HOW FAR CAN SCHOLARLY NETWORKS GO? EXAMINING THE RELATIONSHIPS BETWEEN DISTANCE, DISCIPLINES, MOTIVATIONS, AND CLUSTERS

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ABSTRACT

This study aims to understand the extent to which scholarly networks are connected both in person and through information and communication technologies, and in particular, how distance, disciplines, and motivations for participating in these networks interplay with the clusters they form. The focal point for our analysis is the Graphics, Animation and New Media Network of Centres of Excellence (GRAND NCE), a Canadian scholarly network in which scholars collaborate across disciplinary, institutional, and geographical boundaries in one or multiple projects with the aid of information and communication technologies. To understand the complexity in such networks, we first identified scholars' clusters within the work, want-to-meet, and help networks of GRAND and examined the correlation between these clusters as well as with disciplines and

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geographic locations. We then identified three types of motivation that drove scholars to join GRAND: practical issues, novelty-exploration, and networking. Our findings indicate that (1) scholars' interests in the networking opportunities provided by GRAND may not easily translate into actual interactions. Although scholars express interests in boundary-spanning collaborations, these mostly occur within the same discipline and geographic area. (2) Some motivations are reflected in the structural characteristics of the clusters we identify, while others are irrelevant to the establishment of collaborative ties. We argue that institutional intervention may be used to enhance geographically dispersed, multidisciplinary collaboration.

Keywords: Scholarly network; multidisciplinary collaboration; motivation; distance; cluster

INTRODUCTION

Research collaboration has been undergoing a confirmed to shift from traditional organizations toward research networks (Hars & Ou, 2002; Nokkala, 2007; Olson et al., 2008; Pohoryles, 2002). Research networks are a specific type of networked organization that are, in essence, networks of teams or work units progressing towards a common goal. As they are flexible, laterally coordinated, team-based, networked organizations are characterized by boundary-spanning work and a shift towards reduced bureaucratic structures (Rainie & Wellman, 2012). Compared to traditional bureaucracies, networked organizations may exhibit a flatter and more decentralized structure, tend to enforce fewer rules, have less hierarchical reporting relationships, and a more informal work culture. Employees in such environments work in multiple, fluid teams that are often ad hoc and temporary. Additionally, because they have more relationships with peers rather than with superiors or subordinates within hierarchies, employees in networked organizations may have more autonomy and discretion in their endeavors. As employees work and network across groups, organizations, and frequently across distance, work and communication flows may become boundary spanning. Furthermore, such organizations are often geographically distributed and facilitated by information and communication technologies (ICTs) and, as such, they can become both networked and virtual.

The trends of networked work play out loud and clear in research settings, which are especially conducive for organizing work in a networked

fashion. Research networks have been increasing in number along with the growth in scholarly collaboration (Jones, Wuchty, & Uzz, 2008). At the same time, the social networks of scholars have become larger and more far-flung (Wagner & Leydesdorff, 2005), alongside substantially increased investment in the improvement of networking technologies that facilitate work in geographically disparate groups (Hara, Solomon, Kim, & Sonnenwald, 2003).

Recent research suggests that we are at a crucial stage in the development and adoption of technologies aimed at enabling remote scholarly collaboration (Nentwich, 2003). Even as access to these technologies spreads, adopting and using these for effective collaboration remains difficult. Additionally, collaboration must occur within a work and reward structure that is largely focused on individual achievement and status (Kennedy, 2003).

To improve research environments requires an improved understanding of collaboration. How does scholarly collaboration work, and what makes collaboration desirable for individual scholars? By understanding these issues it becomes possible for funding agencies to invest their limited resources in collaborations that are most likely to succeed, as well as allowing them to foster conditions under which other successful collaborations are likely to take shape.

Confirming the trend toward networked research, existing literature has identified various motivations to explain why academics are inclined to participate in scholarly networks (Hara et al., 2003; Nokkala, 2007; Olson et al., 2008; Pohoryles, 2002). Meanwhile, other studies have found that new challenges may hinder the formation of scholarly networks due to their structures as multidisciplinary collaboration and dispersed network structures become barriers to communication (Bos et al., 2008; Cummings & Kiesler, 2005; Dimitrova & Koku, 2009; Dimitrova, Koku, Wellman, & White, 2007; Olson & Olson, 2003, 2013; Rhoten, 2003; Zheng, Veinott, Bos, Olson, & Olson, 2002). A gap in the literature is obvious: the motivations identified as driving research collaborations are yet to be connected to the dynamics of collaborations that are actually taking place.

This study aims to elaborate on the relationships between scholars' motivations for being involved in collaborative networks and the structural characteristics of such networks. We ask two broad questions: (1) Are scholars interested in developing cross-boundary collaborative ties, and if they have such interests, are they reflected in their ongoing collaborations? (2) How do scholars' motivations for participating in scholarly networks shape these networks?

To answer these questions, we combine social network analysis (SNA), statistical analysis, and qualitative analysis. Our findings show that scholars' interests to meet potential collaborators from different disciplines and locations are hardly translated into reality, as their work is often constrained in disciplinary or geographic boundaries. In addition, we found that the formation of clusters in collaborative networks can be partly explained by scholars' motivations for engaging in the network.

This study makes four contributions to the study of scholarly collaboration. First, it uses a mixed methods approach to reveal the relationship between network structure and individual motivation by using the voices of those under study. Second, we also reveal the gap between scholars' willingness to expand their collaborative networks and their limited number of actual collaborative ties, confounded by disciplinary and geographic boundaries. Third, we elaborate that some motivations merely drive scholars to become involved with a scholarly organization rather than to actually build collaborative ties. Lastly, we identify networking as a motivation for scientific collaboration that has been neglected in the literature. Based on our findings, we argue that organizational interventions may improve the efficiency of communication, promote a greater quality of work, and maximize the benefits inherent in the network structure of research collaborations.

