# Emergence of Collaborative Projects and Coalitions: a Framework for Coordination in Humanitarian Relief

Kang Zhao, Carleen Maitland, Louis-Marie Ngamassi Tchouakeu, Razvan Orendovici, Andrea Tapia and John Yen

College of Information Sciences and Technology
The Pennsylvania State University, University Park, PA 16802, USA.
kangzhao@psu.edu, cmaitland@ist.psu.edu, ltchouakeu@ist.psu.edu,
ruo3@psu.edu, atapia@ist.psu.edu, jyen@ist.psu.edu

**Abstract.** In order to simulate the coordination of non-governmental organizations (NGOs) in humanitarian relief, we propose a theoretical framework for the emergence of collaborative projects and corresponding coalitions. In this framework, NGOs are represented as autonomous and heterogeneous agents who are embedded in social networks. They interact with each other in various ways, deliberatively identify collaborative projects they would like to work on, and form coalitions for collaborative projects. The impacts of several social network factors are also incorporated into the coordination framework.

## 1 Introduction

In the past decade the world has experienced several major natural disasters, including the south Asian tsunami, hurricane Katrina and the Pakistani earthquake. These tragedies have highlighted the need for improved decision making and greater levels of coordination in humanitarian relief, particularly in the area of information and communication technologies (ICTs). While efforts in this realm are currently under way, it is unclear how this goal can best be accomplished.

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, undertaken independently with donor funds or through the auspices of larger ongoing inter-agency bodies. They may also be permanent incorporated non-profit organizations that facilitate ICT coordination as their exclusive mission. Target coordination bodies in our research include the Information Technology for Emergencies Alliance group, the GlobalSympoNet and the ReliefTechNet.[1]

To date, the level of effectiveness achieved by these coordination bodies is unclear. Further, the bodies vary significantly on their organizational designs,

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

including characteristics such as the criteria for membership, funding mechanisms, and size. Thus, this research seeks to first establish their various levels of effectiveness and second understand how changes to the organizational designs of coordination bodies might improve their effectiveness.

One means of assessing the effects of organizational design changes is through the use of an agent-based computational model, with which we can try various sets of parameters in organizational design and simulate the coordination outcomes in different scenarios. In this research, the development of the model and subsequent validation will be informed through qualitative case study research into the designs, decision making processes, and effectiveness of the three coordination bodies mentioned above. In particular, the first phase of model development will simulate emergence of collaborative projects and coalition formation, a critical mechanism for inter-organizational coordination in the ICT realm. In this paper we provide the theoretical framework for project emergence and coalition formation, which extends existing research into emergent collective deliberative behavior among heterogeneous agents.

The paper is structured as follows. We begin with a brief discussion of the nature of coordination in the non-profit ICT domain. This is followed by a brief overview of research on agent-based models and subsequently the specification of the theoretical framework. The paper closes with a discussion of our plans for future research.

## 2 Focus of Research

While our goal is to eventually model the entire coordination process, this paper starts with a focus on the phase of collaborative project identification and coalition formation, one of the core processes in influencing the coordination. To date our research on the coordination bodies has identified two key findings that inform the development of the framework.

First, despite the similarities and differences in the characteristics of these three coordination bodies [18], they all use collaborative projects as a means of facilitating coordination between their members. The ReliefTechNet ICT Skills Building Program is an example of such projects. This project was developed with inputs and contributions from more than ten different members of ReliefTechNet. It aimed at helping NGOs serving developing countries to improve on their response to emergency and enhance their organizational effectiveness.

Collaborative projects may represent a primary means of coordination or be supplementary to other coordination facilitation modes. For example, in addition to projects, a coordination body may also attempt to facilitate real-time coordination at the onset of a disaster. As compared to projects, which require planning, are undertaken over longer periods of time, and are designed to promote ongoing coordination, these 'real time' coordination activities may or may not generate lasting coordination practices within the member agencies. Also, as compared to projects, they are a less frequently used mechanism.

