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The Interdisciplinarity of Collaborations in *Cognitive Science*

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Abstract

We introduce a new metric for interdisciplinarity, based on co-author publication history. A published article that has co-authors with quite different publication histories can be deemed relatively "interdisciplinary," in that the article reflects a convergence of previous research in distinct sets of publication outlets. In recent work, we have shown that this interdisciplinarity metric can predict citations. Here, we show that the journal *Cognitive Science* tends to contain collaborations that are relatively high on this interdisciplinarity metric, at about the 80th percentile of all journals across both social and natural sciences. Following on Goldstone and Leydesdorff (2006), we describe how scientometric tools provide a valuable means of assessing the role of cognitive science in broader scientific work, and also as a tool to investigate teamwork and distributed cognition. We describe how data-driven metrics of this kind may facilitate this exploration without relying upon rapidly changing discipline and topic keywords associated with publications.

Keywords: Interdisciplinarity; Jensen–Shannon divergence; Publication history; Scientometrics; Big data

In the past few decades, multiauthor collaborations have become the norm across the sciences (Wuchty, Jones, & Uzzi, 2007). These collaborations are often based on multidisciplinary teams—a property that has long been recognized as important for scientific progress (Fiore, 2008). Cognitive science, since its inception, has been regarded as a radically interdisciplinary agenda. Recent reports in this journal have presented scientometric analysis suggesting that the field significantly exports and imports ideas from other domains and may also serve to interconnect domains (Goldstone & Leydesdorff, 2006; Leydesdorff, Goldstone, & Schank, 2008). These results contrast with other findings that

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the field may be becoming less diverse due to an increasing influence of psychology (Gentner, 2010). Further scientometric analysis could serve to test these issues in cognitive science. The scientometric agenda may also provide new operationalization of "interdisciplinarity" and reveal how cognitive science performs under these metrics. For example, the distribution and historical progression of topics in our journals may unveil patterns of topical diversification over time (Cohen Priva & Austerweil, 2015). In addition, coauthorship analyses may offer a better understanding of how interdisciplinarity is changing through emerging collaborative networks (Huang & Chang, 2011).

To further investigate the important issue of interdisciplinarity in cognitive science, we explored whether publishing cognitive scientists *themselves* coauthor with each other in ways that reflect interdisciplinary activity. The most recent work regarding cognitive science involved a quantification of citation networks in journals (Leydesdorff & Goldstone, 2014). Here, we look at coauthorship networks: Do papers published in the journal *Cognitive Science* (*CogSci*) tend to involve collaborations between coauthors who have, in the past, published in different domains? To do this, we apply a data-driven metric for interdisciplinarity that is applicable to any coauthorship data for which some publication history of authors is known. Here, we demonstrate that the journal *Cognitive Science* is among the highest on this interdisciplinarity metric compared to other journals in the cognitive sciences.

Interdisciplinarity has been quantified using different methods. Some studies have relied on topic models (Nichols, 2014), while others use citation networks (Leydesdorff & Goldstone, 2014; Porter, Cohen, Roessner, & Perreault, 2007). In a recent study, we quantified interdisciplinarity based on publication history: Two authors likely derive from different fields if their history of publication is quite different leading up to the given article which they have coauthored (Bhat, Huang, Rodriguez, Dale, & Heit, 2015; Bhat, Rodriguez, Dale, & Heit, 2015). Taking coauthor publication history, we calculated the Jensen–Shannon divergence (JSD) (see Lin, 1991) over the frequency distributions of journals that authors have published in. If authors publish in different journals, the distributions diverge from each other, resulting in a high JSD, and thus, interdisciplinarity score. This measure has been shown to not only correlate with citation count, but it can also be used to successfully predict these citation counts. Fig. 1 shows examples of JSD measures for three pairs of coauthors in our database. Panel A shows an example where the two authors overlap in their publication history, producing a low JSD. Panel B is of medium interdisciplinarity, while panel C shows very high interdisciplinarity. There is hardly any overlap between the two distributions, producing a very high JSD score.

As part of this broader project on quantifying interdisciplinarity, we have built a data set of millions of articles using the Thomson Reuters Web of Knowledge resource. The database was constructed by collecting articles from the top 250 JCR Social Sciences Edition journals and the top 250 JCR Science Edition journals. We extracted all articles published in these top journals from 2005 to 2010. For each of these articles, we extracted the publication history of authors from the 5 years prior. This resulted in over 7 million total articles suited to exploring the publication patterns of coauthors and estimating whether journals tend to involve collaborations among coauthors who have distinct publication tendencies.

