Assortativity Patterns in Multi-dimensional Inter-organizational Networks: A Case Study of the Humanitarian Relief Sector

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Abstract. We use computational tools to study assortativity patterns in multi-dimensional inter-organizational networks on the basis of different node attributes. In the case study of an inter-organizational network in the humanitarian relief sector, we consider not only macro-level topological patterns, but also assortativity on the basis of micro-level organizational attributes. Unlike assortative social networks, this inter-organizational network exhibits disassortative or random patterns on three node attributes. We believe organizations' seek of complementarity is one of the main reasons for the special patterns. Our analysis also provides insights on how to promote collaborations among the humanitarian relief organizations.

Keywords: Assortativity, multi-dimensional inter-organizational network, network analysis, humanitarian relief.

1 Introduction

Networks can represent relationships among entities by connecting related nodes with edges. Many real-world systems can be modeled as networks, such as social networks and the World Wide Web. However, a one-dimensional network can capture only one type of relationship. Take the network among people as an example. A colleague network depicts who work together, while a kinship network is based on family ties. However, people may have multiple types of relationships between them. Thus a person's social network is inherently multi-dimensional and combines multiple one-dimensional networks, such as friendship, kinship, and co-workership. Similarly, an inter-organizational network, in which nodes represent organizations and edges denote relationships, may also have multiple dimensions on the basis of partnership, patronship, sponsorship, and so on.

Assortativity describes the tendency of nodes in a network being connected with similar nodes. For example, sociologists found assortative patterns in social networks. One tends to bond with those who are similar to oneself in demographic characteristics, such as age, gender, race, and education [1]. In other words, assortative patterns emerge from the homophily-based network growth.

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When talking about assortativity for a multi-dimensional network, one needs to be aware of (1) which node attribute and (2) what type of relationship the assortativity is based on. Assortativity depends on node attribute, because assortativity is based on inter-node similarity, which can be measured by various node attributes. Consequently, a network may exhibit different assortative patterns when it is evaluated using different attributes. For example, when we focus on race, a dating network among students in a university may be assortative, which means people tend to date with those who are in the same ethnic group. However, such a dating network may exhibit disassortative patterns when we measure it with students' gender. In addition, even when we measure assortativity with the same node attribute, a multi-dimensional network may have different assortative patterns on different dimensions. For instance, if we only look at the gender of students in a college student social network, then the friendship network may be assortative while the dating network may be disassortative.

The study of assortative patterns in networks can improve our understanding of the network structure and the behaviors of network members. Research in this area can also provide insights on how to improve or attack a network. Network researchers often study assortativity using topological attributes of nodes [2]. Sociologists who study homophily are more interested in individuals' demographic characteristics [1]. Few have considered both the topological and individual attributes of nodes. Also, while some studied homophily of collaborations among companies [3], we find little research on assortativity of multi-dimensional inter-organizational networks. In this research, we study such a multi-dimensional inter-organizational network in the humanitarian relief sector and explore its assortativity using node attributes on both macro and micro levels.

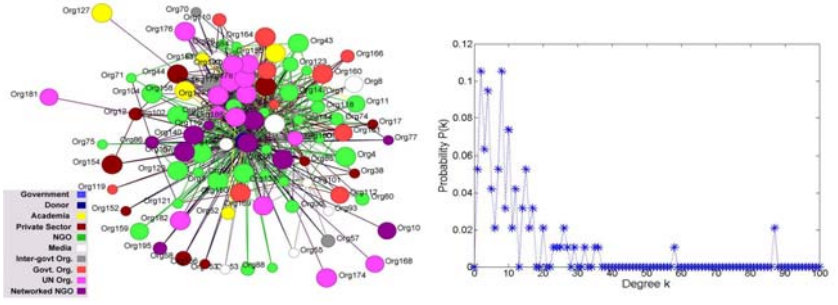
The remainder of the paper proceeds as follows. In Section 2, we introduce our case study–an inter-organizational network in the humanitarian relief sector. Section 3 describes how we analyze assortative patterns on the basis of several node attributes, and illustrates the results. After discussions on the implications of the research, the paper concludes with directions for future work.

