Linguistic Analysis of Scientific Research

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Overview:

In the modern era, most scientific research is conducted by specialists who concentrate on highly specific areas of inquiry. Owing to the centrality of scientific research in modern society, the behavior of these communities is itself an interesting object of study. In this research project we attempt to create a map to explore the commonalities and differences among the various mathematical sciences.

This research is grounded in the assumption that a community will tend to form a unique jargon to describe objects of common interest to the community. Consequently, when two different communities have less and less common experience of the world they will also have more and more divergent lexicons. Thus it should be possible to explore the differences and similarities of various scientific research communities by analyzing their linguistic patterns.

In the project we present a computational analysis of the linguistic patterns found in a corpus of text comprised of the abstracts of research published on Arxiv.org - a free and open source repository of research in the quantitative sciences.

Methods:

To study the linguistic content of various fields of knowledge, it was necessary to create a linguistic corpus that is arranged by subject matter. Arxiv.org offered an excellent choice since it offers publicly available research statements that are categorized by research area.

We used Python Beautiful soup to download and extract the text of abstracts and primary topics of articles submitted to arxiv.org. This corpus consisted of over 100,000 abstracts, spanning 127 sub-fields. Since the content of arxiv skews toward more theoretical and quantitative research, we attempted to obtain an even sampling across various fields by limiting the number of abstracts to a given sub domain to 1000 articles.

Once we had assembled a corpus of abstracts, we used python's natural language toolkit (nltk) to transform the corpus into a vector space representation of word frequency. To process this corpus we did the following. First stop words removed. Our list of stop words consisted of nltk's standard stop word list with the addition of words unique to academic publishing, like 'article' and 'paper'. Next words in the corpus were stemmed using a porter 'snowball' stemmer.

Subsequently, the processed corpus was used to create a document-term matrix, where X, with the i,jth entry is equal to the number of instances of the jth word in the corpus found in the ith Abstract. In order to ensure that more common words did not have an undue influence we performed a td-if normalization where the row vectors of this matrix were normalized by their entropy.

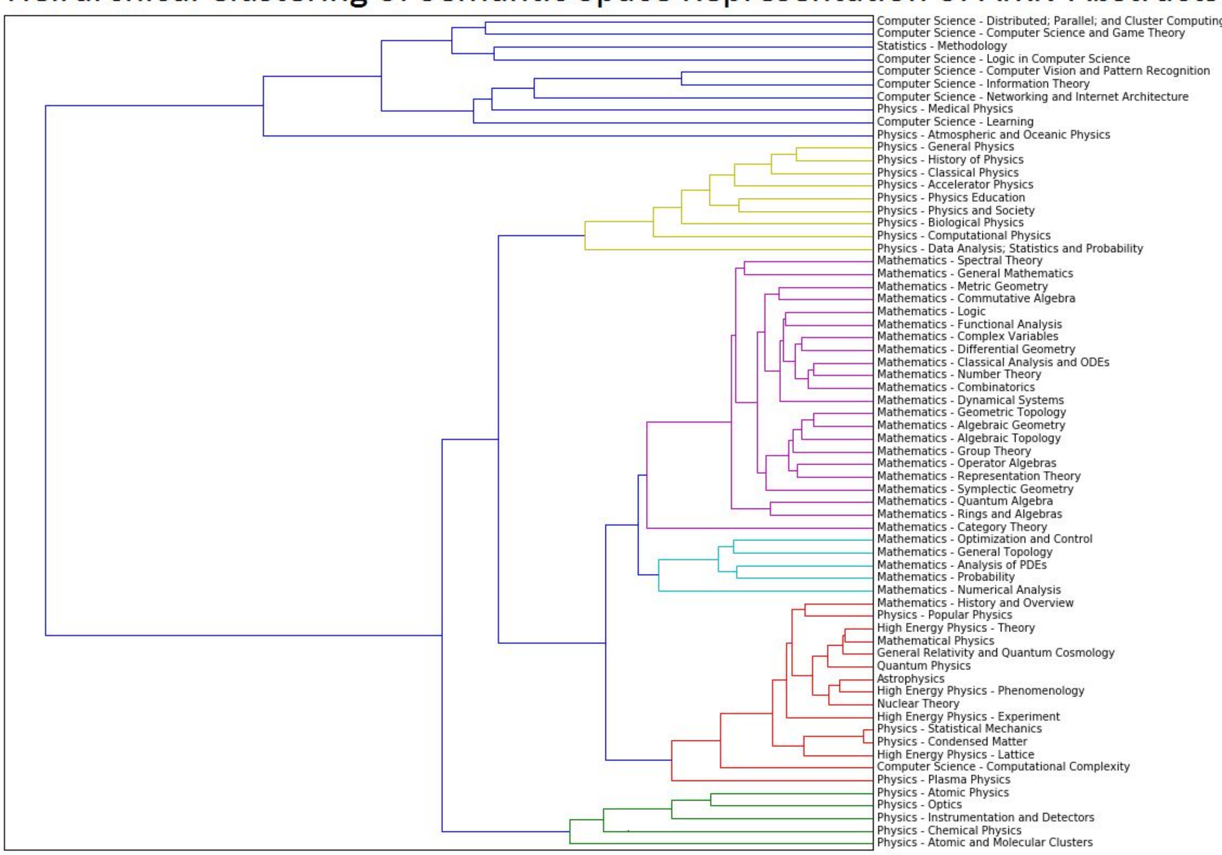
The preprocessing generated a document-term matrix. To eliminate the sparsity of this data-matrix, we used single-value decomposition to reduce the number of columns in this matrix to 300.

It should be noted that the document-term matrix that we created is the transpose of the term-document matrix commonly used in LSA, and the use of SVD for dimensionality reduction mirrors the procedure of LSA. The difference between these two procedures is that in LSA the dimensionality of documents is reduced to measure the similarity between terms, whereas in this analysis the dimensionality of the terms is reduced to find the semantic similarity between documents.

For our final analysis we chose to use a 300 dimensional representation of abstracts. This was chosen on the basis of the dunn separability index of the resulting subject clusters. This number is within the order of magnitude of the dimensionality that Landauer et all found to be optimal for mapping semantic similarities between words.

To visualize the structure of this data, we then performed agglomerative clustering on the centroids of the semantic space representation of each of the various fields of research. This was done using Ward's method - a technique to minimize the variance as a result of agglomeration. The result of this clustering can be shown below:

Heirarchical Clustering of Semantic Space Representation of Arxiv Abstracts



This clustering shows good agreement with the traditional breakdown of fields, and also elucidated more subtle similarities within fields. It can be seen that mathematics and physics and computer science are each partitioned on their own branches. Looking deeper we can observe some interesting patterns. For instance it can be seen that Mathematical Physics is classified here as being closer to the various disciplines of Theoretical Physics than it is to other branches of pure Mathematics.

Conclusions:

This work looked at the linguistic patterns found in scientific research and attempted to draw inferences from how these patterns might reflect the social organization of these research communities. We have shown that this technique is capable of producing a compelling semantic space representation of the quantitative sciences - suggesting the such methods may be useful in mapping out the sociology of knowledge more generally.