Second, while the coordination bodies facilitate collaborative projects in unique ways, a generalized model of project identification and selection among NGOs can be discerned. Within the 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, although projects typically overlap with the work being done in home organizations. In the process of identifying collaborative projects and forming coalitions, there may be persons or organizations that take the initiative. However they are often not considered as leaders because they do not have the authority over, the complete information about, or the access to all the other NGOs. Instead, even though it may not be the first organization to propose a project, every member in the coordination body is able to act as the coalition organizer by asking acquainted NGOs to consider a project that it supports.

This is not to say, however, that the coordination body is completely devoid of hierarchy or authority. While the coordination body staff may have limited authority over powerful members, because of their position in the coordination body hierarchy and their external connections to funders and other important actors they are afforded a level of respect. Nevertheless, such authority is observed mainly in later stages of coordination and thus can be disregarded in the project identification and coalition formation phase.

In this phase, members of coordination bodies must come together to identify mutually beneficial projects that fulfill a variety of requirements including having adequate resources, overlapping with home organization agendas, being feasible, and having long-term benefits, among others. Collaborative projects and corresponding coalitions thus 'emerge' from the collective behaviors of NGOs. In the following sections we examine the extant theoretical and empirical research upon which our computational model of this project identification phase will be built.

## 3 Extant Research

Computational simulations, especially agent-based models, have been widely used to study a variety of social and organizational phenomenon [3]. These models have addressed a variety of topics in coordination, such as organizational structure [24], adaptation [4] and communication [13], etc. Concepts of social networks have also been incorporated [14][21][26]. However, as an important stage in organizational coordination, coalition formation did not draw much attention from the research of these simulations, which often start from agent organizations or coalitions that have already been formed.

Research on multi-agent coalition formation has been conducted mainly in the multi-agent system (MAS) and distributed artificial intelligence community.

A great amount of their research aims at forming multi-agent coalitions or teams for collaborative tasks in sensor networks [12] and electronic markets [25][15]. Major approaches are through task or sub-task allocation, inter-agent dependency [11][22], and corresponding optimizations [20].

A lot of research focused on hierarchical or top-down coordination and coalition formation. There are often "leading agents" who play the roles of managers, coordinators, leaders or organizers. They will usually determine the collaborative project, evaluate other agents' competence in contributing to this project, recruit or solicit assistance from agents with desired capabilities, and assign (sub)tasks of this project to those agents or monitor and facilitate the coalition formation process [1][23][10]. Other agents in the multi-agent environment have lower ranks in the hierarchy and can only respond to the behavior of "leading agents".

Some research has been done on bottom-up coalition formation without designating fixed hierarchical roles to agents [2][5][6]. For example, [27] does not designate any agent to be the "leading agent". Instead, when facing a problem or a task, every agent in the multi-agent environment can be the "leading agent" and try to form a team and collaborate on the problem.

Nevertheless, some characteristics of NGO coordination in our research have not been reflected in extant research. First, little research has been done on the deliberate behaviors of agents in the coalition formation process. Specifically, when one NGO proposes a collaborative project and solicits peer NGOs to support this project and join the coalition, most NGOs in the coordination body do not simply react passively by accepting or rejecting the proposal. Instead, after evaluating the project, if they decide to support it, they will deliberately recommend this project to other NGOs. In this sense, the coalition formation process for a project may have more than one "leading agents".

Second, more research is needed on the impacts of social networks on agents' decision-makings in coalition formation. [8][19] explicitly talked about the role of social networks in coalition formation, but their considerations were limited to agent communications through social network connections. In organizational coordination, other social network factors may also have considerable impacts. For example, one may tend to trust information from those with high reputation [17]. Specifically, an NGO may prefer coalitions that already include NGOs with high reputation or influence or NGOs that it has strong tie with.

