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From Communication to Collaboration: Simulating the Emergence of Inter-organizational Collaboration Network

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***Abstract*—Inter-organizational networks often have multiple dimensions, each one denoting a type of relationship. In this research, we studied how one dimension of the network, a collaboration network, emerges from organizations' interaction on another dimension–the communication network. We modeled the emergence of collaboration as an event-based multi-agent team formation process that incorporates the structure of the underlying communication network, the diffusion of project information, and network-based influence. As a case study, we used an agent-based simulation to study the collaboration among humanitarian organizations. We also analyzed how changes to the communication network among humanitarian organizations affect their collaboration network. The experiment results suggest that different strategies to promote communication may have positive or negative impacts on the future collaboration network.**

***Keywords*-multi-dimensional network, agent-based simulation, network influence, inter-organizational collaboration**

I. Introduction

A person's social network involves multiple types of relationships, such as friendship, kinship, and co-workership. Similarly, an inter-organizational network, in which nodes represent organizations and edges denote inter-organizational relationships, often combines more than one type of relationship. The existence of multiple types of relationships in such a network requires us to represent the network as a multi-dimensional one (also referred to as multiplex network). Each dimension is a one-dimensional network that represents one type of relationship. For example, if two organizations exchange information with each other, they are connected in the dimension of communication; if they work together, an edge connects them in the collaboration network. Meanwhile, a dimension of the network is often inter-related in some way with each other. For instance, if two organization compete with each other, they are neighbors in the dimension for rivalry relationship, which may hinder them from forming ties in the communication network. In this research, we focus on understanding the relationship between two dimensions of inter-organizational networks: the communication network and the collaboration network.

Literatures in organization science have stressed the benefits and the importance of inter-organizational collaboration. Collaboration among organizations is an important strategy used by public, private, and nonprofit institutions to achieve both short-term and longterm organizational goals. Many researchers advocate that inter-organizational collaboration can help organizations to share risk, and to utilize pooled complementary resources to achieve individual and common goals effectively and efficiently [1].

In the real world, collaboration among independent organizations is often about forming a team to work on a joint project or task. Organizations interact with peers, identify joint projects that are of interest, and make decisions on whether to join a team and work on the joint project. Thus communication often antecedes collaboration and serve as the basis for future collaboration relationship, because the establishment of collaboration often needs the exchange of information about organizations and the potential joint project. Moreover, through communication, organizations are often able to exert influence on others' decisions on whether to collaborate [2]. In other words, the collaboration network often emerges from individual organizations' interaction and subsequent decisions on another dimension of the inter-organizational network–the communication network.

From a social network simulation perspective, the emergent phenomena across the multi-dimensional inter-organizational network involves an organization's decision to create new links in the collaboration network. Such a decision is often influenced by the project prioritization of neighboring organizations in the communication network. Hence, it is related to existing network modeling literature in two areas: (1) modeling the network growth (i.e., the creation of links), and (2) modeling the diffusion and influence in networks. We will discuss how our approach relates to existing research in the two areas in the next section. From a network modeling perspective, our approach models the information and influence, which are transmitted in one dimension (communication) but affects a node's decision on link creation in another dimension (collaboration) of the network.

We believe a better understanding of how an inter-

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organizational collaboration network emerges may reveal ways to facilitate and improve collaboration. In this paper, we will use the humanitarian relief sector as a case study and apply an agent-based simulation to explore the emergence of the inter-organizational collaboration network from organizations' interaction on their communication network. With a validated simulation of this emergent phenomenon, we are able to study how changes to the communication network among humanitarian organizations affect their collaboration. A better understanding on this phenomenon will eventually benefit disaster victims.

The remainder of the paper is organized as follows. We first briefly review related research and describe an event-based multi-agent team formation model. Section III discusses the humanitarian relief sector, as well as the implementation and validation of our agent-based simulation. This section also leads up to an experiment that studies how to facilitate collaboration among humanitarian organizations. The paper will conclude with discussions of future research directions.

II. Previous Work

In a sense, the study of how edges form in a network is a link predication problem [3]. Previous research in this area often focuses on networks with only one dimension, e.g., predicting the future collaboration network from the structure of the current collaboration network, but does not address how one dimension of a network affects the link creation on another.

