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A T-Shaped Multidisciplinarity Measure: The GRAND Research-Network Case Study

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Service-science research has long been studying T-shapedness, argueing that service scientists should be T-shaped individuals, deeply knowledgeable in one field and able to collaborate and communicate across disciplines. The value of multidisciplinary has also been recognized in academic environments, as funding agencies are committing substantial support to large-scale research initiatives that span across disciplines, organizations, academia and industry, even across national borders, and aim to address the major challenges of our time, from climate change, to energy shortage, to pandemics. New incentives and perfromance indicators are needed to encourage and reward interdiciplinary collaborative work. In this paper, we introduce a metric for multidisciplinarity based on the notion of T-Shapedness and we report on the application of this measure on data collected over four years from the GRAND Network of Centres of Excellence, a large-scale, Canadian, multidisciplinary research network conducting research on digital media with numerous academic and industrial partners. We describe our findings on how the community evolved over time in terms of its T-Shaped multidisciplinarity and compare the multidisciplinarity of GRAND researchers to their non-GRAND peers.

Key words: research networks, t-shapedness, multidisciplinarity, research evaluation

1. Introduction

The GRAND Network of Centres of Excellence (NCE) is a Canadian multidisciplinary research network, conducting research on digital media, the technologies that produce them, and their applications in our everyday lives. GRAND was funded from the Canadian government through the NCE (Networks of Centres of Excellence) program and, in its first four years (2010-2014), supported 41 research projects, across 26 Universities, involving over 200 researchers and their trainees. GRAND was a highly multidisciplinary network, with researchers from science and engineering, social sciences, health sciences, and arts and humanities. The GRAND digital-media research agenda was also very broad, related to new algorithms and tools to support the production of digital content; constructing platforms to host and enable the efficient access to this content; developing

and empirically evaluating applications using digital media in a variety of settings (e.g., entertainment, training, work, and healthcare); and, formulating policies around the use, sharing, and dissemination of digital content.

GRAND is an example of a new breed of large, geographically distributed, multidisciplinary research programs. The international research community and funding agencies are recognizing the need to support large-scale initiatives to address the grand challenges of our time. Driving this trend is the belief that these problems cannot be effectively addressed solely by researchers in a single discipline or a single organization, and that their study has to involve a broad spectrum of expertise across multiple centres of excellence. However, even as this belief is generally, and increasingly, shared, the questions of when, why, and precisely how these research networks are made effective are still very much open and the subject of considerable debate.

The investigation of these general questions and, more specifically, the study of how digital collaboration tools can contribute to the effectiveness of research networks has been part of the GRAND agenda since its inception. To that end, we developed a software platform, the GRAND Forum, to support communication and collaboration across the network members and projects and to streamline the administrative workflows and data collection required by the NCE program that is funding GRAND. The Forum has become a rich repository of data about the activities and research production of the GRAND research community. The availability of this dataset presents us with a unique opportunity to study some of the core questions around the effectiveness of large-scale research networks in fostering interdisciplinarity.

We base our study on a few key methdological assumptions. Multidisciplinary research integrates understanding, knowledge, techniques, tools, data, etc. from more than one body of knowledge to produce solutions that are beyond the scope of any one field (Porter et al. 2007). Multidisciplinarity also emerges as another dimension of research excellence, beyond the more traditional metrics, i.e., publication and citation counts (Wagner et al. 2011). Even though these statements may intuitively make sense, there is no generally accepted measure of a researcher's multidisciplinarity. The main contribution of this paper is the **formulation of a quantitative measure of multidisciplinarity**, or, more specifically, a measure of fitness with a generally accepted notion of ideal multidisciplinarity, namely T-shapedness (Guest 1991, Demirkan and Spohrer 2018). Our measure reflects the multidisciplinarity of the output of a researcher. The second contribution of this paper is our **use of our multidisciplinary metric to analyze the multidisciplinarity of the GRAND community before and after involvement in GRAND against (a sample of) their Canadian peers**. In order to examine the multidisciplinarity of Canadian researchers within and outside GRAND, we use data from Scopus.

