A Formal Model for Emerging Coalitions under Network Influence in Humanitarian Relief Coordination

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Abstract

Identifying collaborative projects and forming coalitions for those collaborative projects are important means of coordination for humanitarian relief non-governmental organizations (NGOs). Our previous work revealed that an NGO's evaluation of candidate collaborative projects and subsequent decisions on forming coalitions are influenced by evaluations done by their peers in the NGO network. Based on a social influence model, we propose a formal model to simulate this type of influence for NGO coordination in a network setting. This model incorporates network topology, organization size of NGOs and strength of ties as network influence factors. It will be used to inform the future development of an agent-based simulation for NGOs' coordination in humanitarian relief.

1. INTRODUCTION

The world has suffered from several major natural disasters, including the south Asian tsunami, hurricane Katrina and the Pakistani earthquake, in the past a few years. Humanitarian relief efforts after these tragedies have highlighted the need for improved decision making and greater levels of inter-organizational coordination among NGOs, particularly in the area of information and communication technologies (ICTs). One approach taken by NGOs has been to organize 'coordination bodies,' whose goals are to improve the efficiency of ICT use in disaster relief through greater coordination. These ICT coordination bodies may be temporary, special initiatives, or permanent incorporated non-profit organizations that facilitate ICT coordination as their exclusive mission.

The goal of our research is to understand how changes to the organizational designs of coordination bodies might affect their effectiveness, so that recommendations can be provided for efficient ICT coordination in humanitarian relief, which will eventually bring benefits to disaster victims.

One means of assessing the effects of organizational design changes is through the use of an agent-based computational model, because it is capable of simulating organizational structures or patterns resulting from low-level interactions and decision-making of heterogeneous agents within complex systems [2]. In this research, the development of the agent-based model and subsequent validation will be informed through qualitative case study into the designs, decision making processes, and effectiveness of several coordination bodies.

While the eventual goal is to model all the coordination activities, our research starts with the process of collaborative project identification and coalition formation. This process is one of the core processes in affecting the eventual coordination outcome. It has been found that, despite the similarities and differences in the characteristics of coordination bodies, they all use collaborative projects as a major means of facilitating coordination between their member NGOs [13][18]. The ICT Skills Building Program of the ReliefTechNet[1] is an example of such projects. The goal of this project was to provide training on latest ICTs to NGO staff. It aimed at helping NGOs serving developing countries to improve their response to emergency and enhance their organizational effectiveness with the help of ICTs. This project was initially proposed by one NGO in the coordination body ReliefTechNet, but was then developed with inputs and contributions from more than ten different member NGOs of the ReliefTechNet.

It is also worth mentioning that, within coordination bodies, project identification and coalition formation occur in an environment that differs from a traditional organizational hierarchy. Each member is a representative of a 'home organization' and comes to the coordination body with priorities, resources and power that are in part determined by their 'real jobs'. Participation in the coordination body and subsequently the collaborative projects that are identified is undertaken on a purely voluntary basis.

In this coordination process, there is no NGO that can command others to work on a specific project. Members of coordination bodies must come together to identify mutually beneficial projects that fulfill a variety of requirements including overlapping with home organization agendas, having adequate resources, being feasible, and having long-term ben-

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

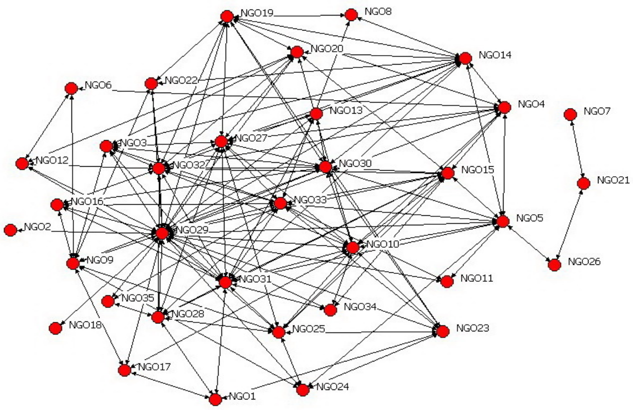

Figure 1. Collaboration network inside the GlobalSympoNet

efits, among many others. Collaborative projects and corresponding coalitions thus ‘emerge’ from the collective behaviors of individual NGOs. Intuitively, NGOs’ evaluations of candidate projects will have great impacts on their decisions about what collaborative projects to work on and the subsequent formation of coalitions.