Also, many statistical link-prediction models are based on the assumption that each edge or node pair is an independent sample. By contrast, the collaboration relationship among multiple nodes is often based on events and thus edges are usually dependent. For example, if four organizations collaborate on a project, this event brings the four organizations together and they are connected to each other by six edges in the collaboration network. All the six edges originate from the same event and are dependent on each other. If one organization does not want to collaborate, the project may not even start due to the lack of some essential resources. In this case, all the edges caused by the event will be gone. Therefore, instead of the statistical approach, we decide to use computational simulations.

Computational simulations, especially agent-based simulations, have been widely used to study a variety of social and organizational phenomenon. Agent-based simulations are capable of simulating macro-level structures or patterns resulting from micro-level interactions and decisions of heterogeneous agents [4]. An agent-based simulation is especially helpful for decision-makers and policy-makers in organizations, because it is often very difficult to manipulate a real-world organization to evaluate the impact of a policy or a decision.

In our previous research [5], we modeled the emergence of inter-organizational collaboration networks as an event-based multi-agent team formation process with network influence. In the model, agents represent heterogeneous and self-interested organizations. Each agent varies in several attributes, for example size, goal, operation area, and history. Agents are embedded in a communication network. An event refers to the formation of a multi-agent team for a collaborative project. The emergence of collaboration among agents is an iterative process with 3 steps in each iteration.

The first step is to propose candidate projects and diffuse project information. Each agent keeps an ordered to-do list with various sizes. The list contains candidate projects, on which they would like to collaborate with others. Projects with higher priorities are ranked higher. To find collaborators, an agent first needs to inform others of the project by proposing highly-ranked projects in its to-do list to its acquaintance through the communication network.

The second step is the evaluation of candidate projects. Upon receiving a candidate collaborative project proposed by its neighbors, an agent will evaluate the project using various criteria of its own. Moreover, other agents also exert various levels of influence on the agent through the communication network. The outcome of the evaluation process is a priority score that an agent assigns to a candidate project. A network influence model, which extends the social influence model in [6], handles how to calculate priority scores [5].

The last step in each iteration is to support a candidate project. With priority scores for candidate projects from the last step, an agent may add new projects with higher priority scores to its to-do list, re-evaluate and re-rank existing projects, or remove projects with lower priority scores from the list. If a candidate project is on an agent's to-do list, we say this agent supports the project. As a supporter of a candidate project, an agent may advocate this project and diffuse information about this project to its neighbors in the next iteration, even though this supporter did not initiate the project.

After a few rounds of such inter-agent interactions through the communication network, a candidate project may be able to get enough supporters and contributions for implementation. Supporters of such an emerged project are said to form a team and will work on the project together. The team-formation event through the communication network also leads to the establishment of collaboration among agents in the same team and edges are added to connect all the team members in the collaboration network. For example, if three agents form a team, they will be linked to each other and the resulting collaboration network will feature a triangle structure.

As you may notice, the process depends on the diffusion of project information. However, this model is different from traditional network diffusion models such as [7] and

[8], which often use a simple threshold or a probability to determine whether a node will accept and diffuse incoming information. In our model, as information about projects diffuses through the network, an agent's decision on whether to work on a project and further spread the project's information depends on (1) the agent's independent evaluation of the project; (2) influence from the agent's neighbors' evaluation of the project; and (3) the project's relative importance or priority compared with other projects.

III. The Case Study of Humanitarian Collaboration

In this section, we apply the event-based multi-agent team formation model to simulate the emergence of collaboration networks among organizations in the humanitarian relief sector. We implement and validate a simulation with data from the real world. We also conduct an experiment to evaluate the effectiveness of different strategies that aim at facilitating collaborations. Before we get into the technical details, we first introduce the target of our case study–the humanitarian relief sector.

A. The Community of Humanitarian Organizations

In the past a few years, the world has suffered from several major natural disasters, such as the Haiti earthquake, the south Asian tsunami, and the hurricane Katrina. Humanitarian relief efforts after these tragedies have highlighted the need for greater levels of collaboration among humanitarian organizations. In this research, we focus on GlobalSympoNet[1], a major coordination body with 119 member organizations.

The humanitarian relief sector has a group of diverse organizations. One approach taken by humanitarian organizations has been to organize 'coordination bodies,' whose goals are to improve disaster relief efforts through greater coordination among its member organizations. These coordination bodies may be temporary, special initiatives, or permanent incorporated non-profit organizations that facilitate coordination as their exclusive mission. In addition, previous research has found that many coordination bodies use collaborative projects as a major means of facilitating coordination between their member organizations [9].

