Team Formation in Complex Networks

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Abstract

The concept of team formation, or joint action, is central to a wide variety of disciplines including organizational design, computational organization theory, planning and learning in multi-agent systems, and distributed artificial intelligence. One key feature of team formation is the underlying social network topology which determines the direct interactions among the individuals of the organization. Traditional models of social phenomena have been restricted to regular lattice, or fully-connected, network topologies, but recent results have shown that real-world networks have much different and much richer structure. Using a simple agent-based computational model of team formation, various virtual experiments are conducted to examine the impact of complex network structures on the dynamics of team formation.

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Successful organizations generally foster the formation of teams to accomplish complicated tasks. Cooperation, collaboration, delegation, resource allocation, skill distribution, and other factors are influential in an organizations' ability to leverage the collective actions of individuals. Understanding the impact of organizational design and structure on organizational dynamics can help provide better management of complex organizations. Team formation is one type of organizational dynamic that is impacted by network structure.

Over the past several years, two interdisciplinary trends have emerged that have a great impact on the study of organizations: agent-based computational modeling and the study of the structure and dynamics of complex networks. Agent-based computational modeling [2, 3, 5] has impacted many disciplines including physics, chemistry, biology, ecology, the social sciences, medicine, and computer science. The impact of complex network structures [9, 10] on understanding the behavior of systems is equally diverse.

Studies of team formation and cooperation in organizational dynamics have suggested the importance of network structure on organizational performance. Huberman and Hogg [7] use a probabilistic modeling approach to study organizational change in large-scale organizations, finding that clustered organizations (i.e., those in which each agent has a relatively small number of neighbors) are more stable than organizations with high connectivity. While this study did not focus on task performance, it highlights the importance of various features of the organizational network. Similarly, Glance and Huberman [6] show that cooperation is more likely to take place in organizations that are hierarchically structured with fluid (changeable) groupings. Also, for other organizational behaviors, the network structures of an organization impact various collective behaviors. Miller [8] demonstrates the importance of network structures on information processing and suggests mechanisms for evolving an organization toward more efficient performance. To study the adoption and spread of social conventions in an organization, Delgado [4] evaluates organizational efficiency of this dynamic on complex networks.

The work presented here focuses on examining the effects of various network structures on the dynamics of team formation in an organization. Four different network topologies impose different structure on the organization and virtual experiments provide insight into the team formation performance of the simulated organizations.

Complex Network Structures

Recent studies of real-world networks suggest several general properties of social networks and other types of networks. Most notable are the properties of short-average path length (i.e. the *small-world* phenomenon), excess clustering, and skewed degree distributions [9, 10]. Imposing various network structures on an organization changes these properties and affects the dynamics within the organization. The performance of the organization depends on both the dynamic in question and the network structure imposed.

In this study, four network structures are used to evaluate the performance of team formation in response to these network properties. A regular two dimensional lattice represents the more traditional organizational structure used in modeling. For similar reasons, the Erdös-Renyi Random graph model provides the "order for free" [8] model of organizational structure. The two other network structures considered in this study are the small-world networks of Watts [11] and the scale-free model of Barabasi [1]. Excess clustering appears in lattice networks, and the extension to small-world networks provides short-average path length. Neither the lattice nor the small-world network contain a skewed degree distribution. Both the random graph and the scale-free graph maintain short-average path length and the scale-free model produces a skewed degree distribution. Just as the lattice and the small-world models lack the degree distribution, both the random and scale-free models lack clustering.

A Simple Agent-based Model of Team Formation

To explore the effects of network structures on team formation, a simple agent-based organizational model is proposed. Tasks are generated and globally advertised to the agents in the organization and agents form teams to accomplish the tasks. The network structure restricts which agents can participate on which teams. The tasks are generic in that they only require that a team of agents with the necessary skills forms to accomplish the specific task (i.e., once all of the skill requirements for a given task are filled, the group of agents filling these skills becomes an active team).

