Measuring Multidisciplinarity Using the Circle of Science

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Abstract

In this paper we introduce a method for measuring multidisciplinary research that is based on the assumption that the underlying structure of science is stable and has extremely low dimensionality.

Introduction

Popular measures of multidisciplinary research (MDR) are based on the assumption that the underlying structure of research has very high dimensionality. For example, the most common approach is to characterize research into tens or hundreds of weakly related disciplines where each discipline is composed of journals and relatedness is based on the citation data from the articles in these journals. One can then use simple measures of dispersion to characterize MDR, such as publications or references across disciplinary categories (Leydesdorff, 2007; Porter, Cohen, Roessner, & Perreault, 2007; Porter, Roessner, & Heberger, 2008; Rinia, van Leeuwen, Bruins, van Vuren, & van Raan, 2002). Studies using network centrality measures between journals assume an even higher level of dimensionality to science (Leydesdorff, 2007; Rafols & Meyer, 2009).

This paper is based on an alternative assumption – that the underlying structure of research has extremely low dimensionality. We have recently shown that one can represent the vast majority of relatedness between disciplines using one dimension (Klavans & Boyack, 2009a). Disciplines can be placed around the perimeter circle of science in such a way that disciplines that are related tend to be close to each other. Millions of articles can correspondingly be placed on the edge of the same circle using co-citation analysis, where co-citation clusters (of papers) are assigned to their dominant disciplines. The location of a department or a researcher can then be plotted as the average position of all of their corresponding publications. Research that is closer to the center of the circle is more multidisciplinary. Research that is not multidisciplinary is located at the edge of the circle. In this paper we describe this approach along with some advantages and disadvantages associated with its use.

Data and Models

This paper builds on three data sources: a meta-analysis of 20 maps of science, a disciplinary analysis of 16,000 journals, and a co-citation analysis of 2.08 million reference papers and the corresponding 5.68 million articles that cite these references. Following is a short description of each data source and how they relate to each other.

The meta-analysis of 20 maps of science focused only on maps that were relatively comprehensive (covering the majority of the natural and social sciences). The earliest maps (from 1939 and 1948) were done by hand; experts drew major areas of science on a piece of paper with the assumption that proximity (between areas) corresponded to relatedness. Subsequent maps used computer algorithms to locate clusters of reference papers, journals, journal categories and, in one case, college course prerequisites. Various facets of these 20 maps were remarkably similar even though there was extreme diversity in sampling and methodology. A consensus map, based on relationships that were common to more than half the maps, emerged as a ring structure, with the sequence of scientific fields shown in Figure 1. Detailed information on the consensus map, how it was generated, and measures of its robustness, are available in (Klavans & Boyack, 2009a).

