A typology of collaborative research networks.

Abstract

Purpose - Many studies have investigated how the structure of the collaborative networks of researchers influences the nature of their work, and its outcome. Co-authorship networks (CAN) have been widely looked at as proxies that can help bring understanding to the structure of research collaborative ties. In this study we provide a framework for describing what influences the formation of different research collaboration patterns.

Design/methodology/approach - We use social network analysis (SNA) to analyze the co-authorship ego networks of the ten most central authors in twenty-four years of papers (703 papers and 1118 authors) published in the proceedings of CASCON, a computer science conference. In order to understand what lead to the formation of the different co-authorship networks we examined, we conducted semi-structured interviews with these authors.

Findings - Based on this examination, we propose a typology that differentiates three styles of co-authorship: Matchmaking, Brokerage, and Teamwork. We also provide quantitative SNA-based measures that can help place researchers' CAN into one of these proposed categories. Given that many different network measures can describe the collaborative network structure of researchers, we believe it is important to identify specific network structures that would be meaningful when studying research collaboration. Our proposed typology can offer guidance in choosing the appropriate measures for studying research collaboration.

Originality/value –The results presented in this paper highlight the value of combining SNA analysis with interviews when studying CAN. Moreover, the results show how co-authorship styles can be used to understand the mechanisms leading to the formation of collaborative ties among researchers. We discuss several potential implications of these findings for the study of research collaborations.

Keywords: Social Network Analysis; Research collaboration; Co-authorship; Interviews

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Introduction

Research collaboration is a social process, taking place in a social context, in which researchers interact to share meaning, develop understanding, and perform tasks to achieve a mutually-shared superordinate goal, which generally produces knowledge (Sonnenwald, 2007). During the last two decades research collaboration has continued to increase in frequency and importance (Kumar, 2015). The investigation of research collaborations has important implications for the facilitation of research. Many studies have investigated how the structure of the collaborative networks of researchers influences the nature of their work, and its outcome. Co-authorship networks (CANs) have been widely looked at as proxies that can help understand the structure of research collaborative ties. These studies have mainly focused on the position of individual actors within the overall CAN, rather than looking at the structure of the individual authors' networks.

In this paper we build on previous studies of CANs and extend them by closely examining aspects related to the structure of researchers' networks. By doing so, we contribute to the understanding of what influences the formation of different co-authorship patterns. These patterns are then used as foot prints that can help us examine, and understand, researchers' collaboration patterns. Structural properties of researchers' CANs can only tell part of the story. They assist in capturing images of collaboration where individuals work together for a common goal (i.e. publication). But they are not always sufficient for revealing the motivations for this collaborative work, nor do they provide insights regarding the mechanisms that lead to the formation of the collaborative ties. Thus, in the research presented in this paper, we combined social network analysis with semi-structured interviews with key authors to develop a typology of co-authorship styles. These authors were selected based on their central position within the CASCON community (i.e. the authors that had the highest number of co-authorship ties with other CASCON authors). We gathered and analyzed data from twenty-four years of the CASCON conference, dating back to the first CASCON conference in 1991 (Perelgut et al., 1997). The rest of this paper is organized as follows: In the Relevant literatures section, we present a review of CANs as well as discuss the social network analysis (SNA) literature and its structural determinants. In the Research method section, we present our research method and provide an overview of the data collected. Our results are then described, followed by Discussion, and suggestions for future research.

Relevant literatures

Co-authorship

Co-authorship networks (CANs) are constructed from a list of published papers by considering authors as connected nodes if they co-authored one or more papers together (Logan and Shaw, 1991). Over the past decade, the number of articles focusing on CANs has increased rapidly (Gaskó et al., 2016, Kumar, 2015). CANs have recently been used to study different aspects of research collaboration by extracting various types of information. Some key examples for these examined aspects are: relating authorship patterns with innovation (He et al., 2013, Lungeanu and Contractor, 2015), summarizing best practices in scientific collaboration, and making recommendations for institutional cooperation (Parada et al., 2013), recommendations for cooperation within specific academic fields (Holzinger et al., 2013, Velden and Lagoze, 2009, Xu et al., 2014, Cheong and Corbitt, 2009), or for interdisciplinary collaboration (Valdez et al., 2014). Some scholars have further enhanced these type of studies, and tried to use CAN to infer about researchers' research impact (Ortega, 2014), to determine their future publication likelihood (Kurosawa and Takama, 2012), for generating article recommendation systems (Taraghi et al., 2013), and to define the collaboration potential between authors (Giuliani et al. ,2010).

The majority of existing co-authorship studies focus on networks constructed from papers selected either from a geographical region, from one or more specific fields or from a combination of both (e.g., papers authored by researchers from a country publishing papers in a certain field) (Gaskó et al., 2016). Most co-authorship studies use network indicators to describe the co-authorship data (Barabasi, 2002, Kumar, 2015), and the above discussed studies serve as exemplars for the growing body of work that employs Social Network Analysis (SNA) to study co-authorship patterns in academic and scientific circles.

Social Networks Analysis and Co-authorship networks

Co-authorship patterns have been widely and actively studied from a social network analysis perspective for over two decades (Kumar, 2015). Network theory in general is concerned with networks of nodes and links. Social Network Analysis (SNA), which can be considered a specialization of network theory, focuses on nodes as social objects. The links in social networks

depict various kinds of relationships including collaboration, kinship, shared ideologies, economic exchange, or communication, among others (Wasserman and Faust, 1994).

A large portion of the studies looking at CANs have looked at the entire network of ties that exist among the authors. Studies that have utilized this SNA complete network analysis approach, have used different network indicators such as degree and centrality measures (Matusiak and Morzy, 2012, Ortega, 2014) among others. Some of these studies focus on structural properties that are illustrated by connectedness among the examined co-authors (Cardillo et al., 2006). Other move toward a more advanced analyses, such as detecting community structures (Velden and Lagoze, 2009) and hubs (Ghafouri et al., 2014), and identifying mechanisms that lead to attachment among co-authors (Perc, 2014) or looking at the overall structural properties of the CAN (Xu et al., 2014).

When looking at the overall structural properties of CANs, some authors try to identify small-world structures (Cheong and Corbitt, 2009, Liu et al., 2013) networks where the average distance between collaborating scientists is small but varies logarithmically with community size; or scale-free properties, i.e., the centrality of the nodes in the network is characterized by a power law, sometimes referred to as "long tail" (Liu et al., 2013), while others propose entirely new measures for evaluating researcher collaboration. One recent example is the work of He et al., (2013) where the authors analyze interdisciplinary collaborations by developing a topic model, which was broadly based on the notion that connected authors tend to write on similar topics.

Other studies have combined the networked measures with additional information about the authors attributes. Olmeda-Gómez et al. (2009) used a visualization tool to study scientific co-authorship and found that collaboration patterns are influenced by geographic proximity and administrative and political affiliations. Another study supplemented the co-authorship data with social activity collected from Twitter (Pujari et al., 2015). Gender was also examined within the CAN studies, a notable recent example is the work of Kumar (2016), where it was shown that authors preferred to co-author with authors of their gender, as well as a significant effect of gender over the research productivity of authors. As the above examples show, complete network analysis is helpful for visualizations of the examined network and for understanding the network structure, authors' position in the network, and the linkages between authors. In previous work, an SNA analysis of the CASCON CAN showed that, in the CASCON

community, social capital is maintained by the density of the connections (cohesion) among its members

In this paper we wish to provide a more detailed study of the structure of the CAN of each author. In order to do so, we conducted an ego-network analysis of key authors in the CASCON CAN. Ego-network analysis deals with the relationships that exist from the perspective of a particular node which is referred to as an "ego" (Wasserman and Faust, 1994), in our case from the point of view of a specific author. Thus, we offer to build on previous SNA studies of CANs by closely examining aspects relating to the structure of researchers' ego networks. By doing so, we are able to focus on the mechanisms that effect the formation of different co-authorship patterns. These patterns can then be used as footprints that can help us examine and understand researchers' collaboration patterns. In this paper, we define ego networks as networks consisting of a single actor (ego) together with the actors they are connected to (alters) and all the links among those alters. These networks are also known as the neighbourhood networks or first order neighbourhoods of egos (Wasserman and Faust, 1994). Ego networks have a constrained and simple structure which delivers a benefit in data collection and analysis.