The rest of this paper is organized as follows. We first review background research related to our work. We then describe the GRAND research network as the subject of our study, and present the T-shaped multidisciplinary metric, followed by the methodology, data collection, and analysis of our study. Next, we present our findings and discuss their implications. Finally, we conclude by summarizing the lessons we learned through our study.

2. Related Work

There are many quantitative measures of research and scholarly information broadly called informetrics (Bar-Ilan 2008). More recently, measures of interdisciplinary research have received attention (Wagner et al. 2011) as have alternative measures of scholarly influence in social media and the web (Bar-Ilan et al. 2013). Given our quantitative study of the multidisciplinary GRAND research network, we summarize here the most relevant work on measures of multidisciplinary research.

A large number of categorizations of interdisciplinarity has been reviewed by (Huutoniemi et al. 2010); this conceptual framework for interdisciplinary research considers three criteria: the scope of interdisciplinarity, multidisciplinary and interdisciplinary research interactions, and the objectives of the research activity. However, this qualitative framework requires a domain expert and adopts, as the unit of analysis, the research-proposal document.

In contrast, our work aims at a quantitative measure of multidisciplinarity that can be applie dto a researcher or a research network. To that end, we have been inspired by the notion of a T-shaped individual – or a person with T-shaped skills – who displays depth in a particular field of study (the stem of the T) and a breadth of abilities and skills across disciplines (the bar or top of the T) (Guest 1991, Iansiti 1999, Oskam 2009, Wu et al. 2012). The concept was first attributed to Guest in 1991 (Guest 1991) but many others have described T-shaped skills as necessary components to building multidisciplinary teams (Donofrio et al. 2009, IDEO and Brown 2010). Intuitively, an academic researcher with a perfect T-shapedness score should have a substantial percentage of his/her publications in one discipline, while the remainder of his/her publications should be fairly smoothly distributed over a number of other disciplines (Stirling 2007). T-shapedness has been studied in the context of service science where it is argued that Service scientists should be T-shaped individuals. Recently, it has been suggested that education systems should develop T-shaped professionals in part to encourage and reward academics to collaborate with colleagues in other disciplines and to research agendas that are transdisciplinary (Demirkan and Spohrer 2018).

Two additional studies are very closely related to our own in that they investigate the multidisciplinarity in research projects. First, (Cummings and Kiesler 2005) studied a number of projects receiving two particular National Science Foundation's grants. They analyzed and compared methods of collaboration, in order to highlight gaps in existing collaboration methods and practices.

However, this study does not provide a clear metric for multidisciplinarity. The second, (Yegros-Yegros et al. 2010), studied interdisciplinarity by classifying publications into disciplines according to the ISI Subject Categories. The degree of multidisciplinarity was measured through indicators of disciplinary diversity as suggested by (Rafols and Meyer 2010). According to (Rafols and Meyer 2010), interdisciplinarity requires the consideration of diversity (defined by the variety, balance of the distribution, and disparity of production), and coherence (the degree to which the process of integration is taking place). Our approach follows the diversity aspect of interdisciplinarity, defining the T-shapedness metric to capture variety and balance.

3. The GRAND Network and its T-shaped Multi-disciplinarity

The GRAND NCE is an example of todays large-scale, geographically distributed, multidisciplinary research programs, with numerous academic and industrial partners. The first objective of this study is to gain a deeper understanding of how the GRAND network of researchers worked during the first four years of the networks life and how their collaborative practices changed over time. Our second objective is to compare the GRAND community against a sample of the Canadian research community in terms of the multidisciplinarity of their research outcomes, in order to examine whether the GRAND network led to a higher degree than what is typical of other Canadian researchers.

In order to measure the multidisciplinarity of researchers within and outside GRAND, we enhanced the information collected in our GRAND Forum with information from Scopus about the disciplinary range of each researchers productivity. This information can be retrieved for GRAND researchers and a sample of Canadian researchers from outside GRAND, which enables us to comparatively examine the relative multidisciplinarity of these two groups. Scopus associates each publication with a subset of 26 different subject areas; therefore, for a given researcher, we can identify the union of their publications subject-area sets for a given year, and the number of publications associated with each of these subject areas.

