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A longitudinal analysis of link formation on collaboration networks

Alireza Abbasi

School of Engineering and IT, The University of New South Wales (UNSW Australia), Canberra, Australia

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ABSTRACT

Understanding the structural change and evolution of networks for predicting their dynamics is one of the fundamental problems in network related studies. In order to uncover the dynamic structural patterns of a network over time, it is vital to investigate the ways nodes behave at a local level. So, it is important to know the reasons why nodes stop a relationship or select a new partner, compared to other alternatives, for establishing a link. This study aims to understand the processes of network evolution by quantitatively examining the attachment behaviors of nodes in a real collaboration network by identifying the characteristics of the existing nodes which can impact on their link formation process. To do so, different link formation or attachment processes such as cohesiveness, cumulative advantage, assortative mixing, and structural position are examined. The results indicate that *structural position*, the tendency to connect to the nodes in a strategic intermediating position in the network, is the most effective processes that expose the attachment behavior of nodes during the evolution of a collaboration network. Understanding these effective processes can help to predict more precisely how the nodes' local structure and consequently the overall network structural change over time. This could support researchers, decision makers or practitioners to manage the nodes (agents) in their social or technical networks (systems) for reaching their organizational goals.

1. Introduction

Our life is surrounded by a wide range of complex systems including natural networks (e.g., human brain, proteins, and ant colonies), socio-economical networks (e.g., corporations' organizational structure, world trade union) and socio-technical networks (e.g., the World Wide Web, the Internet, and Facebook). The ubiquity of these networks has led to the development of the interdisciplinary field of 'network science' covering topics such as 'graph theory' in mathematics and computer science; 'social network analysis' in sociology, anthropology, business; and the analysis of complex networks in statistical physics and biology. The concept of network is the same through all related fields: a network forms when at least two nodes (also called actors in social networks in which they are often humans or organizations) often of a similar type (e.g., humans, computers, organizations) connect, or can be considered virtually connected, to each other because of commonalities (natural, social, and technical relationships) and/or shared goals.

Network structure, the way all nodes in a network are connected, is the main characteristics of networks and has been studied vastly by researchers in different fields. Different forms of network structures and nodes' positions may suggest either

E-mail address: a.abbasi@unsw.edu.au

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benefits or restrictions for the nodes embedded in the network (Ahuja, Soda, & Zaheer, 2012; Burt, 1992). For instance, the structural positions of nodes in their collaboration networks have shown to have positive effect on their productivity and citation-based performance (Abbasi, Altmann, & Hossain, 2011; Abbasi, Wigand, & Hossain, 2014).

Understanding the structural positions of nodes in a network has been instrumental in driving a growing interest in the study of networks especially from an evolutionary perspective, to consider not only the status of a network at a specific point in time (static) but also during its evolution (dynamic) over time. Identifying how the networks change and evolve and determining the drivers of these changes are fundamental issues which are not well understood yet (Ahuja et al., 2012).

Several studies such as (Glückler, 2007; Powell, White, Koput, & Owen-Smith, 2005) identified the following processes or rules of attachment for nodes to explain the dynamics of networks during their evolution over time: *Cumulative advantage*, the tendency of nodes to form links with highly connected nodes; *Assortative mixing*, the tendency of node to form links to node with similar attributes such as connectivity rate; and *Cohesivness*, the tendency of node to form links with others with past histories of connection. Another important link formation process which is often not emphasized properly in the literature is the *structural position* of the nodes in their networks which is the main focus of this study. The structural position of a node in a network reflects how it is connected to others. It is regarded as an attribute of the node reflecting its role and influence on the overall network structure. The structural position of nodes in a network can be measured by how connected and/or close on average to others they are and to what extend they intermediate by linking disconnected nodes (Freeman, 1979; Scott, 1991).

This research aims to determine the factors that affect the attachment behavior of nodes in a network. This will help to identify nodes which make a network more resilient to the potential changes. To achieve this goal, it is pivotal to discover the attachment or link formation processes of the nodes in a network over time. This can be accomplished through studying the characteristics of the existing nodes that better attract new partners to investigate the potential effect of these characteristics on the dynamics of the network. Nodes with strategic structural position, such as intermediating position measured by high betweenness centrality, attract more partners for the future interactions, i.e., establishing new links (Abbasi, Hossain, & Leydesdorff, 2012). Recognizing such strategic positions is beneficial for organizations to identify and invest on such actors for information dissemination and viral marketing campaigns to help selling their products faster. Also, controlling (removing or vaccinating) the actors in a disease outbreak network can improve the community's resilience toward the disease. Therefore, determining the strategic positions of the nodes has implication for decision makers and managers to control and manage the evolution of networks.

The remainder of this paper reviews the literature on link formation processes during the evolution of networks in Section 2. The data sources and collection methods are described in Section 3. Section 4 provides the results of analysis discussing the findings, and highlighting the implications, future directions and limitations of this study.

2. Link formation processes in social networks

Nodes in a network expend economic or human capital in order to build their social capital (i.e., their connections to other nodes in the network) from which they hope to profit afterwards (Abbasi et al., 2014; Burt, 1992). However, in social networks often the selection of a partner depends on both the mutual interests and decisions of both actors and also the external environment (Glückler, 2007). For instance, managing interdependencies between firms (as actors) and gaining access to resources are important external factors affecting firms' alliance (link) formation. Or in a co-authorship network, a link may form as a result of the deliberate or forced choice of authors or the external issues such as the power relationship (e.g., student-supervisor or researcher-sponsor) that requires including supervisors or sponsors as authors of a paper regardless of their actual academic contribution. Understanding the link formation processes helps to uncover the structural changes and dynamics of networks. The following processes have been recognized in different studies as the primary factors for node to form links with other nodes:

2.1. Cohesiveness

Knowing and trusting a partner is an important motivation for establishing new relationships among people in their social life. Repeated connections among people often build trust among them (Burt, 1992). The more interactions two parties have, the better they will know each other and reinforce the trust among them. Trust is often one of the best reasons for interaction among actors in social networks including financial interactions. For instance, Gulati (1995), in analyzing the alliance formation among firms, found that the more frequent past alliances between two firms leads to more new alliances between them. This is an important enabler not only for establishing new links but also facilitates existing connections. Glückler (2007) explained this as an '*embedding*' process and showed that "future ties form around strong ties by processes of trust and indirect referrals". Later Rosenkopf and Padula (2008), examining almost similar process, claimed that '*cohesiveness*' (i.e., the history of connection between two actors) increases the likelihood of forming new ties with each other in the future.

Exploring the effect of existing connections among firms on their future alliances, it has been shown that actors' positions in the pre-existing network structure affect the formation of new ties (Gulati, 1995; Podolny, 1994; Walker, Kogut, & Shan, 1997). This process and the cumulative advantage process (see below) are based on a general mechanism through which a relatively favorable position becomes a resource to generate additional gains (DiPrete & Eirich, 2006). Thus, it is hypothesized that: