MACHINE LEARNING OF CONCEPT DEPENDENCY GRAPHS FROM TEXT

QDS Research Project
Final Presentation
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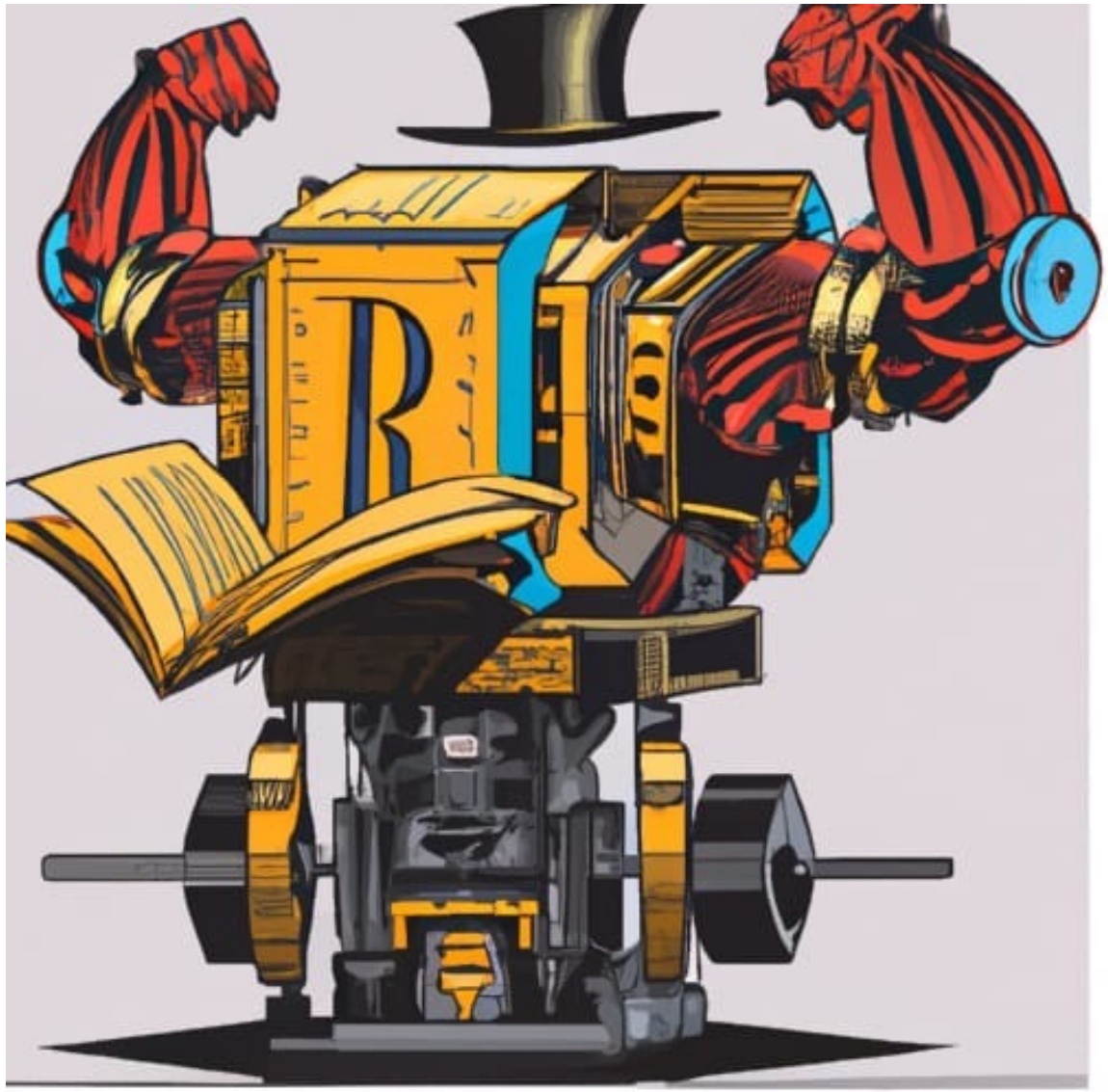
Dominik Glandorf, Anastastiia Alekseeva