We begin with a short review of the shift towards networked research and research collaborations and continue with a discussion of the motivations to participate in such arrangements. We then explain the mixed methods used in our research as well as detailing the background of GRAND, the collaborative network used as our case study. In our analysis, we first identify relevant characteristics of work, help, and want-to-meet networks among GRAND members by linking them to participants' disciplines and geographic locations. Second, we identify different types of motivations exhibited by scholars to participate in GRAND and use these motivations to explain the characteristics of the network. In our discussion, we reflect on how the factors of discipline, distance, and motivation affect collaborative interaction, both separately and jointly.

NETWORKED RESEARCH

Scholarly Networks: The Shift to Networked Research

Scholarly collaborations are increasingly conducted in a networked manner rather than through bureaucratic structures (Wellman, Dimitrova, Hayat,

Mo, & Smale, 2014). Ever since the emergence of big science in the 1930s and 1940s, scientific research has become the domain of large collaborative projects (Galison & Hevly, 1992). The scope and complexity of research issues today foster their multidisciplinary nature, while economic concerns, such as maximizing the return for initial investments or, in some disciplines, maximizing the efficient use of expensive equipment, have led to multi-organizational involvement (Olson et al., 2008). Research collaborations are often larger and more complex, and they tend to be multidisciplinary, multi-institutional, multi-site, and reliant on ICTs. The type of boundary-crossing work and information flows that are unique to networked organizations are becoming common in scholarly networks.

Today, large collaborative networks are a given in research, especially in scientific research. While scholars have traditionally collaborated in informal scholarly networks – "invisible colleges" (Crane, 1972) – they are now collaborating through more formal structures, including networked organizations. Within collaborative networks, scholars are able to gain easy access to various resources through their collaborators, given their diverse knowledge, backgrounds, and skill sets. The implicit expectation in scholarly networks is that information exchange will not be restricted to the lines of formal hierarchical structure, but rather, that information will be shared widely with all interested participants (Stevenson, 1990). Recent empirical studies have demonstrated the performance-enhancing effects of networked work, specifically in enriching communication and advice exchange (Agneessens & Wittek, 2012).

Hypothesis 1. Scholars working in collaborative networks are more likely to help each other compared to those not working together.

Collaboration across Institutions, Distance, and Disciplines

Collaborative networks often face significant challenges and are not always successful (Olson et al., 2008; Olson & Olson, 2013). Multi-institutional collaboration can bring the benefits of pooling research expertise, coordinating research activities on a broader scope, and more efficient use of infrastructure, but may be hindered by competition for funding or efforts to guard intellectual property (Bos et al., 2008). Just as in networked organizations, coordinating research activities across large bureaucracies, such as universities or governmental organizations, can be difficult and slow. Some studies have even shown how complex collaborative research can

produce negative effects. For instance, Cummings and Kiesler (2005) found a negative correlation between the success of collaborative networks and the number of participating institutions (see also Rhoten, 2003).

In large scholarly networks, researchers often work in dispersed teams relying on collaborative tools and technologies that, in turn, foster the emergence of cyber infrastructure and e-science (Hey & Trefethen, 2008). Yet, mediated communication can increase opportunities for misunderstanding, slow down communication, decrease the incentive of participants to adapt, and make the development of trust difficult (Bos, Gergle, Olson, & Olson, 2001; Jarvenpaa & Leidner, 1999; Olson & Olson, 2003). Perhaps that is why scholars who need to communicate novel and complex knowledge prefer face-to-face meetings to digitally mediated communication (Bos et al., 2008; Dimitrova & Koku, 2009; Rhoten, 2003). Despite their collaborative traditions and familiarity with ICTs, scholars do not make flawless distant collaborators (Bos et al., 2008) as managing dispersed cross-organizational research teams remains difficult even when technology is ubiquitous (Bos et al., 2008; Cummings & Kiesler, 2005; Olson & Olson, 2003, 2013; Zheng et al., 2002).

Hypothesis 2. Scholars in collaborative networks are more likely to collaborate with collocated scholars than with dispersed ones.

The complexity of current research problems often requires the contributions of multiple researchers from a variety of disciplines. Yet scholars from different disciplines do not necessarily share an understanding of the issues as well as lacking common methodologies and practices created by disciplinary training and interactions in scientific forums (Caruso & Rhoten, 2001; Cummings & Kiesler, 2005; Rhoten, 2003; Shrum, Chompalov, & Genuth, 2001). Studies have found three major challenges for researchers involved in multidisciplinary collaborations. First, collaborators like to work with people from the same disciplinary background. Researchers can collaborate across disciplines as needed, but they are more willing to discuss ideas with members in their own fields (Dimitrova & Koku, 2009; Rhoten, 2003).

Second, scholars view misunderstandings that occur from the differences in their specializations as sources of frustration. Monteiro and Keating (2009) identified various types of misunderstandings that may arise among multidisciplinary collaborators, including the fact that scholars with less-collaborative experience consider differences in vocabularies and expertise challenging (Olson et al., 2008).

Third, coordinating research activities across large bureaucracies, such as universities or governmental organizations, can be difficult and slow. Rhoten (2003) found that increasing the number of participating institutions potentially led to lower performance. Also, multi-university collaborations can be impaired when members have to compete with each other for funding, or make efforts to guard intellectual property (Bos et al., 2008). Thus, in large scholarly networks, the difficulties created by distance are compounded by disciplinary and institutional differences.

