# Networks of Neuroscientists: Professional Interactions within an Interdisciplinary Brain Research Institute

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**Abstract:** *This paper uses social network analysis to evaluate how the formation of an interdisciplinary brain research institute affected interaction and collaboration among neuroscientists at one Canadian university. The research institute, formed in 2004, has about 100 members representing ten different departments across the university campus. We conducted a whole network survey of the members in 2010, asking them to report on their professional interactions (advice seeking, co-supervising, co-teaching, co-authorship, holding grants, and organizing conferences together) with each of the other members during the five years before and the five years since the foundation of the Institute. Whole network measures examined include density, isolates, average degree and multiplexity. We compared these measures over time. Our findings indicate that professional interactions among the neuroscientists have increased since the founding of the Institute. The main networks of collaborators are now clustered around the three organizational themes of the Institute, which were formalized in 2010. We also examined how individual-level characteristics of the scientists affected professional interaction. We show that departmental co-membership, office co-location and Institute themes are all significant predictors of interaction among neuroscientists at this university since the foundation of the Institute. Social network analysis is a useful tool for evaluating the impact of the establishment of an interdisciplinary institute on scientists' relationships.*

Keywords: *interdisciplinary research; social network analysis; collaboration; neuroscience*

## Introduction

This project aimed to assess how the formation of the Hotchkiss Brain Institute (HBI; www.ucalgary.ca/hbi) at the University of Calgary (UCalgary) in October 2004 affected professional interactions among neuroscience researchers. Prior to the formation of the HBI, there was no single administrative structure linking neuroscientists who work in different academic departments at UCalgary. Since the formation of the HBI, essentially all neuroscientists working at UCalgary (including new hires) are encouraged to become members of the HBI. Thus, the establishment of the HBI provides a case study through which to examine whether the formation of an explicitly interdisciplinary administrative unit affects professional interactions among scientists at one institution. We conducted a whole network survey of the members of the HBI in November, 2010. We asked all current HBI members (N = 95) to fill out an online

survey reporting on their professional interactions with each of the other members since the foundation of the HBI (2005-2010). In addition, for those members who joined the HBI in 2005, we asked about their interactions with other members before the foundation of the Institute. Eighty-one scientists (a response rate of 85%) filled out the survey, indicating their working relationships with other HBI members.

We analyzed the data using social network analytic techniques, described below, as well as descriptive statistics. We also examined whether individual-level characteristics of the scientists such as gender, rank, department, office location, research theme, and research pillar affected their relationships with other scientists. Research pillar is a term used in Canada to classify all health researchers into one of four categories - biomedical, clinical, health services or population health (Canadian Institutes of Health Research, 2009). Finally, for each of the professional interaction networks, we examined the positions of those who hold leadership roles in the HBI. We use our results to discuss the effect that the establishment of the HBI has had on professional relationships among neuroscientists at UCalgary. We conclude by reflecting on the usefulness of social network analysis as an evaluation method for interdisciplinary research institutes.

## *Background*

The need for collaboration in science is well accepted (Adams, Black, Clemmons, and Stephan, 2005), and many academic fields now encourage interdisciplinary work (Hackett, 2005). Funding agencies are increasingly mandating interdisciplinary teams on grant applications (Bammer, 2008; Mattson, Laget, Vindefjard, and Sundberg, 2010). However, there remains much debate in the literature over how to measure, classify and evaluate interdisciplinary research and collaboration (see Huutoniemi, Klein, Bruun and Hukkinen, 2010 for a recent overview).

The first large-scale interdisciplinary research centres were set up in the United States in the 1980's, in an attempt to encourage both cross-disciplinary and cross-sector (university and industry) research collaboration. Most evaluations of such centres have focused on productivity as measured by publications and patents (Geiger, 1990; Ponomariov and Boardman, 2010). Typically, co-authorship is used as a measure of collaboration, and journal subject categories are frequently considered as a measure of interdisciplinarity.

Collaboration involves more than simply co-authorship, though, and evaluations of interdisciplinary research teams need to capture the achievements of such teams beyond publications and patents (Katerndahl, 2012; Katz and Martin, 1997). Over the past twenty years, interdisciplinary institutes, centers and groups have been established at many institutions, yet methods for assessing and evaluating interdisciplinary scientific endeavors are still in their infancy (Harris, 2010; Yang, Park & Heo, 2010; Levitt & Thelwall, 2008).

Fundamentally, interdisciplinary scientific collaboration materializes through relationships and interactions among people from different academic disciplines. These relationships may involve people from different administrative units within one institution, or from many institutions. In order to evaluate interdisciplinary collaboration properly, we first need to understand how such relationships and interactions emerge and change. Second, we need to assess the factors

that both encourage and hinder interactions among scientists (Katerndahl, 2012). In this paper, we utilize the case study method to examine how the professional interactions among scientists at one university change with the establishment of an interdisciplinary research institute. We draw upon the theories and techniques developed in the field of social network analysis to guide our study.

*Literature Review*

Social network analysis, which prioritizes the structure of social relationships over the attributes of individuals, would suggest that, fundamentally, scientific output is the product of social relations (Emirbayer, 1997). While this claim may be too broad, as it neglects additional factors that influence scientific productivity (such as discipline and funding) (Quinlan, Kane, and Trochim, 2008), social network analysis does provide data collection methods and data analytic techniques that have been developed specifically for relational data (Scott, 2000; Wasserman and Faust, 1994). Thus, we employ social network analytic techniques to examine and assess the professional interactions among the members of the HBI.

Social network analysis has been used in a variety of ways to examine collaboration in academic research. Most commonly, scholars have applied whole network analytic techniques to bibliographic databases to investigate how networks of co-authorship and citation change over time (Barabasi, Jeong, Neda, Ravasz, Schubert, and Vicsek Borgatti, 2002). Findings from these co-authorship studies highlight several factors which facilitate collaboration among scientists. Mattson et al. (2010), examining European research collaboration networks in the life sciences, found that while co-authorship is affected by geographical proximity and language, funding mechanisms also have a large impact on scientific collaboration. Wagner and Leydesdorff (2005), on the other hand, concluded that the recent growth in international research collaboration in six scientific fields was not driven by funding, but rather by the scientific interest of researchers.

Johnson, Christian, Brunt, Hickman, and Waide (2010) examined the US Long Term Ecological Research (LTER) Program using intersite publications as a measure of collaboration. They found the most important predictors of collaboration were common research theme and communication at meetings and conferences. Sun and Manson (2011) examined the growth of co-authorship in geographic information science from 1992 to 2007. They found language and country of practice to be important in predicting co-authorship. Braun, Glanzel, and Schubert. (2001) examined co-authorship in the field of neurosciences. They found that scientists in the middle of their career are most likely to work collaboratively than both newcomers and senior authors. Thus, findings from co-authorship studies suggest that while geography, language and funding all affect collaboration, shared research interests, communication channels, and career stage are also important.

Other researchers have used network survey data to highlight barriers and facilitators to interdisciplinary research both within and across universities (Aboelela, Merrill, Carley and Larson, 2007; Haines et al., 2010; Katerndahl, 2012; Godley, Barron & Sharma, 2011). These studies demonstrate that although researchers are still most likely to collaborate

with those in their own discipline, established collaborations of researchers organized into institutes or research groups can increase interdisciplinary work. Thus, the results from both network analyses of co-authorship and network surveys of researchers attempting to engage in interdisciplinary research would seem to suggest that scientific collaboration should be enhanced by the establishment of an interdisciplinary research centre.

