Unraveling the hidden Influence of Ernst Mach on the Foundations of Cognitive Science – Interdisciplinary approach

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Abstract

Existing narratives often overlook the significant impact of Ernst Mach and the Vienna Circle on the foundations of cognitive science. In this study, we delve into the underexplored influence of Mach's theories on the emergence of cognitive science, employing a unique interdisciplinary approach that blends rigorous argumentation with cutting-edge computational methods in network science and natural language processing. Our findings reveal multiple, previously unexplored pathways of influence from Mach to pivotal figures in cognitive science, thereby showcasing the efficacy of our combined approach in illuminating the intricate web of intellectual connections. This innovative method offers valuable insights into tracing the potential influences of key thinkers, addressing a longstanding challenge in the history of science arising from the ever-growing corpus of academic literature. To our knowledge, this is one of the first papers to use both citation networks and natural language processing for the investigations of the history of cognitive science.

1 Introduction

The foundations of cognitive science are often associated with research conducted in the United States and the United Kingdom (Riedl, 2022; Thagard, 2020). However, we know that before 1940s, Vienna was one of the world leading intellectual hubs with dominant figures such as Mach, Boltzmann, Schrödinger, and later it became the center of logical positivism regularly hosting Carnap, Schlick, Gödel, Neurath, Tarski, Popper, etc. Today we call this center, Vienna Circle. Furthermore, the Vienna Circle formulated novel philosophical doctrines that were deeply grounded in logic and science. This reconceptualization of philosophy contributed significantly to the emergence of the discipline of philosophy of science and several members

and forerunners of the Vienna Circle were particularly interested in epistemology, the philosophical theory of knowledge. Therefore, the question arises: how did Austrian philosophers and scientists of the late 19th and early 20th century influence the birth and development of cognitive science? We focus on Mach's influences.

2 Methods

We used citation networks and natural language processing along with data mining techniques to find and validate these hypotheses. The approach is roughly outlined in Fig. 1, and summarized in several steps here:

1. Firstly, the citation network referring to Mach's publication *The analysis of sensations* in both English and German versions were extracted from Google Scholar. It contained 15,101 nodes and 16,707 links, and was extracted to a maximum depth of two citations away from the target papers. To reduce the scope of the extraction, only the first 200 most relevant papers (sorted by Google Scholar relevance algorithm) at a distance of one citation and a maximum of 100 papers for each of those 200 at a distance of two citations from the Mach's publication were extracted for further analysis.
2. We compiled a list of people that a) might have been influenced and b) were key to the development of cognitive science, and c) we extracted a subgraph with all the connections to these authors if indeed they were in the citation network. We call these connections *possible paths of influence*.
3. We downloaded the publications that satisfied a-c.
4. To begin with, we created a keyword frequencies plots for each publication, and searched for the overlapping keywords.
5. Then, we created UMAP representation of sentences from each publication for visual indications.

6. Furthermore, the classification model was trained using gradient boosting to classify sentences to publications using the H2o Python library and a set of default hyperparameters: $ntrees = 200$, $max\_depth = 4$, $col\_sample\_rate = 0.5$, $min\_rows = 10$, $nfolds = 5$, $learn\_rate = 0.1$, $learn\_rate\_annealing = 0.99$.

7. Hierarchical clustering was done on TF-IDF vectors extracted from texts using multiple linkages.

8. Lastly, we have read the relevant parts of publications to understand the possible paths of influence.
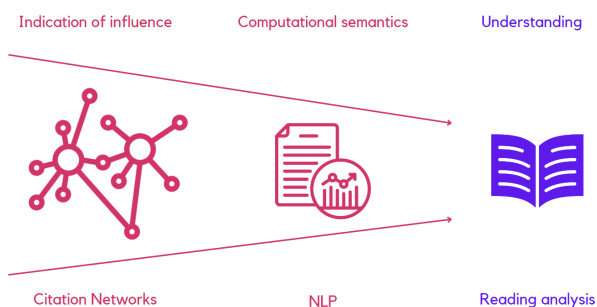
Fig. 1: The image shows a workflow of interdisciplinary approach for history of sciences. Firstly, citation networks are analyzed to identify potential indications of paths of influence. Then, NLP methods are used on the texts of publications to identify potential content of influences. Lastly, classical reading analysis is performed to confirm and elaborate on the findings.

3 Results

1. In the citation network, we found 22 connections to notable figures in Cognitive Science within two citations away from Mach, including Piaget and Skinner that directly cited Mach.

2. Furthermore, the word *Gestalt* was used in Mach's original publication in German, *Beiträge zur Analyse der Empfindungen*.

3. The classification model achieved $\approx 70\%$ accuracy with 0.99 r^2 and nice convergence.

4. Hierarchical clustering differentiated between publications as predicted.

4 Conclusion and discussion

Given that some publications were short, and many publications were of the same authors on similar topics, it was easier for the model to misclassify these publications. For instance, Skinner had 5 out of those 22 connections, some of which had only several sentences. In view of these limitations, we think that the model has nice performance which is supported by high r^2. However, for bigger publications, we hypothesize that misclassifications might signify similarities between authors and provide a supporting argument. For this reason, we constructed hierarchical clustering based on TF-IDF, and found another supporting data-driven evidence that some of these works are clustered according to the possible influences as expected.

Ernst Mach's ideas have had a significant impact on the development of Cognitive Science. He advocated for the unification of the physical and psychological, which is a fundamental characteristic of modern Cognitive Science (Pléh & Gurova, 2013). He interpreted cognition in an evolutionary selectionist framework, where hypotheses and trials are a key aspect of both science and everyday cognition (Mach, 1959). This view was further developed by Piaget (2005). Moreover, both Mach and Piaget share similar ideas about the adaptation of thoughts to sensations and the construction of reality and cognition (Riegler, 2012). The connection between Mach and Gestalt psychology lies primarily in Mach's similar use of the Gestalt concept in his publication *Contributions to the Analysis of Sensations*, which he used well before the Gestalt school even arose. Furthermore, his concept of economy of thought and the idea that the mind simplifies and abbreviates information aligns well with the Gestalt focus on global patterns and holistic processing. Additionally, Mach's idea that all is made out of sensations aligns with the Gestalt emphasis on the active role of perception in constructing the world. Several other paths of influence were identified without completing the last step of reading analysis.

Data availability

Data, analysis, and the code used in this study are available on GitHub at https://github.com/JanPastorek/mach_influence.

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