Exploring the Impact of Network Structure on Organizational Culture Using Multi-Agent Systems

William Ross, Alexis Morris, Mihaela Ulieru
Adaptive Risk Management Lab
University of New Brunswick
{william.ross, alexis.morris, ulieru}@unb.ca

Social networks of influence exist as a topology that impacts the emergence of culture, which is characterised by the formation and diffusion of beliefs within organizations. Improved models are needed to understand the dynamics of culture, but such models are difficult to implement, as the notion of culture itself is inherently "fuzzy." Previously, a multi-dimensional approach to modelling culture as an emergent property of a complex system was explored. As a proof of concept, this approach used a multi-agent-based simulation to explore belief-based equilibrium in a fully-connected organization. In this paper, further network types are examined (i.e., small-world, random, and scale-free), which reflect a wider spectrum of possible organizational structures. Because these networks exhibit different properties, unique cultures can emerge and the key driving forces behind this emergence can be identified. Ultimately, it is anticipated that this work will help enable the "engineering" of culture within organizations so that specific organizational benefits can be unlocked.

1 Introduction

Previous work, [8], explored the challenges of modelling the inherently fuzzy notion of culture using multi-agent systems. Specifically, it used as its basis the idea that organizational culture results from the interaction of seven unique

dimensions: physical, individual, functional, structural, normative, social, and informational. It then presented an experiment in which an organization, initially consisting of three agents, was expanded one agent at a time until nine agents were part of the organization. Of interest in the experiment was how the influence of the agents interacted to produce the resulting organizational culture. Using a fully-connected network topology, the influence and confidence calculations in the experiment resulted in the emergence of a completely homogeneous culture.

In this work, as in the previous work, organizational culture is defined as the set of all belief values within the organization for which there is majority consensus. This is based on the notion of cultural homogeneity, or the "integration perspective" of culture, in which people share a common set of beliefs ([1] (ch. 10), [3], and [5]). The value for each belief comes from deontic logic (used in normative studies) and can assume one of three possible discrete values: prohibited, permitted, or obligated. For instance, a belief that "punctuality = prohibited" means that it is culturally unacceptable to be punctual; "punctuality = permitted" means that it is culturally neutral whether or not someone is punctual; and "punctuality = obliged" means that it is culturally required to be punctual. Still, we recognize that subcultures exist within societies and, as such, also support the broader definition of culture as the distribution of belief values across the population [3].

In this paper, the previous work will be extended in three ways. First, the mechanism for computing influence will be enhanced using a well-known result from sociology: Friedkin and Johnsen's Social Influence Network Theory [5]. Secondly, in addition to considering the fully-connected topology, three more network topologies will be incorporated to determine their impact on culture: small-world, random, and scale-free. Thirdly, the number of agents that are initially in the organization and that are ultimately part of it will be increased to six and 30, respectively.

The remainder of this paper is structured as follows. The next section outlines the cultural mechanisms being explored in this study, i.e., the influence computation and the various network topologies. Section 3 outlines the experiment used to examine the impact of network topology on culture and presents and discusses the results. Section 4 closes with the conclusion and recommendations for future work.

2 Cultural Mechanisms

There has been much work done in sociology and management science on the impact of influence and network structure on beliefs and culture (see [4], [7], and [11] for surveys). Widely speaking, the existing research can be divided into two broad categories: work related to *social process*, in which the reasons for changing ones beliefs are explored ([5] and [3]); and work related to *network topology*, in which the impact of ones structural position on ones social capital is investigated ([2], [6], [10], and [14]). In this section, our previous work to

incorporate influence into agent-based cultural models is summarized, [8], and then extended using results from [5]. This is followed by a description of the sociological significance of the four network topologies under investigation in this paper.

2.1 Social Process

The term *social process* describes how agents modify their beliefs by taking into account their own circumstances and the influence of other agents [5]. Based on work in [8], the influence of one agent over another can be computed using specific instances from the seven dimensions described previously. For example, for two agents *a* and *b*, such factors as how physically proximate $agent_a$'s workstation is to $agent_b$'s, how similar $agent_a$'s and $agent_b$'s functional roles are, and whether or not $agent_a$ trusts $agent_b$, all have a bearing on how much these agents influence each other.

In terms of social process, when a new agent is added to the organization, all the agents must recompute the confidence of the three possible deontic values for each belief. This is because new, potentially disruptive, information has been added to the system (i.e., an agent with its own influences, connections to other agents, and a particular set of initial belief values). In fact, the process used is similar to Carley's action → adaptation → motivation cycle: the action is a new agent being added; the adaptation is the updating of belief value confidences; and the motivation to communicate is pre-specified in the connections between agents (agents communicate to all agents they are connected to) [3]. After each cycle, whichever computed belief value is greatest for the agent becomes (or remains) the belief value of that agent for that particular belief.