Most previous evaluations of interdisciplinary research centres have not used social network analytic techniques, but rather have relied on survey data and measures of productivity such as funding received and peer-reviewed publications to assess the success of the centres (Bozeman et al., 2010; Ponomaniov and Boardman, 2010; Wagner, Roessner, Bobb, Klein, Boyack, et al., 2011). Discussing methodological issues that arise in studying large research initiatives, Quinlan et al. argue that ideally evaluators should utilize multiple methods (including bibliometric analysis, surveys, and interviews) to gage the success of interdisciplinary research centers (Quinlan et al., 2008). Findings from these studies highlight several additional factors which appear to be important for the success of an interdisciplinary research centre, including infrastructure, shared vision, communication, and leadership.

Meyer, Fabor, and Hesselbrock (1988), in a study of an interdisciplinary research centre for alcohol addiction, found that success was determined by four factors: the strength of the infrastructure (including resources, facilities and personnel); the articulation of a shared vision; efficient management; and clear communication networks. Hagen et al. (2011) studied a multicenter clinical research network and also argue that the following are key to success: shared vision; governance; infrastructural support; and communication. Studying several university research centers in science and engineering, Boardman and Corley (2008) argue that while multidisciplinarity within a centre is necessary for research collaboration, funding had the biggest effect on the amount of time scientists allocate to collaborative work.

However, Bammer (2008) argues that the key to research collaboration is effectively harnessing differences through strong leadership. Using the Human Genome Project as a case study, he demonstrates that strong leadership is needed to encourage productive differences and discourage unproductive differences in interdisciplinary research collaborations. Chompalov, Genuth, and Shrum (2002) further argue that the structure of the interdisciplinary research organization, and the type of leadership, are dependent on the disciplines involved.

Others suggest that the success of an interdisciplinary research centre is largely dependent on the individuals involved, and the fields they represent. Rijnsoever and Hessels (2011) found that scientists in Basic fields are more likely to collaborate within their own disciplines, while scientists in Applied fields are more likely to work with those from other disciplines. Neuroscience involves both Basic and Applied researchers. Neuroscience not only involved both Basic and Applied researchers, it is also inherently interdisciplinary, as it emerged in the 1970's as an amalgamation of brain research in many fields, including anatomy, physiology, pharmacology, neurology, psychology and psychiatry (Doty, 1987). Birnholtz (2007) conducted a survey to measure scientists' "propensities to collaborate." He found that neuroscientists have a 'medium' propensity to collaborate, lying somewhere between physicists (high propensity to collaborate) and engineers (low propensity to collaborate).

To summarize, while results from both network analyses of co-authorship and network surveys of interdisciplinary researchers suggest that scientific collaboration may be enhanced by the establishment of an interdisciplinary research centre, previous evaluations suggest that a strong infrastructure (including funding), a shared vision, a clear means of communication, and solid leadership will be necessary for a centre's success. Additionally, previous research suggests that the success of any interdisciplinary endeavor is largely dependent on the individuals involved, and the disciplines they represent.

## *Setting – the* Hotchkiss Brain Institute

This paper takes a case study approach, examining the effect of the establishment of an interdisciplinary research centre on the collaborative activities of a group of neuroscientists at one Canadian University. We do not attempt to generalize from this case study to any other institutions or research centres, but rather present it as an example of the effect of administrative endorsement of interdisciplinary work on the professional interactions of researchers at one institution.

The Hotchkiss Brain Institute (HBI) was established in 2004 at UCalgary with a generous philanthropic donation from a local family. All of the faculty members who were working in neuroscience at the UCalgary in 2004 were encouraged to become HBI members when the Institute was established. The original membership consisted of 64 faculty members, representing ten different disciplines. All new faculty members who were hired in neuroscience after 2004 became members of the HBI when they joined UCalgary. By 2010 the number of members had risen to 95. The HBI has operated under the leadership of the same Director since its establishment, and has several sub-committees and programs led by other members.

Initially, researchers in the HBI were organized by department (discipline) and research pillar, and some of the researchers were in translational research programs. In 2010, following an extensive external review and evaluation, the leadership of the HBI formalized three research themes within the Institute: Axon Biology and Regeneration; Cerebral Circulation; and Neural Systems and Behaviour. These research areas cross disciplinary boundaries, as stated on the HBI website (www.ucalgary.ca/hbi).

"The mission of the Hotchkiss Brain Institute (HBI) is to be a centre of excellence in neurological and mental health research, translating discoveries into innovative health care solutions. This mission will aim to support and conduct research on the healthy and diseased brain, spinal cord and peripheral nerves to assess, understand and disseminate knowledge about the diseases affecting the nervous system...It is the aim of the HBI to have a collective expertise in the field of neurosciences, increased collaboration and elevated synergism in our research efforts."

From the outset, the HBI appeared to incorporate many of the elements which comprise a successful interdisciplinary research centre. The HBI has strong funding support, maintains a strong collective vision, and benefits from strong, consistent leadership. Communication is encouraged among members through weekly seminars, mentoring programs, and internal peer review panels.

Quantitative measures such as publication output and research funding indicate that the HBI has had considerable success since 2004. The HBI is now recognized internationally as a top research Institute in neuroscience. It is one of the 100 most active neuroscience research organizations in the world, as measured by publication output (Haustein, Cote, and Beaudet, 2013). The success rate of HBI scientists in terms of peer reviewed grant support over the last few years has been about twice that of the national average. Grant support has increased 120% from 2004 – 2010, with only a 50% increase in faculty members over that time period. Additionally, the HBI has successfully raised money from private, community, and governmental sources for ongoing research and educational activities.

In 2010, as part of an extensive evaluation process, and in an effort to supplement the traditional measures of success such as publication output and research funding, HBI leaders set out to assess how the formation of the HBI had affected working relationships among neuroscience researchers at UCalgary. One of the aims of the HBI was to build on existing collegial interactions and enable natural linkages to form amongst scientists. In order to evaluate this process, HBI leaders turned to social network analysis.

Network analysts typically conduct one of two types of relational analyses: whole network studies, where the boundaries of the population are known and information is gathered from the whole population; or ego-centred network studies, where individuals are asked to report on others with whom they have certain relationships (Wasserman & Faust, 1994). For the current study, an online whole network survey was designed and administered to all members of the HBI.

In the fall of 2010, HBI members were asked about their professional relationships with one another. For the original members of the institute, data was collected on their relationships both before and since the founding of the HBI, as well as on individual-level attributes of the HBI members, including gender, home department, and academic rank. Using social network analytic techniques, this data was assessed to determine the extent of professional interactions, and the predictors of (and barriers to) professional interactions within the HBI.

## Methods

### *Study Description*

A complete list of all the current members of the HBI was compiled in the fall 2010. Ninety-five members were identified. An email message was sent to each of these researchers to ask them to complete the online network survey. Each researcher was given a list of the other 94 HBI members, and asked to indicate if they had any of the following relationships with the other researchers over the past five years (from January 2005 to the present): "went to for advice or mentorship"; "organized a conference with"; "held a grant with"; "co-authored papers with"; "co-supervised students with"; "co-taught a course with." The sixty-four original members, who had joined the HBI when it was founded (in October 2004), were also asked to report on relationships with other original members prior to January 2005. Descriptive

information collected on the respondents included: gender, department, professorial rank, CIHR Pillar membership, HBI Theme membership (three thematic areas, as described above), and office location. Data collection continued for two months. Eighty-one questionnaires were returned, fifty-two of which were from original HBI members (response rates of 85% for the current members, and 81% for the original members). A copy of the survey is provided in the Appendix.

The study design was approved by the Research Ethics Board at UCalgary. In order to comply with recommendations from the Ethics Board, all individuals who did not respond to the survey were completely removed from the data. Thus, the complete networks consist only of the 81 individuals who returned their surveys for the second time period and the 52 individuals who returned their surveys for the first time period.