Supervisors: Álvaro Tejero-Cantero and Hanqi Zhou (ML ⇌ Science Colaboratory)

https://github.com/mlcolab/learning-dependencies



ml science colaboratory

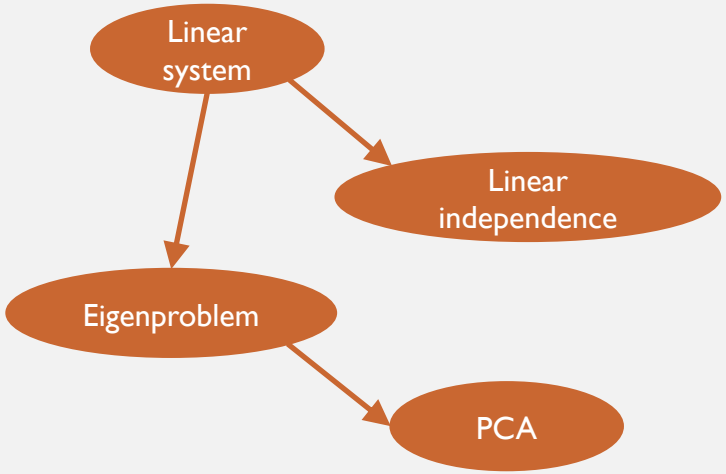
MOTIVATION

Education Sciences

- Instructional Sequencing: Learning is more efficient when dependencies between concepts are reflected in the learning path

Computational Linguistics

- Large Language Models (LLM) such as GPT3 and BLOOM are trained on huge text corpora from multiple sources



RQ: Can LLMs provide a valid dependency structure of concepts based on contextual structures among their training material?

Morrison et al. (2019). Designing effective instruction
Vaswani et al. (2017). Attention is all you need

PROJECT SUMMARY

Project

We automatically extracted concept dependencies from sources such as textbooks, Wikipedia, and LLMs

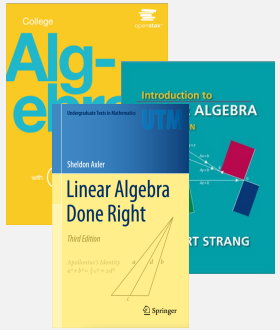
Contribution

We provide a scalable evaluation framework to assess a LLM's educational knowledge structure

Challenges

1. Baseline graph extraction
2. Prompt Engineering
3. Cloud Computing Resources

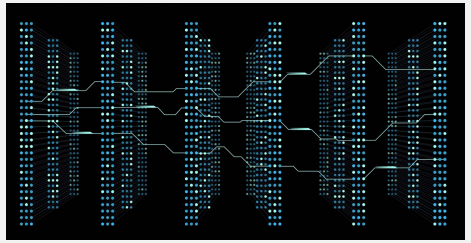
DATA SOURCES



- 10 books on Linear Algebra
- 584 pages on average (652,297 characters)
- Median of 382 concepts in index

WIKIPEDIA

- 1,462 unique articles for book index entries → set of concepts



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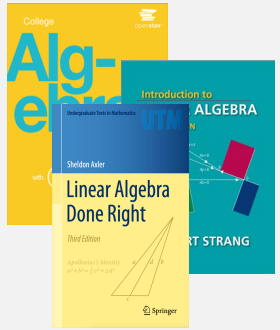
- Fine-tuned BLOOM on several question-answering datasets
- 11 billion parameters (44GB RAM)
- ~3 to 10 seconds per request on our infrastructure

Sanh et al. (2021). Multitask Prompted Training Enables Zero-Shot Task Generalization
Wang et al. (2016). Using prerequisites to extract concept maps from textbooks

METHODS: TEXTBOOKS



Problem	Description	Information sources	Algorithms
Disambiguation	Identifying and matching the concepts across textbooks	Index entries and full text	Semi-manual index extraction, Wikisearch, Wikifier
Relation Extraction	Mining dependencies between the concepts	Index entries and full text	common introductory usage, order pruning