In previous work, [8], the confidence (Φ) of the belief value of the current agent was based on the belief value and influence of itself and the agents connected to it, according to the following equation:

$$\Phi_\mu(x) = \sum_{i=1}^{k} \frac{\beta(x, i, \mu) * \iota_i}{k} \tag{1}$$

where the value of μ is one of the three possible belief values: prohibited, permitted, obligated; x is the belief under consideration; k is the number of agents connected to the current agent; ι_i is the influence of $agent_i$ on the current agent; β is the function, below, which produces a 1 if $agent_i$'s value for belief x matches the value currently under consideration, i.e., μ.

$$\beta(x, i, \mu) = \begin{cases} 1 & \text{if } belief_i(x) = \mu \\ 0 & \text{otherwise} \end{cases} \tag{2}$$

Using the empirically validated results from [5], in which a simple mathematical model is presented of how influence impacts the process of belief formation, Equation 1 can be extended to include a "history" term in which the initial belief value of each agent is maintained. The presence of this term suggests that the

initial belief value of an agent is more difficult to overcome than was previously assumed in [8]. Furthermore, two other values can be added to the equation: S and $(1 - S)$ relating to the resistance and susceptibility, respectively, of the current agent to succomb to influence. The value S is the "influence-of-self," i.e., the degree to which the current agent will rely on its own judgement. Taking these changes into account, Equation 1 becomes:

$$\Phi_\mu(x) = S * \Phi_\mu(x)_0 + (1 - S) * \sum_{i=1}^{k} \frac{\beta(x, i, \mu) * \iota_i}{k} \tag{3}$$

This revised confidence calculation will be used in the experiment presented in Section 3.

2.2 Network Topology

The importance of network topology within social systems cannot be overstated—as evidenced by the scholarly research in this area—, and there are specific properties and characteristics of networks that help shed light on social phenomena. For example, in [7], the authors note the importance of *network density*, and state that the ability to coordinate increases in difficulty as the network becomes more dense. This is similar to work done in [10] in which the authors show that sparse social networks afford managers with greater influence than do dense networks. Moreover, in [2], the concept of *homophily* is described, which refers to the tendency of people to interact with their own kind based on individual characteristics (e.g., shared beliefs). This underscores the relevance of computing influence based on similarity, as described previously, and also provides details into how people connect to one another in the real-world. Similarly, the concept of *local influence* is important. This refers to the tendency of people who interact frequently to become more similar over time [7], which has important implications on culture. Finally, in [7], the authors also discuss the concept of *transitivity*, which suggests that a person's friends tend to interact with each other as well.

When considering network topology, the nodes become the agents and the connections represent the links between agents. These links can represent formal connections (e.g., superior to subordinate), informal ones (e.g., friendship), or both. The assumption of our previous work—that every agent is connected to every other agent—does not always hold. This type of topology represents a fully-connected, or complete, network (see graph in upper-left corner of Figures 1 and 2) and might be the case when an organization is quite small and everyone works closely with each other and communicates regularly. In such cases, every agent influences every other agent and based on the principle of *local influence*, the agents tend to reach the same belief values over time.

A small-world network (see graph in lower-right corner of Figures 1 and 2) is synonymous with the famous six-degrees of separation study, which hypothesizes that every agent in the network is connected to every other agent by only a few steps [13]. It has its roots in sociology and is based on the observation that most

people tend to have many friends that live nearby, but also have a few friends who live far away [13]. Similar situations could be considered within organizations. For example, people might have more friends in their department, but have a few friends in other departments. As such, it is a relevant topology in the study of organizational culture and bears traces of *homophily*.

A random network (see graph in lower-left corner of Figures 1 and 2) is one in which the connection between nodes is established randomly, following some probability distribution. In the case of this paper, the probability of nodes connecting is based on a binomial distribution. Interestingly, in general, a random network does not show clustering [13], which provides an interesting topology to consider. It means that the agents connected to the current agent have no greater probability of being connected to each other than two randomly selected agents within the network. This topology thus ignores the notion of *transitivity*.

Lastly, a scale-free network is one in which the node degree distribution follows a power law (see graph in upper-right corner of Figures 1 and 2). Essentially, this means that there are a few nodes that are highly connected, and relatively more nodes that are sparsely connected. These graphs grow according to the preferential attachment (similar to the concept of "the rich get richer") [13]. In this topology, the highly-connected nodes play a key role in bringing the other nodes of the network close to each other. This has parallels in the organizational world, and the highly-connected nodes can be thought of as key management within the organization which are themselves connected to less connected nodes (this speaks to *network density*).

3 Simulation Experiment

Taking the revised confidence equation along with the four topologies, a soon-to-be-growing organization of six agents is considered as the initial starting condition for the experiment. There are two kinds of actions that can take place within this organization. First, a new agent can be inserted. When this happens, the agent is added, with its initial belief value and possible connections to existing agents, based on a particular network topology (as seen in Figure 1). Once added, the belief value of this new agent is communicated to any agent with which it is connected, and these agents then request the belief values of the other agents they are connected to. This can be thought of as seeking feedback from established agents within the organization. Following this initial interaction, these requesting agents recompute their belief value confidences and communicate, individually, their belief value with the highest confidence back to the new agent. Worth noting is the fact that the new agent does have the power to sway an existing agent's perspective as its initial belief value is used in the recomputation. In turn, the new agent recomputes its confidence value based on the feedback provided, and this social process can be viewed as "instructing the newcomer" in the culture of the organization.