*Research Questions*

This paper is organized around the following four central research questions:

Research Question 1: How many and what type of professional interactions existed among HBI members before the formation of the HBI, and how many have occurred since the formation of the HBI? Has the extent of involvement in professional interactions among the HBI members changed over time?

Research Question 2: What is the composition of the professional interaction networks within the HBI, with regards to individual-level attributes such as gender, department, research theme and research pillar?

Research Question 3: Which individual-level characteristics of respondents predict professional interactions between researchers? Have these predictors changed over time?

Research Question 4: Are the currently appointed HBI leaders occupying leadership positions in the professional interaction networks?

Exploring these research questions will enable an assessment of the success of the HBI that goes beyond traditional measures of success such as publication output and research funding. This research will evaluate the success of the HBI in terms of encouraging and promoting interdisciplinary, collaborative working relationships among neuroscientists at UCalgary. Moreover, this research will shed light on the potential benefits of using network analysis to develop focused themes to enhance collaborations amongst interdisciplinary groups of researchers beyond the neurosciences.

*Networks*

We constructed six professional interaction networks for each time period from the survey data: the 'advice' network; the 'conference' network; the 'grant' network; the 'co-authored' network; the 'co-supervised' network; and the 'co-taught' network. For each analysis, we examined three different sets of networks. First, we examined the six networks of the 52 original HBI members reporting on activities prior to 2005. Second, we examined the six

networks of the same individuals (the 52 original HBI members) reporting on activities since 2005. Finally, we examined the six networks of the full 81 HBI members in 2010 reporting on activities since 2005. Although the networks of the 52 original members reporting on activities since 2005 are in some sense 'incomplete' (because they do not include the new HBI members), we looked at these separately in order to make statistical comparisons with the original 52-member networks.

### *Descriptive Analyses*

We used the network statistical software package UCINET 6.0 (Borgatti, Everett and Freeman, 2002) to conduct analyses of our network data. To answer our first research question (How many and what type of professional interactions existed among HBI members before the formation of the HBI, and how many have occurred since the formation of the HBI?), we examined the following whole network measures: density; reciprocity; average degree; and number of isolates. Density is the proportion of actual linkages to possible linkages among group members (Wasserman & Faust, 1994). Density can be regarded as a measure of how interconnected individuals in a network are, where a density value of 100% would indicate that every person in the network is directly connected to every other person in the network (Scott, 2000). Reciprocity is the percentage of linkages that are reciprocated, or returned.

Isolates are individuals who are not connected to any others in a network. The number of isolates in a network indicates the percentage of respondents who are not involved with any other network members for a particular activity (Wasserman & Faust, 1994). Degree or the number of ties is the number of alters a respondent mentions.

To answer our second research question (What is the composition of the professional interaction networks within the HBI, with regards to individual-level attributes such as gender, department, research theme and CIHR pillar membership) we examined and compared compositional measures for each network, across the various individual-level variables. We assessed the diversity of these networks with regard to individual-level characteristics.

### *Statistical Analyses*

To answer our third research question (What individual-level characteristics of respondents predict professional interactions between researchers? Have these predictors changed over time?), we performed Quadratic Assignment Procedure (QAP) regression (Carley & Krackhardt, 1996; Brewer & Webster, 1999; Burris, 2005). Network data violates the assumptions of Ordinary Least Squares (OLS) regression. The QAP regression procedure, which overcomes these limitations, is best understood as a form of simulation (Burris, 2005). First, OLS coefficients are calculated for the independent variables in the regression. Next, the rows and columns of the dependent variable matrix are randomly permuted and the OLS regression coefficients are re-calculated. The simulation is repeated 2,000 times in UCINET 6. The initial regression coefficients are then compared with the distribution of all possible coefficients, and significance tests are based on these distributions.

To answer our fourth research question (Are the appointed HBI leaders occupying leadership positions in the professional interaction networks?) we examined two network measures of centrality: degree centrality and betweeness centrality. Degree centrality simply measures the number of ties individuals have, while betweeness centrality examines the number of times any individual lies on the shortest path between two other individuals in the network (Freeman, 1979).

Both centrality measures can be thought of as measures of leadership roles within a network (Katerndahl, 2012). Degree centrality can be thought of as a comparative measure of activity, while betweeness centrality can be thought of as a measure of comparative control or gate keeping within the network. Gatekeepers act as important hubs within a network, who can assist with the diffusion of knowledge and information (Cowan and Jonard, 2004). We compared these measures for HBI leaders and non-leaders.

### *Visualizations*

Finally, we produced and examined a network visualization of each of the networks. Network visualization presents information on network structure in graphic form. This method of analyzing network data is an important part of social network analysis because graphic representations can reveal information that may not be statistically obvious (Luke and Harris, 2007). In these graphs, the researchers are represented by shapes, and the relationships are represented by lines. In all of the graphs except those for the 'advice' network we present reciprocal ties only. In the 'advice' network graphs, the arrows are used to represent the direction of the interaction (the arrow pointing away from the responding researcher (seeking advice) and towards the researcher they nominated (from whom they sought advice)). We do not include isolates (respondents with no ties) in the graphs, but we note the number of isolates underneath each graph. To produce the graphic representations of our networks, the layout uses the spring embedded procedure in Netdraw 2.24 which graphs the nodes (the researchers) according to their geodesic (shortest distance) proximities. We present the most illustrative of these diagrams in the results section.

## Results

### *Sample*

Table 1 describes the composition of the sample. Of the 52 original members who responded to the survey, 11.5% were female. This percentage rises to 21% of current members in 2010. HBI members come from ten different departments. Examining the 2010 data, the largest group (34.6%) are from the Department of Clinical Neurosciences, followed by 17.3% from Physiology and Pharmacology. The rest are fairly evenly split between the Departments of Psychiatry, Psychology, Radiology, Cell Biology and Anatomy, Community Health Sciences and 'Other.' The 'Other' group is comprised of individuals from three different departments, each of which had fewer than 2 respondents. We combined these departments to avoid deductive disclosure.

| | Pre-HBI (N = 52) | | Post-HBI (N=81) | |
|---|---|---|---|---|
| | **F** | **%** | **F** | **%** |
| Gender | | | | |
| Male | 46 | 88.5 | 64 | 79 |
| Female | 6 | 11.5 | 17 | 21 |
| CIHR Pillar | | | | |
| Biomedical | 35 | 67.3 | 46 | 56.8 |
| Clinical | 14 | 26.9 | 28 | 34.6 |
| Population / Health Services | 3 | 5.8 | 7 | 8.6 |
| Theme | | | | |
| Axon Biology & Regeneration | 10 | 19.2 | 18 | 22.2 |
| Cerebral Circulation | 12 | 23.1 | 18 | 22.2 |
| Neural Systems & Behaviour | 30 | 57.7 | 45 | 55.6 |
| Department | | | | |
| Psychiatry | 2 | 3.8 | 6 | 7.4 |
| Psychology | 3 | 5.8 | 8 | 9.9 |
| Physiology & Pharmacology | 13 | 25 | 14 | 17.3 |
| Clinical Neurosciences | 19 | 36.5 | 28 | 34.6 |
| Radiology | 5 | 9.6 | 6 | 7.4 |
| Cell Biology & Anatomy | 6 | 11.5 | 8 | 9.9 |
| Community Health Sciences | 2 | 3.8 | 4 | 4.9 |
| Other | 2 | 3.8 | 7 | 8.6 |
| Office Location | | | | |
| Main | 4 | 7.7 | 10 | 12.3 |
| FHH | 16 | 30.8 | 25 | 30.9 |
| HM | 7 | 13.5 | 11 | 13.6 |
| HRIC | 10 | 19.2 | 12 | 14.8 |
| HSC | 12 | 23.1 | 16 | 19.8 |
| TRW | 3 | 5.8 | 7 | 8.6 |
| Rank | | | | |
| Full | 33 | 63.5 | 42 | 51.9 |
| Associate | 13 | 25.0 | 20 | 24.7 |
| Assistant | 6 | 11.5 | 19 | 23.4 |
| Year Joined | | | | |
| 2004 | 52 | 100 | 52 | 64.2 |
| 2005 | | | 5 | 6.2 |
| 2006 | | | 3 | 3.7 |
| 2007 | | | 6 | 7.4 |
| 2008 | | | 9 | 11.1 |
| 2009 | | | 6 | 7.4 |