Brank et al. (2017). Wikifier

METHODS: WIKIPEDIA

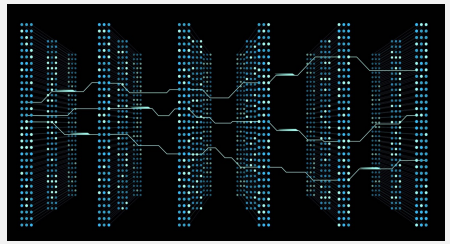
- Assumption: understanding the concept requires understanding the concepts in its definition
- Operationalization: links to other articles in the first sentence of Wikipedia article
- Filtered out links to fields ("Mathematics"), persons ("Gabriel Cramer), and concepts that linked even earlier to the concept of interest

Example

In mathematics, the **determinant** is a scalar value that is a function of the entries of a square matrix. It characterizes some properties of the matrix and the linear map represented by the matrix. In particular, the determinant is nonzero if and only if the matrix is invertible and the linear

Talukdar & Cohen (2012). Crowdsourced Comprehension: Predicting Prerequisite Structure in Wikipedia

METHODS: LLM



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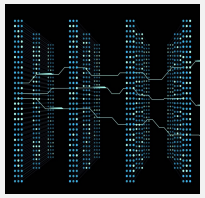
New Prompt Engineering method: **Output refeeding**

concept

1. "What is the mathematical definition of {**concept**}?"



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2. {**definition**}

3. "What mathematics concepts are mentioned here: {**definition**}"