Moreover, within coordination bodies, forming teams for collaborative projects occur in a network that does not have formal hierarchies. Participation in collaboration teams is undertaken on a purely voluntary basis. No one has the authority to impose their activities or agenda on other organizations. Mutually beneficial collaborative projects and corresponding teams 'emerge' from the collective behaviors of individual organizations.

However, our empirical study of humanitarian organizations' behaviors revealed an organization's evaluation of a project is often influenced by exogenous factors [10]. For example, an organization tends to support a project if this organization communicates with a supporter of the project. Also, a project supported by a leader organization in the community is often able to get more supporters. Therefore, our multi-agent team formation model with network-based influence is a good fit to study humanitarian organizations' collaboration behavior in coordination bodies.

[1]In this paper, pseudonyms of organizations are used to protect the confidentiality of these organizations.

B. Implementation and Validation of the Simulation

The agent-based simulation is based on our multi-agent team formation model. In order to implement a trustworthy simulation, we go through two steps: (1) configure an initial simulation using empirical data of humanitarian organizations' demographics and decision making heuristics; (2) validate the simulation with inter-organizational collaboration network in the real world and calibrate the parameters in the simulation.

For the first step, we conducted several surveys and interviews among member organizations of GlobalSympNet. We collected these organizations' demographic data, including missions, focus regions, numbers of full-time employees, who they communicate and collaborate with, etc. Table I lists the 9 major missions and 7 focus regions of member organizations in GlobalSympNet. Note that an organization may have multiple missions and multiple focus regions. We also gathered data about many collaborative projects that humanitarian organizations worked on. With the data, we build a multivariate distribution for projects' information, including where the project was implemented, the goal of the project, who initiated the project, and how many organizations got involved, etc. In addition, the surveys and interviews also helped us to understand how humanitarian organizations evaluate candidate collaborative projects and how their decisions are influenced by others. In addition, although we expected collaborative projects that were implemented immediately after disasters, most of the projects we found were pre-disaster projects whose goals are to improve humanitarian organizations' capabilities in disaster response and relief. Therefore, time pressure, which is very important in forming team for poster-disaster projects, does not seem to be a key issue when organizations evaluate pre-disaster projects.

In order to configure and validate the simulation, we simulate the collaboration network among 30 member organizations of the GlobalSympNet. The simulation takes as inputs the 30 organizations' demographic data, candidate collaborative projects that are simulated on the basis of the multivariate distribution of project information, and the inter-organizational communication network that we identified in May 2008. Note that, by communication network, we mean the inter-organizational advice exchange network, through which organizations seek and provide informal advice on humanitarian projects. Research has shown that such advice

Table I: List of missions and focus regions for organizations in GlobalSympNet

Mission	Focus Region
1. Provide food	1. Sub-Saharan Africa
2. Provide shelter	2. Middle East & North Africa
3. Provide water	3. Europe & Central Asia
4. Provide sanitation	4. South Asia
5. Provide medical care	5. South East Asia
6. Provide funding	6. North America
7. Provide information services	7. Latin America & Caribbean
8. Provide training and advice	
9. Provide IT infrastructure and/or applications	

exchange behavior often plays a major role in the diffusion of information [11]. More importantly, the advice exchanged among humanitarian organizations through the network is mostly about humanitarian projects, thus we can consider this network as a more focused communication network with stronger ties. We run the simulation for a pre-determined period of time. After the simulation stops, a collaboration network among the 30 organizations will emerge from the simulated inter-agent interaction through the communication network.

Then we compare the simulated collaboration network with the actual collaboration network, which we gathered in a follow-up survey in October 2009. To compare the two networks, we evaluate how close the simulated one is to the actual one using several metrics, including the number of total edges, the clustering coefficients, the average path length, and the accuracy of edge prediction. On the basis of evaluation outcomes, we adjust and calibrate the configuration of the simulation and re-run the simulation till we find a satisfactory results.

Table II shows the basic statistics of simulated collaboration networks, along with those of the actual one. Statistics of simulated networks are the average of results from 30 different runs. Simulations with this configuration also gets an average accuracy rate of 66.6%, with an average sensitivity of 60.4% and an average specificity of 71.3%. This means that the simulated network can predict whether two specific nodes are connected or not with a chance of 66.6%.

Overall, our simulation is able to generate collaboration networks that have very similar number of edges, average path length, and clustering coefficient with the actual collaboration network, although it does not get very high prediction accuracy. Most of all, the configuration's validity in simulating the number of edges in the collaboration network paves the way for our experiment in the following subsection, because in the experiment we use the number of edges in the collaboration network to evaluate the effectiveness of different strategies.

Table II: Statistics of the simulated and actual collaboration network

	Simulated Network	Actual Network
Number of Edges	183.6 (178.9-188.3)	186
Clustering Coefficient	0.69 (0.68-0.71)	0.73
Average Path Length	1.64 (1.63-1.65)	1.63
Note: 95% CIs are reported in parentheses.		

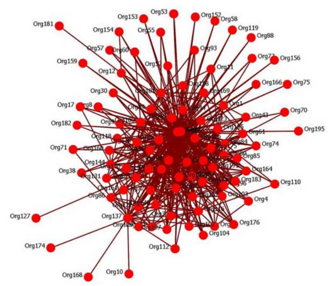

Figure 1: The communication network among the 95 humanitarian organizations.

C. How to Facilitate Inter-organizational Collaboration in Humanitarian Relief

The GlobalSympNet is very interested in finding effective strategies to facilitate collaborations among its member organizations. Although the GlobalSympNet cannot directly ask its members to collaborate, it would like to increase the chance of collaboration by promoting communication among its members by introducing one to anther.

Our analysis of the inter-organizational communication network (Figure 1) inside the GlobalSympNet reveals that organizations in the community are polarized in their network positions. The network has 95 nodes and 576 edges. As the degree distribution of the communication network in Figure 2 shows, there are some highly-active core organizations with high degrees. In other words, some organizations communicate with a lot of other organizations and are in the core of the community. Meanwhile, many organizations only talk to few other organizations and are at the periphery of the community [12]. Then the question for the GlobalSympNet is, among many organizations that have not communicated with each other before, which ones should the GlobalSympNet picks so that its staff members can try to introduce them to each other and encourage them to communicate. This provides a good scenario to use our simulation, because trying different strategies on its member organizations in the real world is often difficult, risky, or expensive.

In this experiment, we compare the effectiveness of two strategies to facilitate collaboration: Strategy 1 encourages core members to communicate more with other core members; Strategy 2 encourages core members to communicate with peripheral members. To simulate the first strategy, we add 57 new edges (about 10% of the total number of existing edges) to the inter-organizational communication network as

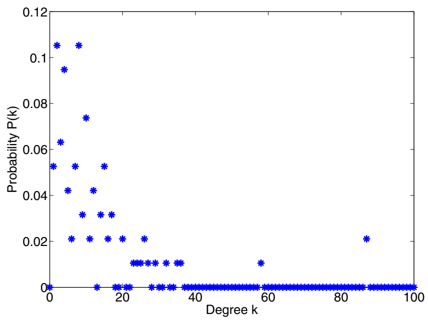

Figure 2: Degree distribution of the collaboration network among the 95 humanitarian organizations.

of October 2009 (Figure 1). Each new edge lies between two high-degree nodes, whose degrees are within the top 25% of all nodes. For the second strategy, we also add 57 edges to the existing communicaiton network but each edge has to connect a high-degree node, whose degrees are within the top 25%, and a low-degree node, whose degrees are within the bottom 25%.

We then run simulations for three scenarios: one for Strategy 1, one for Strategy 2, and the third one is a baseline scenario. In all the three scenarios, we use the simulation configuration that is validated in the previous subsection for agent-based simulations. The three scenarios also use the same organizational demographic data and simulated candidate collaborative projects. However, they differ in the inter-agent communication network: the scenario for Strategy 1 will use the 95-node communication network with added edges between high-degree nodes as the input; the scenario for Strategy 2 takes the communication network with added edges between high and low degree nodes; the baseline scenario uses the original communication network with no new edges.

After running simulations for each scenario, we compare the collaboration networks generated in each scenario. The scenario that generates a collaboration network with more edges is considered a more effective strategy to facilitate inter-organizational collaboration, because a collaboration network with more edges often means a more collaborative environment. Figure 3 shows the number of edges in simulated collaboration networks after implementing different facilitation strategies on the communication network. Each data point is the average of 30 runs.

