A Failure to Communicate: The Role of Networks in Inter- and Intra-Group Cooperation

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Abstract

How can groups incentivize cooperative behavior when news about behavior spreads slowly or limitedly? I present a game-theoretic model in which rational agents encounter in- and out-group members at random and communicate about their encounters according to a fixed, possibly incomplete communication network determined by their social structure. The novel approach presented here makes the study of arbitrary group structures tractable, which opens the door to comparisons of social structures, of individuals within a social structure, and of potential improvements to a group's cooperative prospects. I show that despite the prevailing intuition that "the more communication the better," the volume of communication is insufficient for assessing cooperation. More links in the communication network does not imply more cooperation; the arrangement of links— exactly who communicates with whom— matters.

1 Cooperation in a limited information environment

Decentralized punishment mechanisms maintain cooperation well when everyone knows and communicates with everyone else in a group. This logic is well-known and has been used to explain a wealth of examples of cooperation outside the 'shadow of the law,' from ethnic groups peacefully coexisting to traders keeping their word to ranchers minding where their livestock graze [10, 12, 8].

When instead there is heterogeneity in the extent of direct communication between group members, so that some members are more peripheral than others, ensuring that everyone cooperates is more difficult. Some players are more likely to get away with offenses than others, and some players are more tempting targets than others, which ensures that universal cooperation is more difficult. This paper is a first attempt to relate the exact network of communication in a group— a map of who communicates with whom— to how well that group can enforce cooperation using decentralized institutions.

1.1 Incomplete communication networks

Network games with strategic players quickly become intractable [11]. While the relationship between the structure of communication or interaction has been studied when players are assumed to be non-strategic (see, for example, [4]), studying strategic players is generally made tractable by considering a single network or class of networks [5, 3, 6], by assuming that information problems are experienced homogeneously by all players [9, 13], or by imposing types and restricting their

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arrangement [2]. Here, I consider strategic players who encounter other players at random and communicate according to an arbitrary network. The network is not restricted to a particular class and players may have heterogeneous access to information.[1]

2 The model

The game is a generalization of [10], modified so that players communicate according to an arbitrary communication network, not necessarily the complete network (implicitly assumed in [10]). Consider two groups, A and B, each with a set of players $N = \{1, \dots, n\}$. In each time period, all players play one round of prisoner's dilemma with a randomly assigned opponent. With probability p a player is paired with a member selected uniformly at random from the other group; with probability $1 - p$ a player is paired with a member selected uniformly at random from his own group. Each pair plays a single round of the prisoner's dilemma with common payoff matrix

$$\begin{array}{cc} & \begin{array}{cc} C & D \end{array} \\ \begin{array}{c} C \\ D \end{array} & \begin{pmatrix} 1,1 & -\beta,\alpha \\ \alpha,-\beta & 0,0 \end{pmatrix} \end{array}$$

where $\alpha, \beta > 1$ and $\frac{\alpha-\beta}{2} < 1$. Rounds occur indefinitely. A player's total payoff is then a stream of discounted single round payoffs. Players have common discount factor $\delta < 1$.

Let $(N, g)_A$ be a fixed simple, undirected communication network for group A with nodes N and $n \times n$ adjacency matrix g such that entry $g_{ij} = 1$ indicates the presence of a link between players i and j, $g_{ij} = 0$ indicates the absence of a link between players i and j. Let $(N, g)_B$ be the same for group B. No links span $(N, g)_A$ and $(N, g)_B$.

Players can perfectly identify and recognize in-group members, but can only identify the group of out-group members. The network $(N, g)_A$ is common knowledge among players in A and $(N, g)_B$ is common knowledge among players in B; players know the shape of the other group's network but not who sits where (i.e. players only know the permutation class of the network of the other group). The roster of random assignments and the actions played in each round are not observable to all players. Instead, this information is revealed via messages to a subset of other players determined by the communication network.

In each period t, after playing one round of prisoner's dilemma, a stage of communication occurs. Information about each game played between two players in each round is packaged in a message m containing the identity of the players (as specific as possible), the time period of the round, the actions of both players, and the motives of the players (relevant motives are determined by the strategy. For the strategy profile σ^{NWIGP} below, the relevant motive will be whether D was played out of punishment or defection.) Messages about games between same-group members i and j in t perfectly identify both players, $m_{i,j,t}$, and are sent to the neighbors of i and the neighbors of j in the communication network, e.g. to $N_g(i)$ and $N_g(j)$. Messages about games between players from different groups cannot perfectly identify the opponent, and so if $i \in A$ and $j \in B$, a message $m_{i,B,t}$ is sent to neighbors of i and a message $m_{A,j,t}$ is sent to neighbors of j. A message $m_{i,j,t}$ expires after T^p rounds, in $t + T^p$. Let r govern the speed of communication so that player i does the following r times before $t + 1$ begins: send an unsent message about i's own game played in t and forward all unsent, unexpired messages to all of i's neighbors. This means that unexpired messages originating at i in time t are received by all players reachable in r degrees or fewer before $t + 1$. Messages are sent deterministically and are not manipulated strategically.[2]

[1]The innovation here is that players are matched at random but learn about others via the network. This setup, combined with "presumption of innocence" strategies, simplifies players' inference problem and adds tractability. Once nice consequence is that the model implies a single parameter—the probability of punishment (z)—which reduces the usually multidimensional problem of comparing networks to a single dimension.

[2]Strategic manipulation of messages is considered in [18].