Diverse measures have been used to analyze co-authorship ego networks (CAENs), these include density of connections, strength of ties, connectivity (e.g. structural holes; Burt, 1992), attributes of the alters (e.g. homophily) or combinations of these measures (Abbasi et al., 2012). For instance, Abbasi et al. (2012) found that maintaining a strong co-authorship relationship with one primary co-author within a group of linked co-authors is better than to maintaining multiple relationships with the same group of linked co-authors. In a recent study Wagner et al. (2015) looked at Nobel laureate CAENs to find significant patterns that describe a potential laureate. Hayat and Mo (2015) looked at the relationship between CAENs and advice exchange among researchers. Quan-Haase et al. (2015) discusses how collaborative models, which were based on ego-level centrality measures, offer different benefits to researchers in the humanities as compared to their counterparts in the sciences. Lungeanu and Contractor (2015) have shown that innovative publications were more likely to be a result of co-authorship among authors that have worked together in the past, are based in the same country, and come from different academic backgrounds.

Building on the work conducted within the field of CAENss, we offer to study ego networks in the context of key CASCON authors. We used indicators of centrality to identify key authors

from among the entire population of CASCON authors (n=1118). Centrality indices are aimed at providing answers to the question "What characterizes an important node in the network?" The answer is given in terms of a real-valued function on the node of a graph, where the values produced are expected to provide a ranking which identifies the most important nodes (Borgatti, 2005). Specifically, we followed Burt (1983) and used the degree centrality measure to identify the most central authors in the CASCON CAN. Degree centrality is defined by the number of a ties a node has (in our case the number of co-authorship ties with other CASCON authors).

It is important to note that structural properties of the ego networks in CANs can only tell part of the story. They assist in capturing images of collaboration where individuals work together for a common goal (i.e. publication), but they do not reveal the insights regarding the steps leading to the formation of such structural properties (Vidgen et al., 2007). Thus, in order to supplement our SNA-derived data, we also conducted semi-structured interviews with key authors in the CASCON CAN.

Research Method

The focal point of our study is CASCON, the annual conference of the Centre for Advanced Studies (CAS). The focus of this conference is to bring together researchers, government employees, industry practitioners, and technology users in a forum for sharing ideas and results of the CAS collaborative research projects (Perelgut et al., 1997). The CASCON conference is an interesting object of study in this way because it is an annual forum for research collaborations from within a collaborative research centre (CAS) (Perelgut et al., 1997). Given the sense of community among CAS researchers, and their evolving collaborative ties (Hayat and Lyons, 2013), we believe that the CASCON proceedings can serve a twofold purpose: (1) as a case study for the examination of co-authorship patterns and (2) as footprints of the collaborative work that takes place among CAS researchers. The study of the CASCON proceedings can thus enhance our understanding of changes in the collaborative ties among CAS researchers over time. In that sense, this study differ from other studies that examine more ad-hoc co-authorship ties among researchers, where the examination of work practices and their change over time is more prone to errors, given the large scope of potential publication that need to be monitored and analyzed.

As stated above, in this paper we wish to provide a study of the structure of the CAN of each author (i.e., their ego network). We gathered the CASCON co-authorship data from the ACM Digital Library for each paper published since the first CASCON in 1991, to 2014 including title, year, and authors' names. The data extracted was imported into a Microsoft Access database. Our dataset consisted of 703 papers and 1118 authors. In our analysis we studied the ties that exist among an author and his or her immediate neighbours (i.e. co-authors), as well as the ties that exist among these neighbors. This kind of analysis allows us to assess the structure of an author's CAEN as well as its evolution over time. In order to perform our SNA analysis we used the ORA software tool (Carley et al., 2012).