4. {list of dependencies}

WIKIPEDIA

5. {canonical list of dependencies}

RESULTS: CASE STUDY

Choose a source of data

○Textbooks○Wikipedia

◉Large Language Model

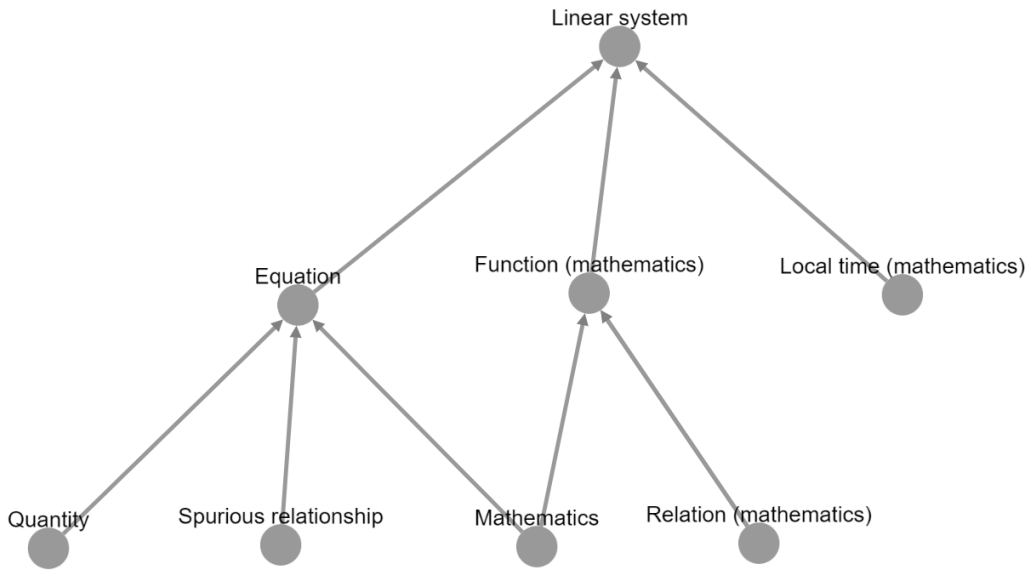
Type a concept

Linear system

Choose the depth of dependencies

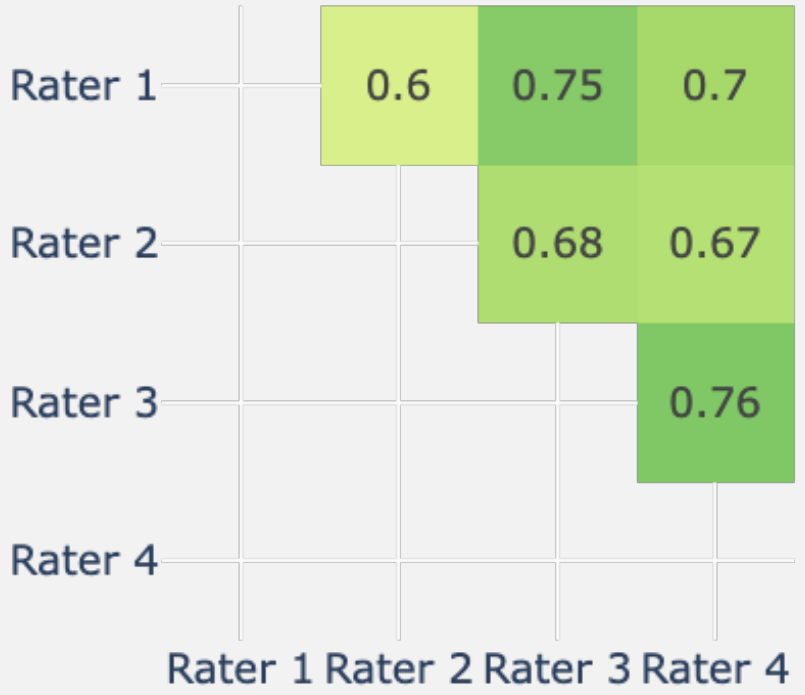
2 × ▾

Submit



RESULTS: EVALUATION

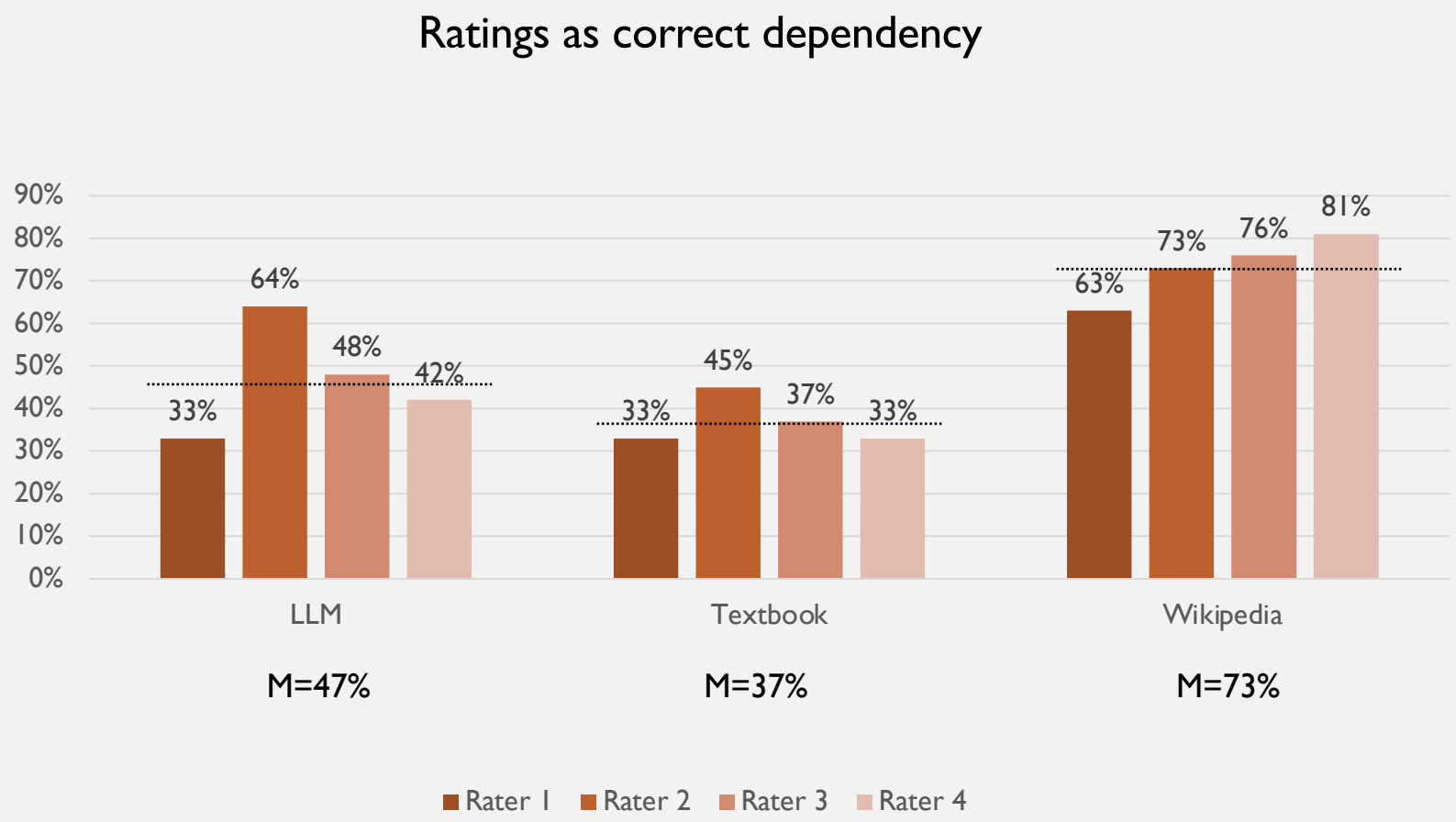
- Manually annotated dataset (N=300, binary response)
- Cohen's Kappa as interrater reliability
  - .6 - .8: substantial agreement
  - .8 - 1.0: strong agreement