As we have already discussed, a researcher with a perfect T-shapedness score should have a substantial percentage of his/her publications in one of the Scopus subject-area, indicating depth of expertise in this primary area (the T stem), while the remainder of his/her publications should be fairly smoothly distributed over a number of other subject-areas, indicating multidisciplinary breadth of knowledge (the T horizontal bar) (Donofrio et al. 2009), balance, and disparity. The breadth of disciplines outside the primary discipline increases as (a) the number of breadth disciplines increases, and, (b) the amount of work is evenly balanced across these breadth disciplines. The third diversity principle, disparity, refers to the way in which the disciplines are different from or similar to each other. Our analysis relies on the Scopus discipline categories, and we assume

that all categories are equally distinct from each other. Therefore, we define our T-shaped metric of multidisciplinarity (referred to as MD henceforth) based on: (a) the ratio of a researchers productivity in his/her primary subject area to his/her overall research output, and (b) the degree to which the rest of his/her production is smoothly distributed over all areas other than his/her primary subject area. Intuitively, a "perfectly T-shaped" researcher would have an ideal ratio (r) of publications in his/her primary subject area and the rest of his/her publications should be smoothly distributed over the other (non-core) subject areas. Intuitively, a value of 0.5 or lower might suggest less expertise in a core area while $r = 0.75$ or higher might signify a higher depth with relatively little productivity outside a core area of expertise. The value of r for the purposes of this study was chosen to be 0.618, which we call the golden ratio. We experimented with a number of different values for r between 0.6 and 0.70 (0.6, 0.618, 0.65, 0.7) and found that the results presented below are consistent using each of these alternative values.

We have implemented the MD measure in terms of two vectors: v_1 and v_{breath}. The core-discipline vector (v_1) captures the divergence of the researchers productivity in his/her primary discipline relative to his overall productivity from the ideal ratio. The breadth vector ($v_{breadth}$) captures the degree to which the researchers productivity is balanced across the other (non primary) subject areas. Considering n as the number of subject areas, $|s_i|$ as the number of publications associated with discipline i, s_1 as the core subject area, and R as the ratio of productivity in his/her core area over his/her overall productivity, we can define the vectors v_1 and $v_{breadth}$ as:

$$v_1 = \left(1, 1 - \frac{|r - R|}{r}\right) \qquad v_{breadth} = (|s_2|, |s_3|, ..., |s_2 n|)$$

We can identify the theoretical best case, $v_{1Best} = (1, 1)$ and $v_{breadthBest} = (1, 1, ..., 1)$ for the core and breadth vectors, respectively. Given the vectors v_1 and $v_{breadth}$, we calculate two angles: (a) the angle between v_1 and the vector v_{1Best} and (b) the angle between $v_{breadth}$ and $v_{breadthBest}$. Both of these angles capture some aspect of the "divergence" of the researcher's productivity profile from the ideally T-shaped profile, whether in the ratio of his/her productivity in his/her core subject area to his/her overall production, or in the smoothness of the distribution of the rest of his/her work in all other non-core subject areas.

Next, we calculate the overall multidisciplinary score of a researcher as the normalized weighted average of the above two angles. To normalize the $\angle v_1 v_{1Best}$ and $\angle v_{breadth} v_{breadthBest}$ angles such that they are values between 0 and 1, we divide them by the theoretical worst-case angles, $\angle v_{1Worst} v_{1Best}$ and $\angle v_{breadthWorst} v_{breadthBest}$ respectively, which essentially produces a measure of the distance between the researcher and the worst case. Each normalized angle is then weighted based on the value of r and the result is subtracted from 1 to give a positive value between 0 and 1 for the final value of MD.

Table 1 Comparing Average MD of GRAND Researchers and the Control group

	Min	Max	Mean	Std. Dev.
MD@2009 GRAND	0.00	0.622	0.366	0.171
MD@2009 Control	0.00	0.614	0.390	0.168
MD@2013 GRAND	0.00	0.629	0.398	0.151
MD@2013 Control	0.00	0.640	0.401	0.164
MD@2013-MD@2009 GRAND	-0.25	0.449	0.032	0.134
MD@2013-MD@2009 Control	-0.53	0.499	0.011	0.138

To investigate the potential impact of the GRAND NCE on the multidisciplinarity of its members, we had to establish a comparison data set for the community of GRAND researchers. This motivated us to only compare GRAND researchers to researchers with Canadian federal research funding: our sample of Canadian researchers would be a subset of those researchers in Canada who are not part of GRAND but receive funding in the same areas as GRAND researchers and are at the same universities as GRAND researchers. This resulted in a total of 186 GRAND researchers and 534 researchers in the Canadian researcher sample in our dataset. We refer to the Canadian researcher sample as the control group.

