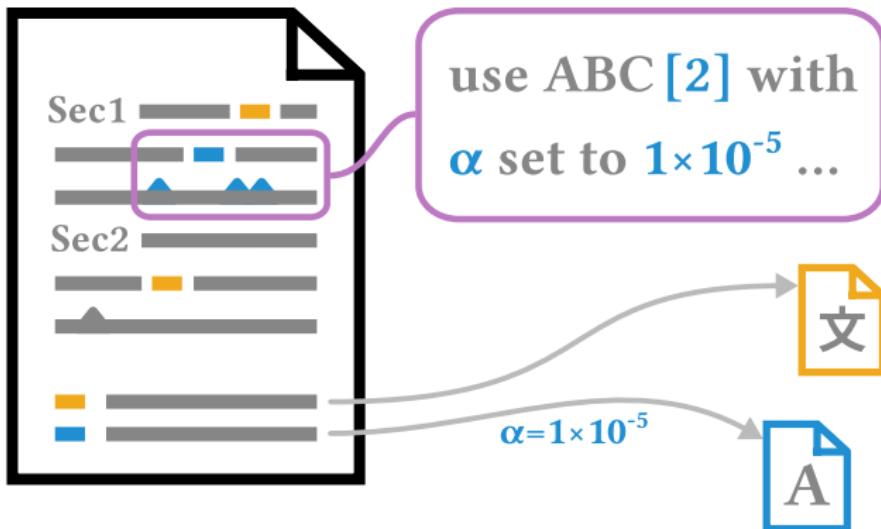
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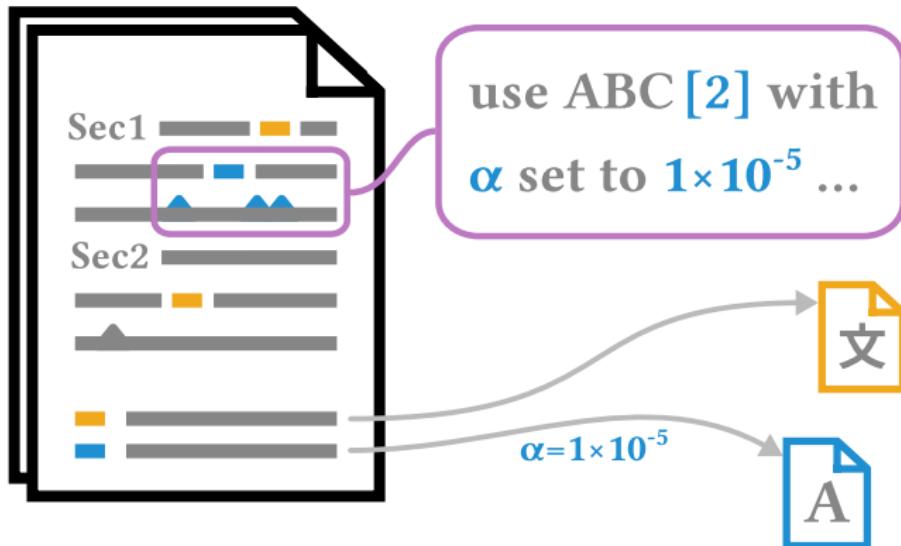
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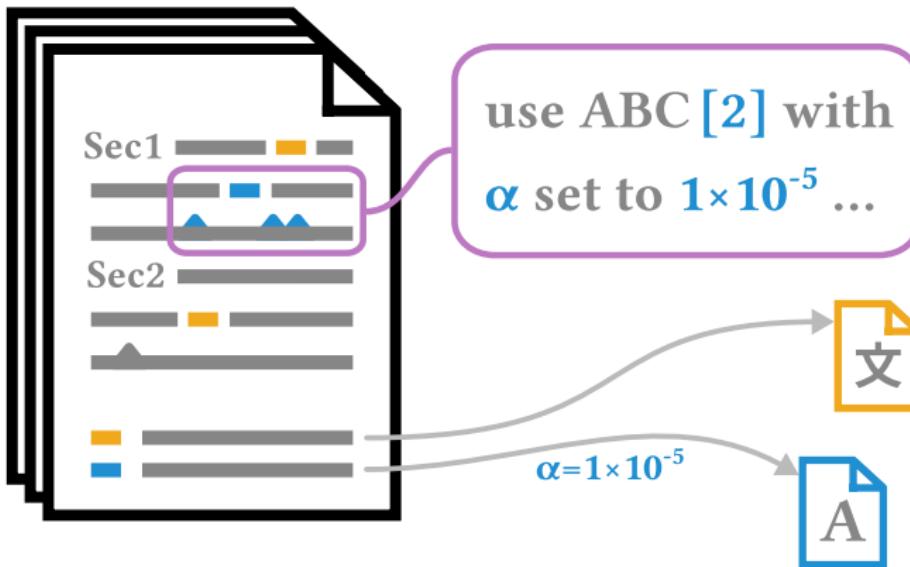
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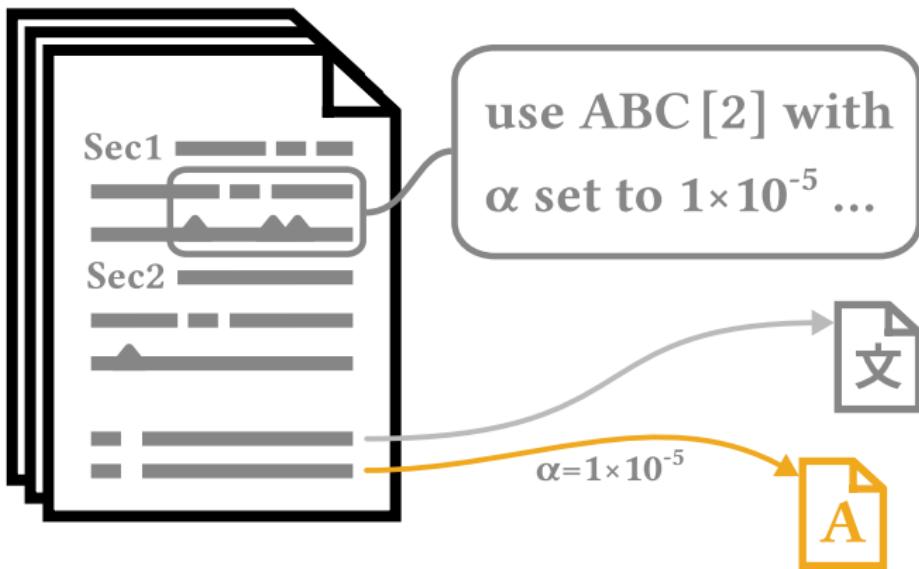
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# Research Gap: Citation Network



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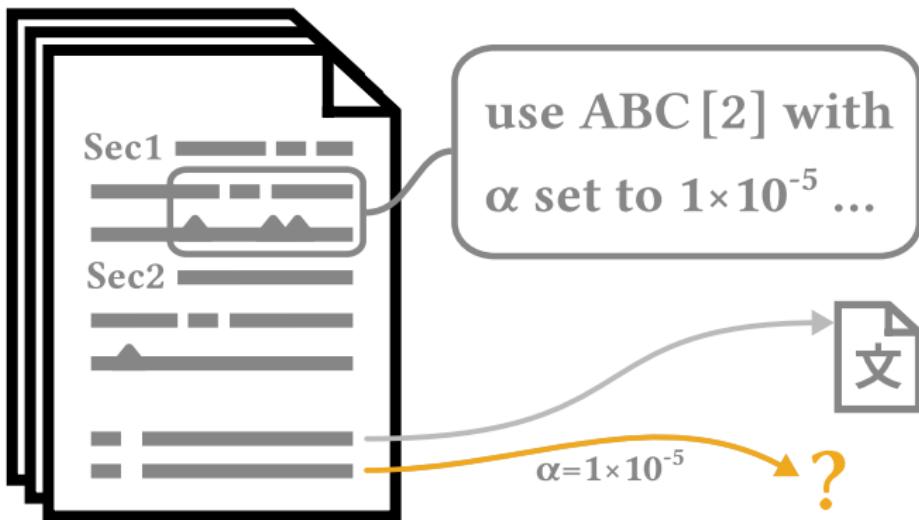
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# Research Gap: Citation Network



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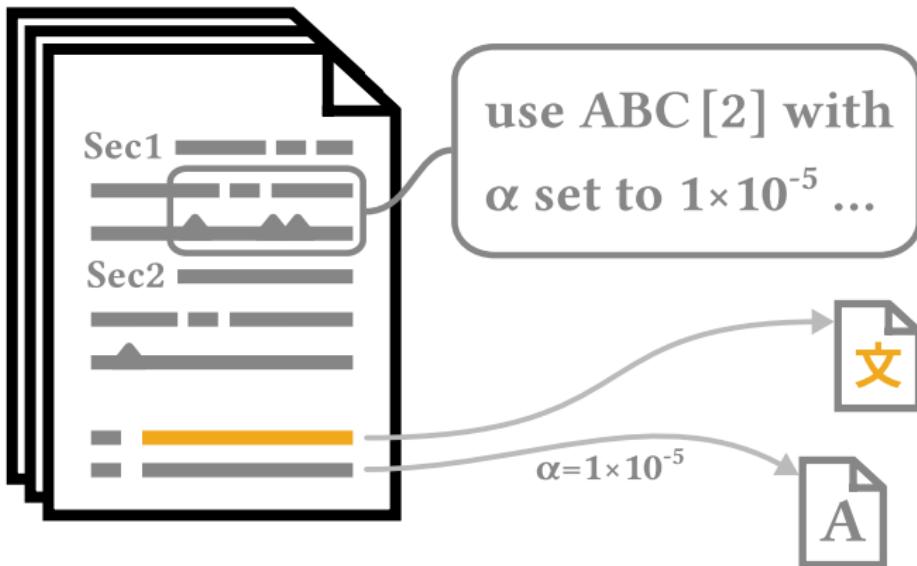
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# Research Gap: Non-English Documents



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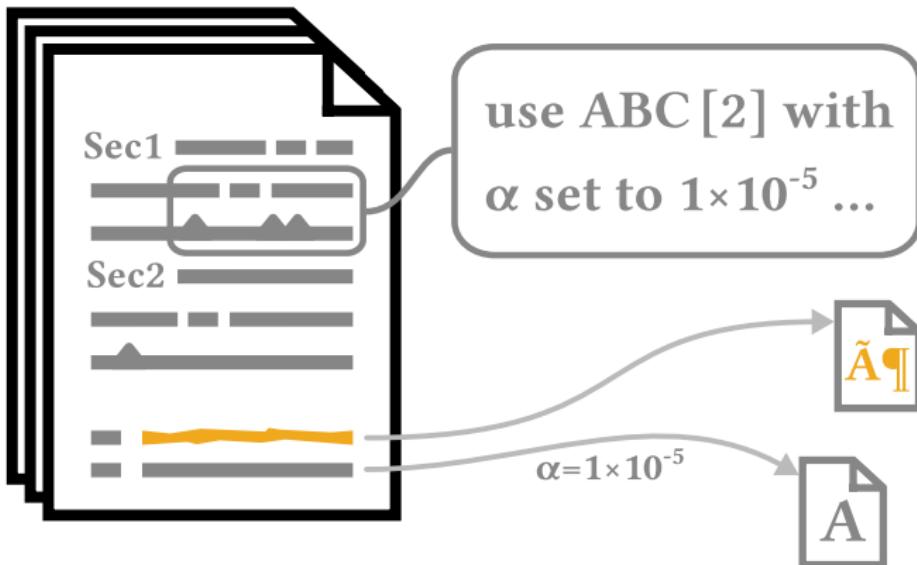
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# Research Gap: Non-English Documents



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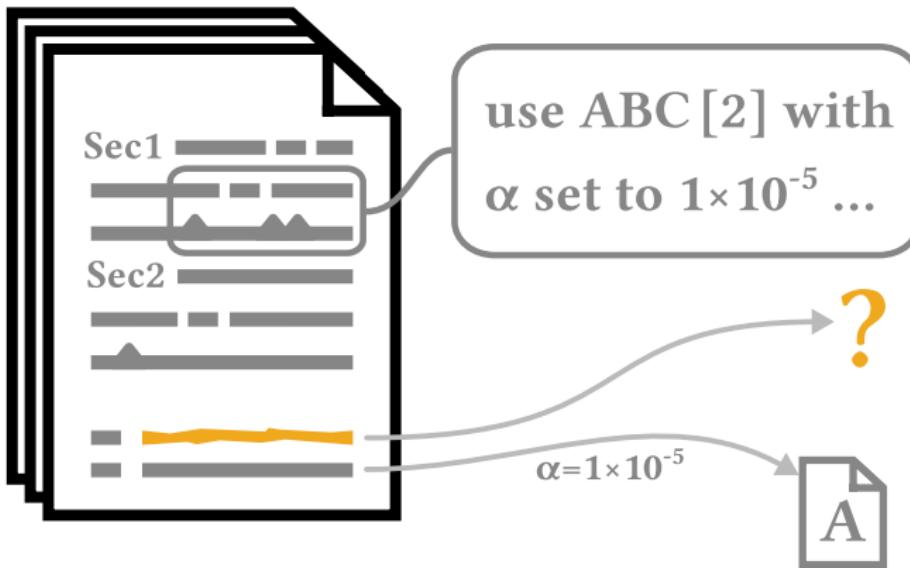
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# Research Gap: Non-English Documents