The comparison first suggests an intuitive result that we expected: Strategy 2, adding edges between core and peripheral members in the communication network, can increase the density of the resulting collaboration network. In other words, if the GlobalSympNet can help peripheral members to communicate more with core members and get them more involved in this community, collaborations among humanitarian organizations will be facilitated.

Surprisingly, Strategy 1, adding edges between core members in the communication network, performs a little worse than adding no edges to the communication network. In other words, adding edges to the communication network does not always may have negative impact on the collaboration network. In the context of the GlobalSympNet, focusing only on promoting communication among its core members may not help to facilitate collaboration.

Why does Strategy 1 work while Strategy 2 does not? We believe the diffusion of candidate project information on the communication network leads to the difference in collaboration networks. In the simulation scenario for Strategy 1, the average number of candidate projects that an agent evaluates is about 5% higher than in the baseline scenario, in which no edge is added to the communication network. However, this average number in the scenario for Strategy 2 is about 9% lower than the baseline scenario. In other words, Strategy 1 promotes the spread of information about candidate projects, while Strategy 2 hinders such diffusion, even though more edges are added to the communication network.

The results can also be explained from an organizational science perspective. We find that core organizations are often larger organizations that are well funded and have less need from others, while peripheral organizations are often smaller ones with limited information, resources or expertise. Thus peripheral organizations have greater need for external resources and information and are generally more motivated to collaborate. If we add more edges between core and peripheral organizations, information about candidate projects can diffuse more easily between information- and resource-rich organizations and organizations who desperately need more information and resources.

On the other hand, if core organizations are more densely connected to each other, project information is often exchanged among this highly-connected sub-network more than between core and peripheral organizations. Organizations at the periphery of the communication network have to rely on its one or two points of contact among core organizations to get information of other candidate projects. Consequently, if an organization, especially one at the periphery, has a candidate project which fails to get support from core organizations, the project will have little chance to be evaluated by other organizations, who may be very interested in collaborating on the project.

IV. Conclusion

In this research, we study how organizations' interaction on one dimension of the inter-organizational network–the communication network–affects another dimension–the collaboration network. On the basis of an event-based team formation model, we develop an agent-based simulation to simulate how an inter-organizational collaboration network emerge from organizations' interactions through the communication network and their decisions on whether to join

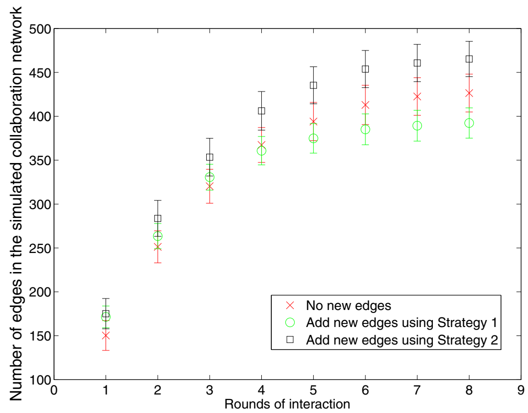

Figure 3: Comparison of different strategies to promote collaboration.

a team to work on a collaborative project.

We apply this simulation to organizations in the humanitarian relief sector. We first configure the simulation with empirical data, such as the inter-organizational network, organizations' demographic information, and how organizations make decisions and handle external influence. Then we calibrate and validate the simulation with small-scale real-world network data on humanitarian collaboration.

With the validated simulation, we run an experiment to evaluate different strategies that aim at facilitating collaboration among humanitarian organizations. The experiment results suggest that different strategies to promote inter-organizational communication may have different impacts on the collaboration network. While more communication between well-connected organizations and those who are at the periphery of the community can facilitate the collaboration, encouraging communication only between well-connected organizations may hinder collaboration. We believe our experiment can provides insights to humanitarian coordination bodies and help them to enact effective policies and strategies to facilitate collaboration among humanitarian organizations.

For future research, we would like to calibrate the simulation configuration to improve the accuracy of edge prediction, so that we can use this simulation for more experiments on other humanitarian collaboration issues. In this research, we study how the communication network affects the collaboration network and the interaction between the two dimension is one-way only. We also hope to explore how the collaboration network in turn affects the influence and information diffusion among nodes in the communication network. Another possible research direction is to incorporate other dimensions of a inter-organizational network, such as the business transaction network and the funding network, into the team formation model.

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