We selected ten authors to interview based on their centrality in the CASCON CAN. The number of interviews was based on theoretical saturation of information gained through the interviews. Saturation occur when subsequent interviews do not provide any new theoretical insights or reveal any new properties of the core theoretical categories which are examined (Sandelowski, 1995). Centrality measures give us insight into the various characteristics of a given author in the CASCON network. There are many different metrics that could be used to assess centrality in such a network. The most intuitive and widely used of these is degree centrality, which is defined as the number of links incident upon a node (Burt, 1983) . In our case these links represent the number of co-authorship ties for a given author. In our analysis, we focused on the ten authors with the highest degree centrality. In other words the most central authors in our network are those who have authored papers with the highest number of authors in the CASCON CAN.

Since structural properties do not provide insights regarding the processes that lead to the formation of the collaborative ties, we also conducted semi-structured interviews with each of the ten most-central authors. Unlike quantitative social network data collection, the purpose of interviewing is not to evaluate or to examine a phenomenon. Instead, interviewing provides a means with which to understand peoples' experiences, and the meaning they give to their own behavior (Seidman, 2006). The interviews were focused on the authors' collaboration practices within the context of CASCON. The interviews lasted between 45 minutes and an hour. The data gathered in the interviews were analysed thematically, using the Saturate software tool (Sillito and De Alwis, 2009), while looking at the notion of collaboration and determining whether a

theoretical saturation had been reached. We specifically looked for particular indicative examples that could help us understand what leads to the formation of the ego network. These interviews also helped us better understand the context for collaborative relationships and the participants' own accounts of the interactions in which they have been involved. We used a narrative analytic strategy that focused on the themes within the narrative. Our analysis was conducted throughout our sampling process, and we completed our sampling when we reached theoretical saturation (Sandelowski, 1995), as no new data appeared in our later interviews. We specifically searched for experiences that may not be shared by all authors (Berg, 2009). This enabled us to better grasp the differences in authors' collaborative practices and thus enabled us to differentiate between the structures of each of the CAENs.

In order to ensure informant anonymity when discussing what was said in the interviews we use pseudonyms in the reminder of this paper. Furthermore, as we discussed in our literature review and in our discussion of the CASCON case study, the co-authorship relationships serve as a proxy for research collaboration patterns; thus, though our analysis looks at co-authorship patterns, in the reminder of this paper we will also discuss our results in terms of researchers and their collaborative research work.

Results

In order to better understand the structures of the CAENs that we examined, we weave together the stories of individual researchers with insights derived from a typological social network analysis. Two measures have been found to be central in the study of research networks: betweenness centrality and effective network (Newman, 2001). Betweenness centrality is calculated as the number of shortest paths from all nodes to all others that pass through a given node (Freeman, 1977). The shortest path between two nodes is the path that connects the two nodes with the shortest number of edges. Previous studies have found that a shorter average path in a group is critical to social cohesion and collaborative development (Barabasi, 2002). The effective network of an ego is the number of alters that ego has minus the average number of ties that each alter has to other alters (Burt, 1992). In other words, a tie in the ego's effective network is one that an ego has to an alter who is not connected to any of the other alters.

For each author in our examined CASCON CAN (n=1118) we calculated these two measures. In Table 1 we show the betweenness centrality and effective network size for each of the authors

we interviewed. We also indicate the percentile of the presented value relative to the entire body of authors in the CASCON network. When looking at Table 1 we can see that there are three groups of authors who share similar network characteristics. Bill and Anna (i.e. category 2) have a high betweenness centrality and effective network size. Mike, John and Kathy (i.e. category 1) have high betweenness centrality, but lower effective network size. Andrew, Christian, James, Max, and Adam (i.e. category 3) have high betweenness centrality, but the lowest effective network size[1].

Insert table 1 here

In the following sections we discuss how we used the interview information and the ego networks of our informants to understand their co-authorship styles, following which we explain the network measures values that the authors in each of these styles demonstrate.

Matchmaking style:

Based on the interview information and the ego networks of our informants, we identified that three out of the ten authors we studied, had a similar co-authorship style (category 1 in Table 1), which we titled "Matchmaking style". As will be discussed below, this style was identified by weaving together the visual ego network attributes of these three authors, alongside the information they provided throughout their interviews. Figure 1b shows the ego network of Mike who is one of these authors. Mike collaborated extensively with and worked on a continuing basis with three clusters of authors. Several of Mike's co-authors are connected to one another, however, not extensively and most of the interconnections are via co-authorship with Mike.

We then decided to take a deeper look into this ego network, and try to understand how it evolved to into its current structure. We started to remove the ties in a reverse chronological order. An interesting pattern emerged when we removed all the ties that were established after 2002. When we compare the ties that were established between 1991 and 2002, i.e., after our tie removal process (Figure 1a) with the entire set of ties, i.e., ties that were established between 1991 and 2014, (Figure 1b) we can see that the co-authorship ties between Mike and the

[1] In order to ensure informant anonymity when discussing what was said in the interviews, we use pseudonyms in the reminder of this paper.

members of clusters A, B, and C were initially established between 1991 and 2001 (Figure 1a). More interestingly, we can see that the ties in clusters A, B, and C became denser through co-authorship ties that were established between 1991 and 2014. Cluster A has an additional two ties, cluster B has an additional two ties, and cluster C has an additional five ties.

We interviewed Mike, John and Kathy, the three authors that demonstrated the Matchmaking style. In these interviews we learned that in many cases the papers that the three authors published with the members of the different clusters in their ego networks were the first papers published by their co-authors at CASCON. According to Kathy, once her co-authors had the experience of writing a few papers at CASCON, they began to write CASCON papers on their own or with other collaborators.

John also indicated that in some instances, his co-authors explicitly indicated that they had an interest in working with some of his other co-authors. In these cases John indicated that he introduced the authors to one another. According to John, quite a few of these introductions led to new collaborations among the newly introduced researchers.

Based on our SNA analysis of the typology and evolution of these ego networks, we see that this style of co-authorship is one in which the ego has co-authored with different groups of authors who have not co-authored with one another at CASCON. Furthermore, the members of these separate groups began co-authoring with one another after they first co-authored a paper with the ego. Based on these patterns and on the interviews conducted with Mike, John and Kathy we have chosen to refer to this style of co-authorship as the Matchmaking style.

Insert figures 1a and 1b here

Brokerage style:

Based on the interview information and the ego networks of our informants, we identified that two out of the ten authors we studied had a similar co-authorship style (category 2 in Table 1), which we titled "Brokerage style**"**. Figure 2b shows the ego network of Bill who is one of these authors. The clusters of connected collaborators with whom Bill is co-authoring are completely separate from each other. By simply looking at Figures 2a and 2b we might suspect that this co-authorship style fits the Matchmaking style discussed above; however, the interviews with Bill and Anna, the two authors that demonstrated this co-authorship style, reveal a different story.

Insert figures 2a and 2b here

In the interview, Bill indicated that he has a number of fairly separate streams of research in areas that are not closely related. It appears as though Bill explicitly seeks out groups with sub-specialties needed for a particular paper or research project on which he is working. Anna described a similar scenario when she discussed the ways in which she chooses her co-authors. Furthermore, she indicated that her specialty groups (groups of people with whom she is co-authoring) represent sub-disciplines and are tightly coupled within their subspecialty. As we can see in Figure 2b, members of these different specialty groups indeed tend not to co-author with each other.

When discussing this Brokerage co-authorship style it is important to note that, despite the recognition of the growing importance of interdisciplinary collaboration (Jones et al., 2008), Bill was the only author who actually addressed this notion in his interview. Bill recognized that his research is "interdisciplinary" in that it applies certain research tools in a wide range of contexts. He further stated that this background had helped him to find a mutual language with researchers coming from different backgrounds. Based on the interviews conducted with Bill and Anna, we have chosen to refer to this style as a Brokerage style of co-authorship.

