Multiplayer Ultimatum Games and Collective Fairness in Networked Communities

Fernando P. Santos[1,2], Jorge M. Pacheco[3,2], Ana Paiva[1], and Francisco C. Santos[1,2]

[1]GAIPS/INESC-ID and Instituto Superior Técnico, Universidade de Lisboa, Portugal
[2]ATP-group, Portugal [3]CBMA and Universidade do Minho, Portugal

The outcome of human interactions is influenced by fairness (Fehr and Fischbacher (2003)), which often stands in disagreement with typical payoff-maximising – and rationality – assumptions. In this context, while the dynamics of fairness in two-person interactions has been given significant attention, mostly in the context of Ultimatum Games (UG) (Güth et al. (1982)), the challenge introduced by groups has not received a corresponding emphasis. In many situations individuals decide, collectively, to give up some of their wealth to punish unfair behaviour of others (Fehr and Schmidt (1999)): collective bargaining of work contracts, the Chinese concept of *tuangou* (or group buying), policy-making by coalitions, international climate summits or the simple act of scheduling a group dinner are a few examples where interactions take place in groups in which individual assessment of fairness contributes to the overall degree of fairness reflected in the (collective) group decision process. Also, the fact that individuals often participate in multiple groups makes it important to understand to which extent our network ties and the way groups are assembled influence overall fairness. Here we present a summary of our recent works in which we employ computer simulations to analyse the population dynamics arising from Multiplayer Ultimatum Game (MUG), where proposals are made to groups, and interactions take place in complex networks of exchange and cooperation **(Santos et al. (2017, 2016, 2015))**.

In MUG, we assume that proposals are made by one individual (the Proposer) to the remaining $N-1$ Responders, who must individually reject or accept the proposal (Santos et al. (2015)). Since individuals may act both as Proposers and Responders, each individual has a strategy characterised by two real numbers, p and q. The Proposer will try to split the endowment, offering p to the Responders. Each of the Responders will individually accept the offer made to the extent that his/her q-value is not larger than the p-value of the Proposer. Overall group acceptance will depend upon M, the minimum fraction of Responders that must accept the offer before it is valid. Consequently, if the fraction of individual acceptances stands below M, the offer will be rejected. Otherwise, the offer will be accepted. In this case, the Proposer will keep $1-p$ to himself and the group will share the remainder, each obtaining $p/(N-1)$. If the proposal is rejected, no one earns anything (Santos et al. (2015)).

We shall note that the theoretically predicted outcomes in MUG follow the same forecast as for the 2-person UG. The maximum payoff of an individual is obtained when p (value of proposal) is the smallest possible. As any accepted proposal yields more payoff to a Responder than a rejection, we anticipate frequent acceptances and very low proposals. In fact, reasoning in a backward fashion, the conclusions regarding the *sub-game perfect equilibrium* of both UG and MUG anticipate the use of the smallest possible p and q, irrespectively of N and M (Santos et al. (2016)).

On top of explicitly considering the role of groups, by using MUG we also provide an additional path to disambiguate the true intentions of individuals when playing Ultimatum Games. It is a long-standing debate whether people propose fair offers because they fear a rejection – thus earning 0 – or due to other-regarding preferences and equalitarian motives. With MUG, increasing M increases the risk in having a proposal rejected, by imposing stricter rules for a group to accept a proposal. This way, if proposals rise in response of an increase in M, we may anticipate that people fear their proposals being rejected. Contrariwise, proposals rising with N increases means that people care about the overall level of group equality and fairness.

Here we report the results of computer simulations (Santos et al. (2015, 2016, 2017)) that were previously built and executed in order to address some of the previous questions: **1)** what is the effect of varying N on the overall fairness in agents' societies? **2)** What is the effect of varying M? **3)** What is the effect of considering different group arrangements – e.g., groups overlapping to different extents, a property that can be formalised through complex networks metrics (see below) – in the ensuing levels of fairness? **4)** What are the differences between different types of learning processes (e.g., social vs individual learning)?

In the results here reported, we assume that MUG is played over an underlying network of contacts, considering the usual group formation process of multiplayer games on

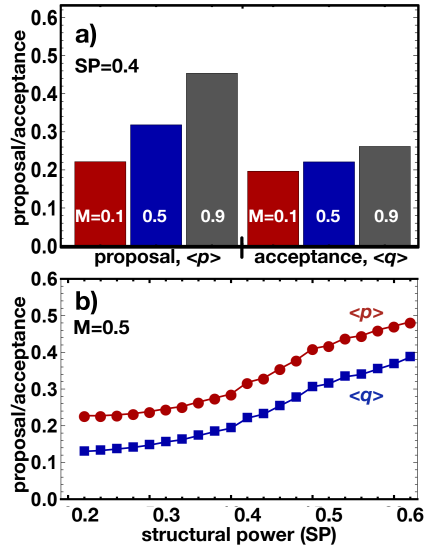

Figure 1: The levels of fairness when playing MUGs increase with **a)** the fraction of individuals needed to render a proposal accepted (M) and **b)** the level of structural power (SP) between individuals in the population, a property controlled by the underlying network of contacts. population size=Z=1000. These results correspond to an average over 100 runs considering 10 different networks for each SP.

networks in which one node defines, together with his/her direct neighbours, a group (Santos et al. (2008)). This way, individuals may appear repeatedly in the interaction groups of others, which may provide increased structural power (SP) to some individuals over others. We define the SP of A over B as $SP_{A,B} = \frac{|I(A) \cap I(B)|}{|I(B)|}$, where $I(X)$ represents the groups in which individual X appears and $|I(X)|$ represents the number of groups in $I(X)$. One may note that, using the Kronecker $\delta_{A,B}$ to identify edges between A and B (e.g, 1 if an edge connects nodes A and B and 0 otherwise), denoting by $o_{A,B}$ (overlap) the number of common neighbours between A and B and by k_x the number of neighbours of X, then the SP of A over B is given by $SP_{A,B} = \frac{2\delta_{A,B}+o_{A,B}}{k_B+1}$. Intuitively, if one individual is a direct neighbour of other ($\delta_{A,B} = 1$), they will meet in at least two groups, where each one will be the focal in each group. They will meet one more time for each of their $o_{A,B}$ common neighbours. If B has connectivity k_B, then this node participates in $k_B + 1$ groups, providing the proper normalisation to $SP_{A,B}$ The average SP of one node is defined as $SP_A = |R(A)|^{-1} \sum_{i \in R(A)} SP_{A,i}$, where $R(A)$ is the set of individuals reached by individual A, either directly or through a common neighbour.

We simulate the evolution of p and q in a population of size Z=1000, much larger than the group size N (average N is 7). Initially, we equip individuals with values of p and q drawn from a discretised uniform probability distribution in {0, 0.01,...,1} containing 101 values. The fitness F_i of an individual i of degree k is determined by the payoffs resulting from the game instances occurring in $k+1$ groups: one centred on her neighbourhood plus k others centred on each of her k neighbours. Values of p and q evolve as individuals tend to imitate (i.e., copy p and q) those neighbours that obtain higher fitness values. First of all, we observe that the values of proposal systematically increase with M (see Fig. 1a) supporting the idea that stricter group decision rules augment the levels of fairness in the population (Santos et al. (2015)). Preliminary experimental results with humans (Santos et al., in preparation) also support this conclusion. In (Santos et al., 2015) we also show that the effect of N is contingent on M: fairness increases with N if M is high. These conclusions are valid if, instead of imitation, individuals interact with the same probability with anyone in the population (well-mixed assumption) and strategies are adopted resorting the agents' own experience, following a process of individual reinforcement learning (Santos et al. (2016)). Also, Fig. 1b shows the average proposal p and acceptance threshold q that we obtain, as a function of the network SP (Santos et al. (2017)). Clearly, high values of SP lead to higher average values of p and q, in which case individuals adopt fairer strategies. Our results suggest that a strong interdependence of groups taking part in collective decisions, here quantified by means of the SP, may be central in promoting seemingly paradoxical human features such as fairness.

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