The organization contains a set of N agents situated in a graph $G = (V, E)$. There are N agents, $A = \{a_1, a_2, \ldots, a_N\}$, where each agent a_i is situated at a corresponding node v_i in the graph G, and $N = |V|$. Each agent is assigned one of three states, $s_i \in \{0, 1, 2\}$, which correspond to uncommitted, committed, and active respectively. An *uncommitted* agent is available and not assigned to any task. A *committed* agent has chosen a task, but the full team to work on the specific task has not yet formed. Finally, an *active* agent is a member of a team that has fulfilled all of the skill requirements for a task and is actively work on that task. Active agents become uncommitted when the task is completed. Committed agents become uncommitted if the advertisement duration is reached without fulfilling the skill requirements for a given task. The agents are also assigned a single skill, $\sigma \in [1, \Sigma]$, where Σ is the number of different types of skills that are present in the organization. The edge set E restricts the interactions of the agents.

Tasks are introduced at a fixed rate, μ, into the organization and are globally advertised. Each task K has an associated size requirement, $|K|$, and a $|K|$-dimensional vector of required skills, R_K. The skills required for a given task K are chosen uniformly from $[1, \Sigma]$. Each task is advertised for a finite number of time steps proportional to its size (namely $\delta|K|$, where δ is a model parameter) to ensure that the resources (i.e. agents) assigned to the tasks are freed if the full requirements of the task cannot be met. Similarly, teams that form to fill the requirements of a given task are only active for a finite number of time steps (namely $\alpha|K|$, where α is a model parameter).

While tasks are being advertised, agents commit to tasks based on various sets of rules. The interesting dynamics of this team formation model arise from the strategies that the agents employee to select tasks and from the definition of a valid team.

> **Definition**: A **valid team** is a set of agents $\{a_i\}$ whose corresponding set of nodes $\{v_i\}$ induce a *connected subgraph* of G and whose skill set $\{\sigma_i\}$ fulfills the skill requirements for a given task K.

In the virtual experiments, various strategies for this decentralized task allocation and team formation model are explored. It is shown that the network structure drastically affects the organizational performance of team formation. Attention should be paid to the strategies employed by the agents as it may be possible to develop strategies that are not affected by the network structure.

Virtual Experiments and Preliminary Results

Various virtual experiments are conducted to show the impact of network structure on organizational performance for team formation. The results of using a simple agent task selection strategy are shown in Figure 1. For this instance of the model, an agent selects empty (i.e. no committed agents) at random. If a given task has at least on agent already committed, other agents may commit if at least one of their adjacent agents is committed to the task. They then choose to commit to the task with a probability proportional to the number of positions filled for the task (i.e., a task that has more agents committed is more likely to become active).

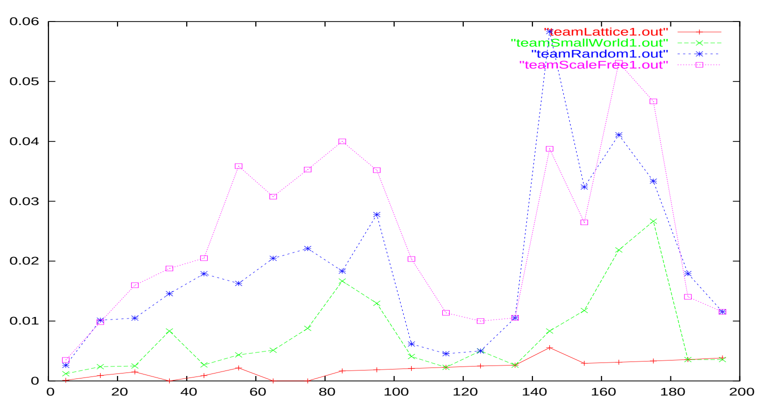

Figure 1: Organizational efficiency for an organization with $N = 100$, $|K| = \Sigma = 25$, and $\alpha = 2\delta = 4$. The task introduction rate, μ, is varied along the x-axis and the effeciency is shown along the y-axis. The curves represent the scale-free (–□–), random (–∗–), small-world, (–×–), and lattice (–+–) network models.

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These results show that the network structure does impact the ability of the organization to form teams to fulfill tasks. The efficiency is measured as the proportion of the total number of tasks that the simulated organization can fulfill. The scale-free network structure is the most efficient for this particular task selection strategy. One justification for this is the existence of hubs in the network as a result of the skewed degree distribution [1]. These hubs "facilitate" the formation of teams and ensure that a great number of skill mixes can be satisfied.

Based on this result, it is clear that the network structure impacts the organizational dynamic of team formation. Other strategies will be suggested and examined using this agent-based computational model. A discussion of the effects of various structural properties of the organizational network and suggestions for further study are provided.

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