Teamwork style:

Based on the interview information and the ego networks of our informants, we identified that five out of the ten authors we studied had a similar co-authorship style (category 3 in Table 1), which we titled "Teamwork style". Figures 3a and 4a show the ego networks of Andrew and Max (respectfully), both of whom display this style. Both Andrew and Max have a large network that, while far from fully connected (where every member co-authors with every other), is quite connected. There are a fairly even number of ties among co-authors, rather than a few links between a small numbers of them (as was the case with authors who typify the Matchmaking or Brokerage co-authorship styles).

Insert figures 3a and 3b here

Insert figures 4a and 4b here

We interviewed Andrew, Max, James, Christina and Adam, the five authors that demonstrated this Teamwork co-authorship style. These five authors all described a strong preference for a collaboration community that involves linking collaborators with one another. Max spoke at length about the importance of working with a diverse group of co-authors as an important aspect of his work. He mentioned that he both enjoys it and that he finds it constructive for his work. One of the interesting points Max brought up was the importance of being familiar with people that he does not work with directly but with whom his colleagues work. Max was the only author to mention this, which serves as another indication of the importance Max gives to the structure of his CAN. Max's view about the importance of collaborating with a diverse group of peers was reflected in his highly connected CAEN .

Andrew mentioned reciprocity a number of times as a driver of his research. He described a situation in which a group's body of research compelled one researcher to work on behalf of others on a particular paper or as part of a project with the assumption that this would be reciprocated. Christina mentioned longevity and common development paths (i.e. evolving in similar directions as researchers) or recurring convergence of research interests after periods of diverging—as drivers of longer term associations with her co-authors.

In interviews with the five authors, they recalled information about the general process of co-authoring a paper, but were less likely to recall the specifics of the co-authoring process. This was not surprising as some of the papers discussed were published over 15 years ago. Yet they did indicate that their work was easily coordinated and needed little articulation. There was no need for the negotiation that is often reported within the collaboration literature (Kennedy, 2003) to manage the process of doing collaborative research and/or co-authoring a paper. The only obvious driver James and Max mentioned as key for their collaborative patterns was personal preference for particular collaborators. This is in line with the body of literature that highlights different dynamics in collaboration and with theories of social psychology that highlight enjoyment in cooperation (Olson et al., 2008). Andrew and Christina used words such as "comfortable" and "familiar" to describe their long term co-authorship ties.

Though Andrew, Max, James, Christina and Adam all demonstrate a very similar co-authorship type, one we refer to as a Teamwork style, the five authors' styles can be divided into two different style subtypes. These two subtypes are based on the authors' importance in the structure of their ego networks. The importance of each author can be studied by observing what

happens to the ego-network structure when the author is removed from it. Figure 3b and 4b shows the CANs of Andrew and Max, respectfully. Figure 3b show Andrew's CAN when the node representing him and the ties incident upon it are removed. Figure 4b show Max's CAN when the node representing him and the ties incident upon it are removed.

In order to quantify this effect we use betweenness centrality to measure the importance of the ego (i.e. Andrew and Max) within its ego network. Betweenness centrality of a node can be measured relative to the entire network or relative to the ego network (Everett and Borgatti, 2005). As we are interested in studying the structure of the ego networks, and the position of egos within these networks, we consider ego-level betweenness centrality scores. In our case, the betweenness centrality of Andrew's ego network is .005 and the betweenness centrality of Max's ego network is .001. When compared to all the other authors in CASCON (n=1118), Andrew's betweenness centrality is on the 77nd percentile and Max's betweenness centrality is on the 48th percentile. We believe that this difference offers quantifiable support for a meaningful dissimilarity in the position these two authors occupy in their ego networks. Although both authors display a teamwork co-authorship style, they each demonstrate different betweenness centrality measures within their ego network. Therefore, Andrew is a more central actor in his CAN relatively to Max in his network. Using the same measure (see Table 1) Christian and James were also found to be more central than Adam.

Looking at CAEN structures and their evolution over time as well as interviewing the authors is a good way to learn about different co-authorship styles. In our discussion so far we have identified three different co-authorship styles: *Matchmaking, Brokerage*, and *Teamwork*. Based on our analysis, we offer the following short descriptions of each of these styles. Authors who demonstrate the Matchmaking style bring other authors in the network (i.e. his or her alters) together. In many cases the ego is the one who introduced his or her alters into the CASCON community by co-authoring with them on their first CASCON paper. Furthermore, the ties among alters in this ego network were established only after they co-authored with the ego. In many cases the new co-authorship ties that resulted were directly facilitated by the ego author.