*Table 1.* Sample Composition

In 2010, over 50% of respondents place themselves in the 'Biomedical Research' CIHR pillar, followed by almost 35% in 'Clinical Research.' We combined the 'Population' and 'Health Services' pillars, as together they represented only 8.6% of the sample. In terms of the HBI research themes, which were formalized in 2010, 55.6% of the sample are in the Neural Systems and Behaviour theme, with the rest evenly split (22.2% each) between Axon Biology and Regeneration and Cerebral Circulation. HBI researchers' offices are spread over six different buildings on the UCalgary campus. Just over half the researchers are Full Professors, while approximately a 25% are Associate Professors, and 23% are Assistant Professors.

### *Descriptive Results*

We first examined the extent of professional interactions among researchers who are members of the HBI, both before and since the founding of the Institute. Table 2 contains the density and reciprocity figures for each of the six professional activities across three sets of networks. The first two columns present figures for the 52 original HBI members, before the founding of the Institute. The middle columns present figures for the original HBI members since the founding of the Institute. And the final two columns present figures for all 81 HBI members since 2005.

The first column of Table 2 illustrates that prior to the founding of the Institute, the 52 neuroscientists at UCalgary were already involved in many professional activities together. Before 2005, they were most likely to co-supervise students, write papers together, teach together and request advice from one another. However, they also held grants together and organized conferences together. While the density figures may appear low at

| | Pre-HBI (N = 52) | | Post-HBI (original 52) | | Post-HBI (N = 81) | |
|---|---|---|---|---|---|---|
| | *Density* | *Reciprocity* | *Density* | *Reciprocity* | *Density* | *Reciprocity* |
| Advice | .040* | .10 | .072* | .20 | .047 | .16 |
| Conferences | .009 | .17 | .012 | .42 | .009 | .34 |
| Grants | .019* | .61 | .032* | .55 | .024 | .62 |
| Papers | .046 | .68 | .051 | .71 | .034 | .73 |
| Supervise | .059 | .42 | .076 | .51 | .050 | .50 |
| Teach | .044 | .40 | .050 | .35 | .033 | .42 |

*Note: *Densities are significantly different at p<.05*

*Table 2.* Density and Reciprocity of Networks Over Time

first glance, it is important to remember that density is recorded as a percentage of all possible ties. There are 2,652 possible ties among the 52 original members. Thus a density of .046 for co-authorship indicates that HBI members reported 122 unique co-authorship ties before the founding of the Institute.

The third column of Table 2 illustrates that since the founding of the Institute, the original 52 members again report that they have been most likely to co-supervise, request advice, co-author papers and co-teach with others. They have also held grants and organizing conferences with the other original members.

The fifth column of Table 2 shows that since the HBI was founded, the 81 current members report that they have been most likely to co-supervise, seek advice and co-author with other HBI members, followed by co-teaching, holding grants, and organizing conferences together. There are 6,480 possible ties among the 81 current members. Thus a density of .034 for co-authoring papers indicates that HBI members reported 220 unique co-authorship ties between 2005 and 2010.

Statistical comparisons can only be made for densities of networks of the same size. UCINET 6.0 tests for statistical significance using a bootstrap technique to compare the densities of networks with the same members, allowing two different time points to be compared (Snijders and Borgatti, 1999). There are statistically significant increases in density for the original 52 members for both the grants and advice network.

We turn now to the results for reciprocity in Table 2. Theoretically, all of the relationships except for 'advice' should be reciprocal. However, we find that network reciprocity (the percent of all ties that are reciprocated) (Wasserman & Faust, 1994) ranged from a high of 73% for 'co-authored' since 2005 down to a low of 17% for 'conference' before 2005. There are many potential reasons for low reciprocity. The salience of some activities is obviously higher than others (writing papers compared to being on a supervisory committee together, for example). Additionally, reciprocity is generally higher for the more recent time period. However, in order to avoid potential bias introduced by including non-reciprocal ties, from this point forward in the paper we only examined reciprocal ties for all networks except 'advice'. The practice of only examining confirmed ties is considered to increase the reliability of self-reported network data

(Scott, 2000). In future analyses, we plan to conduct analyses including the non-reciprocal ties in order to determine if the predictors of non-reciprocal ties differ from the predictors of the reciprocal ties.

Table 3 illustrates the average number of people researchers are tied to for each professional relationship at each of the two time periods, and the number of isolates in each network. We can see that on average before 2005, the 52 neuroscientists at UCalgary reported seeking advice from 2.8 others, co-authoring with 2.4 others, and co-supervising with 2.3 others. Between 2005 and 2010, on average, the 81 members of the HBI reported seeking advice from 5 other HBI members, co-authoring with 2.8 others and co-supervising with 2.8 others.

| | **Number of Ties** | | | **Isolates** | |
|---|---|---|---|---|---|
| | Average | Std.Dev. | Maximum | Number | % |
| Pre-HBI (N=52) | | | | | |
| Advice (In) | 3.62 | 3.34 | 14 | 23 | 44 |
| Advice (Out) | 2.84 | 1.57 | 7 | 15 | 29 |
| Conference | 1.00 | 0.00 | 1 | 48 | 92 |
| Grants | 1.36 | .658 | 3 | 30 | 58 |
| Papers | 2.40 | 1.67 | 8 | 17 | 33 |
| Supervise | 2.28 | 1.25 | 6 | 23 | 44 |
| Teach | 1.70 | 1.10 | 5 | 25 | 48 |
| | | | | | |
| Post-HBI (N=81) | | | | | |
| Advice (In) | 4.84 | 5.31 | 27 | 19 | 23 |
| Advice (Out) | 5.00 | 4.08 | 18 | 21 | 26 |
| Conference | 1.18 | 0.39 | 2 | 64 | 79 |
| Grants | 2.33 | 1.73 | 7 | 39 | 48 |
| Papers | 2.77 | 2.00 | 11 | 24 | 30 |
| Supervise | 2.83 | 1.99 | 10 | 23 | 28 |
| Teach | 2.20 | 1.71 | 8 | 40 | 49 |

*Note: All networks contain only reciprocal ties except for the advice network. Advice (In) indicates reports that others sought advice from the member. Advice (Out) indicates that the member reports seeking advice from others.*

*Table 3.* Ties Over Time

While we cannot compare the average ties over time statistically (because the total number of network members changes between the two time periods), it appears that HBI members have more ties to other neuroscientists at UCalgary since the founding of the Institute. The average number of ties goes up for every professional activity. An analysis of the isolate data also shows that the percent of people who have NO ties to other neuroscientists at UCalgary has gone down across all of the professional activities except teaching.