Our empirical study of NGOs’ coordination behaviors revealed that, besides rational cost-benefit analysis, the social network of an NGO influences the NGO’s evaluation of candidate collaborative projects and the subsequent decision-making on coalition formation. Factors such as who it has connections with, strength of ties and peer pressure all affect their attitudes towards a project [14]. Specifically, in this paper, we will try to model how peers from an NGO’s network influence the NGO’s evaluations of candidate collaborative projects. To support our study, we identified a network inside GlobalSympoNet, a large humanitarian affairs coordination body consisting of about 100 international organizations. A survey was conducted at a meeting of GlobalSympoNet and a collaboration network of 35 NGOs was found (See Figure 1). Each node in this network stands for an NGO. A tie between two nodes means that the two NGOs collaborated before or are working on collaborative projects at the time of the survey.

The rest of the paper is structured as follows: First, the research on agent-based coalition formation and social influence models is briefly reviewed. Then the formal model of network influence on project evaluation is proposed and illustrated. The paper closes with a conclusion and a discussion of the future research plan.

2. RELATED WORK

Computational simulations, especially agent-based models, have been widely used to study a variety of social and organizational phenomenon. However, as an important topic in organizational coordination, coalition formation did not draw much attention from the study of these models, which often start from agent-based organizations or coalitions that have already been formed.

Research on agent-based coalition formation has been conducted mainly in the community of multi-agent system and distributed artificial intelligence. A great amount of their research aims at forming multi-agent coalitions for collaborative tasks. There are two popular approaches to form such task-oriented coalitions.

One approach is task or sub-task allocation [10][20][21]. Tasks or sub-tasks are allocated to agents who are able to or willing to accomplish them. The allocation of tasks can be done through top-down assignments in a hierarchical multi-agent environment [1] or through market-based bidding and contracting among self-interested agents [9][19].

The other popular approach is to divide the agents into groups using set covering or set partitioning algorithms, depending on whether overlapping coalitions are allowed. The goal is to find agent groups that have enough capabilities or resources to accomplish the given task, yet do not contain surplus members [8][20]. Agents are attracted to join in the group because they can get fair individual pay-offs by jointly working on the task [24].

The interplay between agent networks and agent-based coalition formation has also been studied, although there has been relatively little research on this topic. Set covering algorithms have been used to divide a network of agents into coalitions of bounded size [22]. However, a coalition must be a clique, i.e., an agent in a coalition must have direct network connections with all the other agents in the coalition. Study has also found that social network topology affects coalition formation outcomes. Scale-free networks outperform random and small-world networks in terms of coalition formation efficiency [6]. Interestingly, some coalition formation strategies in dynamic social networks may lead to the scale-free topology [5].

Meanwhile, in the research of agent-based systems, inter-agent influence is an important topic, because agents often influence others based on the influence they received from others [12]. Such influence has been used to the study agents’ behavior or belief changes [7][15], the computing load of distributed multi-agent systems [11], etc. One of the popular ways to model inter-agent influence is based on similarity [3][16]. In these models, agents tend to interact with those who are more similar to themselves based on how much knowledge or how many attributes they have in common. Therefore, an agent is more likely to be influenced by similar peer agents. However, structures of the agent network are not reflected in these models.

From outside the agent research literature, we found the network-based model for social influence [4]. Models of this type describe how a network of interpersonal influences affects the process of opinion formation. Basically, individuals in the network take into considerations the opinions of their network neighbors and adjust their own accordingly. Influence in social networks is represented as an iterative process based on structural parameters of the network.

Nevertheless, the aforementioned social influence model focuses more on group stability and has been applied to the dynamics of simple, sometimes binary, opinions on a single issue. The network-based model also takes the centralized approach and does not prescribe how the inter-agent influence is calculated. On the other hand, coalition decision processes in NGO coordination involve dynamic, iterative and deliberate evaluations of multiple candidate collaborative projects. Also, there are a lot of practical factors that will affect inter-NGO influence, such as size of an NGO, geodesic distance, i.e., the length of the shortest path, between NGOs, resources possessed by an NGO, etc.

Therefore, to simulate network influence on each individual NGO's evaluation of projects in a less-hierarchical environment like a coordination body, we will have to extend existing influence model.