## 4 Framework for the Agent-based Model

Therefore, we propose a theoretical framework for an agent-based model to simulate the emergence of collaborative projects and corresponding coalitions, and incorporate impacts of various social networks into the process.

### 4.1 Basic Constructs

This section specifies the basic symbols and constructs used to represent agents in our framework and their underlying characteristics including project lists and

their knowledge bases, as well as project resources, and social networks where agents are embedded. We will also define a valid collaborative project and its coalition.

In the framework, NGOs are represented as intelligent agents. A group of $n$ agents is denoted as $G = \{A_1, A_2, \ldots, A_n\}$. $R = \{R_1, R_2, \ldots, R_r\}$ refers to $r$ types of resources required by all possible collaborative projects in $P$.

$P = \{P_1, P_2, \ldots, P_m\}$ are $m$ potential collaborative projects for humanitarian relief, where a project $P_j \in P$ is represented as a four-tuple construct $\langle id_j, GOAL_j, SP_j, RR_j \rangle$. Each project is identified by its unique project id. $GOAL_j$ represents the ultimate goal of this project, such as improve the IT skills of relief workers, facilitate the sharing of victim information, etc. Agents who want to work on project $j$, i.e. supporters of project $j$, are specified in the array $SP_j = [SA_{j,1}, SA_{j,2}, \ldots, SA_{j,n}]$. $SA_{j,k} = 1$ when agent $k$ supports project $j$. Otherwise $SA_{j,k} = 0$. Each project will also require resources. $RR_j$ denotes the types and amounts of resources required by project $j$. It is an array $[rr_{j,1}, rr_{j,2}, \ldots, rr_{j,r}]$, where $rr_{j,k}$ refers to the amount of resource $k$ required by project $j$.

NGOs in our framework are heterogeneous in several aspects. An agent $A_i$ is defined as a six-tuple construct $\langle OC_i, NT_i, PL_i, AR_i, KB_i, DM_i \rangle$. First, $OC_i$ is a construct that denotes the organizational characteristics of agent $i$, such as goals, strategies, size, reputation, etc. Second, NGOs are also embedded in social networks, which are specified in the array $NT_i = [nt_{i,1}, nt_{i,2}, \ldots, nt_{i,n}]$. Weak ties and strong ties are also differentiated. Greater value of $nt_{i,k}$ means stronger tie between agent $i$ and $k$ in the social network. For example, when agent $i$ has no connection with agent $k$ ($i = k$), $nt_{i,k} = 0$; while $nt_{i,k} = 10$ denotes the strong tie between the two agents. Third, each NGO has its own ordered to-do list consisting of projects they would like to work on. Projects are arranged in descending order based on their priorities assigned by the NGO. For example, in agent $i$'s project list $PL_i = \left\{P'_{i,1}, P'_{i,2}, \ldots, P'_{i,l}\right\} \subseteq P$, $P'_{i,1} \in P$ is the project that agent $i$ wants to accomplish the most. The length of the list $l$ may vary from agent to agent. Fourth, each NGO possesses different types of resources in various amounts. This is denoted by array $AR_i = [ar_{i,1}, ar_{i,2}, \ldots, ar_{i,r}]$, where $ar_{i,k}$ is the amount of resources $k$ controlled or possessed by agent $i$. Fifth, NGOs have different knowledge about humanitarian relief and peer NGOs in the coordination body. The knowledge base of agent $i$, $KB_i$, will act as a dynamic knowledge repository, actively updating itself with new knowledge and tagging knowledge that is not valid anymore as obsolete during coordination. Finally, each NGO may also have different ways to evaluate collaborative projects and adjust the project to-do list. $DM_i$ is thus used to represent the decision-making module of agent $i$. Details about agents' decision-making schemes and how they evaluate projects will be introduced in section 4.2.