4. Research Findings and Discussion

We calculated the T-shapedness (MD) of the productivity of the GRAND researchers and the control group for two periods: from 2006 to 2009 and from 2010 to 2013. These two timeframes were chosen to provide us with two data points for each researcher: one for their multidisciplinarity during the four-year period just before GRAND started, referred to as MD@2009, and a second one for the four-year period during GRAND, referred to as MD@2013.

We then considered three questions. *Q1: Has the multidisciplinarity of researchers improved over time (2013 - 2009)?* To answer this question we computed the paired-difference t-test between the MD@2009 and MD@2013 values of every researcher in GRAND and the control dataset. We found that both GRAND and control researchers improved in terms of their multidisciplinarity. For GRAND researchers the p-value was 0.0006256 and for the researchers in the control group the p-value was 0.03286 - see Table 1. It appears that both groups of researchers had more multidisciplinary research output in the period from 2010 to 2013, as compared to the period from 2006 to 2009. The two p-values indicate that the phenomenon is slightly stronger for the GRAND community.

We then proceeded to investigate this phenomenon more precisely, asking whether *Q2: the multidisciplinarity increase in GRAND was stronger than the corresponding increase in the control group.* To answer this question, we computed the increase of the MD measure, i.e., MD@2013-MD@2009, for each researcher in the GRAND community and in the control group. An independent-samples

t-test revealed support for the hypothesis that "participation in GRAND led to a more pronounced increase in the researcher's multidisciplinarity" (p-value=0.03474).

Finally, we examined *Q3: whether there were any significant differences in the multidisciplinarity of the two groups in 2009 or in 2013*, effectively asking whether the GRAND community was more (or less) multidisciplinary than the control community in 2009 (or in 2013). An independent-samples t-test between the MD@2009 and the MD@2013 values of GRAND and control researchers revealed that in 2009 the control group was marginally more multidisciplinary than the GRAND Researchers (p-value=0.08522), but in 2013 this difference was practically eliminated (p-value=0.7982); the researchers in GRAND had a slightly more pronounced increase in multidisciplinarity during the four years of GRAND participation than the control group, which led to the elimination of this difference.

Our findings indicate that researchers in GRAND benefited from their participation in GRAND in that they became more multidisciplinary than their Canadian peers who were not participating in GRAND. As a community, GRAND researchers started slightly less multidisciplinary than their peers, but at the end of the four years they became slightly more multidisciplinary. This finding implies that, to some degree, GRAND met its objective of pulling expertise from different areas together to produce research that can potentially have impact across areas. At the very least, this finding provides evidence that the NCE program fulfills its mandate since a researchers participation in a NCE encourages increasingly multidisciplinary productivity.

5. Conclusions and Future Work

In this paper, we introduced a T-shapedness measure of multidisciplinarity, defined as the relative ratio of ones research production in ones core area of expertise over ones total production. We used this measure in a study of the GRAND research community, a multidisciplinary pan-Canadian NCE, conducting research on all aspects of digital-media technologie. We found that the GRAND community became increasingly multidisciplinary over time, according to this measure, more so than the control community of their Canadian peers who had obtained research grants from the same NSERC/SSHRC area committees. This result suggests that the GRAND NCE, or, at the very least, the NCE program, has effectively cultivated multidisciplinary research production.

We believe that this work, beyond offering insights in the evolution of the GRAND researcher community, its activities and its research output, puts forward a general methodology for analyzing large research communities and comparing them against each other. In the future, we plan to examine in depth the record of individual researchers who best exemplify (or constitute exceptions to) the trends we discovered in order to gain insights on specific activities and best practices for researchers to take advantage of belonging in such a research network. We feel the T-shaped

measure of multidisciplinary should be further applied to other such networks and communities of researchers.

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