Analogy-based Assessment of Domain-specific Word Embeddings

Derek Koehl, Carson Davis, Udaysankur Nair, Rahul Ramachandran

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Analogical Reasoning

Analogical reasoning is fundamental to human cognition and plays an important role in a wide-range of problem solving scenarios.

"Analogy is our best guide in all philosophical investigations; and all discoveries, which were not made by mere accident, have been made by the help of it." – Joseph Priestley

Prediction of new thermoelectric materials

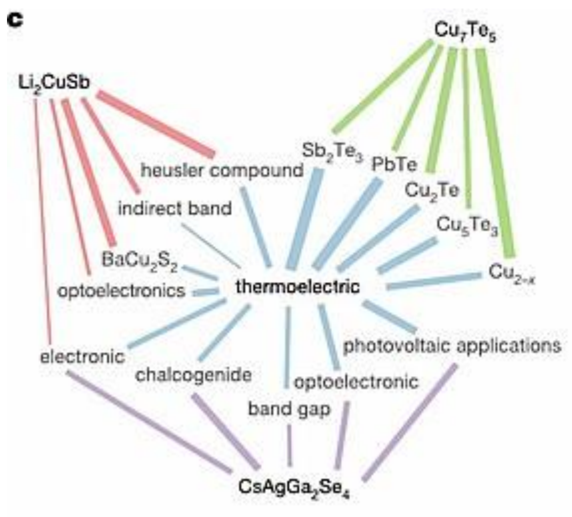


Figure: Tshitoyan et al., 2019.

Characterizing diseases

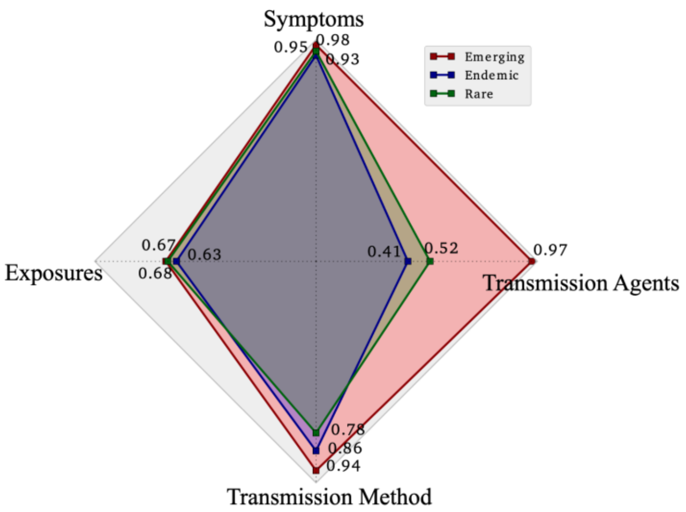


Figure: Ghosh et al., 2016.

Analogy Prediction: Successes and Reality

$$\overrightarrow{king} - \overrightarrow{man} + \overrightarrow{woman} \approx \overrightarrow{queen}$$

$$\overrightarrow{London} - \overrightarrow{England} + \overrightarrow{France} \approx \overrightarrow{Paris}$$

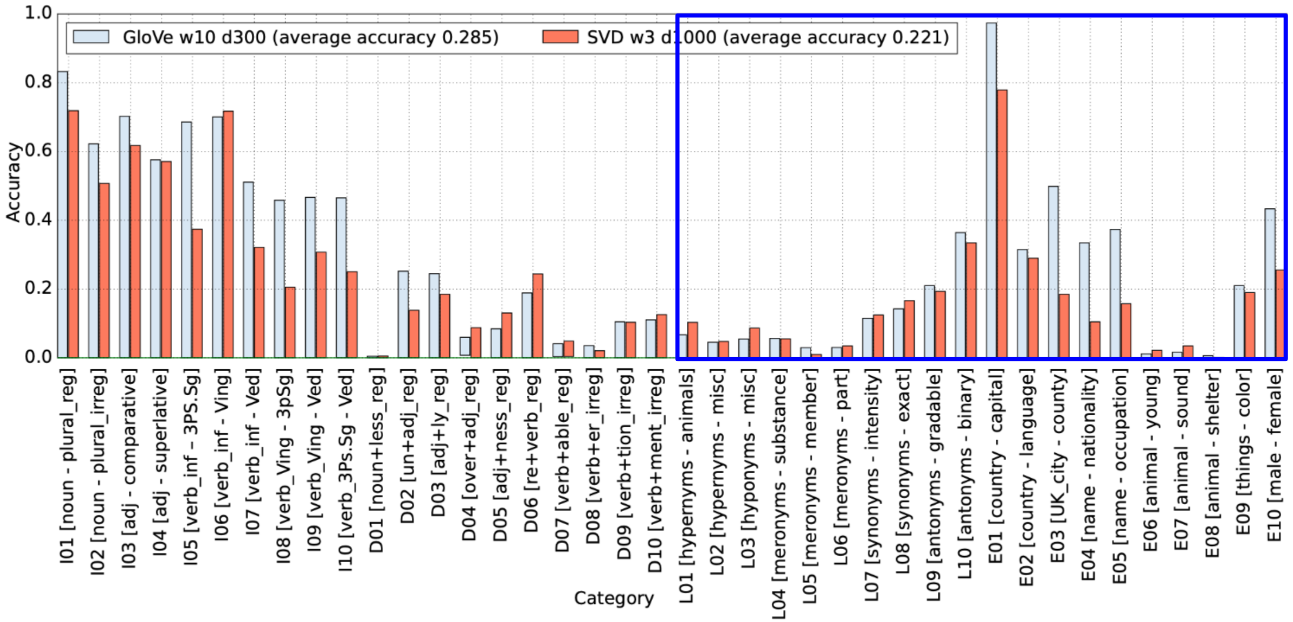
Reported prediction accuracies exceeding 80%