3. THE PROPOSED APPROACH

3.1. The Basic Framework

We have proposed an agent-based simulation framework to study the emergence of coalitions and collaborative projects among NGOs [23]. In the framework, NGOs are modeled as heterogeneous and self-interested agents. Each NGO varies in organization size, organization goal, available resources, social networks, the way of evaluating candidate collaborative projects, etc. Each agent will have an ordered to-do list consisting of potential projects on which they would like to collaborate with others in the multi-agent environment.

We also designed an agent interaction scheme to simulate the interactions among NGOs inside a coordination body. The scheme consists of two phases of interactions: group meetings and private discussions. In a group meeting, each agent will propose the project at the top of its to-do list, which is often the project that it wants to accomplish the most, to all the other agents by broadcasting information about the project. On the other hand, in private discussions, agents only interact with previously acquainted agents in their social networks.

In both phases, agents will evaluate received candidate collaborative projects based on various criteria of their own, such as whether the goal of the project matches the goal of the agent, the cost and benefit of the project, the feasibility of the project, etc. A priority score for each project is the outcome of the evaluation process. Due to the heterogeneous nature of agents, different agents may assign different scores to the same candidate project. Then an agent may add new projects with high priority scores to its to-do list, remove projects with low priority scores from the list, or re-evaluate and re-rank existing projects in the list.

After a few rounds of inter-agent interactions in the agent network, a valid collaborative project may emerge when the following two criteria are met: First, it is supported by more than N_{min} agents in the multi-agent environment, i.e., more than N_{min} agents have this project on their to-do lists. In reality, the threshold value N_{min} often varies for different coordination bodies. It serves as one of the requirements for a project to be endorsed by a certain coordination body. It is often easier for a project to get recognized, receive external funding and thus be successfully implemented if it gets endorsed by a coordination body. When the number of supporters for a project does not reach the threshold, it is still possible that those NGOs carry on with this project, although they may have to do that outside the coordination body without the endorsement. Second, all the required resources for the project can be gathered from the contributions of its supporters. Those who support the emerged collaborative project are said to form a coalition for this project. Other agents that do not support the project are not required to join the coalition.

Our formal model of network influence in project evaluation is based on this framework.

3.2. Influence from Networks

Inspired by Friedkin and Johnsen's social influence model [4], we propose the formal model for network influence on NGOs' evaluation of candidate collaborative projects. As this model is designed for agent-based simulations, it focuses on the perspective of individual agents, i.e., NGOs.

3.2.1. The Formal Model

Our model studies on how the priority score of a candidate collaborative project assigned by an NGO is influenced by the scores of the same project assigned by other NGOs. The model can be represented with the following equations:

$$S_{i,j}(0) = Eval(P_j, KB_i) \tag{1}$$

$$S_{i,j}(t) = C_i \times T_i \times SN_{i,j}(t-1) + (1 - C_i) \times S_{i,j}(0) \tag{2}$$

where $S_{i,j}(t)$ for $t = 0, 1, 2, ...$, is the priority score of candidate project j assigned by NGO i at time t.

Equation (1) describes how the initial score of project j is determined. The $Eval$ function takes two sets of parameters as the input: project j's characteristics P_j and NGO i's knowledge base KB_i, which stores the project evaluation criteria of NGO i. The internal evaluation schemes can be configured by the modeler to cater different scenarios. Our previous work adopted a weighted sum evaluation scheme [23].

Equation (2) is the core of the influence model and represents how an NGO's initial evaluation of a project, i.e. priority score assigned to the project, is iteratively influenced by other NGOs' evaluations of the same project. The right hand side of the equation consists of two parts.

The first part describes the external influence. T_i is a $1 \times n$ vector that represents influences from all the n NGOs in the coordination body, including NGO i itself, on NGO i. Elements in T_i are called influence indexes. For example, $T_i[k]$ is the influence index of NGO k over NGO i. The sum of all influence indexes in T_i is 1, as shown in Equation (3).

$$\sum_{k=1}^{n} T_i[k] = 1 \tag{3}$$

$SN_i,j(t)$ is an $n \times 1$ vector that stores project j's priority scores assigned by all the n NGOs. Namely, $SN_{i,j}(t) = [S_{1,j}(t), S_{2,j}(t), ..., S_{i,j}(t), ..., S_{n,j}(t)]^T$. Thus the product of T_i and $SN_{i,j}(t-1)$ is a score that reflects NGO i's combined consideration of all other NGOs' evaluations of the same project j at time $t-1$.