2.1 In-group policing

The strategy profile of interest is σ^{NWIGP}, which has groups punish their own members to keep them cooperating with in- and out-group members.[3]

Network In-Group Policing (σ^{NWIGP}). *All players always punish a player (play D) they know to be in punishment phase, and always cooperate with a player (play C) they do not know to be in punishment phases, using the following definitions: all players begin as cooperators (not in punishment phase). A player enters (or reenters) punishment phase for T^p periods when that player (1) defects against an out-group member, (2) defects against someone not known to be in punishment phase, or (3) cooperates with someone known to be in punishment phase. A player i is known by his opponent to be in punishment phase when his opponent was the victim of (2) or (3) committed by i in at least one of the past T^p rounds or has received a message that i committed (1), (2) or (3) in at least one of the past T^p rounds.*

In other words, players punish based on what they know. Punishment *would* be T^p rounds of capitulation *if* all opponents in the T^P rounds after the defection know about the defection. If the communication network is sparse or the reach of communication (r) is small, a player can expect fewer rounds of punishment in some cases, and based on the shape of the communication network, different players can expect different amounts of punishment.

3 Full cooperation

The strategy profile σ^{NWIGP} instructs players to punish members of their own group who are known to be defectors, and this punishment threat entices players to be cooperative. Even when the gossip network is incomplete, this strategy profile will result in a fully cooperative sequential equilibrium under certain conditions. Strategies must be sequentially rational given they way players form beliefs over their missing information, and beliefs must be consistent [16].

Proposition 1: Full Cooperation. *σ^{NWIGP} is sequentially rational for game G with networks $g_A = g_B$ iff*

$$\delta^{T^p} \geq \max\left\{\frac{\alpha-1}{(1-p)z^{out}_{min,T^p}(\beta+1)}, \frac{\beta}{(1-p)z^{in}_{min,T^p}(\beta+1)}\right\}$$

and

$$p < \min\left\{\frac{z^{in}_{min,T^p}(1+\beta)-\beta}{z^{in}_{min,T^p}(1+\beta)}, \frac{z^{out}_{min,T^p}(1+\beta)-\alpha+1}{z^{out}_{min,T^p}(1+\beta)}\right\}$$

where z^{out}_{min,T^p} and z^{in}_{min,T^p} are the probability that the least-punishable defection will be punished at the end of the punishment phase when the defection is committed against an out-group member and in-group member, respectively.[4] The minimum probabilities of punishment for a defection against an in-group member and an out-group member are functions of the network and can be written:

$$z^{out}_{min,T^p} = \min_i\{\frac{\#N_i^{rT^p}}{n-1}\}$$

and

[3]This strategy profile is of interest because it can obtain full cooperation in equilibrium in an optimal way– punishment is renegotiation-proof and mistakes do not doom cooperation– without violating a conception of fairness as equal treatment in punishment. The strategy profile also has the desirable property of being realistic– something like it seems to be employed in real-world settings (see[10, 22]).

[4]The behavior in equilibrium is of greater interest than the beliefs in equilibrium. It can be shown that σ^{NWIGP} is sequentially rational in any information set with any beliefs over nodes in the information set. Beliefs can then be constructed which satisfy the definition of consistency, making σ^{NWIGP} part of a sequential equilibrium. The proof of Proposition 1 and a fuller discussion of beliefs can be found in [19].

$$z^{in}_{min,T^p} = \min_{i,j}\{\frac{\#\left(N_i^{rT^p} \cup N_j^{rT^p}\right)}{n-1}\}.$$

where $\#\left(N_i^{rT^p}\right)$ is the number of players reachable from i in rT^P degrees.

3.1 Counting links is insufficient

Proposition 2: More is not necessarily better. *The topology of the network matters. If network $g'(N)$ contains a larger number of links than $g(N)$, this does **not** imply that $z(g'(N))^{in}_{min,T^p} \geq z(g(N))^{in}_{min,T^p}$ or that $z(g'(N))^{out}_{min,T^p} \geq z(g(N))^{out}_{min,T^p}$.*

Consider an example, shown in Figure 1. Let the length of punishment be a single round ($T^p = 1$), and let information spread a single degree after each round ($r = 1$). The group on the left has more channels of communication (11 links) than the group on the right (6 links), but player 3 is less likely to be punished by his own group for defecting against a member of the out-group (not pictured) when he belongs to the left group ($z^{out}_{min,T^p} = .2$) than when he belongs to the right ($z^{out}_{min,T^p} = .4$).

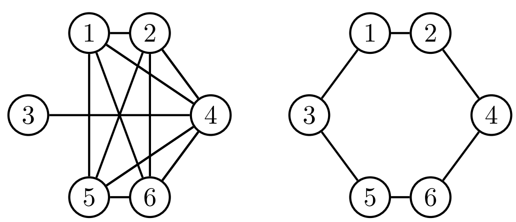

Figure 1: Left: 6 players and 11 links, Right: 6 players and 6 links.

Hence the structure of a group matters; counting links is insufficient to characterize cooperation.

4 Conclusion

When groups are large or busy or sparsely populated or busy or have poor communications technology, information may spread according to an incomplete communication network. The above shows that in-group policing strategies which presume innocence can maintain cooperation in these circumstances, and how well groups can enforce cooperation depends on the structure of communication. While at first blush it may seem that the more communication the better, it turns out that the volume of communication is *not* a sufficient statistic for cooperation.

This setup allows comparisons of groups, and comparisons of individuals within groups. Players who are more peripheral—about whom less is known and who receive less information about others— are the biggest problems for full cooperation. It can be shown that when there are players who are peripheral enough, full cooperation may be impossible and *mostly* cooperative equilibria exist in which *most* players are cooperative but some cheat [17]. This cheating targets the out-group, and can in some cases even targets in-group members.

Empirical social science research is replete with disparate studies finding a relationship between group structure and cooperation [21, 15, 14, 7, 20, 1]. Theory relating group structure to cooperation has lagged behind. This theoretical foundation can guide future empirical work by proposing a precise mechanism by which structure may affect cooperation.

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