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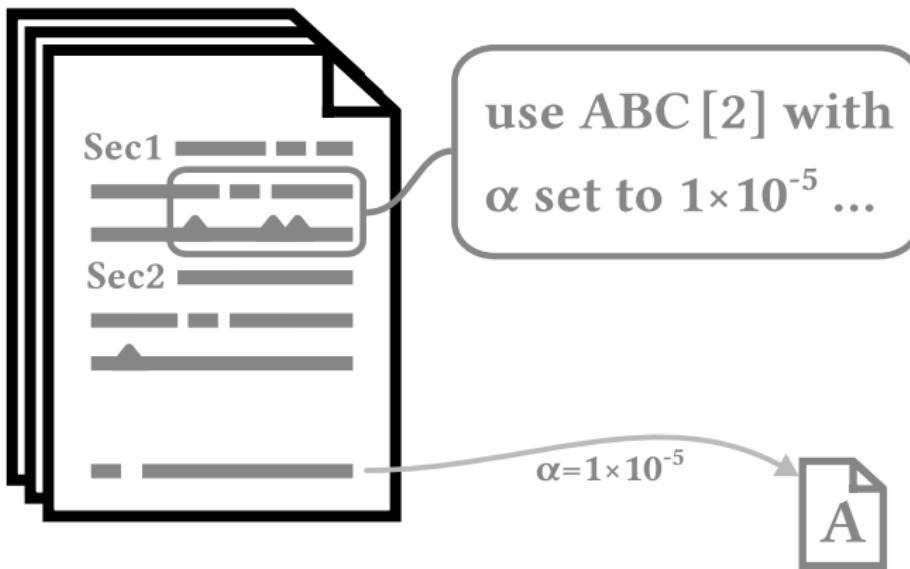
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# Research Gap: Non-English Documents



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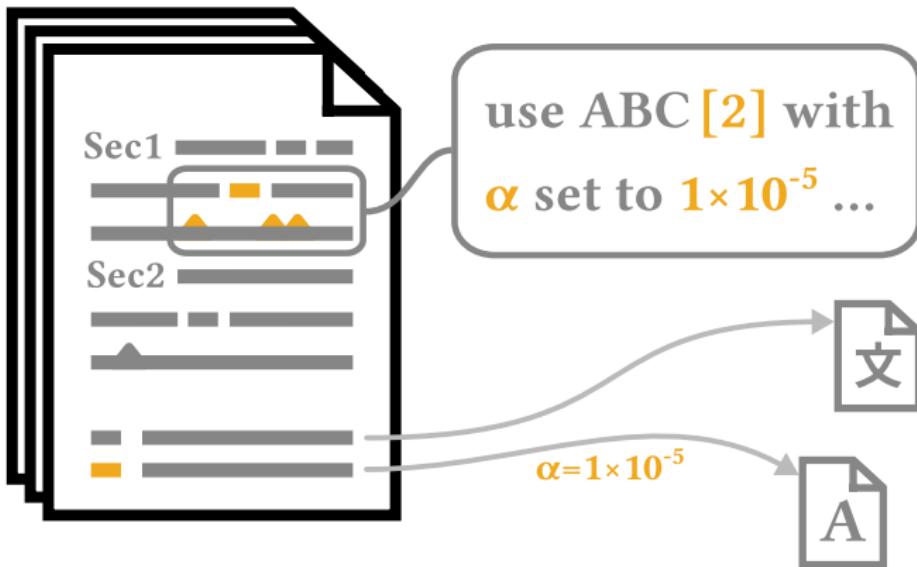
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# Research Gap: Artifact Parameters



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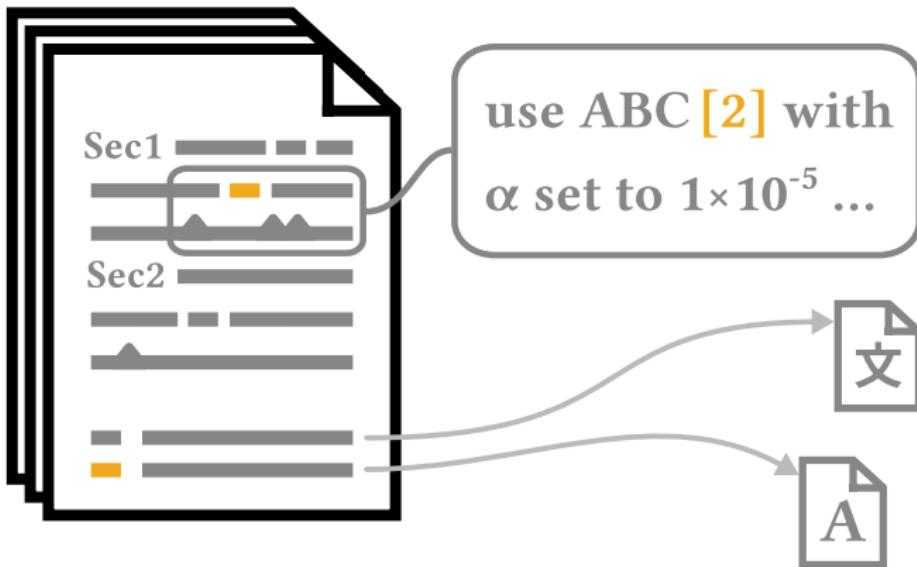
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# Research Gap: Artifact Parameters



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# **Data Mining and Information Extraction Methods**

## for Large-Scale High Quality Representations of Scientific Publications



## Research Objective



## Research Objective

Research Gap



## Research Objective

Base

RT1: Corpus

Research Gap

RT2: Citations

RT3: Non-English

RT4: Artifacts



## Research Objective



Data Quality

Base

RT1: Corpus

Research Gap

RT2: Citations

RT3: Non-English

RT4: Artifacts



## Research Objective



Base

Research Gap

RT1: Corpus

RT2: Citations

RT3: Non-English

RT4: Artifacts

Data Quality





## Research Objective



### Data Quality

#### Base

#### Research Gap

##### RT1: Corpus

##### RT2: Citations

##### RT3: Non-English

##### RT4: Artifacts



✓ | X



✓ | X



✓ | X



✓ | X



✓ | X

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✓ | X



## Research Objective



Data Quality



### Base

#### RT1: Corpus

- ① conversion and linking pipeline
- ② extensive corpus analysis

[Scientometrics'20]

#### RT2: Citations

- ① improved corpus pipeline
- ② blocking method for reference linking

[ULITE'22]  
[JCDL'23]

### Research Gap

#### RT3: Non-English

- ① extraction method for cross-lingual cit.
- ② extensive citation analysis

[ICADL'20]  
[IJDL'22]

#### RT4: Artifacts

- ① novel IE task and data set
- ② IE model development and eval.

[ECIR'24]



## Research Objective



Data Quality



### Base

#### RT1: Corpus

- ① conversion and linking pipeline
- ② extensive corpus analysis

[Scientometrics'20]

### Research Gap

#### RT2: Citations

- ① improved corpus pipeline
- ② blocking method for reference linking

[ULITE'22]  
[JCDL'23]

#### RT3: Non-English

- ① extraction method for cross-lingual cit.
- ② extensive citation analysis

[ICADL'20]  
[IJDL'22]

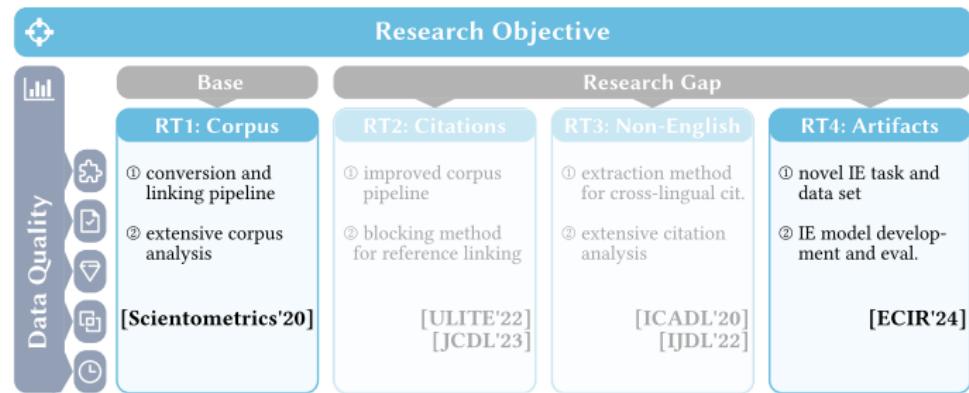
#### RT4: Artifacts

- ① novel IE task and data set
- ② IE model development and eval.

[ECIR'24]

# Outline

- **Corpus**
  - Challenges
  - Methods
  - Resulting Corpus
- **Citation Network**
- **Non-English Documents**
- **Artifact Parameters**
  - Task Definition
  - Methods
  - Results
- **Conclusion**
  - Contributions
  - Impact



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# **Corpus**

**unarXive**

# Corpus - Digest

## ■ Research Task

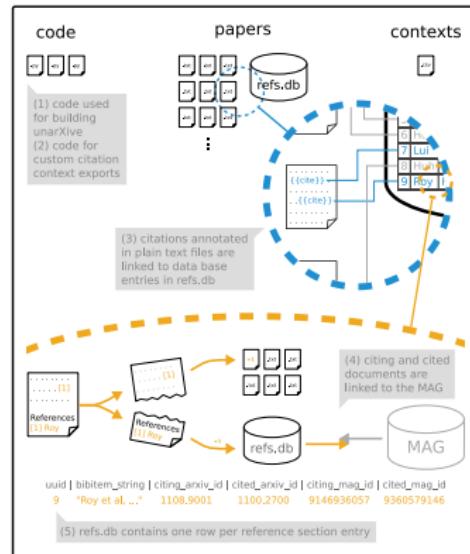
Develop a method for creating large-scale, high quality “base corpus”

## ■ Method

- L<sup>A</sup>T<sub>E</sub>X as data source
- Joint handling of text + references
- Reference parsing + linking to metadata records

## ■ Results

- Corpus among 3 largest full-text corpora
- More extensive, complete, less noisy
- State of the art citation network



Scientometrics'20 [1]

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# Corpus - Challenges

## ■ General

- Volume ( $\sim 10^6$  docs,  $\sim 10^7$  refs)
- Bridging visual medium and text information

## ■ Parsing

- Parser efficiency
- Typesetting info  $\neq$  semantic info
- $\text{\LaTeX}$  is powerful and people are creative

## ■ Reference linking

- Choice of target set
- Parsing (bb1, not bib)
- Variance and information sparsity

```
% Bonnet et al., 2001
\begin{document}
\newcommand{\nc}{\newcommand}
\nc{\be}{\begin{equation}}
```

[4] Jaume, S.C. and Sykes, L.R., Pure and Applied Geophysics **155**, 279-305.



Jaume, S.C. and L.R. Sykes, Evolving Towards a Critical Point: A Review of Accelerating Seismic Moment/Energy Release Prior to Large and Great Earthquakes, Pure Appl. Geophys., 155, 279, 1999.

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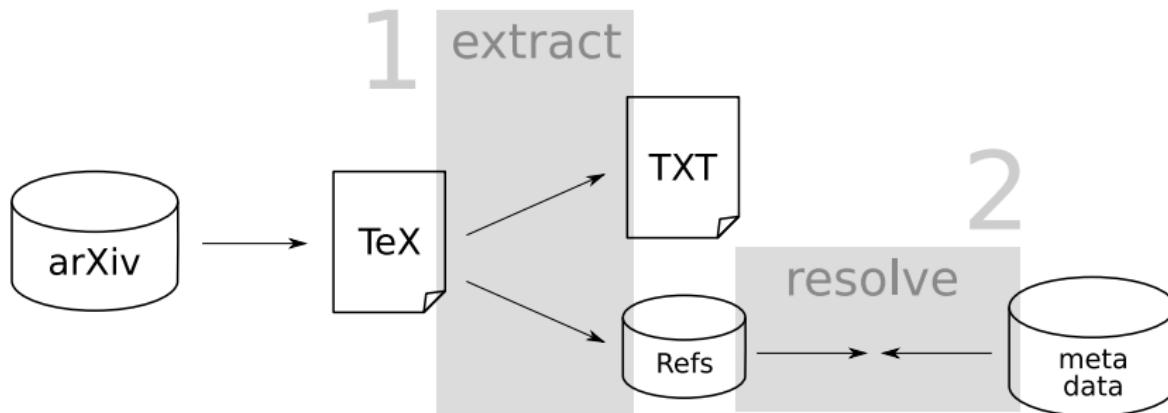
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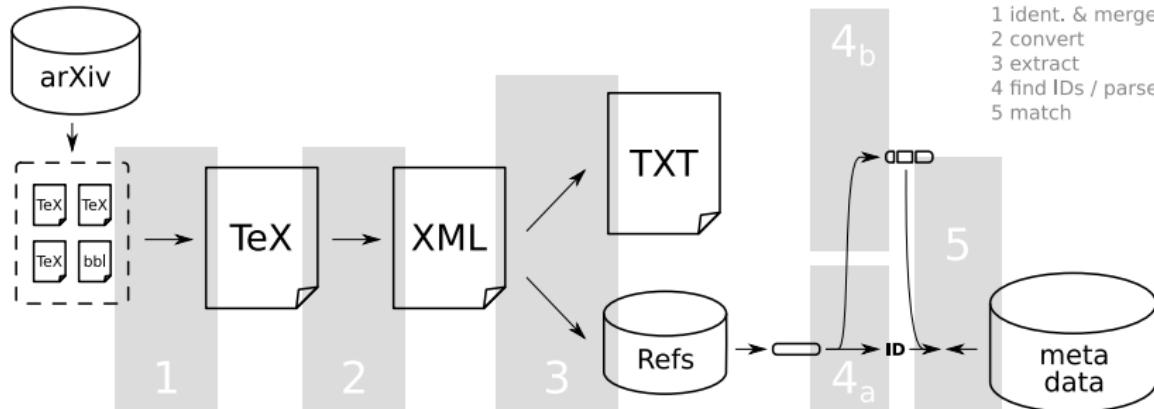
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# Corpus - Methods