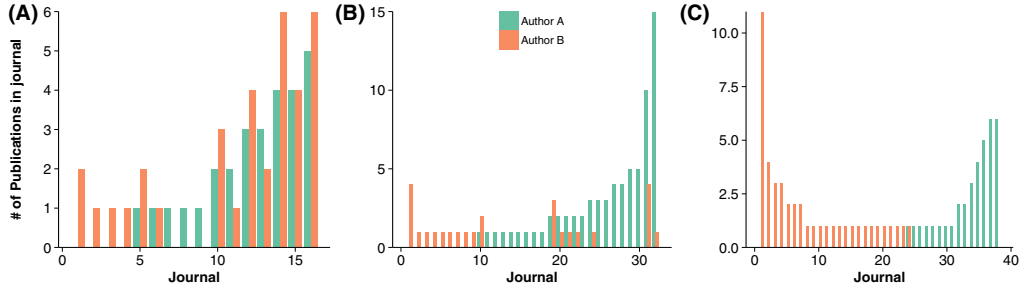

Fig. 1. Three examples of publication history distributions. Interdisciplinarity as measured by JSD between the authors' distributions increased from left to right. Panel A has a JSD of .103; panel B, .401; and panel C, .693.

For the present study, we added *CogSci* to our list of journals and extracted the papers published from 2005 to 2010 (over 300) and, as just described, extracted the publication history of all of the authors from those papers. To investigate the collaboration patterns of *CogSci*, we construct a coauthorship network over authors in the articles of a given journal. An edge in this network thus reflects a collaboration of two individual authors. We quantify the *interdisciplinarity* of an edge by its JSD score.[1] Preserving the individual edges in our calculation of JSD captures these unique collaborations.

How interdisciplinary are the collaborations in *CogSci* compared to other journals? To explore this, we did the analysis described over all 501 journals in our data set, excluding journals with fewer than 100 papers and 50 unique authors. For each of the 425 remaining journals, we randomly selected 500 papers and, from these papers, sampled 500 edges to build a coauthorship network. From these edges, the average divergence score was calculated. To avoid excessive bias from authors with few publications in the data set, we only included edges in our calculation for which authors had published at least five prior journal articles.

Using the average JSD measures, we can statistically compare *CogSci* to other journals and scientific fields. First, we compared *CogSci* to all journals from JCR SOCSCI and JCR SCI; second, in a more detailed analysis, we extracted journals covering neuroscience, psychology, and cognitive science from the 425 journals and compared *CogSci* to these related journals. Table 1 shows the mean and standard deviation of the JSD measures of these different sources.

Table 1
JSDs measures across journals

Source	*M*(JSD)	*SD*(JSD)	Collaborations	Journals
CogSci	0.413	0.156	161	1
Other cognitive science journals	0.391	0.156	7,748	19
JCR science journals	0.383	0.171	103,418	229
JCR social science journals	0.362	0.164	65,001	196

CogSci falls within the general range of interdisciplinary measures collected, but it has a higher JSD, on average, than journals from JSR SOCSCI and JCR SCI. However, other journals covering cognitive science and neuroscience topics are similarly interdisciplinary. While we see a wide distribution of JSD scores within *CogSci*, overall scores sit on the more interdisciplinary side of the distribution of all scientific domains. In fact, it ranks within the top 20% of interdisciplinary journals, being the 85th most interdisciplinary journal out of 426 journals remaining in the analysis. A one-sided Wilcoxon rank sum test (Mann–Whitney test) shows that the distributions of *CogSci* scores and scores in the other journals are different (W = 16,583,787, N_1 = 175, N_2 = 168,419, p = .002). Within selected journals covering similar cognitive topics, *CogSci* ranks fourth (see Table 2). As we hypothesized that *CogSci* would have higher interdisciplinarity than these journals, a one-sided Wilcoxon rank sum test was run, with the result being marginally significant (W = 726,817.5, N_1 = 175, N_2 = 7,748, p = .051). Interestingly, all journals ranking higher than *CogSci* are neuroscience journals, suggesting that *CogSci* may be the highest on the JSD metric among more general cognitive science journals. Our analysis also reveals that journals in the SCI database are more interdisciplinary than SOCSCI journals, yet *CogSci* ranks among these SCI journals.[2]

A data-driven approach to interdisciplinarity presents new opportunities to the cognitive science of groups and teams. There is continuing interest in quantifying team composition and predicting team performance (Goldstone, Roberts, & Gureckis, 2008; Woolley,

Table 2
Average JSD score and ranks within cognitive science and neuroscience journals