We next examined the composition of the professional interaction networks over time, with regards to the individual-level characteristics of the network members. Table 4 shows the

| | % Same Gender | % Same Dept. | % Same Pillar (CIHR) | % Same Theme (HBI) |
|---|---|---|---|---|
| Pre-HBI (N=52) | | | | |
| Advice (In) | 45 | 23 | 37 | - |
| Advice (Out) | 58 | 30 | 50 | - |
| Conference | 100 | 50 | 100 | - |
| Grants | 93 | 33 | 55 | - |
| Papers | 86 | 42 | 68 | - |
| Supervise | 77 | 31 | 76 | - |
| Teach | 77 | 56 | 82 | - |
| | | | | |
| Post-HBI (N=81) | | | | |
| Advice (In) | 72 | 50 | 70 | 54 |
| Advice (Out) | 74 | 50 | 67 | 61 |
| Conference | 88 | 53 | 74 | 77 |
| Grants | 67 | 41 | 57 | 61 |
| Papers | 70 | 40 | 68 | 63 |
| Supervise | 76 | 41 | 78 | 74 |
| Teach | 64 | 45 | 87 | 66 |

*Notes: All networks contain only reciprocal ties, except for the advice networks.*
*HBI themes were not formalized until 2010, thus we do not calculate percent same theme for the earlier networks.*

*Table 4.* Network Composition Over Time

composition of the seven networks at the two time points in terms of gender, department, HBI research theme, and CIHR pillar.

Table 4 shows that the advice networks have become more homogenous by gender between the two time periods. Before 2005, the neuroscientists reported that 58% of those from whom they sought advice were the same gender as themselves, while after 2005 this number increased to 74%. However, all of the other professional activities are less homogenous by gender after the foundation of the HBI.

Overall, department does not appear to be as salient as either CIHR pillar or HBI theme for network composition. Except for teaching and organizing conferences before 2005 and advice and conference organization between 2005-2010, all of the networks were composed of more than 50% people from other departments. The importance of the CIHR pillars for the organization of networks is clear, and went up over time. Between 2005 and 2010, respondents reported that 68% of their co-authors and 78% of those with whom they co-supervised were in the same CIHR pillar as themselves.

The HBI formalized the three research themes in 2010, in an attempt to reflect how members were organizing themselves around research areas. Members clearly find these research themes to be salient, as they report that 61% of the people with whom they hold grants are in the same research theme, and 63% of their co-authors are in the same research theme area.

### *QAP Regression Results*

Tables 5 and 6 contain the QAP regression results for five of the six original networks and the multiplex network for each time point. We chose to eliminate the conference network from the remainder of the analyses, since the network is so sparse. To create the multiplex network, we summed across all of the networks (Koehly & Pattison, 2005). The tie value for each pair is the total number of types of relationships between any two individuals, and can range from 0 to 5. The multiplex network thus illustrates the extent to which actors share multiple relationships.

The QAP regression results illustrate the simultaneous effect of each of the independent variables on the likelihood of a tie between two individuals. Burris (2005) argues that when interpreting QAP regression results, the focus should be on the comparative magnitude of the

| **Original Members (N = 52)** | | | | | | |
|---|---|---|---|---|---|---|
| **PRE-2005** | Advice | Grants | Papers | Supervise | Teach | Multiplex |
| Same department | .067** (.005) | .023 (.201) | .077** (.010) | .023 (.213) | .088** (.006) | .088** (.001) |
| Same gender | .013 (.376) | .040 (.080) | .047 (.106) | -.006 (.405) | .004 (.503) | .031 (.225) |
| Same pillar | .035 (.110) | -.019 (.265) | .007 (.404) | .082** (.007) | .064* (.025) | .053 (.069 |
| Same office | .049* (.019) | .057* (.031) | .037 (.113) | -.007 (.412) | .009 (.368) | .061* (.022) |
| Same rank | .040* (.029) | .021 (.237) | .058* (.030) | .052* (.038) | .019 (.249) | .063* (.013) |
| $R^2$ (adjusted) | .012 | .005 | .014 | .009 | .013 | .024 |
| **PRE-2005** | Advice | Grants | Papers | Supervise | Teach | Multiplex |
| Same department | .109** (.001) | .052 (.059) | .057* (.039) | .090** (.003) | .086** (.004) | .128** (.001) |
| Same gender | .024 (.292) | .018 (.318) | .034 (.167) | .008 (.413) | -.036 (.143) | .020 (.283) |
| Same pillar | .089** (.005) | -.031 (.152) | .010 (.371) | .088** (.002) | .080** (.008) | .084** (.009) |
| Same theme | .075** (.006) | .055* (.032) | .074** (.006) | .098** (.001) | .037 (.106) | .111** (.001) |
| Same office | .097** (.001) | .077** (.010) | .106** (.002) | .064* (.019) | .075** (.008) | .134** (.001) |
| Same rank | .065* (.028) | .047* (.023) | .040 (.087) | .002 (.467) | .017 (.278) | .067* (.016) |
| $R^2$ (adjusted) | .049 | .018 | .024 | .036 | .027 | .072 |

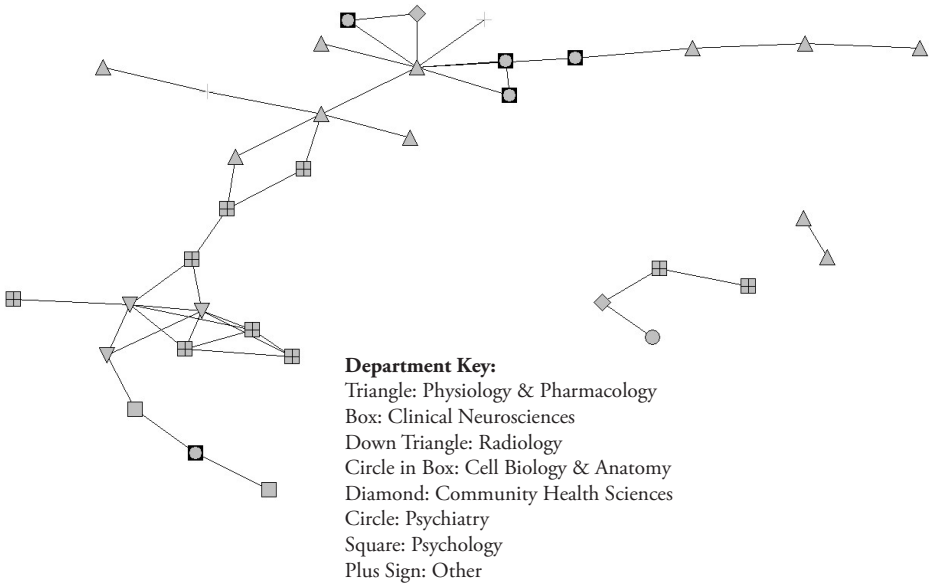
*Notes:*
** significant at the 0.05 level*
*** significant at the .001 level*
*Standardized coefficients and proportion significance in parentheses.*
*All the networks are reciprocal ties only, except for Advice, which includes non-reciprocal ties.*
*All the networks are dichotomized, except for the multiplex network, which is a valued network (0-5).*
*For the multiplex network, the coefficients are predicting the strength of the tie, rather than just the existence of a tie.*

*Table 5.* QAP regression results, PRE-2005 and 2005-2010 Original Members (N = 52)

coefficients, rather than on the overall model $R^2$ or the level of statistical significance for each coefficient. In Tables 5 and 6, we report the standardized coefficients for each independent variable, and their significance level. Our discussion will focus on the comparative magnitude of those coefficients which are significant.

The top half of Table 5 contains the regression results for the pre-HBI networks. There are five independent variables included in these models: belonging to the same department, being the same gender, belonging to the same CIHR pillar, having offices in the same building, and having the same appointment level. Controlling for the other independent variables, department appears to have the largest effect on collaboration among the 52 neuroscientists at UCalgary before 2005. Belonging to the same department was statistically significantly related to seeking advice, co-authoring, and co-teaching, controlling for the other independent variables.