# Corpus - Methods



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# Corpus - Result

## ■ Size

- 1.2 M documents (2.7 M cited)
- 16 M references
- 29 M in-text citation markers

## ■ Scope

- 1991–2018 (current: 2022)
- physics (63%), maths (23%), CS (11%), other (3%)

## ■ Reference matching

- 53% by parsing + matching
- 28% by DOI
- 19% by arXiv ID

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# Corpus - Result

| Data Set                    | # Docs       | Cit. Markers | Linked             | Link Succ.   | Link Acc.  |
|-----------------------------|--------------|--------------|--------------------|--------------|------------|
| ACL-ARC [2]                 | 11 k         | ×            | ×                  | n/a          | n/a        |
| ACL-AAN [3]                 | 18 k         | ×            | ×                  | n/a          | n/a        |
| Scholarly Dataset 2 [4]     | 100 k        | ×            | ×                  | n/a          | n/a        |
| CiteSeerX [5] / RefSeer [6] | 1 M          | ambiguous    | ×                  | n/a          | n/a        |
| PMC OAS [7]                 | <b>2.3 M</b> | exact        | mixed <sup>a</sup> | -            | -          |
| arXiv CS [8]                | 90 k         | exact        | ✓                  | 39.3%        | -          |
| <b>unarXive [1]</b>         | 1.2 M        | exact        | ✓                  | <b>42.6%</b> | <b>96%</b> |

<sup>a</sup> No citation network due to mixed set of IDs (PubMed, MEDLINE, DOI) [9].

# Corpus - Result (2022)

| Data Set                       | # Docs       | Cit. Markers | Linked             | Link Succ.   | Link Acc.  |
|--------------------------------|--------------|--------------|--------------------|--------------|------------|
| arXMLiv [12]                   | 1.6 M        | exact        | ✗                  | n/a          | n/a        |
| PMC-OAS [7]                    | <b>3.3 M</b> | exact        | mixed <sup>a</sup> | -            | -          |
| SciXGen [13]                   | 205 k        | exact        | ✓                  | 41.6%        | -          |
| S2ORC ( $\text{\LaTeX}$ ) [11] | 1.5 M        | exact        | ✓                  | 31.1%        | 92%        |
| <b>unarXive 2022 [14]</b>      | 1.9 M        | exact        | ✓                  | <b>44.4%</b> | <b>96%</b> |

<sup>a</sup> No citation network due to mixed set of IDs (PubMed, MEDLINE, DOI) [9].

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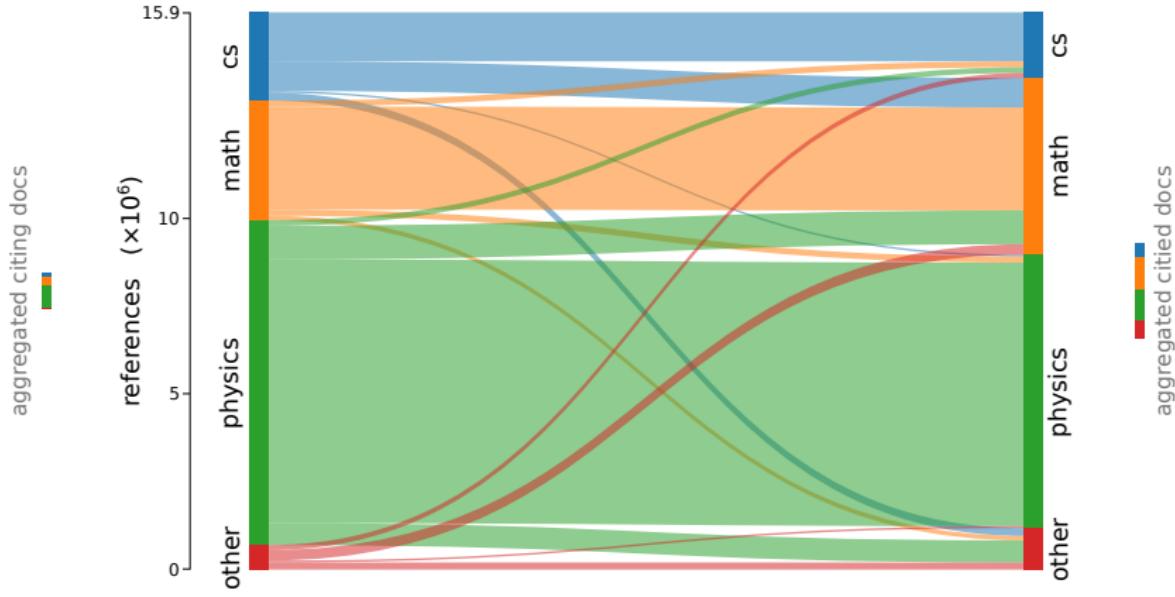
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# Corpus - Citation Flow



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# Corpus - Conclusion

## ■ Advancements

- More extensive
  - single domain vs multi domain
- More complete, high quality citation network
  - 13.3% increase in linked references ( $\leftrightarrow$  S2ORC<sub>LATEX</sub>)
  - 4% more accurate reference links ( $\leftrightarrow$  S2ORC<sub>LATEX</sub>)
- Less noise due to LATEX as source
- Novel types of analyses possible

## ■ Foundation for further studies

- →  RT1 ✓

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# **Citations & Non-English**

# Citation Network - Digest

## ■ Research Task

Develop a method linking references more successfully without compromising accuracy

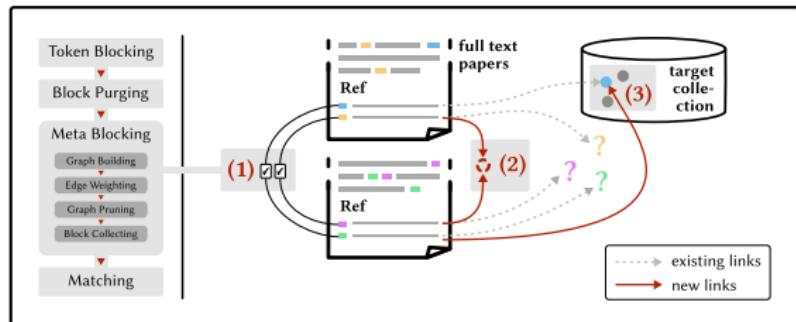
## ■ Method

- Use unarXive data
- Improved reference linking pipeline  
(parser & target set choice, heuristics)
- Blocking & matching within set of references

## ■ Results

- +2% in base matching success (SOTA)
- Manifold increase in bibl. couplings

■ →  RT2✓



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References

# Non-English Documents - Digest

## ■ Research Task

Develop an approach to include non-English publications into large-scale scholarly data

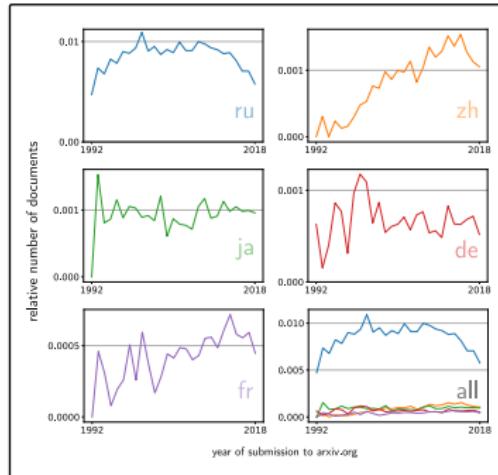
## ■ Method

- Use unarXive data
- Identify cross-lingual citations by reference strings
- Temporal and geographic analyses

## ■ Results

- Reliable method for identification
- Largest study so far ( $<1k \rightarrow >1M$ )
- Identification of trends and challenges

## ■ → RT3✓



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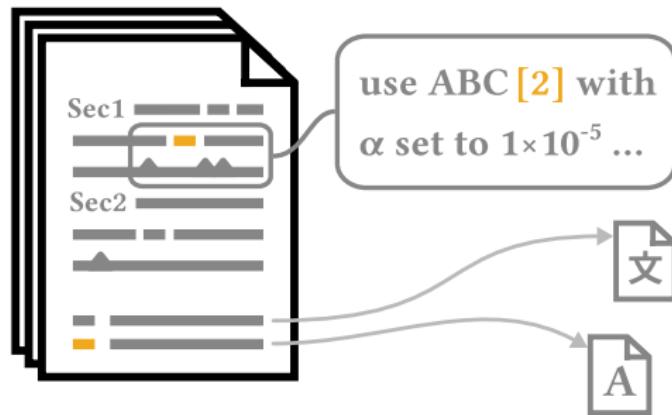
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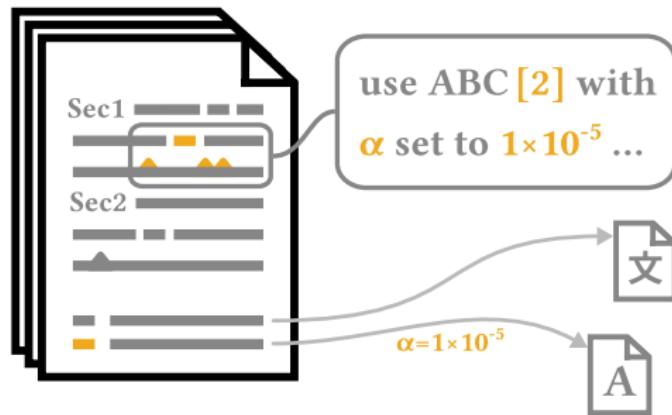
References

# **Artifact Parameters**

# Artifact Parameters

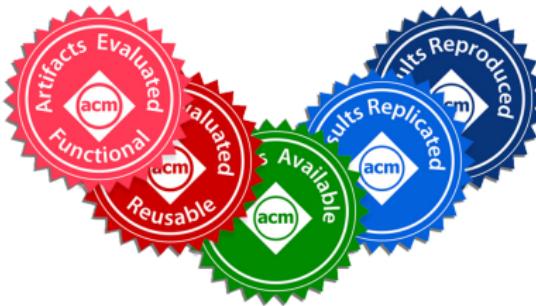


# Artifact Parameters



# Artifact Parameters - Motivation

The image shows two screenshots of scientific platforms. On the left, the D4Science homepage displays a "Trending Research" section featuring a paper titled "Visual Autoregressive Modeling: Scalable Image Generation via Next-Scale Prediction". The paper has 1,386 citations and was published by FoundationVision/VRL on April 3, 2024. It includes links to the paper and code. On the right, the "Dataset Search" interface from Google shows a search bar with the placeholder "Search for Datasets" and a link to "Learn more about Dataset Search".



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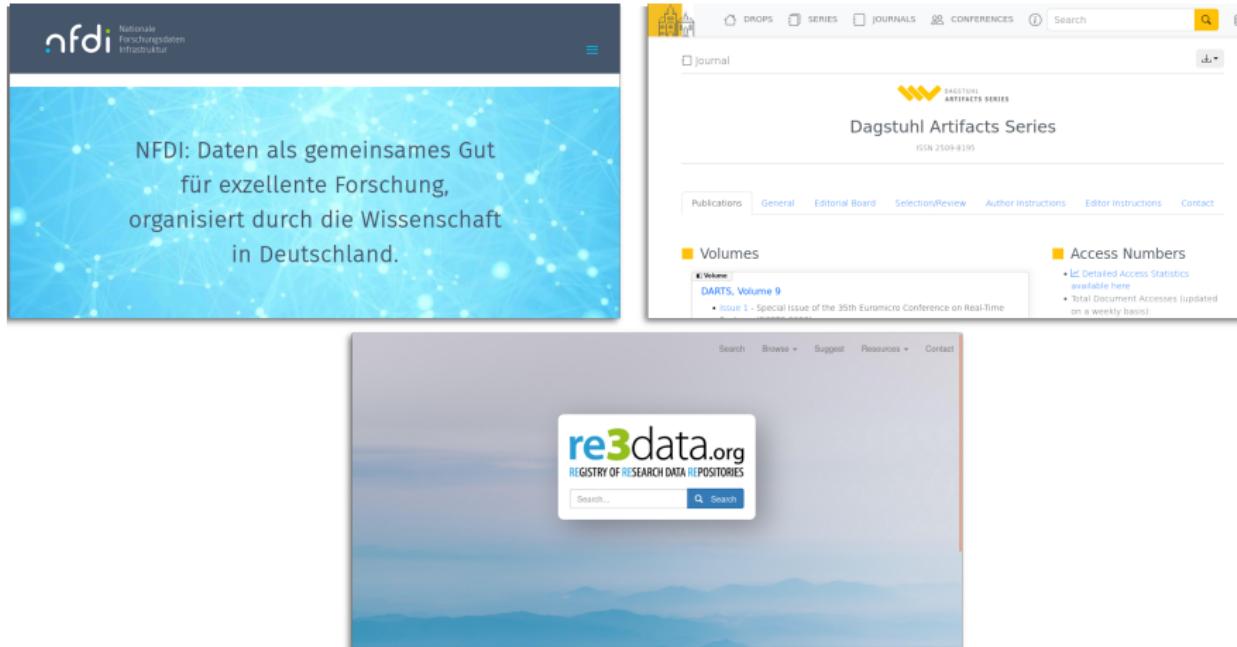
Citations & Non-English  
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# Artifact Parameters - Motivation



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# Artifact Parameters - Motivation

NLP field increasing focus on **data** and its **algorithmic processing**

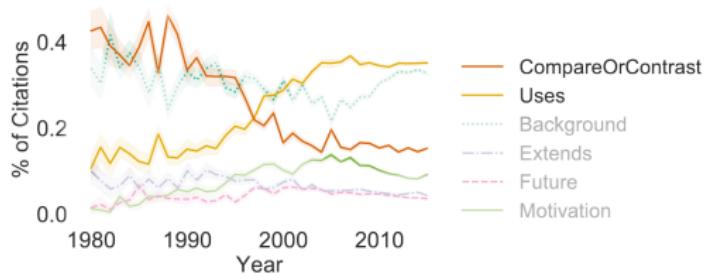


Figure 5: Changes in the average citation frame in ACL papers reveals a continued decline in the percentage of COMPARISON OR CONTRAST and increase in USES citations. The increase in BACKGROUND citations circa 2010 marks the start of the era of unlimited references in ACL conferences. Shaded regions show bootstrapped 95% confidence intervals.