The second part is actually NGO i's initial and independent evaluation of project j. The initial evaluation is kept because it is made independently by the agent under no external influence. This will serve as the base for possible evaluation deviations during the iterative influence process.

The two parts are connected and balanced with the influence coefficient $C_i(0 \leq C_i \leq 1)$, which denotes how likely NGO i's project evaluation is influenced by others'. Larger C_i means NGO i is more subject to external influence, while NGOs with smaller influence coefficient are more independent when evaluating projects and making coalition formation decisions.

3.2.2. The Influence Index

Many may have noticed in Equation (2) that the external influence on an NGO's evaluation seems to come from all the other NGOs in the coordination body and there is no component that explicitly represents influence from an NGO's social network neighbors. So how is influence from network neighbors reflected in the model? The answer of the question lies in how influence indexes in T_i are defined. In fact, influence indexes can be defined to represent various aspects of NGO social networks.

We have talked about the two-phase interaction scheme for NGO coalition formation in Section 3.1. Now we will describe one approach to define influence indexes for the two interaction phases.

In a group meeting, an NGO is influenced by all other peers at the meeting as every NGO is given the chance to publicly advocate projects it supports. The influence index of NGO k over NGO i is first calculated as:

$$T_i'[k] = f(size(k), size(i)) \times g(dist(i,k)) \tag{4}$$

where $size(x)$ is the organization size of NGO x; $dist(x,y)$ denotes the geodesic distance between NGO x and y in the social network.

Equation (4) suggests that influence indexes are based on organization sizes of NGOs and the geodesic distance between NGOs in the network. The reason we use organization size is that, inside coordination bodies, larger NGOs often exert more influence on smaller NGOs, partly because larger NGOs often possess more resources that are critical to the successful implementation of collaborative projects. Hence smaller NGOs often need to cooperate with larger NGOs in order to get access to important resources they do not possess. Meanwhile, NGOs who are closer to each other in the social network tend to be influenced more by each other. Such distance-based influence usually decays very fast as the distance increases.

Therefore, we may use square root of the quotient as f and a Gaussian function as g for Equation (4).

$$f(size(k), size(i)) = \sqrt{\frac{size(k)}{size(i)}} \tag{5}$$

$$g(dist(i,k)) = e^{(-\frac{dist(i,k)}{\sigma^2})} \tag{6}$$

where σ is a coordination body-specific parameter that denote the range of effective influence in the network.

Using Equation (4), we can calculate influence indexes of all NGOs over NGO i and store them in T_i'. Then we will normalize all the indexes in T_i' using the Equation (7), so that Equation (3) holds.

$$T_i[k] = \frac{T_i'[k]}{\sum_{p=1}^{n} T_i'[p]} \tag{7}$$

It is worth noting that, besides organization size and geodesic distance between NGOs, there may be many other factors that may affect inter-NGO influence, such as trust and reputation. We choose the two factors at this moment mainly because the data is easy to get and quantify. Other factors can be incorporated when the data become available.

Now we move to the phase of private discussions, in which an NGO interact only by its immediate network neighbors. Therefore, an NGO can only get the scores of a project assigned by neighboring NGOs. As a result, if NGO m is not an immediate neighbor of NGO i in the network, $S_{m,j}(t-1) = 0$ in the vector $SN_{i,j}(t-1)$. In fact, scores of projects assigned by non-neighboring NGOs do not matter to NGO i. The definition of influence indexes specifies that, in private discussions, $T_i[m] = 0$ and thus NGO m's evaluations of projects do not have impacts on NGO i's evaluations.

This way of defining influence indexes for non-neighbors in the phase of private discussions reflects the network connection of an NGO and answers the question at the beginning of this subsection.

We have clarified that there is no influence from non-neighboring NGOs in private discussion. Now we will consider influences from neighboring NGOs. When calculating the influence indexes of an NGO's neighbors over this NGO, the strength of a tie is taken into consideration. The index is first calculated using Equation (8):

$$T_i[k] = f(size(k), size(i)) \times h(i,k) \quad (8)$$

This equation shares function f with Equation (4) but uses $h(x,y)$, which indicates the strength of tie between NGO x and y, instead of the function g on geodesic distance. Most of the time, the stronger the tie between to NGOs is, the more likely an NGO is influenced by its network neighbor and consequently the higher the influence index becomes. Similar to the phase of group meetings, after all influenced indexes of an NGO's neighbors are calculated, they are normalized using Equation (7).