Figure 1 shows the pre-2005 co-authorship network. Respondents are represented by shapes, and the lines indicate reciprocal co-authorship relations. In this figure, the respondents are shaped by departmental membership. The clustering of certain shapes in different areas of the graph illustrates the importance of departmental membership for co-authorship among the 52 scientists before 2005.




*Notes: Reciprocal ties. Only active nodes are shown (N = 35). There were 17 isolates in this network.*

*Figure 1.* Co-authorship network, Pre-2005, by Department (N = 52)

Turning back to the results presented in the top half of Table 5, the next most important independent variable for the pre-HBI networks is being at the same appointment level, which has a positive impact on the presence of ties for advice, co-authoring, and co-supervising, net of the

other independent variables. Interestingly, having offices in the same building was also positively related to seeking advice and sharing grants before 2005, net of the other variables. In fact, the only variable that predicted shared grants in the pre-HBI time period was office co-location.

The bottom half of Table 5 also examined the predictors of relationships among the original 52 HBI members during the 2005-2010 time period. An additional independent variable is added to these models, belonging to the same HBI theme.

We find that being in the same department is still positively related to requesting advice, co-authoring and teaching, controlling for the other independent variables. However, belonging to the same HBI theme also becomes important for all of the relationships except teaching. During this time period, belonging to the same theme has a stronger effect on holding grants, co-authorship, and co-supervision than belonging to the same department, net of the other variables.

Once again, having offices in the same building is positively related to all the relationships. In fact, shared office location is the most important predictor of shared grants and co-authorship for the original 52 members since 2005, controlling for the other independent variables.

| **All Members (N = 81)** | | | | | | |
|---|---|---|---|---|---|---|
| | Advice | Grants | Papers | Supervise | Teach | Multiplex |
| Same department | .100** (.001) | .050* (.018) | .056* (.011) | .061** (.004) | .044* (.023) | .116** (.001) |
| Same gender | .045* (.036) | -.003 (.466) | .009 (.328) | .032 (.058) | -.028 (.111) | .028 (.134) |
| Same pillar | .080** (.001) | -.015 (.262) | .020 (.160) | .096** (.001) | .099** (.001) | .091** (.001) |
| Same theme | .075** (.001) | .045* (.017) | .066** (.002) | .095** (.001) | .043* (.022) | .112** (.001) |
| Same office | .075** (.001) | .071** (.001) | .085** (.001) | .046* (.013) | .034 (.052) | .106** (.001) |
| Same rank | .022 (.118) | .042* (.027) | .034* (.050) | .008 (.328) | -.012 (.293) | .031 (.057) |
| $R^2$ (adjusted) | .040 | .012 | .020 | .031 | .019 | .063 |

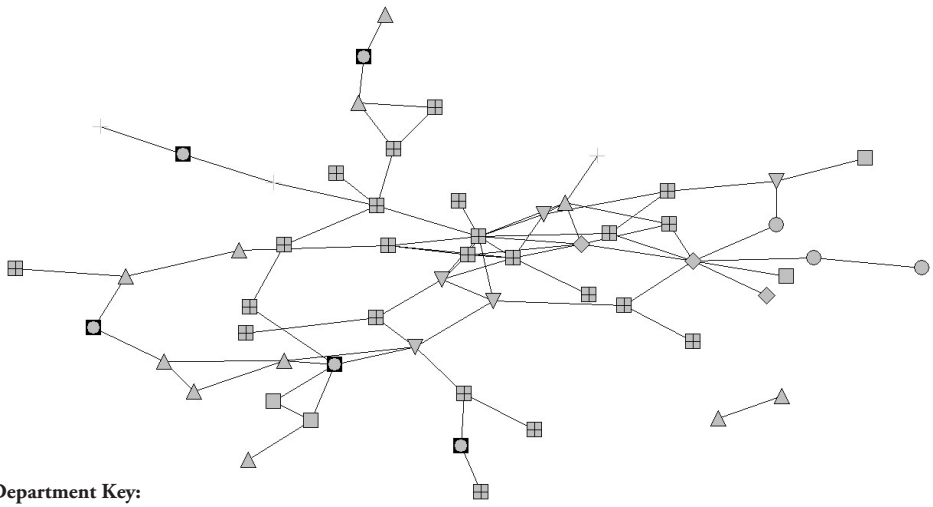
*Notes:*
** significant at the 0.05 level*
*** significant at the .001 level*
*Standardized coefficients and proportion significance in parentheses.*
*All the networks are reciprocal ties only, except for Advice, which includes non-reciprocal ties.*
*All the networks are dichotomized, except for the multiplex network, which is a valued network (0-5).*
*For the multiplex network, the coefficients are predicting the strength of the tie, rather than just the existence of a tie.*

*Table 6.* QAP regression results – 2005-2010

Table 6 shows the regression results predicting relationships among all 81 members of the HBI between 2005 and 2010. These results indicate that belonging to the same department, belonging to the same HBI theme, and having an office in the same building are all positively related to ties across all of the professional activities (except teaching), net of other variables. Shared CIHR pillar affects advice, supervising and teaching, but not grants and papers, net of other variables.

Among the full 81 members, advice is impacted by all of the independent variables except shared rank. It is interesting to note that gender becomes significant in this model, suggesting that women are more likely to seek advice from female colleagues, and men from male colleagues, net of other independent variables. Since the founding of the HBI, the UCalgary has implemented a gender equity policy that has increased the number of women hired in predominantly male disciplines. The effects of this policy are reflected in the fact that the percent of the sample that is female rose from 11.5% in 2005 to 22% in 2010. By 2010, women had more same-gender colleagues from whom to seek advice. However, the effect of shared gender on advice seeking remains half that of shared department.

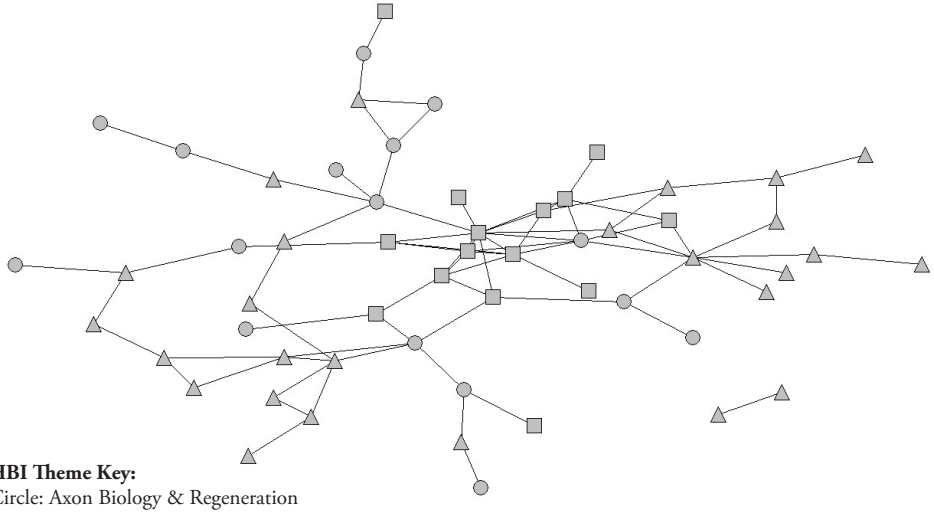
Figure 2 shows the co-authorship network between 2005 and 2010 with individuals shaped by departmental membership, and Figure 3 shows the co-authorship network between 2005 and 2010 with individuals shaped by HBI research theme. Once again, the effect of department on co-authorship is evident in Figure 2 by the clustering of similarly shaped squares. Comparing Figures 2 and 3, we can see that co-authorship is even more clearly clustered by HBI theme.



**Department Key:**
Triangle: Physiology & Pharmacology
Box: Clinical Neurosciences
Down Triangle: Radiology
Circle in Box: Cell Biology & Anatomy
Diamond: Community Health Sciences
Circle: Psychiatry
Square: Psychology
Plus Sign: Other

*Notes: Reciprocal ties. Only active nodes are shown (N = 57). There were 24 isolates in this network.*

*Figure 2.* Co-authorship network, 2005-2010, by Department (N = 81)



**HBI Theme Key:**
Circle: Axon Biology & Regeneration
Triangle: Neural Systems & Behaviour
Square: Cerebral Circulation

*Notes: Reciprocal ties. Only active nodes are shown (N = 57). There were 24 isolates in this network.*

*Figure 3.* Co-authorship network, 2005-2010, by HBI research theme (N = 81)

Finally, we compare the results for the multiplex networks across Tables 5 and 6. For the 52 neuroscientists at UCalgary before 2005, the strength of the tie between two researchers (or the number of different professional activities they engage in together) is affected by shared department, shared rank and office co-location, controlling for gender and CIHR pillar. For these same individuals, the strength of the tie between two researchers from 2005 to 2010 is affected by office co-location, shared department, shared theme, shared pillar and shared rank, controlling for gender. For all 81 HBI members, the strength of the tie between two researchers from 2005 and 2010 is affected by shared department, shared theme, office co-location and shared pillar.

## *Leadership Analysis*

The HBI has eleven members who hold leadership roles, including a Director, a Deputy Director, an Education Director and leaders for each of the thematic research areas. We calculated both degree and betweeness centrality measures for the 2005-2010 data, and then compared these measures for leaders versus non-leaders. The results of this analysis are shown in Table 7.

Degree centrality is a measure of activity; it simply indicates the number of ties reported by each individual. An individual with no ties will not have a value for degree centrality. Table 7 shows that there are significant differences between the activity levels of leaders and non-leaders in the HBI across two of the professional activities: advice giving and co-supervising. On average, leaders were asked for advice by 10.5 others between 2005 and

| | Degree Centrality | | | | Betweeness Centrality | |
|---|---|---|---|---|---|---|
| | Members | | Leaders | | Members | Leaders |
| | Mean (S.E.) | N | Mean (S.E.) | N | Mean (S.E.) N = 70 | Mean (S.E.) N = 11 |
| Advice (In) | 3.63* (.499) | 51 | 10.45* (2.46) | 11 | .420* (.128) | 4.38* (1.92) |
| Advice (Out) | 4.46* (.540) | 50 | 7.70* (4.47) | 10 | .420* (.128) | 4.38* (1.92) |
| Grants | 2.06 (.265) | 32 | 3.20 (.696) | 10 | .506* (.134) | 2.52* (.891) |
| Papers | 2.60 (.294) | 47 | 3.60 (.562) | 10 | 1.68* (.349) | 4.27* (1.36) |
| Supervise | 2.45* (.204) | 47 | 4.45* (.957) | 11 | 1.34* (.231) | 4.40* (1.36) |
| Teach | 2.31 (.325) | 32 | 1.78 (.364) | 9 | 1.29* (.335) | 3.22* (1.16) |

**difference between members and leaders significant at p<.05*

*Table 7.* Comparing Degree and Betweeness Centrality Measures for HBI Leaders and Members

2010, while non-leaders were only asked for advice by only 3.6 other members. Interestingly, leaders also requested advice from more others (7.7) than non-leaders (4.5) during this time period. Leaders co-supervised with an average of 4.5 other members, while non-leaders reported co-supervising with 2.5 others.

Betweeness centrality measures how often an individual lies on the shortest path between two other individuals. Betweeness centrality is often considered a measure of bridging, or an indicator of a brokering tie. Individuals with high betweeness can facilitate (or hinder) the flow of information through a network. Table 7 illustrates that the HBI leaders have significantly higher betweeness centrality than other members in every one of the professional networks.

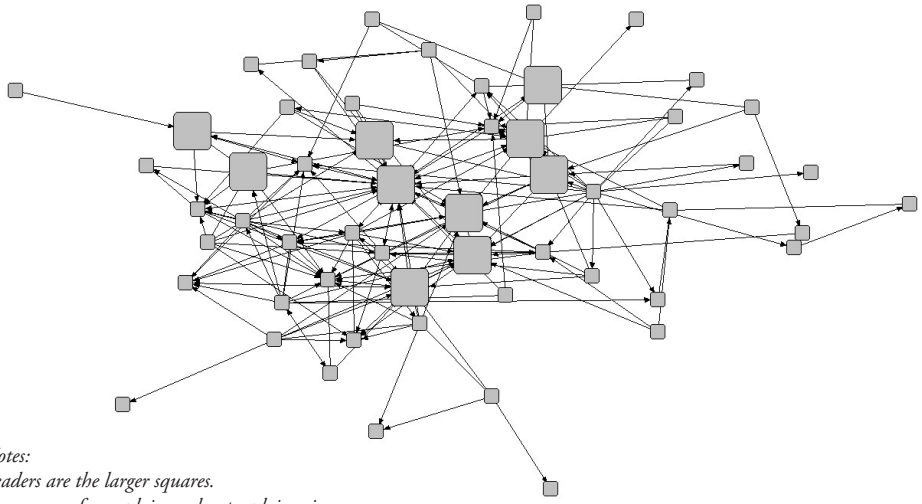
Figure 4 illustrates the advice-seeking network for the 81 HBI members from 2005-2010. The eleven members who hold leadership roles are drawn as large squares, while the rest of the members are shown as small squares. This figure clearly shows how central the leaders are in the network.

## Discussion

We set out to evaluate how the establishment of the HBI affected professional interactions among neuroscientists at UCalgary. We organize our discussion as a set of reflections on our four research questions.

### *Findings*

Our first research question asked how many and what type of professional interactions existed among HBI members before the formation of the HBI, and how many have occurred since the formation of the HBI. We found that while professional interactions did occur among the 52



*Notes:*
*Leaders are the larger squares.*
*Arrows goes from advice-seeker to advice-giver.*
*All 81 network members are included because every respondent either sought or gave advice.*

*Figure 4.* Advice Network, 2005-2010 (N = 81)

neuroscientists at UCalgary before the foundation of the HBI, professional interactions have increased since the HBI was founded. Specifically, we found a statistically significant increase in interactions among the original 52 HBI members in terms of advice seeking and holding grants together.

The percent of the sample who are isolates declined in each network except the teaching network (where it rose from 48 to 49%) over the time period. However, approximately a quarter of the members are isolates in the 2005-2010 advice networks, approximately a third are isolates in the co-author and co-supervise networks, and approximately half are isolates in the grants and teaching networks. Since we only considered reciprocal ties for the latter four networks, some isolates may have been created by recall bias. We performed post-hoc analyses to examine the isolates, in an attempt to determine if they shared similar characteristics. We found that the vast majority of isolates are either recent recruits to UCalgary or clinicians. The recent hires have not had as much time to be involved in professional interactions with other HBI members, and the clinicians spend significant time in their clinical roles, thus leaving less time to be involved in research.

Among the current members, we found that the most common professional interactions within the HBI are co-supervising and seeking advice, followed by co-authoring, co-teaching and holding grants together. On average, between 2005 and 2010, HBI members sought advice from 5 other members, supervised students with 2.8 other members, and co-authored with 2.8 other members. Seventy percent of HBI members co-authored with at least one other member between 2005 and 2010, and over half of HBI members held a grant with at least one other member in the same time period. Thus it appears that the formation of the HBI has indeed increased professional interactions among neuroscientists at UCalgary.