2 An Inter-organizational Network in the Humanitarian Relief Sector

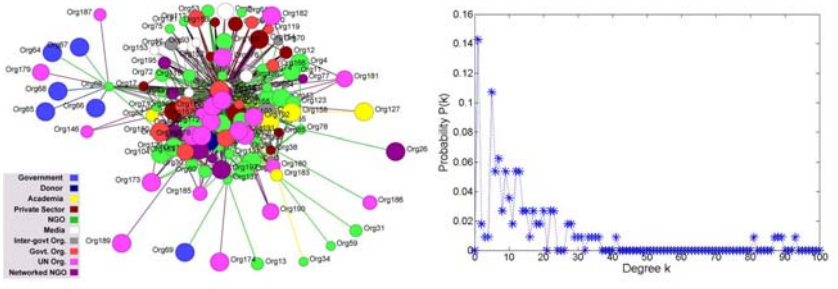
Relief efforts after major natural disasters have highlighted the importance of great levels of inter-organizational coordination. One approach taken by humanitarian organizations has been to organize "coordination bodies" to improve relief efforts through greater coordination among its member organizations [4]. Coordination bodies provide a venue where humanitarian organizations interact with each other and establish further relationships. In this research, we focus on the GlobalSympoNet[1], a major inter-organizational coordination body. Only invited organizations can become members of GlobalSympoNet and attend its meetings.

Through surveys and interviews, we identified a network that consists of about 119 member organizations of GlobalSympoNet. We found 3 dimensions for

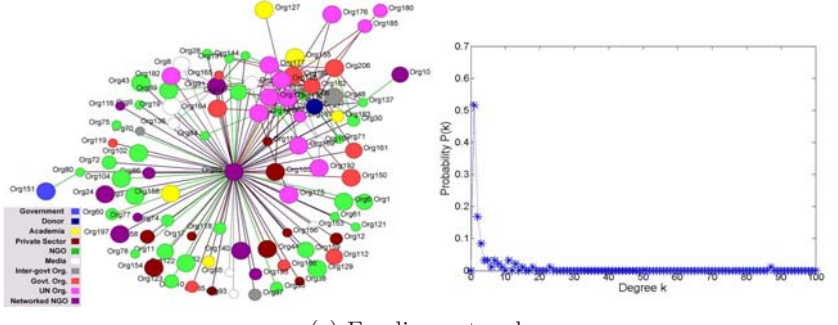
[1] Pseudonyms are used to protect the confidentiality of these organizations.



(a) Advising network



(b) Collaboration network



(c) Funding network

Fig. 1. Multiple dimensions of the inter-organizational network inside GlobalSympoNet

inter-organizational relationships, namely advising, collaboration and funding. An edge in the advising network means the two organizations have exchanged advice concerning policy, technology, data, etc. In the dimension of collaboration, two organizations are connected by an edge if they used to collaborate on humanitarian projects, such as joint training of staff members, coordinated data collection, and shared database. Edges in the funding network denote relations between funding providers and receivers. Figure 1 shows the three one-dimensional networks and their degree distributions.

3 Results

3.1 Calculating Assortativity Coefficients

As we mentioned earlier, the assortativity of a network depends on which node attribute is measured. Nodes in a network basically have two types of attributes: discrete and scalar attributes. A discrete attribute usually describes which category a node belongs to. A person's blood type is such a discrete attribute. By contrast, a scalar attribute is associated with a number and denotes the level, at which a node has certain property. One's age is such a scalar attribute and denotes how old one is. Also, the degree of nodes in a network is a topological scalar attribute. Newman studied degree-based topological assortative patterns [2] and found that human networks are often assortative, such as scholar co-authorship networks. However, technological and biological networks usually feature some disassortativity, such as the Internet and neural networks.

The assortativity for a network is measured by assortativity coefficients [2]. In an undirected network, the coefficient r for a discrete attribute (Equation (1)) is based on the mixing matrix. An element e_{ij} of the matrix denotes the percentage of edges between nodes with attribute value i and value j; $Tr(e) = \sum_j e_{ii}$ is the trace of the matrix; $a_i = \sum_j e_{ij}$ is the fraction of edges between nodes with attribute value i. $r = 1$ means a perfect assortative network and $r = 0$ means a network has no assortative patterns. For a disassortative network, $-1 \leq r \leq 0$.

$$r = [Tr(e) - \sum_i {a_i}^2)]/[1 - \sum_i {a_i}^2)] \tag{1}$$

The assortativity coefficient for a scalar attribute is quite similar. It is essentially the Pearson correlation coefficient of the attribute's value for all pair of nodes connected by edges. In Equation (2), $a_i = \sum_j e_{ij}$; $b_j = \sum_i e_{ij}$; σ_a and σ_b the standard deviations of a_i and b_j respectively. $r = 1$ indicates perfect assortativity and $r = -1$ stands for perfect disassortativity. The expected statistical error σ_r on the value of r can be obtained with the jackknife method [5].