Jurgens, D. et al. Measuring the Evolution of a Scientific Field through Citation Frames. *Transactions of the Association for Computational Linguistics* 6, 391–406 (2018)

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# Artifact Parameters - Digest

## ■ Research Task

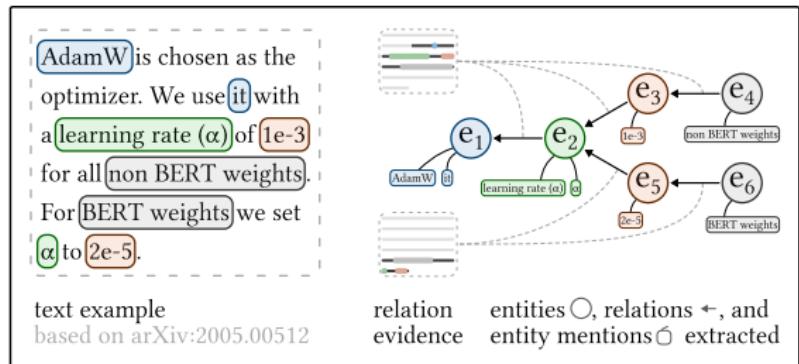
Develop a method to extract fine-grained research artifacts information

## ■ Method

- Task formalization
- Data annotation (data from unarXive)
- Two lines of approaches
  - BERT based model approach
  - LLM based approach

## ■ Results

- Novel task, novel data
- Improvements over SOTA baselines
- Methods applicable to large data sets



ECIR'24 [20]

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References

# Artifact Parameters - Task

AdamW is chosen as the optimizer. We use it with a learning rate ( $\alpha$ ) of 1e-3 for all non BERT weights. For BERT weights we set  $\alpha$  to 2e-5.

text example  
based on arXiv:2005.00512

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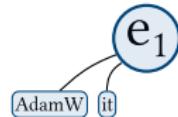
Artifact Parameters  
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References

# Artifact Parameters - Task

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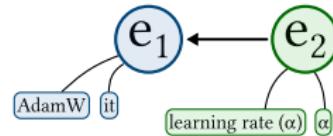


text example  
based on arXiv:2005.00512

entity type  
artifact

# Artifact Parameters - Task

AdamW is chosen as the optimizer. We use it with a learning rate ( $\alpha$ ) of 1e-3 for all non BERT weights. For BERT weights we set  $\alpha$  to 2e-5.



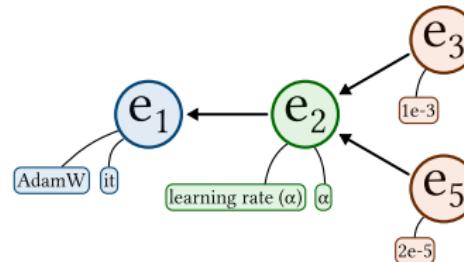
text example  
based on arXiv:2005.00512

entity type  
artifact parameter

# Artifact Parameters - Task

AdamW is chosen as the optimizer. We use it with a learning rate ( $\alpha$ ) of  $1e-3$  for all non BERT weights. For BERT weights we set  $\alpha$  to  $2e-5$ .

text example  
based on arXiv:2005.00512

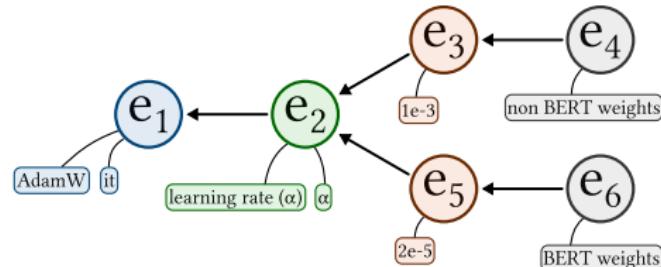


entity type  
artifact parameter value

# Artifact Parameters - Task

AdamW is chosen as the optimizer. We use it with a learning rate ( $\alpha$ ) of  $1e-3$  for all non BERT weights. For BERT weights we set  $\alpha$  to  $2e-5$ .

text example  
based on arXiv:2005.00512



entity type  
artifact parameter value context

# Artifact Parameters - Related Work

## ■ Fine-tuned Models

- SciERC dataset [21]
- SOTA: PL-Marker [22]  
→ **entity type overlap**

## ■ LLMs

- Mostly singular values/lists [24–26]
- Hierarchical [27] (see right)  
→ **data serialization format**

We evaluate our model on the task of **question answering** using

### Section : Dataset

SQuAD is a **machine comprehension** dataset on a large set of Wikipedia articles , .... . Two metrics are used to evaluate models: **Exact Match ( EM )** and a softer metric , **F1 score** .....

### Section: Model Details .

... Each paragraph and question are tokenized by a regular - expression - based word tokenizer ( **PTB Tokenizer** ) and fed into the model .  
....

### Section : Results .

The results of our model and competing approaches on the hidden test are summarized in Table [ reference ]. **BiDAF ( ensemble )** achieves an **EM** score of 73.3 and an **F1**-score of 81.1, outperforming all previous approaches .

# Artifact Parameters - Related Work

## ■ Fine-tuned Models

- SciERC dataset [21]
- SOTA: PL-Marker [22]
- **entity type overlap**

## ■ LLMs

- Mostly singular values/lists [24–26]
- Hierarchical [27] (see right)
- **data serialization format**

Note: all related LLM work is evaluated on **GPT models only**.

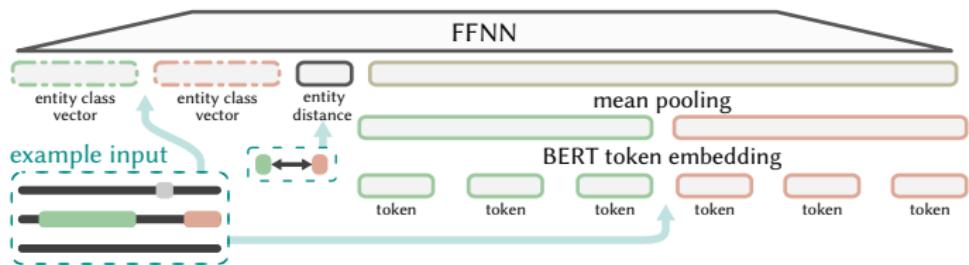
**Document:** The charge and discharge performance of an all-solid-state lithium battery with the LiBH4-LiI solid solution as an electrolyte is reported. Lithium titanate (Li<sub>4</sub>Ti<sub>5</sub>O<sub>12</sub>) was used as the positive electrode and...

List of json documents

```
[ { "formula": "LiBH4-LiI", "description": "solid solution", "application": ["Li-ion battery", "electrolyte"] }, { "name": "lithium titanate", "formula": "Li4Ti5O12", "application": ["Li-ion battery", "positive electrode"] } ]
```

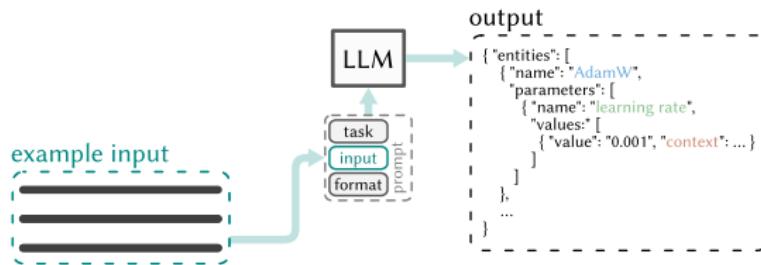
# Approach: Fine-tuned models

- Based on PL-Marker (SciERC SOTA)
- (N)ER: used as is
- RE: new module, utilizing
  - Entity class embeddings
  - Entity distance



# Approach: LLMs

- Data serialization format
  - JSON → YAML
- Compare 6 models
- Base prompt + tuning for each
- Zero-shot: all
- Few-shot: only Vicuna<sub>16k</sub>



# Approach: LLMs

- Data serialization format
  - JSON → YAML
- Compare 6 models
- Base prompt + tuning for each
- Zero-shot: all
- Few-shot: only Vicuna<sub>16k</sub>

| Model                      | Size  |
|----------------------------|-------|
| WizardLM [28]              | 13 B  |
| Vicuna <sub>4k</sub> [29]  | 13 B  |
| Vicuna <sub>16k</sub> [29] | 13 B  |
| Falcon [30]                | 40 B  |
| GALACTICA [31]             | 120 B |
| GPT-3.5 [32]               | 175 B |

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## Artifact Parameters - Data

- No existing data sets  
→ **use unarXive** ML/CV/CL/DL
  - Annotation approach
    - Paragraph level, whole papers
  - **Data Set Size**
    - 444 paragraphs
    - 1,971 entities
    - 614 relations
  - IAA
    - 0.867 for entities
    - 0.737 for relations
    - → **high quality**

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### Artifact Parameters

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# Artifact Parameters - Experiments: Fine-tuned models

## ■ Setting

- 5-fold cross-validation
- Stratified sampling

## ■ Results ( $F_1$ [%])

- ER: 78.0
- RE: 9.9 → 38.8

## ■ Analysis

- Parameter: low performance
- Contexts: not predicted

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# Artifact Parameters - Experiments: Fine-tuned models

## ■ Setting

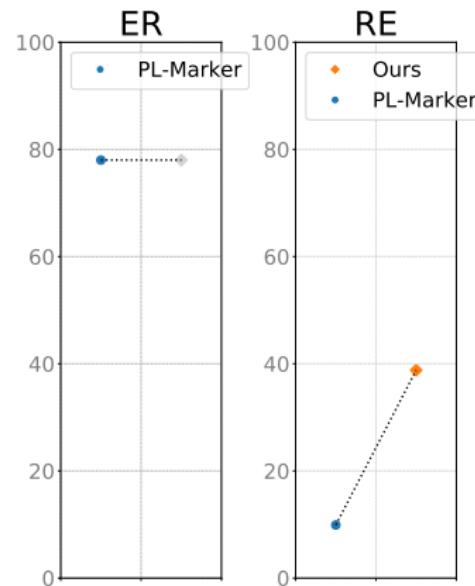
- 5-fold cross-validation
- Stratified sampling

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# Artifact Parameters - Experiments: Fine-tuned models

## ■ Setting

- 5-fold cross-validation
- Stratified sampling

## ■ Results ( $F_1$ [%])

- ER: 78.0
- RE: 9.9 → 38.8

## ■ Analysis

- Parameter: low performance
- Contexts: not predicted

Table: Ablation study results (model inputs are: T = BERT token embeddings, C = entity class embeddings, D = entity distance)

| Used       | P [%]       | R [%]       | $F_1$ [%]   |
|------------|-------------|-------------|-------------|
| $\neg CD$  | 15.5        | 8.8         | 11.1        |
| $T \neg D$ | 16.6        | 29.8        | 19.6        |
| $TC \neg$  | 26.5        | 65.0        | 35.5        |
| <b>TCD</b> | <b>30.7</b> | <b>65.0</b> | <b>38.8</b> |

# Artifact Parameters - Experiments: LLMs

## ■ Setting

- Zero-/Few-shot
- Compare JSON w/ YAML variant

## ■ Results (best F<sub>1</sub> [%]) (zero-shot)

- ER: 44.0 (37.4)
- RE: 7.8 (6.1)

## ■ Analysis

- Very low RE performance
- YAML: avg. +5% in ER
- Format adherence  
+ entity hallucinations

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# Artifact Parameters - Experiments: LLMs