Hypothesis 3. Scholars in collaborative networks are more likely to collaborate with scholars from the same discipline than with scholars from other disciplines.

Motivation for Collaboration

Olson et al. (2008) have identified a number of factors relating to successful collaborations, such as the nature of the work being done as well as the technological preparedness, collaboration readiness, and management of the collaboration. They point out that, among these factors, the motivations to collaborate are an important indicator of collaboration readiness. Their argument is supported by rational choice theory that suggests individuals have to prefer certain actions before they undertake them (Becker, 1974).

Social scientists have found that motivations exist in various forms, across different social settings, representing various reasons for collaborating. For instance, open source programmers are willing to collaborate for gaining revenue related products and services, human capital, self-marketing, peer recognition, and personal needs (Hars & Ou, 2002). Kollock (1999) suggests five possible motivations for contribution to online communities: anticipated reciprocity, personal reputation, a sense of efficacy, an attachment or commitment to an online community, and the need for collaboration. In comparison to motivations identified for specific settings, Powell, Koput, and Smith-Doerr (1996) came to the more generalized conclusion that motivations for participating in networks include the reduction of uncertainty, fast access to information, reliability, and responsiveness.

Researchers have also identified motivations for participating in research collaborations. In their study of multidisciplinary research projects, Hara et al. (2003) found that collaborators from various research institutes were motivated by their desire to obtain funding, develop profitable business opportunities, lobby policy makers, and enhance personal careers.

Pohoryles (2002) categorized motivations into intellectual and economic in his study on the impact of European research policies' on scholarly networks. Nokkala (2007) found that the primary motivations at the industry level were related to achieving research synergies, keeping up with major technological developments, and sharing costs; while at the interpersonal level, multidisciplinary collaboration and funding opportunities attracted people to collaborate.

Hypothesis 4. Scholars in collaborative networks express greater interest in establishing research ties with dispersed scholars compared to collocated ones.

Hypothesis 5. Scholars in collaborative networks express greater interest in establishing research ties with scholars from different disciplines compared to those from the same discipline.

Although existing studies are able to confirm the existence of motivations and identify what they are in particular collaborative settings, they treat these motivations and the structure of collaborative networks separately. The links between these two components of scholarly networks are taken for granted as scholars are deemed to simply develop collaborative networks when motived to do so (Hars & Ou, 2002; Nokkala, 2007; Pohoryles, 2002). By looking at the motivations for participating in research collaborations amongst members of the GRAND NCE, we aim to test whether network clusters are able to explain certain structural characteristics of the entire network. Conducting social network analysis, we first test the hypotheses and then identify scholars' motivations. By linking motivations to network characteristics, we demonstrate why scholars want to be involved in collaborative networks and how their motivations are associated with the structure of these networks.

METHODS

The Case Study of GRAND

The GRAND NCE is funded by the Canadian federal government with the mandate of stimulating countrywide and cross-disciplinary research in media and technology, as well as enabling knowledge and technology transfer across the public and private sector. GRAND is a multi-institution

venture that includes 24 Canadian universities, and supports multidisciplinary collaborations among faculty, students, and staff, as well as across disciplines ranging from computer science to the arts.

GRAND is a networked organization, led by a managing director and a few others administrators, loosely overseen by a board of directors and an academic research management committee. GRAND's 34 projects are conducted with the requirement that each have collaborators from at least three disciplines and three different universities. In each project, there are Network Investigators (NIs) and Collaborative Researchers (CRs). While both NIs ($N = 56$) and CRs ($N = 88$) are equally involved in the collaborative research, NIs have a greater responsibility to foster the network as well as to initiate and coordinate collaborations.

As such, GRAND offers an interesting case study for scientific collaboration:

1. The 24 member institutions – and sometimes even departments within institutions – are physically distant from one another, preventing continuous in-person interactions among scientists: computer-supported communication is the basis of their collaborative work. While the provinces of British Columbia, where GRAND is headquartered, and Ontario predominate, universities from seven provinces participate (Table 1). The francophone province of Quebec is significantly underrepresented, possibly due to the fact that when the proposal to the Networks of Centres of Excellence (NCE) to initiate GRAND was submitted, many leading scholars from Quebec were involved in submitting a competing proposal for the same funding that was ultimately unsuccessful.
2. The research conducted within GRAND projects spans a wide spectrum of disciplines and applications, requiring frequent cooperation among individuals from different disciplines. By contrast, other studies of

Table 1. Number of Members and Network Percentages by Province.

Province	# of Members	% of Network
Ontario	33	33
British Columbia	28	28
Alberta	15	15
Quebec	14	14
Nova Scotia	4	4
Saskatchewan	3	4
Manitoba	2	3

collaboration have often investigated large, but homogeneous, networks. In contrast, half of the participants in GRAND come from computer science, while the other half come from a broad range of disciplines (Table 2).

3. GRAND is part of the Networks of Centres of Excellence (NCE) program, a key part of the Canadian government's strategy to encourage knowledge creation and innovation. The NCE program is specifically designed to support scientific knowledge that fosters socially and commercially relevant research. It funds multidisciplinary and nationwide research collaborations, as well as multi-sectorial partnerships among academia, industry, government, and non-profit organizations. Currently, there are 26 NCEs in Canada. The similarity in network structure between GRAND and other NCEs implies that our study might be applicable to other research networks.
4. Many network studies of scientific collaboration are based on large, domain-centric, bibliographic repositories. As a result, these studies rely on a wealth of bibliographic data but only examine a single aspect of collaboration, co-authorship. By contrast, the manageable size of GRANDs network means we have been able to collect a wealth of socio-academic information by interviewing many diverse scholars about the nuances of their research and interactions.

Data Collection

We use a combination of qualitative analysis through semi-structured interviews, and quantitative analysis using an online survey. Using the open source software "Lime Survey," our survey was conducted between September and November 2010, a few months after GRAND received formal approval. All GRAND members at that time ($N = 144$) were invited via

Table 2. Number of Members and Network Percentages by Disciplines.

Discipline	# of Members	% of Network
Computer Science	50	49
Art & Technology/Art & Media	13	13
Engineering	6	6
Information Science/IT	13	13
Professions	7	7
Humanities/Social Science	12	12

e-mail to participate, and we followed Schaefer and Dillman's (1998) suggestions for increasing survey responses by employing e-mails and phone call reminders. We achieved a response rate of 70% as a total of 101 respondents completed the survey. This instrument was used to collect information about the social networks among GRAND members. Respondents described which participants collaborated with one another, who exchanged advice, ideas, and networked with one another, as well as who they are friends with, or would like to meet in person. In addition, the survey asked about the use of communication media such as landline and cell phone calls, e-mails, and instant messaging. This approach, known as the roster method, is an established procedure in social network research. Analyses of social network data used ORA and UCINET software. For this study, we focus on three types of networks: respondents want-to-meet network, work network, and help network. These three networks are chosen because the *want-to-meet network* elucidates to what extent individual collaborators are interested in building social ties with scholars from different backgrounds, and the potential such networks have for future collaborations; the *work network* elaborates on the structure of collaborations; and *the help network* illustrates the resources produced during collaborations.

Following the survey our team conducted 38, semi-structured interviews with GRAND researchers and partners using convenience sampling. The interviews were carried out face-to-face during three GRAND annual meetings: the GRAND 2011 annual meeting that took place in Vancouver on May 12–14; the GRAND 2012 annual meeting that took place in Montréal on May 2–4; and the GRAND 2013 annual meeting that took place in Toronto on May 14–16. The interviews focused on respondents' motivations for joining GRAND; work, coordination, and communication practices in projects; as well as recent developments in their projects. These topics were chosen as they were identified as central for understanding the daily work of researchers within NCEs in general (Atkinson-Grosjean, 2006), and GRAND in particular (Wellman et al., 2014).

While recruiting these 38 interviewees we made an effort to recruit researchers from diverse backgrounds in order to get as broad a perspective as possible. As a result of this effort, our sample consists of researchers from both genders, diverse geographic regions, divergent disciplines, and differing formal positions within GRAND.

Our analysis began by transcribing the semi-structured interviews with the assistance of three transcribers. After completing this, we reviewed each transcript for accuracy and fidelity to the audio recordings. Completed transcripts were imported into NVivo research software, a particular type

of computer assisted qualitative data analysis tool that allows the researcher to effectively and efficiently manage, organize, and analyze data. To reduce the data into more manageable and recallable forms, as we examined the data we began to code and sort them according to the themes that arose (inductive analysis). Coding is defined as the act of identifying similar data units and assigning an identification code to represent concepts, categories or themes (LeCompte & Schensul, 2010). NVivo utilizes *nodes* – containers for specific topics or references – to assist researchers in their coding efforts. These codes become the terms and themes by which researchers begin to sort and clean up their collected data (Galman, 2007).

When analyzing coded data, we did not merely inspect it to label interesting points, but analyzed them in a systematic matter using an iterative process. We made comparisons between text segments, and across participants, to discern conceptual similarities and differences as well as to discover patterns. We also interconnected text segments and codes to produce relations or cross-settings of categories. By traveling back and forth between each piece of data a narrative emerged describing the creation of research collaborations among GRAND members. In fact, we developed this narrative to unify events into a single story. In doing so, we were able to find out which aspects suggested in the literature were grounded by evidence presented in our interviews, as well as which new aspects emerged.

Our understanding of collaboration among GRAND researchers emerged through a constant interplay between the act of writing our narrative and what we encountered in the transcriptions of our interviews. Writing was part of "getting close to the data," as constructing a plot making use of multiple sources of data and memos helped illuminate important patterns that may have otherwise gone unnoticed.

FINDINGS

Network Structure

To understand the relationship between the structure of the network and scholars various motivations to participate in them, we first constructed work, help, and want-to-meet networks. We then examined the correlation of these three networks with each other, as well as with geographical location and disciplinary affiliation. We used the Spinglass algorithm (Reichardt & Bornholdt, 2006) to deconstruct networks into clusters of

highly connected members within the work, help, and want-to-meet networks. By detecting the existence or absence of social ties among network members, the Spinglass algorithm is able to assign a cluster membership value to each node so that individuals who are in the same cluster are given the same membership value. Figs. 1 and 2 describe the structural clusters found through the Spinglass algorithm in the work and help networks, respectively. These histograms describe the number of GRAND researchers within each identified cluster. The identified clusters are represented in the *x*-axis where we can see that nine clusters were identified in the work

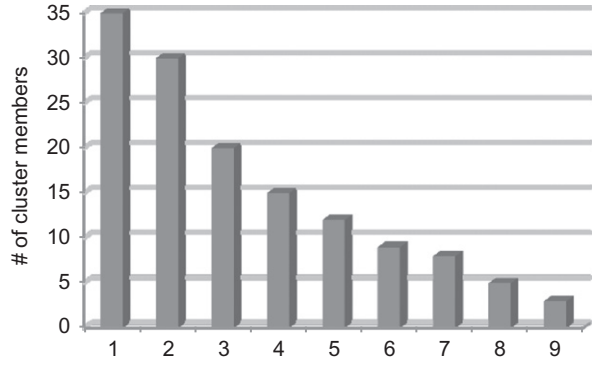

Fig. 1. Histogram of the Clusters in the GRAND Work Network – Frequency Distribution of Each Community.

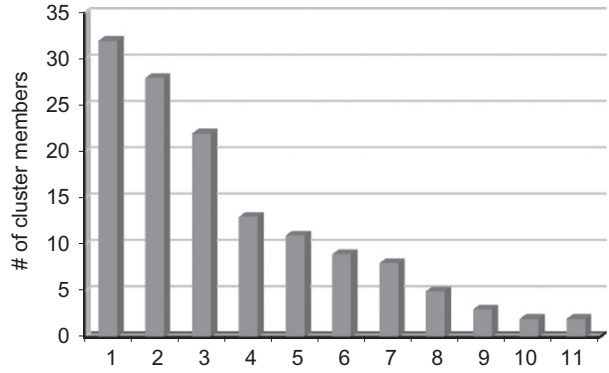

Fig. 2. Histogram of the Clusters in the GRAND Help Network – Frequency Distribution of Each Community.

network (Fig. 1), and 11 in the help network (Fig. 2). The numbers of researchers in each of these clusters is represented on the y-axis. Here, we can see that cluster 1 of the work network consists of 35 researchers (Fig. 1), while cluster 1 of the help network consists of 32 researchers (Fig. 2).

How well do clusters in the work, help, and want-to-meet networks overlap with scholars' groups from the same geographical location, or groups from the same discipline? Do certain scholars tend to fall into the same categories as others across different manifestations of collaboration, that is work and help? We compared the clusters within the work and help networks identified using the Spinglass algorithm, and their correlation with the scholars' disciplinary affiliation and province of residency. In other words, we identify clusters in both the researchers' work and help networks and examine if their members come from the same disciplines and provinces.

We used Pearson's χ^2 (chi-square) to test for statistical independence. The cluster membership values of each network can be expressed as a contingency table where the x-axis represents a distinct cluster membership value in one network, and the y-axis represents a distinct cluster membership value in another network. Cell values in each contingency table identify the number of observed occurrences of an x/y relationship. For instance, we can depict the clusters' membership values in a contingency table by testing for the statistical independence between the work and co-authorship networks (see Table 3). Here the x-axis represents a distinct cluster membership value in the work network, and the y-axis represents a distinct cluster membership value in the co-authorship network. By looking at this table we can learn that eight scholars are identified as both members of cluster A in the work network, and cluster 1 in the co-authorship network. Similarly, we can learn that four scholars are identified as being members of both cluster B in the work network, and cluster 2 in the co-authorship network.

Subjecting this contingency table to Pearson's χ^2 test, we can determine whether cluster membership in the work network is dependent or

Table 3. Example for Spinglass Algorithm.

Co-Authorship	Work	
	Cluster A	Cluster B
Cluster 1	8	4
Cluster 2	0	3

independent of membership in the co-authorship network. In other words, the χ^2 test calculates the values we expect to see in a contingency table if the variables are independent and then computes deviations between expected and actual values. Running such tests for contingency tables enabled us to study the dependency between members' work network, help network, want to meet network, as well as geographic location and disciplinary affiliation.

As indicated in Table 4, the clusters in the work and help networks are significantly correlated. This result supports Hypothesis 1 that scholars tend to obtain more help from network members with whom they work closely. The significant correlations between work network clusters and geographical locations reveal that Hypothesis 2 is also supported. Similarly, work network and disciplinary affiliation are also correlated, supporting Hypothesis 3.

In addition, our findings show that clusters in the want-to-meet network are not significantly associated with disciplines or locations. However, this does not imply that clusters in the want-to-meet network span the boundaries of both discipline and location. To determine this, we examined whether scholars wanted to meet collaborators from other disciplines and locations.

Our want-to-meet network was partitioned twice, according to two different actor attributes: corresponding in the first case to disciplinary divisions and in the second to members' home provinces. In order to assess the ties between these partitions, we tested the want-to-meet networks' Silo index. When testing for Silo values amongst disciplinary divisions, the network was divided into the six categories listed in Table 2. Additionally, all 101 respondents were assigned into one of seven groups, corresponding to the seven Canadian provinces (Table 1).

We use ORA's Silo Index (SI) to examine whether scholars were interested in boundary-spanning collaborations (Merrill, Keeling, & Carley, 2010). The Silo Index is equal to the proportion of links that are internal,

Table 4. Pearson's χ^2 Test on the Contingency Tables Associating Community Membership in the Work, Help, Location, and Discipline.

	Work	Help	Want to Meet	Location	Discipline
Work	–	298.35*	–	57.43*	43.36*
Want to Meet	–	–	–	N.S	N.S

*$p < 0.05$ – correlation was not calculated.
N.S – the result was not statistically significant.

between two members of the same division, as opposed to links that are external, between members of different divisions:

$$\mathrm{SI}_d = \frac{(I-E)}{(E+I)}$$

Here d is the province or discipline, I is the number of internal links, and E is the number of external links. The distribution of SI is between −1 and 1. A score of 1 indicates all links are internal and form a perfect Silo structure where no boundary-spanning collaborations are desired, whereas a score of −1 indicates that all links are external and there is a great desire for boundary-spanning collaborations.

When looking at the Silo index for the want-to-meet network, we learn that: (1) scholars express interest in getting to know people from other disciplines as all Silo indices are negative, thus indicating external links (Table 5), and (2) scholars express interest in getting to know people from other provinces (Table 6). Consequently, Hypotheses 4 and 5 are supported.

Table 5. Want-to-Meet Network Silo Index (Division is Based on Disciplines).

Disciplines	Internal Link Count	External Link Count	Silo Index
PRO	0	39	−1
ENGR	0	62	−1
MED	0	9	−1
SS	1	85	−0.977
HUM	2	43	−0.911
A&T	20	222	−0.835
IS	12	132	−0.833
CS	162	312	−0.316

Table 6. Want-to-Meet Network Silo Index (Division is Based on Provinces).

Provinces	Internal Link Count	External Link Count	Silo Index
Alberta	0	136	−1
British Columbia	39	262	−0.741
Quebec	22	124	−0.699
Ontario	127	316	−0.427

Our findings seem to be contradictory as GRAND members are working more closely with scholars from both the same discipline and province, while they want to meet collaborators from other disciplines and provinces. How can this occur? Why does the work network fail to reflect scholars' willingness for boundary-spanning interactions? In the next section, we analyze the motivations GRAND members have for becoming involved in the multidisciplinary collaborative network, and discussing how these motivations shape the formation of clusters within the network.

Linking Network Structure to Motivations

How is GRAND's network structure associated with the motivations participants report for getting involved in the project? As we have stated above, structural properties do not provide insights regarding the motivations for formatting collaborative ties. Thus, in order to supplement our SNA derived analysis, we also conducted semi-structured interviews with selected GRAND researchers. The motivations found during our interviews can be broadly divided into three categories: practical issues, novelty-exploration, and networking. These categories have influenced researchers' decision to participate in GRAND, separately or jointly.

Practical Issues

Many GRAND members decided to become involved in collaborative projects based on the consideration of practical issues. Interviewees revealed that some GRAND projects are actually continuations of pre-existing collaborative relationships. "We have been working our behinds off for five years. So for us it was just okay to take what we are doing now anyway and work it into the GRAND proposal" says Dan, an NI. The interviewees continue to collaborate in the same project because they are comfortable with their personal relationship and the projects' research questions, as well as understanding their objectives, terms, norms, and zeitgeist.

This pattern is evident in the network structure: The highest χ^2 score obtained is for the contingency table associating the help and work networks (298.35, Table 4). This indicates a strong correlation between community membership in these two networks, suggesting that work and help circles overlap extensively. In other words, as they are part of the same communities of collaboration, people who work together are also likely to help each other. A potential explanation for this pattern may be that pre-existing collaborations are embedded in the help network that, in turn, shapes the work network. In other words, existing ties that provide help might lead to collaborative working relationships.

Some CRs expected that collaboration would have practical results in building their careers. In addition to multiple publications, they wanted good reference letters from "the top people in Canada" (Rose, NI).

> One [of my motivations] is that letters from people, I'm going to have the top people in Canada know who I am and know what I'm doing, and people will write me letters. Considering who is the leader in my area is one of the top people, that is Ronald … he's probably the reason that I decided to be the co-leader just to meet him. Honestly, I asked some people if I should do this. They said this is the opportunity to meet Ronald. So, yes, I am doing this now.

However, the "top people" may not necessarily be members of the same project, and good reference letters are usually produced by professors working in familiar with their work because they are already collaborating or are in the same field. Furthermore, CRs have also addressed the problematic nature of remote collaboration and the difficulties of maintaining and coordinating such endeavors.

People who give practical issues as a motivation want to work with scholars in the same discipline. The third highest score in Table 4 (43.36) was obtained for the contingency table associating work and discipline. This result indicates that communities in the same work network are somewhat more likely to be in the same discipline. Additional evidence for this motivation can be seen in the correlation between work ties and geographical location. The second highest score in Table 4 (57.43) was obtained for the contingency table associating location with work networks, indicating that communities of work tend to be geographically proximate.

For new projects, funding was also a major practical issue. With a stable source of funding, scholars are able to work on sophisticated projects, ideally without interruption. Mary, a CR, noted: "I thought the fact that it could extend to 15 years would provide me with base funding in my research area for a good chunk of my career." Currently, GRAND provides funding for five years, but it may be renewed for two additional five-year terms. The expectation of successful renewals in the future thus encourages collaboration–although in late 2014, GRAND's funding was not renewed.

Related to funding, supporting graduate students is also a practical problem. Besides purchasing equipment and funding travel, a large portion of available funding is used to support graduate students. Some professors feel "more confident" hiring PhD students with GRAND funding, as they know resources exist to maintain the integrity of their team for several years. George, an NI, said:

> [The benefit of being part of GRAND is] obviously the funding. I mean, that's a constant. You're nowhere if you don't have funding for your students. For me, that has

> been the number one motive because I have this very talented student and I want to make sure I have money to fund him well so he could progress and get the equipment he needs and so on.

Similarly, Leanne, an NI, explained that recruiting students is the main purpose for her project to receive funding.

> Yeah it was a great way to get funding although we have an interesting situation going on which is we do need research funding and we are getting research funding and we have a lot of industrial funding, what we really need as well is we really need people. We really need students. The funding itself was really important but the chance to get students was equally important for me.