$$r = [\sum_{ij} ij(e_{ij} - a_i b_j)]/\sigma_a \sigma_b \tag{2}$$

Next we will calculate assortativity coefficients for the three-dimensional network in the GlobalSympoNet. Our computational tool for the analysis was based on the Java-based JUNG framework [6], which provides a library of network analysis tools. At macro-level, we use the topological scalar attribute-the node degree. At micro-level, we use two discrete organizational attributes-the size and type of an organization. It is worth noting that organizational sizes can actually be a scalar attributes. However, most of our survey or interview respondents do not know the exact number of employees in their organizations. Thus we had to classify organization sizes into categories. Our respondents were asked to choose from micro (<20 full-time employees), small (21-50), medium (51-100), large (101-500), and very large (>500). As for organization type, United Nations (UN)

provide a classification scheme. Organizations in the GlobalSympoNet are classified into seven types: Academia, Donor, Government, Governmental organization, Inter-Governmental organization, Media, Non-governmental Organization (NGO), Networked NGO, UN organizations, and Private sector.

3.2 Preliminary Results and Analysis

Table 1 summarizes the assortativity coefficients and errors given by our computational analysis. Degree-based assortativity coefficients suggest that the inter-organizational network in the humanitarian sector exhibit disassortative patterns. This is different from the degree-based assortative patterns in a lot of social networks[2]. We believe the degree distributions of the networks may have contributed to the disassortativity. In the degree distributions of the three networks (Figures 1), there are often a large number of nodes with low degrees and a small number of nodes with high degrees. However, few nodes have medium degrees. This type of polarized distribution has led to the core-peripheral structures of the network. This structures suggest that several organizations are very active in this network, connect with many other organizations, and thus serve as the core or hub of the network. Meanwhile, most organizations have low degrees, mainly connect to high-degree nodes, and are relatively peripheral to the network. Among the three dimensions, the polarization in node degrees is especially obvious the funding network, which also has the highest degree-based disassortativity. In the funding network, 80% of the nodes have degrees lower than 5. The highest-degree node has 87 edges, while the second-highest-degree node has merely 25 edges.

The core-peripheral structure could potentially be explained by the nature of the community, in which several general-purpose humanitarian relief organizations, such as Red Cross, interact with many highly specialized organizations. Those specialized organizations include (1) humanitarian relief organizations that focus on a specific humanitarian relief domain, such as providing shelters or protecting children; (2) humanitarian relief organizations that work in a specific geographical area, such as Sub-Saharan Africa or Mideast; or (3) organizations that provide specialized IT services. For example, a humanitarian relief organization may seek advice or help from a partner with expertise in landmine-detection geographic information systems. Further, these specialized organizations are less likely to work with one another in the humanitarian relief sector. For instance, the chance is relatively low for an organization working mainly in East Europe to collaborate with another one that focuses on Latin America. Similarly, a

Table 1. Assortativity coefficients. Correpsonding errors are listed in paretheses.

	Degree-based coefficients	Size-based coefficients	Type-based coefficients
Advising Network	-0.3896 (0.0006)	-0.0196 (0.0005)	0.0009 (0.0003)
Collaboration network	-0.4293 (0.0005)	-0.0960 (0.0004)	-0.0105 (0.0004)
Funding network	-0.4459 (0.0003)	-0.1898 (0.0012)	-0.1176 (0.0006)

software provider may not need to interact with a telecommunication provider for the purpose of humanitarian relief.

The size-based assortativity coefficients also suggest disassortative patterns, which are similar to, but not as strong as, the degree-based disassortative patterns. This pattern means organizations tend to connect with other organizations with different sizes. We explain this pattern by taking the collaboration network as an example. We find that the average degrees of organizations in each size categories in the collaboration network are significantly different at .05 level. Micro, large, and very large organizations have much higher average degrees than small and medium organizations do. It means that these organizations tend to be active in inter-organizational collaborations and their connections have more influence on the assortativity patterns. Then why do they collaborate with organizations with different sizes? On one hand, some smaller organizations have limited resources, because they have relatively small number of full-time staff members. Instead, they rely heavily on contract workers and volunteers. Therefore, they need to reach out and work with those who have complementary resources. On the other hand, larger organizations often have more resources and experience. In addition, several large organizations have highly specialized departments, which may have initially be developed to serve internal needs, but then subsequently begin to offer these services to organizations, often smaller ones, that do not possess such capabilities.