## ■ Setting

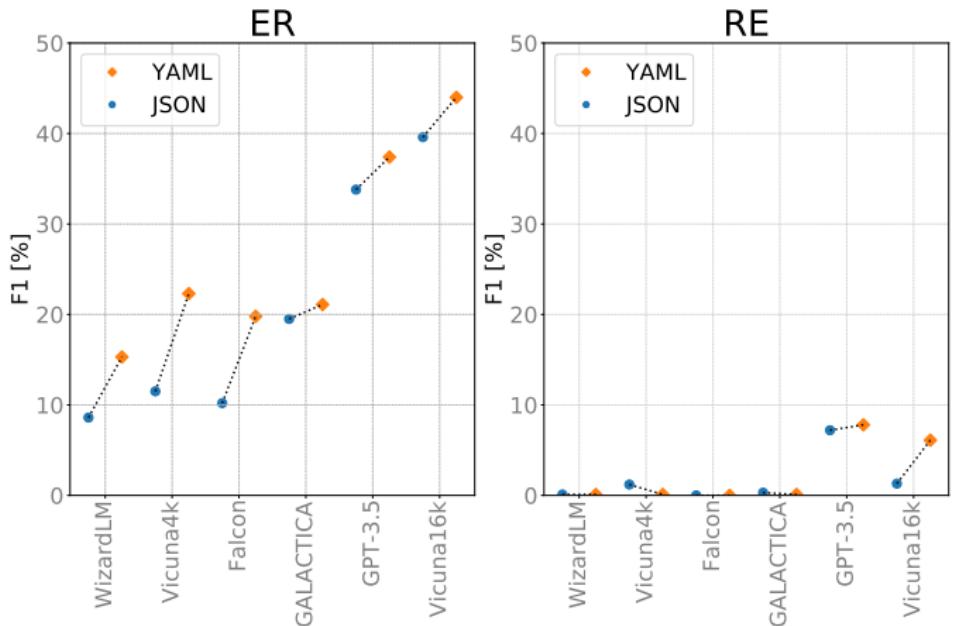
- Zero-/Few-shot
- Compare JSON w/ YAML variant

## ■ Results (best F<sub>1</sub> [%]) (zero-shot)

- ER: 44.0 (37.4)
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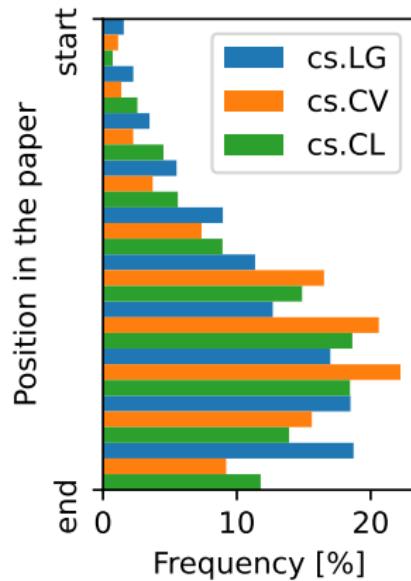
Artifact Parameters  
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References

# Artifact Parameters - Experiments: Application

- Apply best model (BERT based) on 15k paper sample
- Parameters information given in
  - 36% of ML papers
  - 42% of CV papers
  - 36% of CL papers
  - 7% of DL papers
- Distribution towards second half of paper across disciplines



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# Artifact Parameters - Conclusion

## ■ Advancements

- Novel, relevant task  
(data scheme, annotation guidelines)
- High quality manually annotated data set
- Approaches based on BERT, LLMs
  - BERT model based approach  
29%  $F_1$  increase for RE
  - LLM approach  
Avg. 5.5%  $F_1$  increase for ER  
(consistent across all used LLMs)
- Trained model applicable on large scale

■ →  RT4✓

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# **Conclusion**



## Research Objective



## Research Objective

Research Gap



## Research Objective

Base

RT1: Corpus

Research Gap

RT2: Citations

RT3: Non-English

RT4: Artifacts



## Research Objective

### Base

#### RT1: Corpus

- ① conversion and linking pipeline
- ② extensive corpus analysis

[Scientometrics'20]

#### RT2: Citations

- ① improved corpus pipeline
- ② blocking method for reference linking

[ULITE'22]  
[JCDL'23]

### Research Gap

#### RT3: Non-English

- ① extraction method for cross-lingual cit.
- ② extensive citation analysis

[ICADL'20]  
[IJDL'22]

#### RT4: Artifacts

- ① novel IE task and data set
- ② IE model development and eval.

[ECIR'24]



## Research Objective

### Base

#### RT1: Corpus

- ① conversion and linking pipeline
- ② extensive corpus analysis

[Scientometrics'20]

#### RT2: Citations

- ① improved corpus pipeline
- ② blocking method for referent linking

[ULITE'22]  
[JCDL'23]

### Research Gap

#### RT3: Non-English

- ① extraction method for cross-lingual cit.
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[ICADL'20]  
[IJDL'22]

#### RT4: Artifacts

- ① novel IE task and data set
- ② IE model development and eval.

[ECIR'24]



## Research Objective



### Data Quality

#### Base

#### Research Gap

RT1: Corpus

RT2: Citations

RT3: Non-English

RT4: Artifacts



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## Research Objective ✓



Data Quality



Base

### RT1: Corpus

- ① conversion and linking pipeline
- ② extensive corpus analysis

[Scientometrics'20]

Research Gap

### RT2: Citations

- ① improved corpus pipeline
- ② blocking method for referentie linking

[ULITE'22]  
[JCDL'23]

### RT3: Non-English

- ① extraction method for cross-lingual cit.
- ② extensive citation analysis

[ICADL'20]  
[IJDL'22]

### RT4: Artifacts

- ① novel IE task and data set
- ② IE model development and eval.

[ECIR'24]

# Overall Conclusion

## ■ Research Objective

- Addressed research gaps in 3 areas of key importance
- All developed methods demonstrably applicable to large-scale data
- Comprehensive improvements of data quality

## ■ Impact on research community



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# Impact

Adoption by the research community.

## ■ Methodology

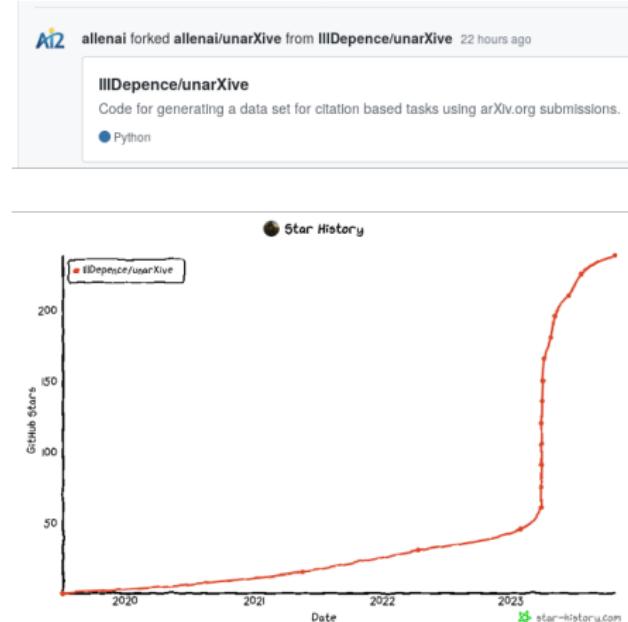
- Document Parsing Methodology [11]
- Reference Matching Methodology [13]

## ■ Model dev/eval

- Citation Recommendation [33]
- Document Retrieval [34]
- Researcher Profile Embeddings [35]

## ■ Analyses

- Interdisciplinary Citations [36]
- Citation Context Semantic Shifts [37]
- Obliteration by Incorporation [38]



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# Big Picture

Compared to others

- **S2ORC** (Allen AI)
  - larger
  - less granular (maths), more noisy (PDF)
- **arXMLiv** (FAU KWARC)
  - more structured
  - no citation network
- **ORKG** (TIB)
  - more rigorously semantic
  - smaller (manual/semi-automated input)



Our work combines (1) **accurate, fine-granular** document representations,  
(2) a **citation network**, and (3) applicability on a **large scale** due to being automated.

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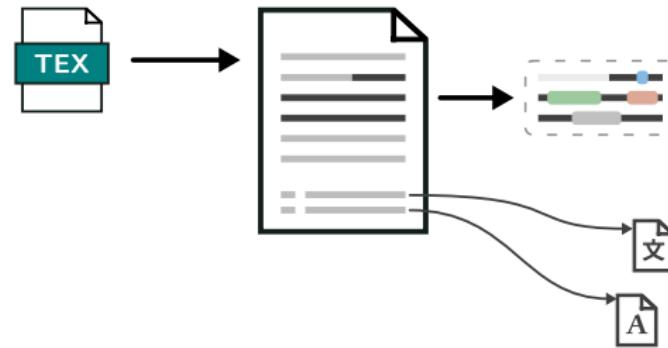
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# Outlook

- **Data Sources**
  - JATS-XML
- **Non-English Publications**
  - English citing docs
- **Artifact Parameters**
  - Applications
- **Long-term**
  - Digital record of science



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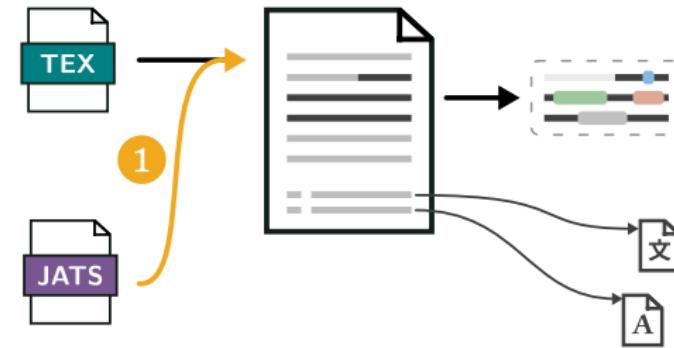
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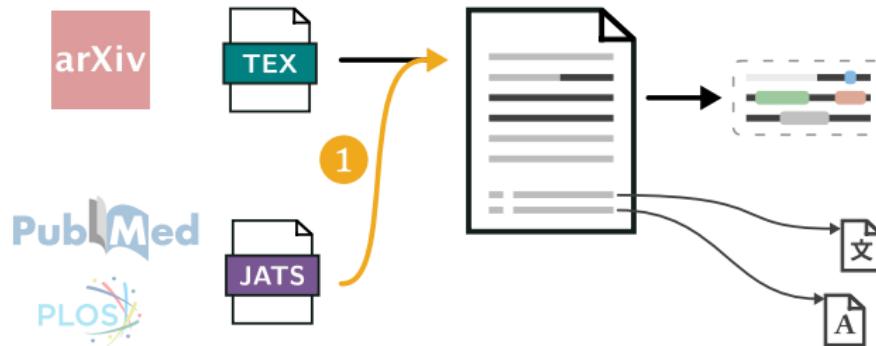
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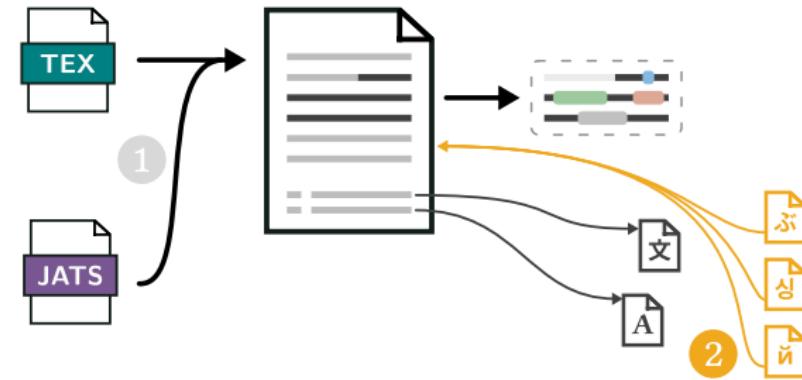
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# Outlook

- **Data Sources**
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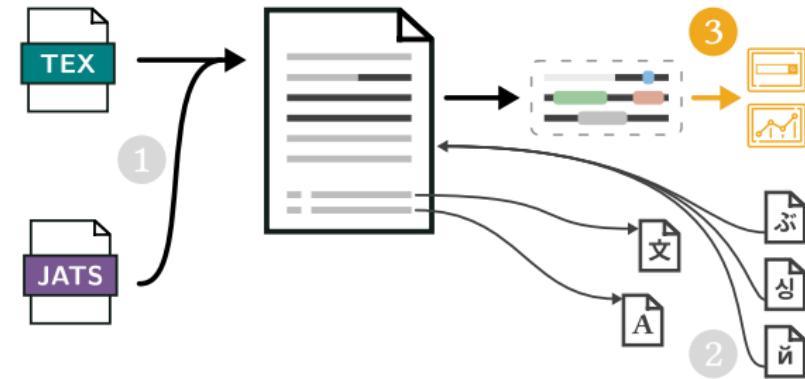
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- **Data Sources**
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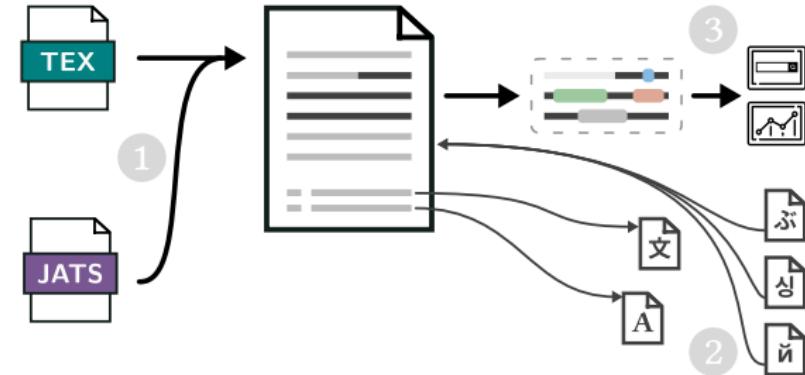
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References