Our second research question asked about the composition of the professional interaction networks within the HBI, with regards to the individual-level attributes of gender, department, research theme and CIHR pillar membership. We found that the networks of grants, papers, supervising and teaching were all more homogenous by CIHR pillar and HBI research theme than they were by department. This result appears to indicate that the HBI has succeeded, at least partially, in overcoming the administrative boundaries that frequently exist between departments. The HBI themes, which have emerged naturally among the members since the founding of the Institute, appear to provide salient groupings within which researchers can cluster.

Our third research question addressed the individual-level characteristics of respondents that predict professional interaction between researchers. We first examined the predictors of professional relationships at two time periods for the original 52 researchers. We found that although shared department was important for predicting relationships at both time periods, its importance had declined by the 2005-2010 time period. Shared theme became more important than department for holding grants together, co-authoring, and co-supervising. Once again, this result suggests that the HBI themes are proving relevant for researchers in the Institute.

We next examined the predictors of relationships among the full 81 members between 2005 and 2010. We found that shared HBI theme predicted all professional relationships among this group. Also important were shared CIHR pillar and shared department. Shared gender also mattered for advice seeking in this group.

An interesting finding in the 2005-2010 data is that office co-location also predicts almost all the professional relationships (except co-teaching among the full 81 members). For relationships among the 52 original members before 2005, office co-location only affected advice seeking and sharing grants. It is important to note that since offices at the HBI are not assigned by department (and departmental co-membership is controlled for in these models), the effect of office co-location is not a disciplinary effect. These findings mirror recent findings in the literature on 'networked organizations' that suggest that even within organizations with an international reach, where workers use communication technology to collaborate across geographic distance, communication with co-located co-workers is considered most important (Olson and Olson, 2010; Quan-Haase and Wellman, 2004). A university or institute may want to consider capitalizing on such findings by relocating members so that all of their offices are closer together, perhaps in a dedicated building. Collaboration may increase even further if all members' offices were all in the same location.

Our final research question asked whether the appointed HBI leaders occupy leadership positions in the professional interaction networks between 2005 and 2010. Using measures of degree centrality, we found that leaders are more active, and therefore more central in both the advice and the supervision networks. Using betweeness centrality, we found that the leaders are more central in each of the professional relationship networks. The HBI leaders are clearly serving as bridges in the Institute, linking members to one another through the various professional relationships. Recently, bibliometric and organizational analyses have begun using measures of betweeness centrality (for journals, for authors, and for organizations) to measure the degree of interdisciplinarity of a journal, an individual author, or an organization

(Cassi, Corrocher, Malerba, and Vonortas, 2008; Wagner et al., 2011). We argue that in the HBI context, the high betweeness centrality of the leaders indicates that they are promoting the interdisciplinary goals of the Institute.

### *Limitations*

We recognize that our data and analyses are limited by several factors. First, and most importantly, we are presenting results from a single case study. We do not have data from a comparable group of scientists (either another group of researchers at UCalgary or neuroscientists at another institution). The increases in professional interactions that we observe over time among the HBI members may simply reflect a historical trend of increased interdisciplinary research (Rimer and Abrams, 2012), and may have occurred even without the establishment of the HBI.

Second, although our response rates are high (81% for the pre-HBI network and 84% for the post-HBI network), we did not receive survey data from all the members of the HBI. In any network survey, missing data issues are compounded by the fact that those who do not take the survey are not only eliminated as respondents, but they are also eliminated as potential ties. We do not know the extent to which those who did not respond differ from our respondents (for example, in engagement with others), and thus cannot comment on the representativeness of our sample.

Third, we may be underestimating the number of professional interactions among these researchers by only including reciprocal ties in our analyses. However, we have more confidence in the self-report data by using only the confirmed ties. Additionally, it is important to note that we do not have any information on professional interactions with researchers outside of UCalgary for either time period. We stress that we recognize that sometimes the most productive collaborative relationships occur cross-institution, and, as yet, we have no data on such relationships.

Finally, we must address the many ways in which time may affect our findings. First, the pre-2005 data may suffer from recall issues. Several respondents reported to us that it was sometimes hard for them to remember relationships they had before 2005 (especially those that did not result in a tangible outcome such as a publication). Second, we have no information on people who were members of the HBI when it was founded in 2004 but left the university before our survey in 2010. Third, the neuroscientists who joined the UCalgary since 2004 joined knowing that they would become HBI members. Thus, the newer Institute members may be pre-disposed to have more professional interactions with other members of the HBI than those who automatically became members in 2004.

## Conclusion

Despite the limitations noted above, this study serves as an example of the use of social network analysis to evaluate the effects of the establishment of a multidisciplinary research institute on scientists' working relationships in a Canadian University setting. We believe our analyses demonstrate that the establishment of the HBI has fostered, encouraged and increased interdisciplinary professional interactions among neuroscientists at UCalgary.

The HBI is emerging as a Canadian centre for neuroscience research and has received substantial funding since its inception. By all traditional measures (publication output, grant funding, and international reputation), the HBI is a success (Haustein et al., 2013). Social network analysis enables us to assess the additional impact of Institute membership on scientific relationships among members.

Reflecting back on the literature on successful collaborative research institutes, four factors were seen as most important: communication, infrastructure, shared vision, and leadership. The HBI's success rests on the integration of these four factors. Communication among the members is facilitated through regular meetings. The Institute has recently received another large donation, further strengthening its already strong infrastructure and funding environment. Shared vision appears to be working through the three thematic research areas, which are drawing scientists together across disciplines and departments. And the leaders appear to be playing a strong leadership role, bringing together researchers across all the professional relationships.

This analysis has enabled us to quantify the success of the HBI in more than just financial terms or the co-authorship of publications. The Institute has been successful in promoting professional interactions among its members. By allowing the natural emergence of research themes, the Institute leadership built on existing interactions and relationships among scientists and encouraged the further formation of professional ties across disciplines.

## Author's Note

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## Appendix – Network Survey Questions

***Part One (Sent to all current (2010) HBI members).***

The following six questions ask about your professional relationships with other full members of the HBI during the time period from January 2005 to the present.

Please note that we have provided 20 boxes for names under each question. You may fill as many or as few boxes as necessary under each question.

NOTE: For each box, respondents were provided with a drop down menu that listed the names of all of the current (2010) members of the HBI, in alphabetical order by last name.

1. With whom have you held grants between January 2005 and the present?
2. With whom have you co-authored papers between January 2005 and the present?
3. With whom have you taught in a course (graduate or undergraduate) between January 2005 and the present?
4. With whom have you co-supervised students, fellows or trainees, or served on student supervisory committees between January 2005 and the present?
5. With whom have you co-organized conferences / symposia between January 2005 and the present?
6. From whom have you sought professional advice or mentorship between January 2005 and the present?

***Part Two (Sent to all original (2005) HBI members).***

The following six questions ask about your professional relationships with other full members of the HBI prior to the formation of the HBI. Please report on any relationships you had with your colleagues BEFORE January 2005.

Please note that only your colleagues who also became members of the HBI in 2004 are listed for these six questions.

Please note that we have provided 20 boxes for names under each question. You may fill as many or as few boxes as necessary under each question.

NOTE: For each box, respondents were provided with a drop down menu that listed the names of all of the current (2010) members of the HBI, in alphabetical order by last name.

1. With whom had you held grants prior to January 2005?
2. With whom had you co-authored papers prior to January 2005?
3. With whom had you taught in a course (graduate or undergraduate) prior to January 2005?
4. With whom had you co-supervised students, fellows or trainees, or served on student supervisory committees prior to January 2005?
5. With whom had you co-organized conferences / symposia prior to January 2005?
6. From whom had you sought professional advice or mentorship prior to January 2005?

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