The Brokerage style is one in which the ego is the only link connecting authors who work in different fields or disciplines. Unlike the Matchmaking style, the alters within the distinct groups in the Brokerage style network have already been working together prior to co-authoring their first CASCON paper with the ego. In essence, the ego taps into different groups of authors, each

of which is disciplinarily homogeneous. By co-authoring papers with the members of these different groups, the ego can potentially gain from the different skill sets and knowledge they hold.

The Teamwork style many of the ego's co-authors (alters) co-author with one another. Unlike the previous two styles, the Teamwork style is characterised by a densely connected group of authors. There are no authors who can be identified as single connection point between different groups of authors. While this is the case, some authors who display the Teamwork style can be more central in the Teamwork CAN than other Teamwork-style authors. This centrality means that a given author is positioned in a way that makes him or her more vital for sustaining the high connectivity among the network authors. As discussed above, we distinguish between central and non-central egos based on their betweenness centrality score. The higher the betweenness centrality of an ego's node, the more important he or she is for sustaining the connectivity of the network.

It is important to note that these three proposed styles are discussed according to the case studies we have examined in our analysis of the CASCON CAN. Our examples provide exploratory illustrations for each of these styles. We don't expect that authors in other examined networks will demonstrate the exact same structure as found in the examples presented here. However, by looking at the structure of the network, and evaluating aspects such as when the authors started to publish with one another, the role the author plays in connecting the different groups of his or her co-authors, and the density of the examined CAN, one should be able to associate an examined CAEN with one of our proposed co-authorship styles.

In order to further clarify how to differentiate between our proposed styles, we wish to supplement the above analysis by also characterizing the structural (graph theoretic) properties of the CAENs. The SNA framework offers several measures that are more precise than merely describing the visual structure of a network as we did in the preceding discussion. We also made use of several common network measures that can help us empirically differentiate between the different co-authorship styles discussed above. These measures are degree centrality, betweenness centrality and the ego's effective network.

The findings presented in Table 2 show the average value of these measures for authors who display each of the previously discussed co-authorship style networks. For each co-authorship style we calculated the average of all the authors that demonstrated that style. We also indicate

the percentile of the presented value relative to the entire body of authors in the CASCON network (n=1118).

Insert table 2 here

All the authors we looked at were chosen based on their high degree centrality. But within this group we can see that authors that demonstrate Matchmaking or Brokerage co-authorship styles also have high betweenness centrality. This finding is not surprising, as these authors in essence connect authors within different groups. It is also not surprising to see that authors that have Teamwork co-authorship styles (both central and non central actors) have lower betweenness centrality, as they are a part of a network that has high redundancy in the ties among co-authors. Thus they don't necessarily "sit" on the shortest paths among different authors. As defined, the central actors in the teamwork co-authorship style enjoy higher betweenness centrality as compared to the non-central ones.

When looking at the effective network numbers, we discover a quantifiable distinction between the Brokerage and Matchmaking co-authorship styles. The effective network of authors with a Brokerage co-authorship style is higher than that of authors with a Matchmaking co-authorship style. This pattern reflects the tendency of authors who display the Matchmaking style to facilitate their co-authors writing papers with one another; thus, increasing the ties among their co-authors and reducing their own effective network.

Discussion

This paper contributes to the growing body of literature addressing collaboration and researchers' CANs. We recognize the importance of this field and believe our work offers a contribution to it. One contribution is methodological in nature. The results presented in this paper highlight the value of combining SNA analysis with interviews when studying CANs. There are three main advantages of using this approach. First, SNA can inform the process of selecting central authors in the network who can then be interviewed.

Second, quantitative SNA can be used to study the structure of an examined network and the insights from which can be shared with authors during interviews. Previous studies have shown that the structure of the network is important for the research work done by the researchers

embedded within the network (Kilduff and Tsai, 2003). Our approach enables the incorporation of SNA-derived insights into the interviews. This can be done both in the process of devising the interview questions as well as in our awareness of the need to probe the authors when issues relating to the network structure come up during the interview.