**Thank You ☺**

**Questions   Discussion   Comments**

# References I

1. Saier, T. & Färber, M. unarXive: A Large Scholarly Data Set with Publications' Full-Text, Annotated In-Text Citations, and Links to Metadata. *Scientometrics* **125**, 3085–3108. ISSN: 1588-2861 (Dec. 2020).
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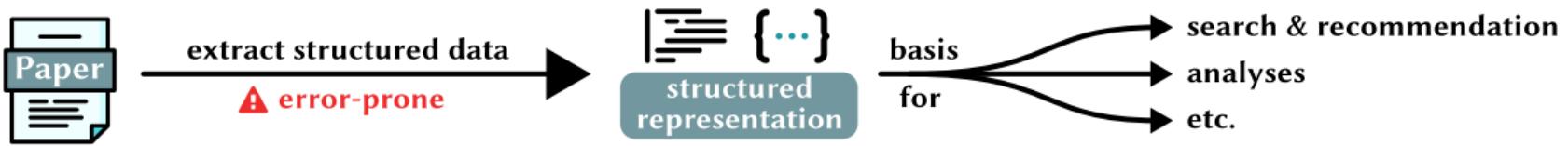
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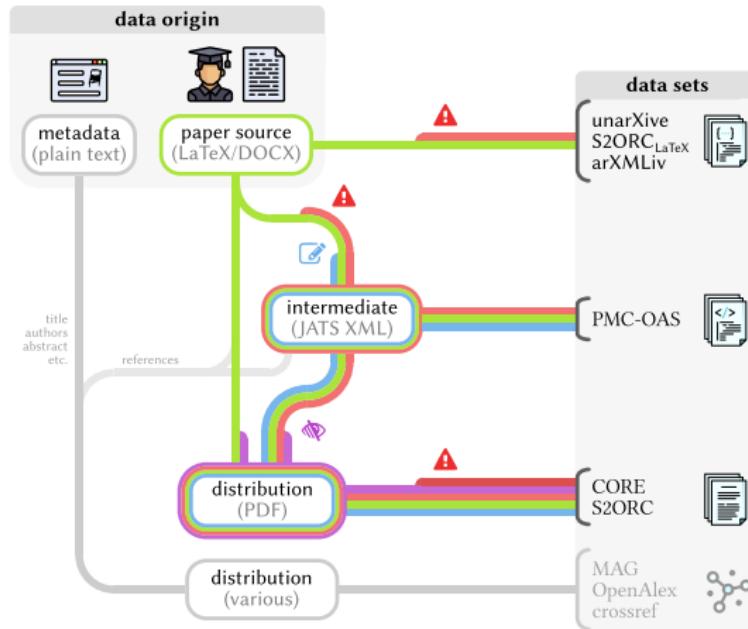
References

# **Extra Slides**

# Scholarly Data IE



# Scholarly Data Origins



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# Corpus - Result Full

| Data set                    | # Docs | Cit. markers | Disciplines      | Full text         | Linked             |
|-----------------------------|--------|--------------|------------------|-------------------|--------------------|
| ACL-ARC [2]                 | 11 k   | no           | comp. ling.      | PDF               | ✗                  |
| ACL-AAN [3]                 | 18 k   | no           | comp. ling.      | PDF               | ✗                  |
| Scholarly Dataset 2 [4]     | 100 k  | no           | CS               | PDF               | ✗                  |
| CiteSeerX [5] / RefSeer [6] | 1 M    | ambiguous    | mixed            | 400 char excerpts | ✗                  |
| PMC OAS [7]                 | 2.3 M  | exact        | biomedical       | XML               | mixed <sup>a</sup> |
| arXiv CS [8]                | 90 k   | exact        | CS               | text              | ✓                  |
| <b>unarXive</b> [1]         | 1.2 M  | exact        | phys., maths, CS | text              | ✓                  |

<sup>a</sup> No citation network due to mixed set of IDs (PubMed, MEDLINE, DOI) [9].

# Corpus - Result Full (2022)

| Data Set   | Source    |   | Citation Network <sup>a</sup> |              |              | # Docs | Disciplines             |
|--|-----------|---|-------------------------------|--------------|--------------|--------|-------------------------|
|  | Data      | Format                                  | general                       | compare      |              |        |                         |
| CORE [10]  | multiple  | PDF                                     | 0%                            | -            | >100 M       |        | various                 |
| S2ORC (PDF) [11]                                     | multiple  | PDF                                     | 69.4%                         | -            | 12 M         |        | various                 |
| unarXive 2020 [1]                                    | arXiv.org | L <small>A</small> T <small>E</small> X | 42.6%                         | 42.6%        | 1.2 M        |        | phys., maths, CS        |
| S2ORC (L <small>A</small> T <small>E</small> X) [11] | arXiv.org | L <small>A</small> T <small>E</small> X | 31.1%                         | 31.1%        | 1.5 M        |        | phys., maths, CS        |
| arXMLiv [12]   | arXiv.org | L <small>A</small> T <small>E</small> X | 0%                            | 0%           | 1.6 M        |        | phys., maths, CS        |
| SciXGen [13]   | arXiv.org | L <small>A</small> T <small>E</small> X | 41.6%                         | -            | 205 k        |        | CS                      |
| PMC-OAS [7]  | PubMed    | XML                                     | mixed <sup>b</sup>            | -            | <b>3.3 M</b> |        | <b>biomedical</b>       |
| <b>unarXive 2022 [14]</b>                            | arXiv.org | L <small>A</small> T <small>E</small> X | <b>44.4%</b>                  | <b>44.4%</b> | <b>1.9 M</b> |        | <b>phys., maths, CS</b> |

<sup>a</sup> “general”: all data; incomparable. “compare”: arXiv.org data 1991–2020; directly comparable.

<sup>b</sup> No citation network due to mixed set of IDs (PubMed, MEDLINE, DOI) [9].

# Corpus - Link Correctness Full

Table: Link correctness (n = 300)

| Confidence level | Method <sup>a</sup> | Lower limit | Upper limit |
|------------------|---------------------|-------------|-------------|
| 0.99             | Wilson              | 0.9613      | 0.9975      |
|                  | Jeffreys            | 0.9666      | 0.9983      |
| 0.95             | Wilson              | 0.9710      | 0.9966      |
|                  | Jeffreys            | 0.9736      | 0.9972      |

<sup>a</sup> Confidence interval given as Wilson score interval and Jeffreys interval [15].

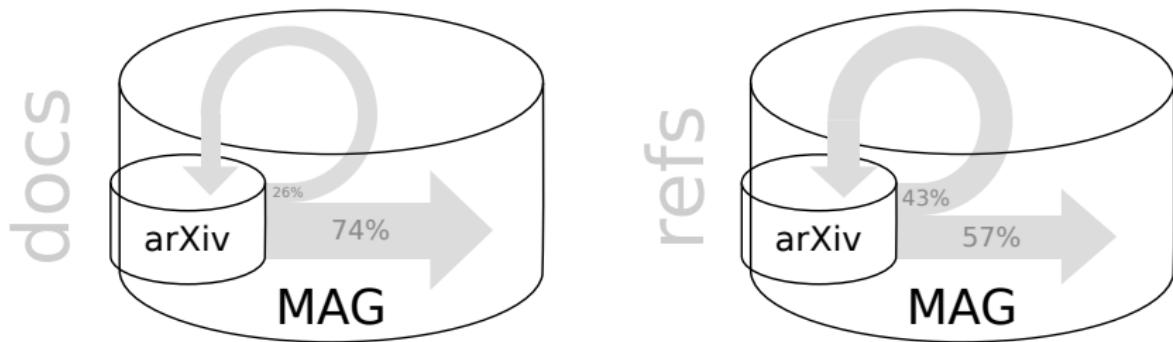
# Corpus - Stats

|                       | citing<br>documents | references        | cited<br>documents |                  |
|-----------------------|---------------------|-------------------|--------------------|------------------|
|                       |                     |                   | outgoing           | incoming         |
| <i>full data set:</i> | <b>1,043,126</b>    | <b>15,954,664</b> | <b>15,954,664</b>  | <b>2,746,288</b> |
| full text             | 1,043,126           | 15,954,664        | 7,181,576          | 736,597          |
| linked to MAG         | 994,351             | 15,846,351        | 15,954,664         | 2,746,288        |
| <i>by discipline:</i> |                     |                   |                    |                  |
| physics               | 662,894             | 9,300,576         | 7,827,072          | 921,852          |
| mathematics           | 237,422             | 3,426,117         | 5,062,033          | 906,301          |
| computer science      | 111,694             | 2,526,656         | 1,876,401          | 425,860          |
| other                 | 31,116              | 701,315           | 1,189,158          | 492,275          |

**data:** <http://doi.org/10.5281/zenodo.3385851>

**code:** <https://github.com/IllDepence/unarXive>

# Corpus - Citation Flow



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# Corpus - Reference Composition

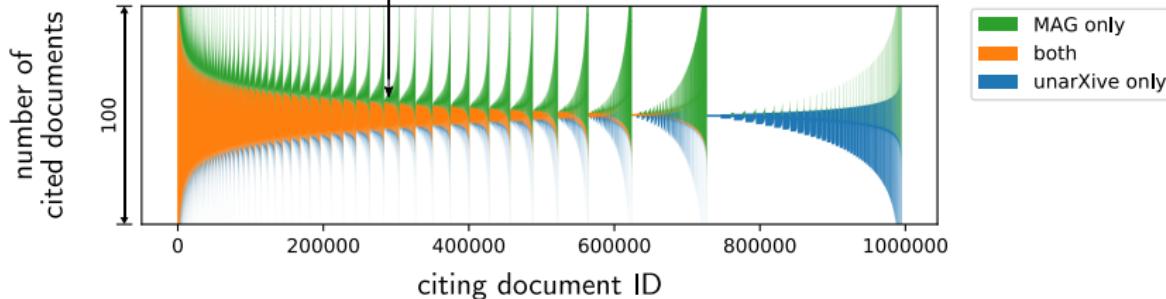
Exemplary visualization  
of a single data point  
on the x-axis.

document #288983

[...]

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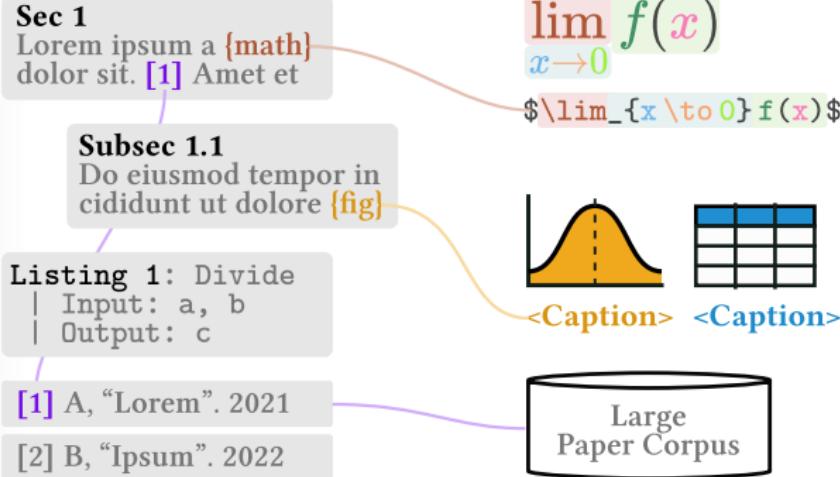
# Corpus - Target Sec. Specific Refs

|               | Discipline <sup>a</sup>                  | Count   | Normalization factor | Normalized ratio (%) |
|---------------|--|---------|----------------------|----------------------|
| <b>Citing</b> | Mathematics                              | 298,009 | 4.66                 | 8.70                 |
|               | CS                                       | 9,123   | 6.31                 | 0.36                 |
|               | Physics                                  | 30,593  | 1.72                 | 0.33                 |
| <b>Cited</b>  | Mathematics                              | 313,651 | 3.15                 | 6.20                 |
|               | CS                                       | 12,179  | 8.50                 | 0.65                 |
|               | Physics                                  | 31,087  | 2.04                 | 0.40                 |
| <b>Pairs</b>  | <u>Math<sup>†</sup>→Math<sup>‡</sup></u> | 200,859 | 5.41                 | 6.81                 |
|               | <u>Math<sup>†</sup>→CS</u>               | 5,134   | 92.13                | 2.96                 |
|               | <u>Math<sup>†</sup>→Phys</u>             | 3,114   | 89.88                | 1.75                 |
|               | <u>CS→Math<sup>‡</sup></u>               | 3,456   | 18.82                | 0.41                 |
|               | <u>Phys→Math<sup>‡</sup></u>             | 3,859   | 16.49                | 0.40                 |
|               | <u>CS→CS</u>                             | 2,500   | 11.38                | 0.18                 |
|               | <u>Phys→Phys</u>                         | 10,374  | 2.12                 | 0.14                 |
|               | <u>CS→Phys</u>                           | 50      | 307.16               | 0.10                 |
|               | <u>Phys→CS</u>                           | 137     | 101.40               | 0.09                 |

<sup>a</sup>  $\dagger$ : Mathematics citing document,  $\ddagger$ : Mathematics cited document, X→X: Citing and cited document are from the same discipline.