Kappa Coefficients (chance=25%)

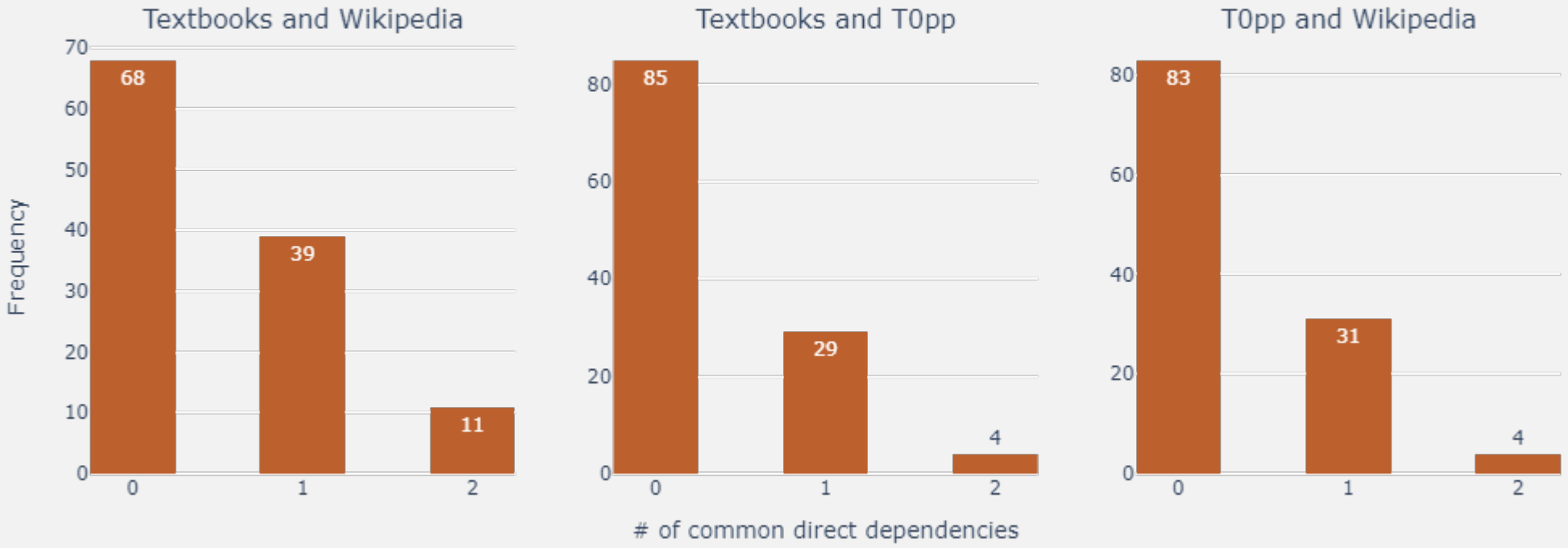
Cohen (1960). A coefficient of agreement for nominal scales