Third, details of co-authoring papers cannot be identified through quantitative-oriented SNA alone. The missing pieces of the picture can be discovered through the stories told by authors. Thus, the interviews can be used to zoom in and better understand the dynamics leading to the formation of different CANs. Coupling SNA analysis with the other dimensions of co-authorship that authors provide through interviews can offer considerable synergy in the interpretation of the co-authorship structure and process.

It is important to also note that key studies dealing with collaborative practices in researchers' social networks have mainly relied on data collected through interviews and surveys (e.g. Cummings, 2009). Though this data is informative in analyzing research networks, it suffers from biases derived from self reporting or from low respondent rates or both. We believe that our mixed-method approach can provide a mechanism for performing a more rigorous analysis of researchers' ego networks. Combined datasets collected through interviews as well as through bibliometric and social network analysis, can supplement the current predominantly self-report driven analysis of collaborative practices of researchers. Combining these data sources offers a more holistic understanding of researchers' networks, one that is less prone to biases derived from data collection issues.

Our contributions are not limited to the methodological component. The exploratory typology of co-authorship styles presented in our paper can be helpful in the understanding of researchers' collaboration practices. Investigations of CANs have important implications for the facilitation of research. Many scholars have attempted to study how the structure of researchers' collaborative networks influences the nature of their work and its outcome (e.g. Palla et al., 2007). CANs have been widely viewed as proxies for understanding the structure of research collaborative ties (Wagner et al., 2011). These studies have mainly looked into the position of individual actors within the overall network rather than looking at the structure of an actor's ego network; thus, ignoring the importance of the structural properties of the researcher's co-authorship pattern.

Previous studies that looked at research collaborations have highlighted the importance of investigating researchers' social networks when studying the process underlying research collaboration. One seminal example is the work of Cummings and Kiesler (2005) in which they discuss how a researcher at the confluence of several disciplines is able to broker the knowledge derived from multiple disciplines to create new concepts. They also point out that researchers occupying central positions in geographically dispersed networks of researchers will have higher innovative outcomes. We build on these studies, and add to them by showing how CAENs can be used as proxies for collaborative ties among researchers. In our work we have focused on understanding the styles of co-authorship as a window to understanding the structure of researchers' collaboration patterns. Based on our examination, we propose an exploratory typology that differentiates among three styles of co-authoring: Matchmaking, Brokerage, and Teamwork. We also provide quantitative SNA based measures that can help categorize a researcher's CAEN into one of our proposed categories.

Future studies can extend the understanding of our proposed co-authorship typology. For example, studies that analyze co-authorship ties in different publication venues and examine them in light of the co-authorship styles we present in this paper can offer an additional more nuanced understanding of our typology. Future studies can also look at the co-authorship styles of specific researchers (e.g. researchers that have made significant contributions in their field). By studying these researchers we can gain better understanding of the interplay between the nature of work they do and the structure of their collaboration patterns as evinced from their CAEN.

Lastly, research collaboration continues to increase in importance, it's assumed to be especially necessary for addressing complex, critical problems (Sonnenwald, 2007). As fresh challenges emerge and introduce new goals for researchers and as the contexts in which research work takes place continue to evolve, new methods for studying collaboration strategies will be required. Building on our proposed typology, future studies could investigate which collaboration patterns best suit the purpose of particular types of collaborative endeavors (e.g., when is it important to have researchers who demonstrate Teamwork co-authorship style and when is it important to have those with Matchmaking style). The work of Monge and Contractor (2003) on very large computer-based communication networks may be instructive in this regard. Their work is beginning to lay out a theory regarding which network structures best suit different

purposes—purposes such as exploring for new information, exploiting existing resources, mobilizing action, swarming (acting together), or bonding among members. Building on their results, one could study which collaboration patterns are more appropriate for different research contexts (i.e. different task demands, available resources, degree of functional dependence among the researchers).

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