# unarXive 2022 Schema

LaTeX  
↓  
{json}



- Created from LaTeX sources
- Document structure and content types preserved
- Math, figures, tables, references linked

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Artifact Parameters  
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# Artifact Parameters - Task

- Task Type
  - (Named) Entity Recognition, Relation Extraction

- 4 entity classes
  - (1) research **artifact**: model, method, data set, ...
  - descriptions of how authors use the artifacts
  - (2) **parameter** ( $\alpha$ , learning rate, k, ...)
  - (3) **value** (1e-3, five,  $\frac{1}{3}$ , ...)
  - (4) **context** (for fine-tuning, during grid search, ...)

- 1 relation type
  - Given by entity type pair

# Artifact Parameters - Task (ext)

## ■ Goal

- Automatically extract hyperparameter information from paper text

## ■ Motivation

- Reproducibility indication [39], automated reproduction [40]
- Uncover conventions and trends
- More fine-grained paper representations (similarity measures, recommendation, search)

## ■ Task Type

- (Named) Entity Recognition, Relation Extraction

# Artifact Parameters - Related Work: Fine-tuned models

- SciERC dataset
  - SCIE [21]
  - PL-Marker [22]
  - → **entity type overlap**
- SciREX dataset
  - TempGen [41] (only RE)
- SemEval 2022 (math symb. to descr.)
  - JBUU-CCLab [42]
  - AIFB [43]
- SemEval 2021 (measurements)
  - LIORI [23]
  - → **utilize mention pattern regularities**

We evaluate our model on the task of **question answering** using

#### Section : Dataset

**SQuAD** is a **machine comprehension** dataset on a large set of **Wikipedia articles** , ..... . Two metrics are used to evaluate models: **Exact Match ( EM )** and a softer metric , **F1 score** .....

#### Section: Model Details .

... Each paragraph and question are tokenized by a regular - expression - based word tokenizer ( **PTB Tokenizer** ) and fed into the model .  
....

#### Section : Results .

The results of our model and competing approaches on the hidden test are summarized in Table [ reference ]. **BiDAF { ensemble }** achieves an **EM** score of 73.3 and an **F1**-score of 81.1, outperforming all previous approaches .

## Artifact Parameters - Related Work: Fine-tuned models (other data sources)

- From code documentation [44]
- From code [45]

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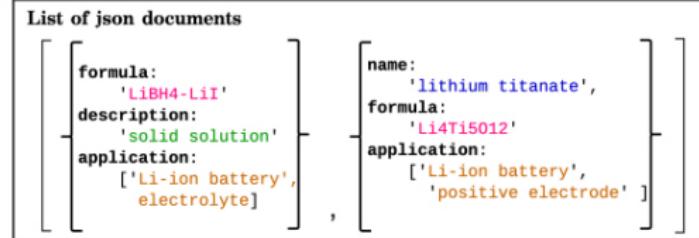
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# Artifact Parameters - Related Work: LLMs

- Medical science [24]
  - singular values
  - lists
- Material science [25–27]
  - singular values
  - lists
  - hierarchical [27] (see right)  
→ **data serialization format**

Note: all of the above evaluate  
on **GPT models only**.

Document: The charge and discharge performance of an all-solid-state lithium battery with the LiBH4-LiI solid solution as an electrolyte is reported. Lithium titanate ( $\text{Li}_4\text{Ti}_5\text{O}_{12}$ ) was used as the positive electrode and...



Dunn, A. et al. *Structured information extraction from complex scientific text with fine-tuned large language models*. Dec. 2022. doi:10.48550/arXiv.2212.05238

# Artifact Parameters - Approach: LLMs

In the context of machine learning and related fields, what (if any) are the entities (datasets, models, methods, loss functions, regularization techniques) mentioned in the LaTeX Input Text below? What (if any) are their parameters and values?

```
[LaTeX Input Text start]
We use AdamW with a learning rate ($\alpha$) of 1e-3 for /* [...] */
[LaTeX Input Text end]
```

Answer in the following YAML format.

Format:

```
---
text_contains_entities: true/false
entities:
  - entity<N>:
    id: e<N>
    name: "<entity name>"
    type: dataset/model/method/loss function/regularization technique
    has_parameters: true/false
    parameters:
      - parameter<M>:
        id: p<N.M>
/* [...] */
...
```

Only include entities that are of type dataset, model, method, loss function, or regularization technique. Do not output entities that are of another type. Do not include entities of type task, metric, library, software, or API.

Only produce output in the YAML format specified above. Output no additional text.

Output:

# Artifact Parameters - Approach: LLMs

In the context of machine learning and related fields, what (if any) are the entities (datasets, models, methods, loss functions, regularization techniques) mentioned in the LaTeX Input Text below? What (if any) are their parameters and values?

Task

```
[LaTeX Input Text start]  
We use AdamW with a learning rate ($\alpha$) of 1e-3 for /* [...] */  
[LaTeX Input Text end]
```

Input Text

Answer in the following YAML format.

Format:

```
---
```

```
text_contains_entities: true/false  
entities:  
  - entity<N>:  
    id: e<N>  
    name: "<entity name>"  
    type: dataset/model/method/loss function/regularization technique  
    has_parameters: true/false  
    parameters:  
      - parameter<M>:  
        id: p<N.M>  
/* [...] */  
...
```

Format

Only include entities that are of type dataset, model, method, loss function, or regularization technique. Do not output entities that are of another type. Do not include entities of type task, metric, library, software, or API.

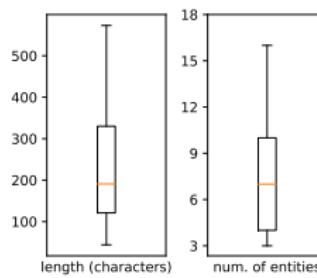
Only produce output in the YAML format specified above. Output no additional text.

Output:

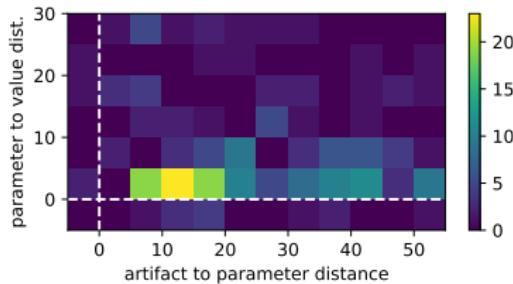
Output Prefix

# Artifact Parameters - Data

- Two annotation rounds
- Initial (pre-filtered text, exploratory, to fine-adjust scheme)
  - 151 text segments
  - 1,345 entities
  - 1,110 relations
- Main (full papers, eval data)
  - 444 paragraphs
  - 1,971 entities  
(1,134 a, 131 p, 662 v, 44 c)
  - 614 relations
- IAA
  - 0.867 for entities
  - 0.737 for relations



(a) text segments



(b) relation distances (#chars)

Figure: Observations of initial annotation round

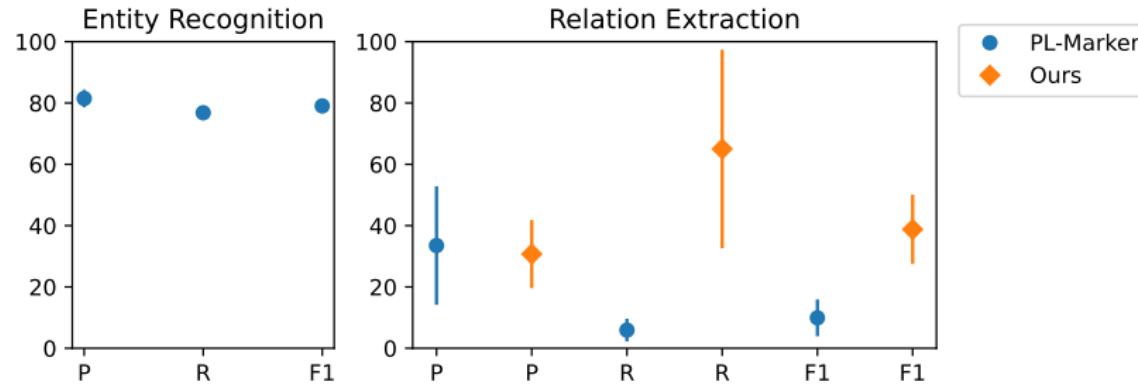
Scholarly Data  
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Artifact Parameters  
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# Artifact Parameters - Experiments: Fine-tuned models



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# Artifact Parameters - Experiments: LLMs

| Zero-shot             |        | Entity Recognition |             |                             | Relation Extraction |             |                            |
|-----------------------|--------|--------------------|-------------|-----------------------------|---------------------|-------------|----------------------------|
| Model                 | Output | P [%]              | R [%]       | F <sub>1</sub> [%]          | P [%]               | R [%]       | F <sub>1</sub> [%]         |
| WizardLM              | JSON   | 6.9                | 11.3        | 8.6                         | 0.1                 | 0.8         | 0.1                        |
|                       | YAML   | 9.7                | 35.6        | 15.3 <sub>△+6.7</sub>       | 0.1                 | 1.5         | 0.1 <sub>△+0.0</sub>       |
| Vicuna <sub>4k</sub>  | JSON   | 15.1               | 9.3         | 11.5                        | 0.7                 | 3.8         | 1.2                        |
|                       | YAML   | 17.3               | 31.5        | 22.3 <sub>△+10.8</sub>      | 0.0                 | 0.8         | 0.1 <sub>△-1.1</sub>       |
| Falcon                | JSON   | <b>37.1</b>        | 5.9         | 10.2                        | 0.0                 | 0.0         | 0.0                        |
|                       | YAML   | 32.7               | 14.2        | 19.8 <sub>△+9.6</sub>       | 0.0                 | 0.0         | 0.0 <sub>△+0.0</sub>       |
| GALACTICA             | JSON   | 25.9               | 15.7        | 19.5                        | 0.1                 | 2.3         | 0.3                        |
|                       | YAML   | 23.1               | 19.5        | 21.1 <sub>△+1.6</sub>       | 0.0                 | 0.8         | 0.1 <sub>△-0.2</sub>       |
| GPT-3.5               | JSON   | 27.9               | <b>42.8</b> | 33.8                        | 5.4                 | 10.7        | 7.2                        |
|                       | YAML   | <u>34.0</u>        | <u>41.7</u> | <u>37.4<sub>△+3.6</sub></u> | <u>5.8</u>          | <u>12.2</u> | <u>7.8<sub>△+0.6</sub></u> |
| 5-shot                |        | Entity Recognition |             |                             | Relation Extraction |             |                            |
| Vicuna <sub>16k</sub> | JSON   | 34.4               | <u>46.7</u> | <u>39.6</u>                 | 0.8                 | 4.6         | 1.3                        |
|                       | YAML   | <b>43.9</b>        | <b>44.1</b> | <b>44.0<sub>△+0.4</sub></b> | <b>4.5</b>          | <b>9.9</b>  | <b>6.1<sub>△+4.8</sub></b> |

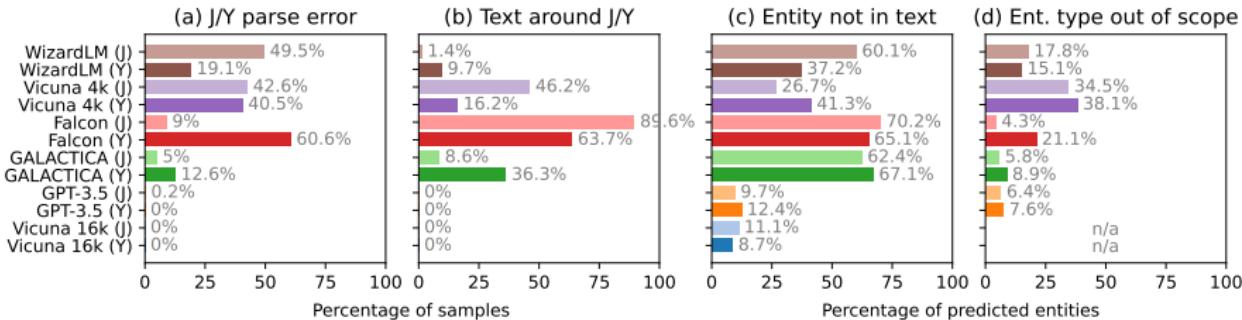
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# Artifact Parameters - Experiments: LLMs



# Publications - primary

| Chap. | Venue          | Year | Type       | Length | Author Position | Venue Rating | Ref. |
|-------|----------------|------|------------|--------|-----------------|--------------|------|
| 3     | Scientometrics | 2020 | Journal    | Full   | 1 of 2          | SJR Q1       | [1]  |
| 4     | JCDL           | 2022 | Workshop   | Full   | 1 of 3          | Core A*      | [16] |
|       | JCDL           | 2023 | Conference | Short  | 1 of 3          | Core A*      | [14] |
| 5     | ICADL          | 2020 | Conference | Full   | 1 of 2          | Core A       | [17] |
|       | IJDL           | 2022 | Journal    | Full   | 1 of 3          | SJR Q2       | [18] |
| 6     | ECIR           | 2024 | Conference | Full   | 1 of 4          | Core A       | [20] |

Venue ranks from Core<sup>1</sup> (conferences) and SJR<sup>2</sup> (journals).<sup>3</sup>

<sup>1</sup>See <http://portal.core.edu.au/conf-ranks/> (last accessed 2023-10-12).