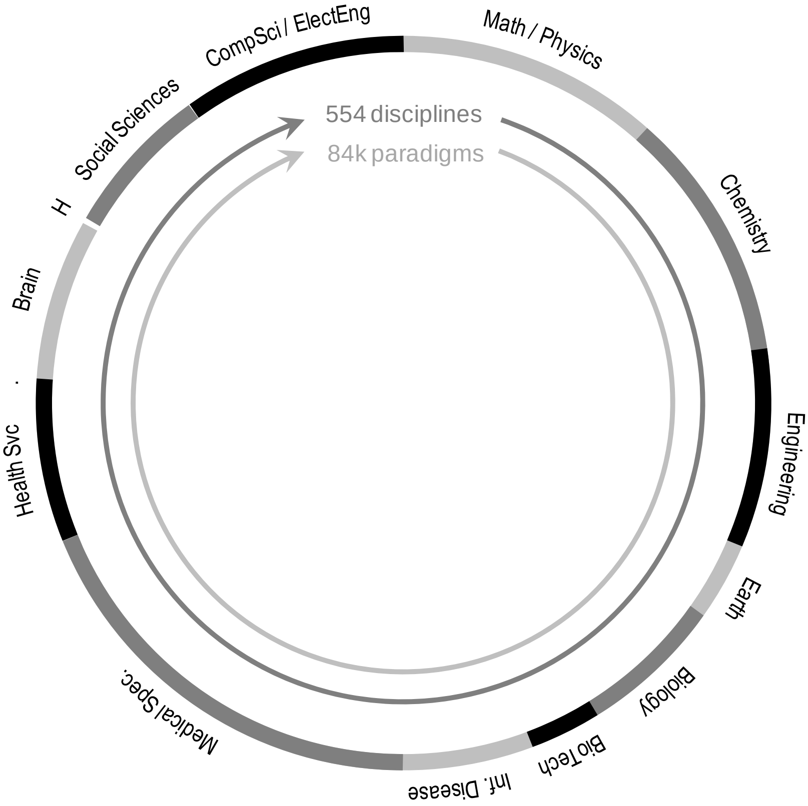

Figure 1. Circle of science showing high-level fields of science. 554 disciplines (journal clusters) and over 84,000 paradigms (co-citation clusters) have been ordered around the circle.

The second data source was a new journal disciplinary classification system of 16,000 journals (Klavans & Boyack, 2009b). Rather than use existing journal classifications (such as the Thomson/ISI categories), we generated our own journal categories using a combination of Thomson (~8,000 journals) and Scopus (~15,000 journals) data. Journal relatedness matrices based on bibliographic coupling using references and keywords were developed for each of the two data sources. These two matrices were then combined, and the resulting single matrix was clustered using a multi-step process leading to our classification system of 554 disciplines. These disciplines are easily assigned to the thirteen fields shown in Figure 1. Thirteen separate factor analyses were then done to order the disciplines within each field. The two fields on either side of each field were included in each factor analysis (thus covering 5 fields each) to provide sufficient information to allow the regressions to properly order disciplines within the central field. The overall ordering of the 554 disciplines thus specified, they were then located around the perimeter of the circle as shown in Figure 1.

The third data source was a co-citation analysis of publications in the Scopus data (Klavans & Boyack, 2009b). Following traditional methods of co-citation analysis (cf. Small, 1999), we first clustered 2.08 million highly co-cited references that appeared in the 2007 Scopus data. This clustering process generated over 84,000 separate paradigms, or co-citation clusters. We then assigned 5.68 million articles from the 2003-2007 Scopus data to these 84,000 paradigms using their reference distributions. Nearly 41% of the current papers were assigned to only one paradigm, while only 22% were assigned to more than three paradigms. In those cases where a current paper was also one of the reference papers, the paper was assigned to the reference paradigm with a fractional weight of 0.5, while the remaining 0.5 was split according to the reference distribution. The 84,000 paradigms span less than two orders of magnitude in size. Each of the paradigms was then assigned to its dominant discipline based on journal counts, and the 84,000 paradigms were then located around the perimeter of the circle based on the discipline orders and locations.

The ultimate result, as suggested by Figure 1, is a circular map of science in which 13 major fields, 554 disciplines, 84,000 paradigms, and 5.68 million articles indexed in the Scopus database between 2003 and 2007, have been placed in a logical order around its perimeter.

Multidisciplinarity

Multidisciplinary is determined by finding the average position of a set of publications that have been located on this circle of science. Since each separate publication is located on the perimeter of the circle, the average position of any set will lie either on the perimeter, or somewhere within the circle. Sets of publications whose average position lies on or very near the perimeter of the circle are not considered multidisciplinary. Sets of publications with an average position nearer the center of the circle are far more multidisciplinary. For example, Figure 2 shows the positions of various departments at the University of California, San Diego (UCSD) as calculated using this technique.