There are certainly many other approaches to define influence indexes when modeling different problems. That is also why we use generic functions f, g and h in the model. One of the advantages of this model is that it is flexible enough to allow various ways to define inter-agent influence and it can be adapted for other network influence scenarios.

3.2.3. An Example

In this subsection, we will illustrate how this model works, especially the calculation of project priority scores, with a simple hypothetical example. Note that the calculation of influence indexes is simplified for illustrative purposes.

Figure 2 shows a hypothetical network of 6 NGOs. Numbers near the edges indicate the strength of ties. We will illustrate how NGO 5's evaluation of project 1 is influenced during the coalition formation process.

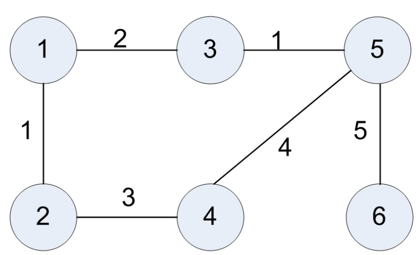

Figure 2. A hypothetical NGO network

Assume project 1 is initially in the to-do lists of NGO 1, 4, 5 and 6. The initial scores of project 1 assigned by the four NGOs are respectively: 10, 5, 20 and 15. As NGO 2 and 3 do not have this project in their to-do lists, the project is assigned a zero score by the two NGOs.

In a group meeting, NGO 5 is able to gather those initial scores and assemble $SN_{5,1}(0) = [10,0,0,5,20,15]^T$. Suppose NGO 5 gets the following influence indexes over itself using Equation (4), (5), (6) and (7), $T_5 = [0.05, 0.05, 0.20, 0.10, 0.50, 0.10]$. Also, suppose NGO 5 has $C_5 = 0.3$. Thus at time 1, NGO 5's evaluation of project 1 becomes $S_{5,1}(1) = 0.3 * T_5 * SN_{5,1}(0) + 0.7 * 20 = 0.3 * 12.5 + 14 = 17.75$. The score decreases from the initial score of 20, because this NGO has been influenced by other NGOs' evaluations of the project, all which of are lower than 20.

Assume after the group meeting, the six NGOs' evaluations of project 1 changed to 12, 2, 5, 10, 18.5 and 17 respectively. The process then moves to the phase of private discussions, in which NGO 5 is only influenced by its neighbors, i.e., NGOs 3, 4 and 6. Thus NGO 5 sets $T_5[1] = T_5[2] = 0$ and $S_{1,j}(1) = S_{2,j}(1) = 0$. Then $SN_{5,1}(1)$ becomes $[0,0,5,10,18.5,17]^T$. Assume NGO 5 updates the influence vector based on Equation (8) and gets $T_5 = [0, 0, 0.10, 0.20, 0.40, 0.30]$, then NGO 5's evaluation of project 1 at time 2 is $S_{5,1}(2) = 0.3 * T_5 * SN_{5,1}(1) + 0.7 * 20 = 0.3 * 15 + 14 = 18.5$. The result suggests that when NGO 5 is not influenced by NGO 2, which rates the project really low, the score rebounds a little bit over time 1.

4. CONCLUSION AND FUTURE WORK

In this paper, we propose an approach to model network influence on the identification of collaborative projects and coalition formation in the coordination of humanitarian relief NGOs. Specifically, the formal model focuses on how an NGO's own evaluation of projects is influenced by other NGOs' evaluations of those projects in a network setting.

The model was inspired by the problem we encountered when simulating network influence among NGOs and thus has the potential to contribute to the research of inter-organizational coordination in humanitarian relief. In addition, to our knowledge, this model is the first that tries to tackle the problem of network influence in agent-based coalition formation and may be applied to other scenarios that involve the formation of multi-agent coalition in agent networks.

Admittedly, this model is not mature at this moment. Experiment results from agent-based simulations that implement this model are needed to validate the model and to identify proper functions to define influence indexes in the context of NGO coordination.

We are developing an agent-based model using the Repast Simphony simulation toolkit [17] to implement our previous framework and this formal model. We plan to use the data we gathered about NGOs and their coordination efforts to inform and validate the agent-based model and to improve the formal model of network influence.

5. ACKNOWLEDGEMENT

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