RESULTS: EVALUATION



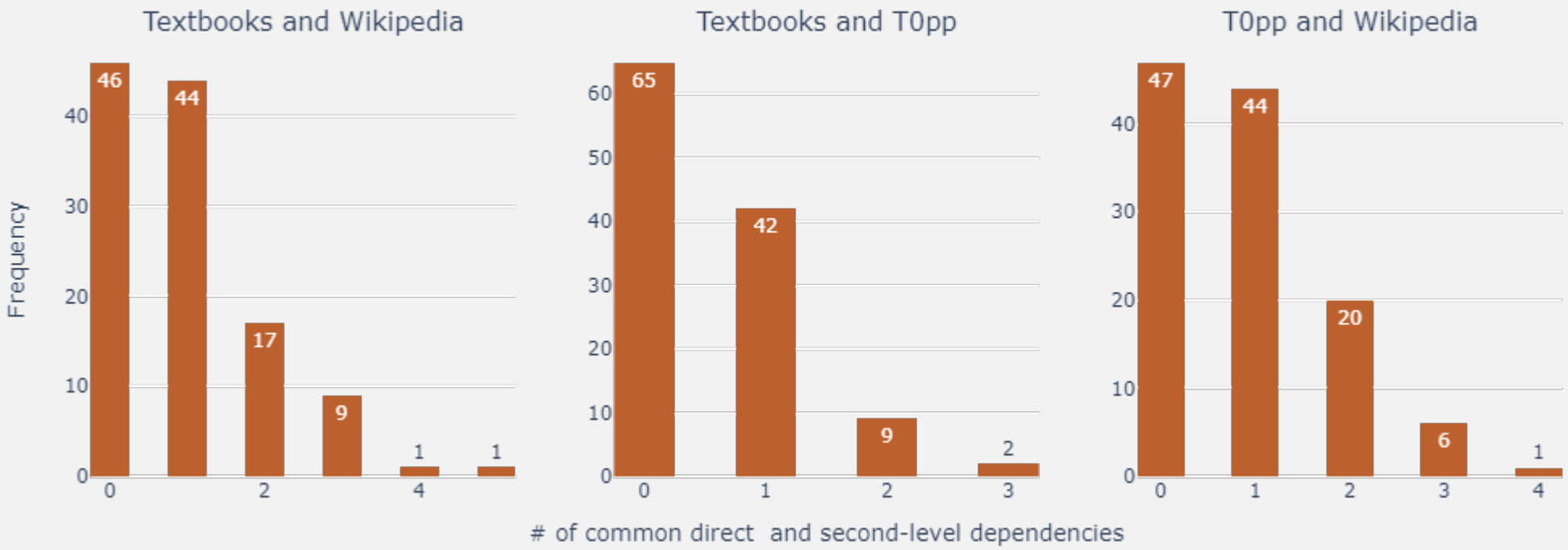
RESULTS: CONVERGENCE METRICS

Number of common direct dependencies between sources



RESULTS: CONVERGENCE METRICS

Number of common direct and second-level dependencies between sources



DISCUSSION

Summary

- Promising results for a complex problem
- Approach can be scaled to more textbooks and new LLMs

Limitations

- Wikipedia disambiguation introduces a lot of noise
- Account for hierarchy of dependencies

Future Work

- Better LLMs, better results?
- Elaborate use cases in education

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