Lastly, research collaborations advance by developing new concepts and narrative forms (Sonnenwald, 2007). However, to develop such concepts and combine the information gained through research collaboration, the different parties must have some overlapping knowledge. Boland and Tenkasi (1995) identified the importance of both perspective taking and perspective making in knowledge creation, demonstrating how the existence of shared vocabulary enables the combination of information. Previous studies specifically address language as a potential constraint on knowledge transfer within NCEs (Klenk, Hickey, & MacLellan, 2010). But in this study neither our Anglophone nor Francophone interviewees indicated language as a barrier to their collaborative work.

In summary, motivations related to practical issues offer an explanation for the high correlation between the work and help networks, as well as in explaining the ties between work, discipline, and location. However, not all motivations are related to the structure of the networks. For example, economic motivation is a reason for participation, but there is no evidence that it builds ties.

Novelty-Exploration Motivation

The novelty-exploration motivation emphasizes the potential that participants perceive to be inherent in collaborations. Some interviewees were driven to participate in GRAND by their enthusiasm for scientific research. In contrast to those who are concerned with practical problems, these interviewees expect to engage in large-scale projects because they foresee broader horizons of new research. As Rafaeli and Ariel (2008) found, research-related motivations are more prominent than economic motivations, a fact that GRAND researchers echoed as they described wanting to challenge new research questions, find new methods, and build new paradigms.

For example, one of the themes found in our interviews was "challenging big questions." Researchers believe that when they are working with

other collaborators in a team they are more powerful than when they work alone. Dan, a CR, says, "Funding is great. I am glad I have the funding. Now you can put more minds to bear on a particular problem you cannot solve by yourself." Many collaborators realize that by working in a project they can produce knowledge that is beyond their expertise. "To put more minds to bear," collaborators have intellectual exchanges in their community, constituting a form of help given to one another.

Apart from concrete expectations, a broad motivation for "intellectual impetus" in GRAND is pervasive. Ben (NI) says, "It is supposed to be a kind of opportunity – people will be kind of pushed into a direction, and I think that will depend more on micro-level collaboration."

The correlation between the work and help networks (Table 4) is consistent with our interviews as these show that when GRAND members receive help from the work network, they are willing to collaborate with scholars on big questions. Moreover, when they are motivated to collaborate with other scholars, they are able to obtain help and additional resources from their work network.

The motivation to collaborate on large exploratory projects is also reflected in the structure of the want-to-meet network. The negative Silo index of the want-to-meet network by provinces shows that scholars want to meet people from different provinces rather than those collocated with them in the same metropolitan area (Table 5). Since GRAND is nationwide, its members are able to work with scholars affiliated with distant institutions, and in either the same, or different, disciplines.

As scholars understand the limits of their expertise, some also seek to expand their intellectual horizons by participating in multidisciplinary collaborations. Peter, an NI in computer graphics, noted that, "graphics, modeling and sketching interfaces are actually quite related to each other." Differing from Peter's plan to work with other computer scientists in various areas, some collaborators aim to bridge different disciplinary areas such as sociology and computer science. For instance, Eva, an NI, talked about a study she would like to conduct with social scientists in the future in GRAND.

> So, for instance here's something I want to do, I want to work with a sociologist and someone who's done surveillance studies. I want to interpret some basics that are known from surveillance studies in a way that will be understandable to people writing software that's supposed to protect privacy and security. Because there's a lot of things known, you know, surveillance studies is an established area, it's got a nomenclature, it's got some principles. And the software, the people developing software don't know the nomenclature, don't know the principles, and in many cases have not even thought

> about these issues, and the surveillance studies literature is inaccessible to those people. So my goal is to write a document that will kind of make it more palatable.

Many NIs play the role of project leader, sometimes even in multiple projects. Part of their job is to recruit collaborators from other disciplines and initiate multidisciplinary collaborations. For instance Henry, an NI, explained the disciplinary expertise he needs for his project.

> I hire designers and artists who have different skill sets – right? – methodologically at least, and coders – people that write code – computer programmers. And we add the social science to it for testing in both of those projects. And then we work collaboratively with David's team, who also are in a project that includes computer scientists and fine artists.

The motivation for multidisciplinary collaboration is elaborated in the want-to-meet network (Table 4). Here, the number of external ties across disciplines is much greater than the ties within them. However, these expectations are yet to be fulfilled as GRAND members are currently working more with collaborators from the same discipline than those from outside their fields (Table 4). The reason for the underdevelopment of multidisciplinary collaboration might be that we collected survey data only in GRANDs initial phase.

Networking Motivation

The motivation to network with other scholars is based on the pre-existing connections and reputations of other collaborators. Networking is a major motivation that has been neglected in previous studies on collaboration, yet we found that it is both separate from, and related to, motivations concerning practical issues and novelty-exploration.

Many interviewees decided to participate in research projects because they wanted to stay in the same community as their colleagues. Rose (NI) noted that, "It is my community. These are people I work with anyways. I was having fun at the reception last night because it's like old friends you're just getting in contact with again." Other interviewees claimed that they just wanted to be part of the group because they do not want to be "left out of their community" (Spencer, CR).

Additionally, scholars also say they want to network with people in other disciplines. Paul (NI) noted that networking provided resources to him. He wants to build friendships with collaborators in GRAND, and expected that the variety of disciplines would provide collaborators with more resources in terms of knowledge and ideas (Erickson, 1996).

The networking motivation is closely related to the practical issues motivation because scholars view networking opportunities enabled by GRAND as a strategy that leads to successful collaborations. Jane (NI) believes that networking will be "the gateway to better research in a global community." Our interviewee Jeff perceived the networks over a longer time span, noting that collaborative networks built in GRAND would outlast it. He believes that when the graduate students working for projects become the next generation of faculty members, the accumulation of resources will grow exponentially. The scale of GRAND means that help is available from far-flung areas of the country, and the motivation to get involved in large networks underlies the low probability that those in geographical proximity will help each other.