	Journal	JCR Database	Mean JSD	Total Rank
1	Nature Reviews Neuroscience	SCI	0.481	8
2	Neuron	SCI	0.458	22
3	Nature Neuroscience	SCI	0.414	83
4	*CogSci*	SOCSCI	0.413	85
5	Psychological Bulletin	SOCSCI	0.411	88
6	Neuropsychologia	SOCSCI	0.409	96
7	Cognition	SOCSCI	0.397	112
8	Neuroscience & Biobehavioral Reviews	SCI	0.394	121
9	Trends in Cognitive Sciences	SOCSCI	0.383	148
10	Psychological Review	SOCSCI	0.38	164
11	Neuropsychology	SOCSCI	0.378	170
12	Trends in Neuroscience	SCI	0.371	191
13	Journal of Cognitive Neuroscience	SOCSCI	0.366	211
14	Annual Review of Neuroscience	SCI	0.366	213
15	Brain and Cognition	SOCSCI	0.359	238
16	Cognitive Psychology	SOCSCI	0.359	241
17	Annual Review of Psychology	SOCSCI	0.357	244
18	Journal of Memory and Language	SOCSCI	0.351	277
19	Neuropsychology Review	SOCSCI	0.346	300
20	Behavioral and Brain Sciences	SOCSCI	0.327	350

Chabris, Pentland, Hashmi, & Malone, 2010). JSD and related measures permit data-enabled tools to correlate team composition and success. Perhaps more provocatively, new metrics might offer quantitative means of predicting *potential* teams, akin to an "interdisciplinary recommender system." This may help to quantify research on group performance that emphasizes the importance of building appropriate combinations of skills and experiences on teams (e.g., Huber & Lewis, 2010). In addition, these measures may overcome traditional approaches to characterizing the interdisciplinarity of teams. Scientific fields rapidly change, and two faculties who happen to be, for example, in a psychology department together may nevertheless reflect a robust interdisciplinary collaboration should they work together. Measures such as JSD of publication history may be able to detect such teams. Unlike Gentner (2010), we have found no evidence for the field becoming more narrow, instead we found a wide range of collaborations consistent with the wide range of topics found by Cohen Priva and Austerweil (2015) and the citation import study by Goldstone and Leydesdorff (2006). A more detailed study is needed, however, to analyze how author-level interdisciplinarity is reflected in the content of the articles.

From these data and models, we can conclude that *CogSci* as a whole can be considered a very interdisciplinary journal, showing a higher JSD score than journals from JCR's SOCSCI and SCI database. In general, however, we find that journals within the SCI database show a higher JSD measure than journals in the SOCSCI database. One possible explanation is the increase of team science, especially in the natural sciences (Cronin, 2001). *CogSci* shows a similar pattern according to the JSD measure, underlining that it is among the outlets where diverse authorships find a home, and novel collaborations are encouraged.

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Notes

1. We chose to quantify the edges of collaboration rather than averaging over journal articles. In a multiauthored paper, this process of averaging may wash out a very unique collaborative coauthorship.
2. Additional visualizations of the distributions and rankings are available on http://shiny.tillbergmann.com/apps/cogsci/ and in the Supplementary Material.

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Appendix S1. Interactive visualizations of the distributions and rankings.

Appendix: Jensen–Shannon divergence

The Jensen–Shannon divergence (JSD) is a method to measure the similarity, or mutual information, between two probability or frequency distributions (P and Q). It is based on the Kullback–Leibler divergence or relative entropy (KLD):

$$\mathrm{JSD}(P,Q) = 0.5 \times \mathrm{KLD}(P,M) + 0.5 \times \mathrm{KLD}(Q,M) \tag{1}$$

where

$$M = 0.5(P+Q) \tag{2}$$

$$\mathrm{KLD}(A,B) = \sum_i A_i \times \log\left(\frac{A_i}{B_i}\right) \tag{3}$$

where i represents a journal either A or B or both have published in, and A_i is the relative frequency with which A has published in that journal. The sum iterates over all these journals.

As an example of collaboration and JSD, let us consider the coauthorship of two of the authors, Rick Dale and Evan Heit (see Table A1). To calculate JSD, the counts need to be converted into probability distributions by dividing with the total number of publications for each author. M represents the mean probability of publication over both author distributions. After calculating M, we can take the KLD (relative entropy) of the author distribution and the mean distribution, and then take the average of the resulting sum. In this example, this leaves us with a JSD measure of 0.62, meaning that the authors have published in different journals and thus their publication history diverges from each other.

Table A1
Partial publication history of Evan Heit and Rick Dale before 2010

	Evan Heit	Rick Dale
Journal of Experimental Psychology: Learning Memory and Cognition	4	0
Psychonomic Bulletin & Review	4	0
Memory & Cognition	3	0
Trends in Cognitive Sciences	2	0
Contemporary Psychology: APA Review of Books	2	0
Journal of Experimental Psychology: General	2	0
Behavioral and Brain Sciences	2	3
⋮	⋮	⋮
Perception	0	2
Proceedings of the Annual Conference of the Cognitive Science Society	0	2
Psychological Science	0	3
Cognitive Science	0	5