To better simulate the coordination process, we introduced another variable called resource sharing coefficient, defined as $RC_{i,j} = f(PR_{i,j})$. The coefficient is a real number whose value ranges between 0 and 1. For example, $RC_{i,j} = 0.3$ means agent $i$ would like to contribute or allocate 30% of its resources to project

$j$. Higher project ranking $PR_{i,j}$ will yield higher resource sharing coefficient, which corresponds to the fact that NGOs would like to allot more resources to projects they considered more important.

Now we are ready to define a valid collaborative project and its coalition. Intuitively, a collaborative project is one that a group of organizations collaborate with each other to accomplish. In our framework, we propose definitions for such a project and the coalition of agents that would like to collaborate on it.

**Definition 1.** *A valid collaborative project $P_{clb} \in P$ and the coalition of its $p$ supporters $C_{clb} = \left\{A_1^{'}, A_2^{'}, \ldots, A_p^{'}\right\}$ must make all the following propositions true:*

$$\forall A_i^{'} \in C, P_{clb} \in PL_i \tag{1}$$

$$\forall k, \sum_{i=1}^{p} RC_{i,k} \times ar_{i,k}^{'} \geq rr_{clb,k} \tag{2}$$

$$p > N_{min} \tag{3}$$

In other words, a valid collaborative project must meet the following two criteria: First, it is supported by more than $N_{min}$ NGOs in the coordination body. The threshold $N_{min}$ is often determined by the coordination body and serves as one of the requirements for a project to be endorsed. It is often easier for a project to get recognized, receive external fundings and thus be successfully implemented if it gets endorsed by the coordination body. In the case of ReliefTechNet, the threshold is often 3. When the number of supporters for a project is not greater than $N_{min}$, 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 do not support the emerged collaborative project are not required to join the coalition.

### 4.2 Evaluation of projects

Agents' adjustments to their to-do lists depend on the outcome of their evaluation of projects, which is done through the decision-making process. The decision making model $DM_i$ of agent $i$ takes a potential collaborative project and information from the agent's knowledge base $KB_i$ as the inputs and produces the project's priority score as the output. The priority score serves as the basis of the evaluation of this project.

We decided to adopt a variation of the weighted tallying decision-making scheme [9][16] for the calculation of the priority score. The priority score that agent $i$ assigns to project $j$ is calculated with the following formula:

$$Score_{i,j} = DM_i\left(P_j, KB_i\right) = GM_{i,j} \cdot \sum_{k=1}^{n} Wt_k\left(KB_i\right) FV_{j,k}\left(KB_i\right) \tag{4}$$

$GM_{i,j}$ is the goal matching coefficient, which denotes how much the goals of the project $j$ matches the goals of the agent $i$. The value of the coefficient ranges from 0 to 1, where 0 means absolute no match and 1 stands for a perfect match. It is obvious from the formula that $GM_{i,j}$ is among the most important factors for the score of a project. This corresponds to the fact that when NGOs evaluate a project, they will first check whether this project can meet their goals. Few NGOs will consider projects whose goals are not of interest.

In addition to the match of goals, $n$ other factors or criteria are also within the consideration, such as project benefits, cost, feasibility, strength of ties with existing project supporters, etc. The weighted sum of the $n$ factors reflects the outcome of the multi-criteria evaluation of the project.

Each factor is rated by the agent on a 10-point scale. For example, assume the IT training project we mentioned in section 2 is represented as 'project 2' and cost of a project as 'factor 1', then $FV_{2,1}(KB_i) = 9$ means the cost of the IT training project is rated by agent $i$ as 9, which means 'very expensive'. Besides the rated value, each factor is also assigned a weight $Wt_j$ by the agent because not all factors are of the same importance to the agent. More important factors tend to have higher weights.

Moreover, the weights for the same factor may also vary from agent to agent as different NGOs may have different perspectives on which factors are more important or less important. Thus agents with different knowledge bases may get different priority scores on the same project.

With priority scores of all projects that an agent is aware of, the agent can then adjust its to-do list. Projects with high scores are kept in or added to the to-do list, and ranked based on the scores. The higher priority score is, the higher the project is ranked in the to-do list. On the other hand, projects with low scores are discarded.