<sup>2</sup>See <https://www.scimagojr.com/> (last accessed 2023-10-12).

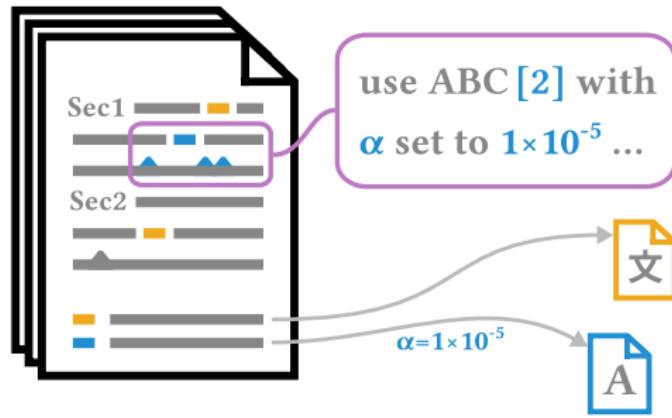
<sup>3</sup>Ratings for publication year or, if not listed, most up-to-date ranking. Workshops ranks are that of the hosting conference.

## Publications - secondary

| Venue | Year | Type       | Length | Author Position | Venue   | Ref. |
|-------|------|------------|--------|-----------------|---------|------|
| ECIR  | 2019 | Workshop   | Full   | 1 of 2          | Core A  | [46] |
| ECIR  | 2020 | Conference | Full   | 1 of 3          | Core A  | [47] |
| NAACL | 2021 | Workshop   | Short  | 3 of 4          | Core A  | [48] |
| AAAI  | 2022 | Workshop   | Full   | 2 of 3          | Core A* | [49] |
| JCDL  | 2022 | Conference | Full   | 3 of 3          | Core A* | [50] |
| JCDL  | 2023 | Conference | Short  | 1 of 3          | Core A* | [51] |

Additional publications (co-)authored leading up to and during the research period which are not a direct part of the dissertation, but nevertheless informed the overall research trajectory. Especially [46] and [48], which constitute the results of the master's thesis preceding the doctoral research period, paved the way for the dissertation.

# Quality Dimensions



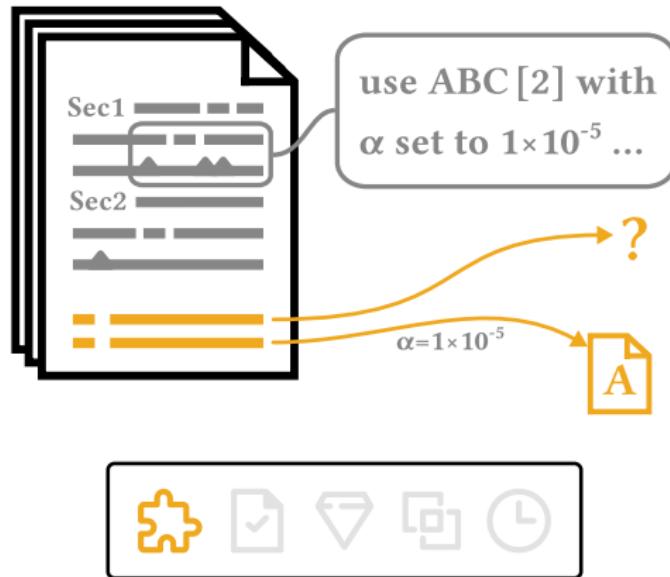
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# Quality Dimensions: Completeness



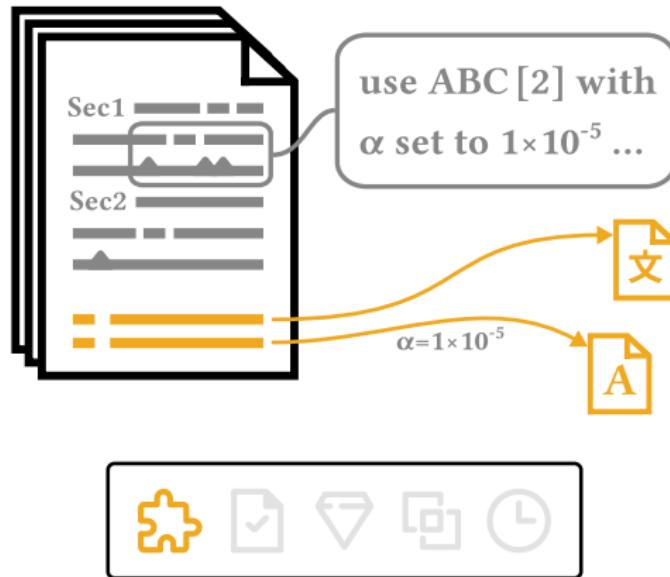
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# Quality Dimensions: Completeness



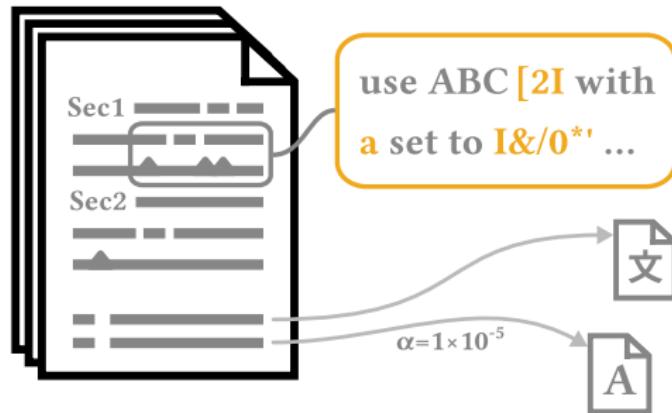
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# Quality Dimensions: Accuracy



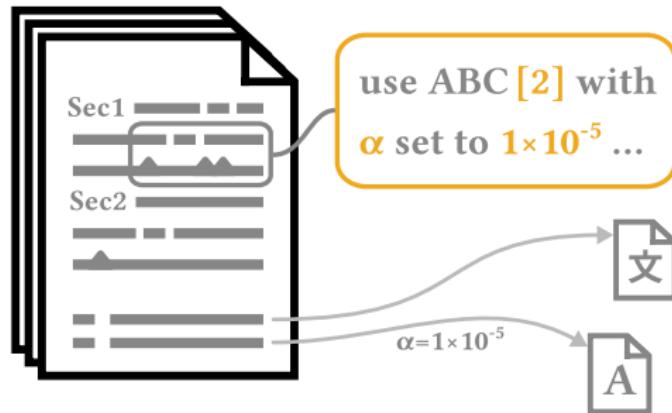
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# Quality Dimensions: Accuracy



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# Quality Dimensions: Relevance



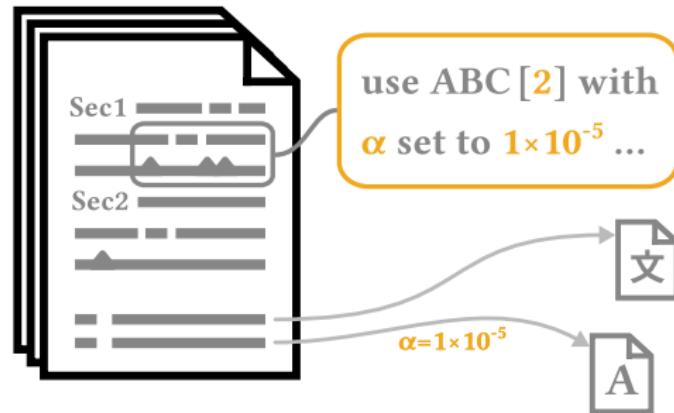
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# Quality Dimensions: Relevance



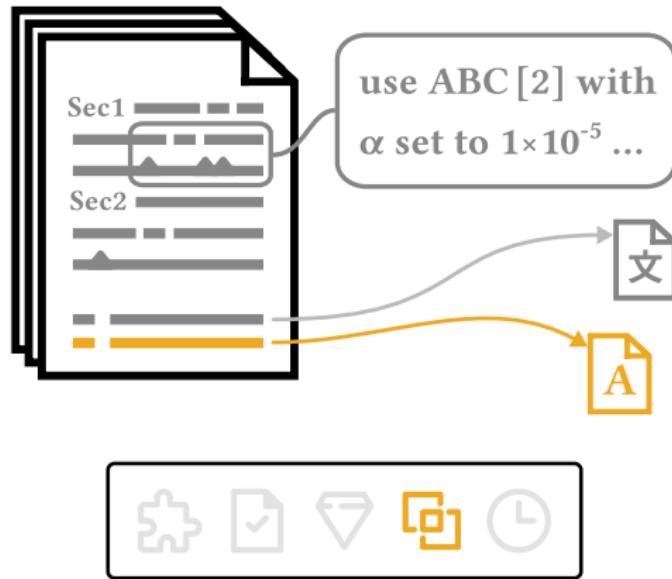
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# Quality Dimensions: Comparability



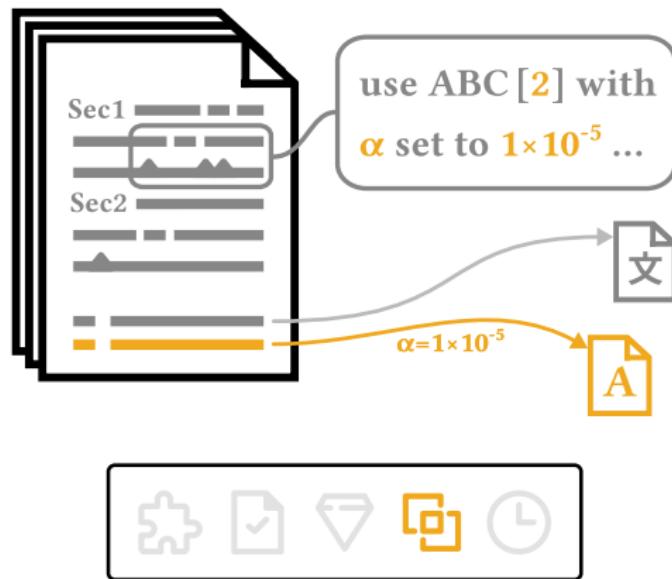
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# Quality Dimensions: Comparability



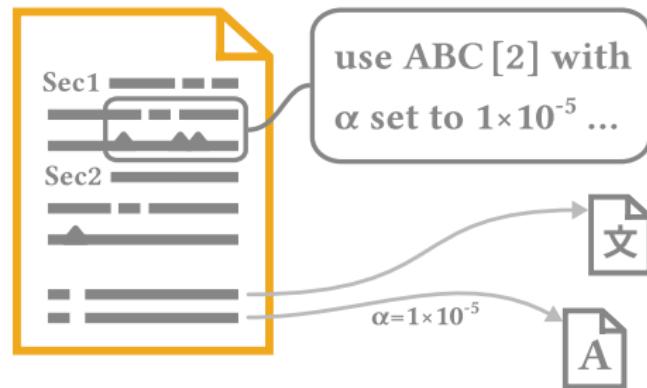
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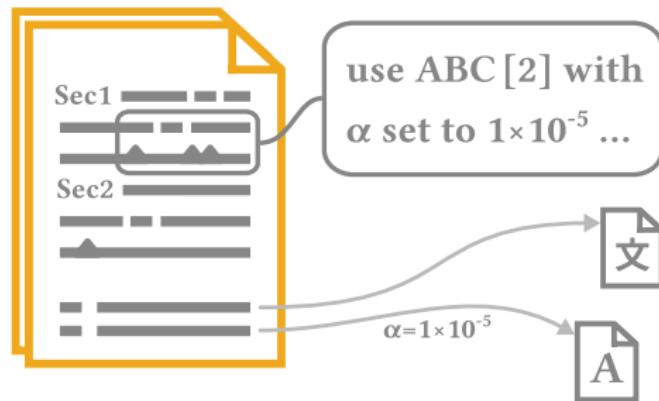
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# Quality Dimensions: Timeliness



# Quality Dimensions: Timeliness



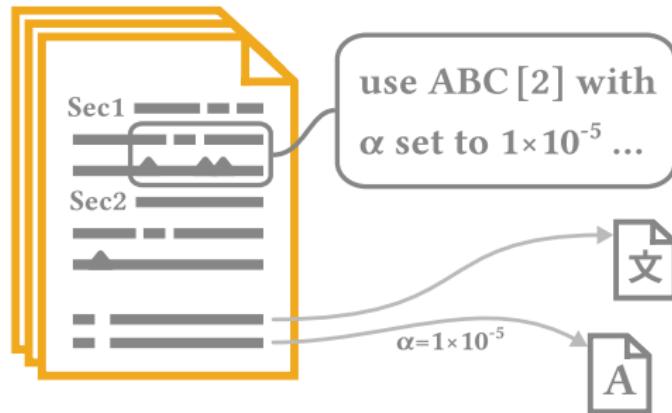
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# Quality Dimensions: Timeliness



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# Limitations

## ■ Corpus

- L<sup>A</sup>T<sub>E</sub>X required (no humanities)

## ■ Citation Network

- Blocking method scalability

## ■ Non-English Documents

- Single “direction”
- Dependency on author notation

## ■ Artifact Parameters

- IE from text, not tables, code, etc.
- ML specific
- English only

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