It is common that researchers have more than one motivation, as each of the three motivational categories is interrelated with the others. During the interview with Chris, a senior computer science, the NI said,

> About the reasons that I am involved in GRAND, I think about 75% research funding and then meeting people would be like the other 25%. I have met a lot of new people the interesting one for me is the collaborations with Sam – I've met a lot of people that way.... [Meeting new people means] new ideas, new ways of looking at things, new problems.

For Chris, although having the opportunities to obtain funding is a greater motivation than networking, networking is more related to the production of innovative outcomes.

DISCUSSION

This study has used mixed methods to examines clusters of researchers within GRAND, a Canada-wide collaborative scholarly network. We found that clusters formed within the GRAND network are closely related to scholars' disciplines, their geographic locations, and the motivations leading them to participate in the collaborative network. We also explained the structural characteristics of the clusters in light of the motivations identified during our interviews. In summary:

1. Scholars are motivated to collaborate by practical issues, novelty-exploration, and networking, and these motivations partly shape the structure of collaborative networks.

2. Scholars express interest in meeting collaborators from different disciplines and geographical locations.
3. Scholars tend to collaborate with others from the same discipline and in geographical proximity to themselves.
4. Collaborators who work together are also very likely to help each other.

Our work contributes to the study of networked scholarly work in four ways. First, this study used mixed methods as these present a valuable approach revealing motivations and multiple aspects of the data by giving a voice to those being studied. We explored how the structural characteristics of collaborative networks, to some extent reflects the researchers' motivations. Past studies dealing with collaborative practices in researchers' social networks have mainly relied on data collected through quantitative methods (e.g., Cummings, 2009). Though this data is informative in analyzing research networks, it suffers from biases derived from self-reporting, from low response rates, or both. We believe that our mixed methods approach can provide a mechanism to perform more rigorous analyses of scholarly networks. Data collected through social network analysis and interviews can enrich the predominantly quantitatively driven analysis of collaborative research practices currently in use. Combined data sources offer a more holistic understanding of researchers' networks, one that is less prone to biases derived from data collection issues. Maximizing the advantages in each method, our work provides an explanation of the formation of GRAND's particular network structure.

Second, our contribution is not limited to a methodological component. We also reveal the gap between scholars' willingness to expand their collaborative networks, as expressed in their interest to form new collaborative ties and their limited existing collaborative ties is affected by disciplinary and geographic boundaries. Being involved in a multidisciplinary scholarly network does not seem to benefit members as expected. Although scholars are interested in meeting new collaborators from other disciplines and locations, they mostly work with those proximate to themselves and from the same disciplinary background. Thus, in spite of the potential networking opportunities provided by GRAND, scholars still need to put in extra effort to forge the collaborative ties they desire.

Third, our findings reveal that motivations are not directly linked to either collaborative interactions or the structure of collaborative networks. The existing literature suggests that collaborations are the result of scholars' various forms of motivation (Hars & Ou, 2002; Nokkala, 2007; Pohoryles, 2002). However, we found that some motivations merely drive scholars to

become involved with the scholarly organization rather than to actually build collaborative ties. This is because some practical motivations, such as obtaining funding, are common among scholars, and these are not necessarily related to collaboration. The influence of such motivations on the structure of the network is minimal and such motivations may be realized by managerial resolutions rather than participating in a collaborative network. To the contrary, other motivations, such as having an interest in multidisciplinary collaboration, can only be realized if certain conditions are met and accommodations made, such as using ICTs for communication, providing funding for longer periods of time, and putting efficient management strategies in place that influence scholars to build collaborative ties.

Finally, networking itself is a motivation for scientific collaboration, one that has been neglected in the literature. As the scale of scholarly collaboration has increased, the networking motivation has grown more important and is explicitly addressed as a driver for becoming involved in research networks. This shapes not only the structure of the network, but also the efficiency of the collaboration as scholars who join the network driven by the motivation to network are more likely to form collaborative ties.

Although scholars understand that the larger a network, the more resources it may make available, it is difficult for them to establish collaborative ties with colleagues in different disciplines or over long distances. We suggest three strategies to help them expand their networks. The first is to promote inter-project ties by encouraging each scholar to be involved in multiple research projects whose members include those the scholar is interested in collaborating with. By joining such projects simultaneously, the invited scholars can obtain more help from multiple networks.

The second is to nurture interpersonal ties among scholars by offering a variety of opportunities to interact, be they formal events such as annual conferences, workshops, and panels, or informal events such as retreats, lab visits, or networking events. If such events are organized more frequently, scholars will be able to expand their individual peer networks within the network and form new relationships that can potentially develop into collaborative ties.

The third is to expand the size of the scholarly network by inviting more members. However, having a large number of scholars affiliated with the network requires effective management strategies to achieve efficient communication and knowledge exchange among members. These three strategies can be combined and applied simultaneously. For instance, GRAND has used all of these strategies by providing scholars with opportunities to work with a large number of collaborators from various disciplines from

across the country, while also organizing conferences and workshops for its members, and involving them in multiple research projects.

All these strategies require some level of organizational intervention in the network. It is notable that such interventions are conducted through hierarchies, that is vertical structures, as well as networks, that is horizontal structures. This increases the complexity of the dynamics and structures of scholarly networks. We suggest that future studies will focus on elaborating the mechanisms of collaborative interactions among scholars in such networks and assess how this structure promotes or hinders the performance of these scholars as well as the productivity of their projects within their scholarly network.

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