Type-based assortativity of the network is slightly different from degree-based and size-based assortativity. Advising and collaboration networks have near-zero assortative coefficients and are close to random mixings, while the funding network is slightly disassortative. The disassortativity in the funding network is intuitive as the flow of funding often exists between two organizations of different types, such as donors and NGOs.

The lack of type-based disassortative patterns in the advising and collaboration networks is somewhat surprising. One might argue that the collaborative groups generally consist of organizations with different skills or expertise and hence would include heterogeneous types of organizations, combining donors, UN organizations, NGOs, together with for-profit firms in the private sector. However, it may be that more than half of all organizations in this symposium are NGOs or UN organizations. By contrast, there are not as many donors or media in the GlobalSympNet. In addition, the similar goals of NGOs enable them to work with each other more than with organizations of other types. Similarly, organizations from UN often have strong ties with each other and tend to interact with UN organizations. Such a tendency may also have diminished the disassortative patterns. Another possible reason is that types assigned to an organization by UN do not truly reflect the function-based contributions the organization is making either in terms of collaborative projects or advice. For example, a for-profit firm in the private sector may have a humanitarian response team that has little to do with its for-profit status overall. In this case, the role of this firm in the GlobalSympNet is not reflected by its assigned type as a private sector organization.

4 Discussions

Overall, the inter-organizational network we studied exhibits disassortative or random patterns on selected node attributes. That means organizations tend to interact with those that are not similar to themselves on those attributes. This is quite different from social networks, which are often assortative, especially on node degrees. We believe this pattern shows that, in the humanitarian relief sector, inter-organizational relationships are often based on complementarities. Similar to firms looking for complementarity from alliance partners [7], humanitarian relief organizations interact with others, because they are seeking complementary resources or expertise that their own organizations do not possess. Among the three dimensions we studied, the funding network is most disassortative, because funding relationships need the highest level of complementarities. If an organization already possesses enough resources for a specific humanitarian project, the chance that it shares the funding with other similar organizations is relatively low. Among the three node attributes, degree leads to the most disassortative pattern, which implies that nodes with different numbers of edges tend to possess different resources. As we mentioned in Section 3.2, nodes with low degrees are often specialized organizations. Their knowledge and expertise on a specific mission, a specific geographic region, or specific technologies are usually what some high-degree general-purpose organizations need.

Admittedly, the disassortative or random patterns we revealed do not necessarily mean that the inter-organizational network has no assortative patterns at all. We mentioned earlier that assortativity depends on which node attribute is chosen. Our choice of node attributes-degree, size, and type-is mainly based on our interests and data availability. Had we chosen some other attributes, we may have found different patterns. For instance, if we look at the focus region of those organizations, we may find an intuitive assortative pattern: organizations tend to interact with those who focus on similar geographical areas.

In addition, some of the assortativity patterns can be validated by our surveys and interviews. For example, according to our assortativity analysis, the advising network and the collaboration network have similar assortativity patterns. This similarity confirms with our interview outcome–advising relationships often serve as the basis and prerequisites for future collaborations. Another example is the near random type-based assortative patterns, which indicates that the GlobalSympNet is not very diverse in terms of member organization types and needs more donors and media members. This mirrors the result from our survey, in which 40% of the respondents consider "introduce new donors" very important for promoting collaborations.

5 Conclusions and Future Work

In this research, we use computational tools to explore assortativity patterns in multi-dimensional inter-organizational networks. Building assortativity on both topological and organizational attributes, we analyzed the three-dimensional

inter-organizational network inside a major humanitarian relief coordination body. The results suggest that organizations tend to connect with those who are not similar to themselves in terms of degree, size and type. We believe organizations' seeking of complementarity from partners leads to the disassortative and random patterns. This research does not only reveal assortativity patterns, but also improves our understanding of the humanitarian relief sector, such as the relationship between the advising and the collaboration networks. As a result, we are able to provide recommendations on how to improve inter-organizational collaboration, which will eventually benefit disaster victims.

There are several areas that we would like to address in the future. We plan to conduct more statistical analyses to find more evidence for the assortativity patterns revealed by the computational analysis. Collecting more data about organizations and exploring assortativity using other organizational attributes are helpful as well. After all, the assortativity patterns of a network depend on what node attributes are chosen.

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