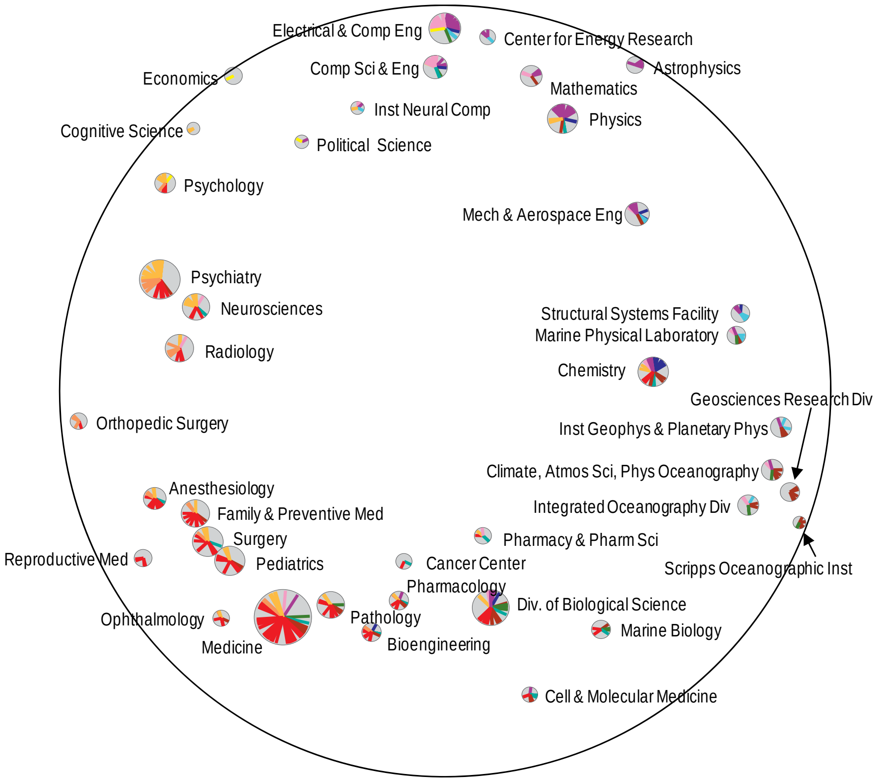

Figure 2. Positions of various departments at UCSD on the circle of science. Each node represents a department, while the colored rays within each node show the positions around the circle of the paradigms in which the papers associated with the department are located.

The Economics (upper left) and Astrophysics (upper right) departments are good examples of departments whose bodies of work are not multidisciplinary. They are located very close to the edge of the circle. By contrast, the Chemistry department (middle right) is an example of a department that publishes in a very wide ranging set of topics that span multiple disciplines. In fact, the Chemistry department publishes as much in medical disciplines (red rays in the Chemistry node) as it does in traditional chemistry (blue rays). We would thus consider this to be a multidisciplinary department.

A similar analysis can be applied for individual researchers. Figure 3 shows the results of this analysis for over 2,000 separate researchers at UCSD. Each dot within the circle represents a single researcher. Most researchers are located near the perimeter of the circle (their recent bodies of work are not multidisciplinary). The colored rays in Figure 3 are for the researcher located in the middle. This individual publishes in computer science (pink rays, 11:30); biology and biotechnology (green rays, 4:30), infectious disease (red rays, 6:00) and brain research (orange rays, 10:00). This particular individual runs a large electron microscope laboratory that services various departments on the campus, and is thus involved in studies in many disciplines.

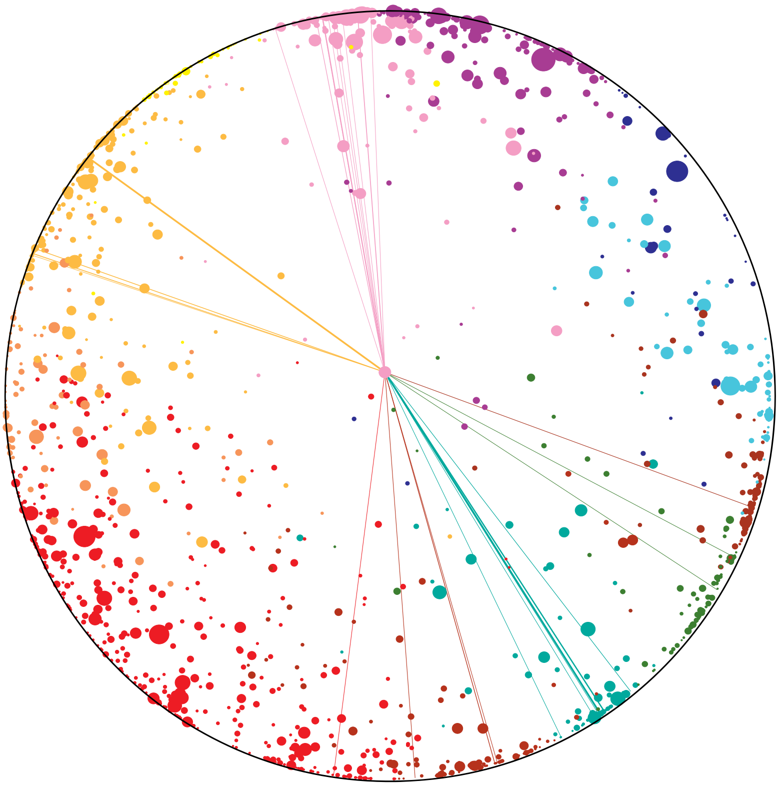

Figure 3. Positions of individual researchers at UCSD on the circle of science. Each node represents a single researcher. The colored rays emanating from the middle node show the positions of the paradigms in which the papers associated with that researcher are located.

Summary and Discussion

Measures of MDR require some assumptions about the nature and dimensionality of the phenomena. The tradition is to assume that disciplines are composed of journals, and there is inherently high dimensionality to these journal categories. We have presented a measure that is based on different assumptions. First, we assume that the proper unit of analysis is a cluster of related papers. Second, we assume that the structure of science can be adequately represented with just one dimension in a polar coordinate system (a circle). Multidisciplinarity can be represented by adding one more dimension – the radius. Using a unit circle, the radial position of a set of publications could be the basis of an MDR index ranging from 0 to 1.

Use of this low-dimensional approach to measuring multidisciplinary has the advantage that it reduces the dependency on any particular set of journal categories. For example, we expect that the 200+ Thomson/ISI journal categories could be easily and effectively ordered around the circle, and would give very similar results to those shown here. This method is also relatively insensitive to the exact ordering of disciplines around the circle. As long as disciplines or journal categories are somewhere near their optimum locations, the averaging effects associated with use of a circle will minimize the effects of any small scale local differences. Stated differently, a discipline would need to be moved 30º or so to have a significant effect on the radial position of a multidisciplinary set of papers.

There are potential disadvantages to this approach as well. Although we feel that the one-dimensional representation of science shown here is adequate for many purposes, it is inherently less accurate than a map with more dimensions (Klavans & Boyack, 2009a). This may reduce its usefulness and accuracy in measuring MDR. Policy makers may want a higher level of disciplinary differentiation than can be provided by a one-dimensional MDR index.

We also note that while this technique can measure the multidisciplinary nature of groups of papers as embodied by a researcher, department, etc., it cannot establish whether, in fact, a particular work or team of researchers is truly integrating their knowledge in an interdisciplinary manner, or if the resulting research is creating new knowledge that transcends traditional disciplines in a transdisciplinary manner (Stokols, Hall, Taylor, & Moser, 2008). These remain challenges for all techniques that purport to measure IDR/MDR using bibliometric techniques.

References

Klavans, R., & Boyack, K. W. (2009a). Toward a consensus map of science. *Journal of the American Society for Information Science and Technology, 60*(3), 455-476.

Klavans, R., & Boyack, K. W. (2009b). Toward an objective, reliable and accurate method for measuring research leadership. *Scientometrics, forthcoming*.

Leydesdorff, L. (2007). Mapping interdisciplinarity at the interfaces between the Science Citation Index and the Social Science Citation Index. *Scientometrics, 71*(3), 391-405.

Porter, A. L., Cohen, A. S., Roessner, D. J., & Perreault, M. (2007). Measuring researcher interdisciplinarity. *Scientometrics, 72*(1), 117-147.

Porter, A. L., Roessner, D. J., & Heberger, A. E. (2008). How interdisciplinary is a given body of research? *Research Evaluation, 17*(4), 273-282.

Rafols, I., & Meyer, M. (2009). Diversity measures and network centralities as indicators of interdisciplinarity: Case studies in bionanoscience. *Scientometrics, forthcoming*.

Rinia, E. J., van Leeuwen, T. N., Bruins, E. E. W., van Vuren, H. G., & van Raan, A. F. J. (2002). Measuring knowledge transfer between fields of science. *Scientometrics, 54*(3), 347-362.

Small, H. (1999). Visualizing science by citation mapping. *Journal of the American Society for Information Science, 50*(9), 799-813.

Stokols, D., Hall, K. L., Taylor, B. K., & Moser, R. P. (2008). The science of team science: Overview of the field and introduction to the supplement. *American Journal of Preventive Medicine, 35*(2 Suppl), S77-S89.