(e.g. Pennington et al., 2016)

Bigger Analogy Test Set

(Gladkova et al., 2016)

- Balanced across four semantic categories
- Average lexicographic accuracy ≈ 0.11
- Average encyclopedic accuracy ≈ 0.26



Underlying chart: Gladkova et al., 2016

Domain knowledge resides in the lexicographic and encyclopedic domains.

Domain Analogy Prediction: An Exploration

Can word embeddings trained on a domain-specific corpus utilizing domain-specific vocabulary outperform in domain-specific analogy prediction as compared to word embeddings trained on a non domain-specific corpus predicting non domain-specific analogies?

carbon dioxide:*acidic* :: *ammonium*:*alkaline*

vs.

horse:*stable* :: *chicken*:*coop*

Domain Analogy Prediction: An Exploration

Domain corpus: 21,380 Earth science articles comprising 81 million words

Domain vocabulary:

- Global Change Master Directory (GCMD) keywords
- Semantic Web for Earth and Environmental Technology (SWEET) ontology

Journal	Number	Percent of Total
Atmospheric Science Letters	273	1.28
Geophysical Research Letters	7,664	36.06
J. of Geophys. Res.: Atmospheres	6,161	28.99
J. of Geophys. Res.: Biogeosciences	539	2.54
J. of Geophys. Res.: Earth Surface	415	1.95
J. of Geophys. Res.: Oceans	1,392	6.55
J. of Geophys. Res.: Planets	483	2.27
J. of Geophys. Res.: Solid Earth	1,474	6.94
J. of Geophys. Res.: Space Physics	2,336	10.99
Meteorological Applications	255	1.20
Q. J. Royal Meteorological Society	8	0.04
Review of Geophysics	168	0.79
Water and Environment Journal	21	0.10
Wiley Interdisciplinary Reviews: Water	63	0.30

Domain Analogy Prediction: Analogy Test Set

The exploratory set of Earth science analogies categorized using a classification framework similar to the one employed by the Bigger Analogy Test Set.

- Allows category-level comparison
- Laying the groundwork for an Earth science analogy test set

Analogy Category	Number
Lexicographical	**12**
Meronym *(graupel:ice)*	4
Member *(potential temperature:temperature)*	3
Hypernym/Hyponym *(stratus:low-level cloud)*	3
Part-whole *(cyclostrophic:centrifugal)*	1
Gradable *(blue:ultraviolet)*	1
Encyclopedic	**16**
Phenomenon-effect *(anticyclonic:divergence)*	9
Compound-effect *(sulfate:scattering)*	4
Property-instrument *(temperature:thermometer)*	2
Compound-property *(carbon dioxide:acidic)*	1

Domain Analogy Prediction: Accuracies

Accuracy tiers:

- **ES_1** – The fourth term of the analogy is the top prediction
- **ES_3** – The fourth term appears in the top three predictions

Comparison accuracies:

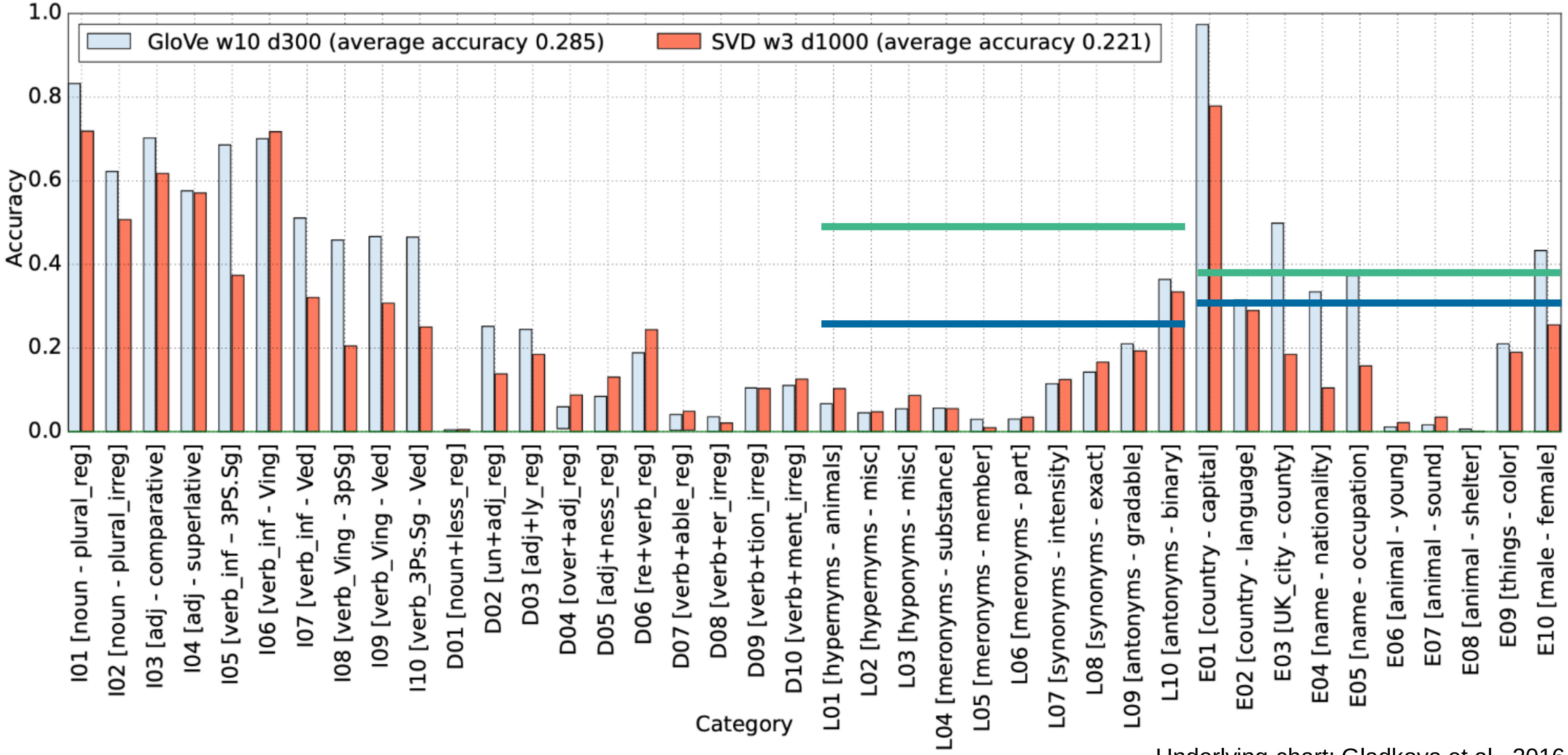
- **GloVe general** – reported by Gladkova et al. using the GloVe model
- **SVD general** – reported by Gladkova et al. using the Singular Value Decomposition model

Analogy Category	Accuracy
ES_3: lexicographical and encyclopedic	**0.43**
ES_1: lexicographical and encyclopedic	**0.29**
GloVe general: lexicographical and encyclopedic	0.21
SVD general: lexicographical and encyclopedic	0.17
ES_3: lexicographical	**0.50**
ES_1: lexicographical	**0.25**
GloVe general: lexicographical	0.11
SVD general: lexicographical	0.11
ES_3: encyclopedic	**0.38**
ES_1: encyclopedic	**0.32**
GloVe general: encyclopedic	0.32
SVD general: encyclopedic	0.20

Domain Analogy Prediction: Comparisons

ES_3: lexicographical – 0.50; encyclopedic – 0.38

ES_1: lexicographical – 0.25; encyclopedic – 0.32



Underlying chart: Gladkova et al., 2016

Domain Analogy Prediction: Next Steps

Expansion of the domain corpus

- Increase the total number of documents to a target of 100,000
- Expand the scope of American Geophysical Union publications
- Ingest the documents into a database for domain subsetting

Develop a comprehensive Earth science analogy test set

- Lexicographical: minimum 10 subcategories
- Encyclopedic: minimum 20 subcategories
- Database-driven to allow for domain subsetting

Domain Analogy Prediction: Contact and Questions

Derek Koehl

derek.koehl@uah.edu

Questions?

Citations:

S. Ghosh et al., “Characterizing diseases from unstructured text: A vocabulary driven word2vec approach,” In *Proceedings of the 25th ACM International on Conference on Information and Knowledge Management*, 2016.

A. Gladkova et al., “Analogy-based detection of morphological and semantic relations with word embeddings: what works and what doesn’t." In *Proceedings of the NAACL Student Research Workshop*, 2016.

V. Tshitoyan et al., “Unsupervised word embeddings capture latent knowledge from materials science literature,” *Nature*, 2019.