The second kind of action involves random "cultural events," in which an agent is selected at random and then communicates its belief value to neighbouring

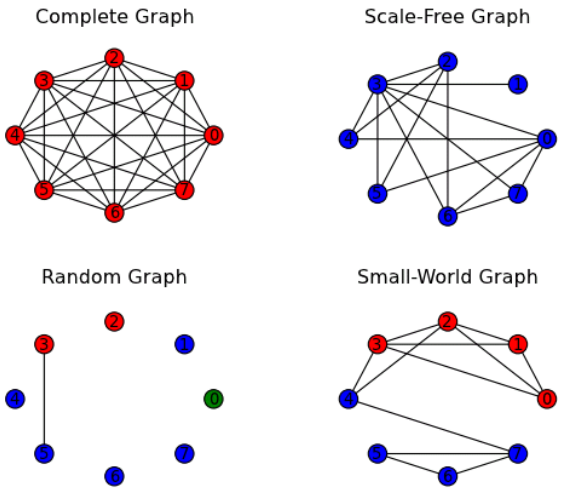

Figure 1: Belief value distribution (i.e., culture) after the insertion of eight agents.

(i.e., connected) agents. These agents, then, all recompute the confidence values of their belief following the process previously described. This particular action is motivated theoretically by work in [1] (ch. 3 and ch. 6), which posits that cultural events serve to create the idea of meaningfulness within an organization. Anyone participating in an organization, in fact, does so by interpreting cultural events and influencing the meanings that others give to these events.

In the experiment, "clone" agents are created such that $agent_{15}$, for example, in the complete graph starts with the same initial values and influences as $agent_{15}$ in all other graphs. This is important as only the impact of the network topology is being explored. Also, in this experiment, only one generic belief is considered. The results of the experiment are shown in Figures 1 and 2, and the three possible deontic values for the belief are each given a different colouring: red = prohibited; green = permitted; and blue = obliged.

The results highlight the different characteristics of the topologies. For example, once again, consistent with our previous findings in [8], the complete graph results in a homogeneous culture, supporting the integration perspective described before. Interestingly, the scale-free graph also achieves homogeneity. However, the resulting belief value is different. This suggests that the more connected agents are in a better position to promote their belief value than are the uniformly-connected agents in the first graph.

Moreover, the results of the small-world network were also consistent with the characteristics of its topology. As can be seen in Figure 2, the culture split across two fronts, perhaps indicative of subcultures within an organization existing along departmental lines.

Finally, in the case of the random network, there were no clear trends. In fact, all three belief values were present. This opens the possibility for future work in

which the role of transitivity on cultural emergence is explored more fully.

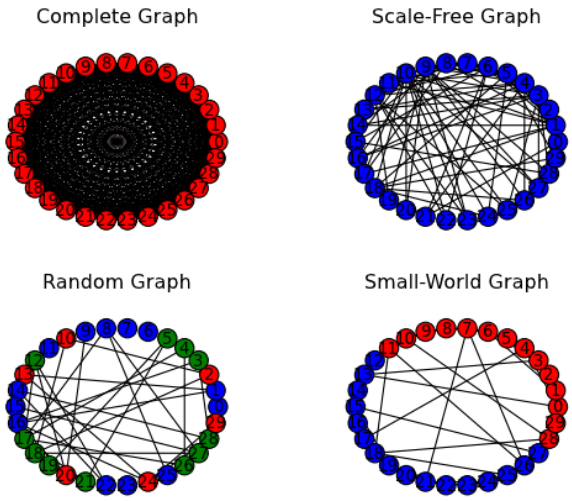

Figure 2: Belief value distribution (i.e., culture) after the insertion of 30 agents.

4 Conclusion and Future Work

This work contributes to the literature on agent organizational modelling and simulation by providing a study of the impact of network structure on culture—specifically, by comparing the fully-connected, scale-free, small-world, and random network topologies. The conclusion of this work is similar to that presented in [9]: In general, cultural heterogeneity is permitted to emerge provided there are fewer connections between an agent and those agents supporting competing belief values. This is evidenced in both the small-world and random network topologies and might indicate that real-world networks lie somewhere in the mix between the four topologies investigated in this paper. Holistically, this underlines the importance of micro-level interactions, i.e., structural influence, on macro-level behaviour, i.e., culture.

In future work, we will examine the possibility of "agents-of-change" [12]. We will focus, in particular, on how inherent qualities, such as a high influence-of-self (which represents the resilience to having ones predominate belief value changed), can be fused with purposeful placement within the network topology to yield a desired culture. This type of "cultural engineering" is particularly relevant when considering mergers and when wishing to unlock specific organizational benefits such as innovation [10].

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