### 4.3 Emergence of Collaborative Projects and Coalitions.

In this section, we will present how collaborative projects and coalitions emerge from the deliberative behaviors and collective decision-makings of NGOs.

At the beginning of the simulation, each NGO enters the coordination body, with different projects they want to work on. The coordination process is divided into two phases of agent interactions: group meetings and private discussions.

In a group meeting, each agent will propose the project at the top of its to-do list, i.e. the project that it wants to accomplish the most, to all the other agents by broadcasting information about the project. Upon receiving information about incoming projects, each agent will first behave reactively. It will check whether the project goal is in accordance with its own goals. If there is a goal match, it will then evaluate the sender's reputation, determine whether to trust the information and accept it into its knowledge base. Also, an agent's source of new information is not limited to what it receives. It will also infer information about other agents through interactions. With updated knowledge base, the agent will compare incoming projects with existing ones in its own to-do list,

evaluate or re-evaluate those projects and then decide whether and how to adjust the to-do list. The agent may add new projects to or drop existing projects from the list. It may also change the priority orders of projects in the list. There could be one or several rounds of group meetings.

If no valid collaborative project emerges from group meetings, the process moves on to the phase of private discussions. In this phase, agents only interact with previously acquainted agents, with whom the agent has direct ties in its social network. In each round of private discussion, an agent may share information about more than one important project with its neighboring agents. The strength of the tie between two agents will be used to determine how much information they would like to share with each other and whether they trust the incoming information from each other. For example, the number of projects agent $i$ shares with agent $j$ depends on the information sharing coefficient, defined as $IC_{i,j} = g\left(nt_{i.j}\right)$. The value of the coefficient is positively related to $nt_{i.j}$, which indicates the strength of the tie between agent $i$ and $j$. The range of the coefficient is between 0 and 1. $IC_{i.j} = 0.4$ means agent $i$ would like to share information about the top 40% of its projects with agent $j$. Furthermore, agent interactions in this phrase are more complex and intelligent than those in group meetings. For example, an agent may proactively send additional information related to one of its top projects to another agent, in order to better persuade others to support the project. If the receiving agent feels it difficult to agree on the project, they may request more information from the sender. Similar to group meetings, after interactions with acquaintances, agents will also process new information, evaluate its new and old projects, and make decisions on how to adjust their to-do lists of projects. However, they tend to place greater trust in information from acquaintances, especially those they have strong ties with. It is also more likely, than in group meetings, that they add projects supported by acquainted agents into their own project lists. This phase usually consists of multiple rounds of private discussions.

If no valid collaborative projects emerge after the two phases of interactions, we say that the group of NGOs fails to reach a collaborative project in our framework.

## 5 Conclusion and Future Work

In this paper, we proposed a theoretical framework to simulate the emergence of collaborative projects and coalitions in NGO coordination for humanitarian relief. The framework addressed two gaps in extant research of agent-based social and organizational simulations and MAS. In addition, the generality and extendibility of the framework make it a good foundation for developments of other organizational coordination simulations.

The framework is being used to guide the development of an agent-based model based on R-CAST [7], a software agent architecture that models and simulates team decision-making. After the implementation, we also plan to conduct validation tests. Through qualitative and quantitative research, we have gath-

ered field data about NGO coordination. Some of the data will be used to aid the design and implementation of the agent-based model, while the remaining will be used to validate and tweak the computational model later.

Admittedly, the framework does not cover every aspect of NGO coordination in humanitarian relief. One direction for us to extend the framework in the future is to create more human-like or intelligent agent. For example, certain NGOs will occasionally agree to work on a collaborative project even though they will not obtain direct benefits from it. Instead, they may want to establish reputation or build collaboration networks through such altruistic behaviors. Another potential direction of future work is to implement dynamic social networks, in which agents' reputations and networks may change from time to time during collaborations.

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