A Multi-level Selection Model for the Emergence of Social Norms

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Abstract. We develop a multi-level selection model in the framework of indirect reciprocity. Using two levels of selection, one at the individual level and another at the group level, we propose a competitive scenario among social norms, in which all individuals in each group undergo pairwise interactions, whereas all groups also engage in pairwise conflicts, modeled by different games. Norms evolve as a result of groups' conflicts whereas evolution inside each group promotes the selection of best strategies for each ruling social norm. Different types of inter-group conflict and intensities of selection are considered. The proposed evolutionary model leads to the emergence of one of the recently obtained *leading-eight* social norms, irrespective of the type of conflict between groups employed. We also compared the individual performance of the norm obtained in the evolutionary process with several other popular norms, showing that it performs better than any the other norms. This reputation assignment rule gives rise to a stern and unambiguous response to each individual behavior, where prompt forgiving coexists with implacable punishment.

1 Introduction

Many biological systems employ cooperative interactions in their organization [1]. Humans, unlike other animal species, form large social groups in which cooperation among non-kin is widespread. This contrasts with the general assumption that the strong and selfish individuals are the ones who benefit most from natural selection. This being the case, how is it possible that unselfish behaviour has survived evolution? Adopting the terminology resulting from the seminal work of Hamilton, Trivers, and Wilson [2,3,4], an act is altruistic if it confers a benefit b to another individual in spite of accruing a cost c to the altruist (where it is assumed, as usual, that $b > c$). In this context, several mechanisms have been invoked to explain the evolution of altruism, but only recently an evolutionary model of indirect reciprocity (using the terminology introduced in [5]) has been developed [6] addressing *unique aspects of human sociality, such as*

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trust, gossip and reputation [7]. As a means of community enforcement, indirect reciprocity had been investigated earlier in the context of economics, notably by Sugden [8] and Kandori [9] (see below). More recently, many studies [10,11,12,13,14,15,16,8,7,17] have been devoted to investigate how altruism can evolve under indirect reciprocity.

In the indirect reciprocity game, any two players are supposed to interact at most once with each other, one in the role of a potential donor, while the other as a potential receiver of help. Each player can experience many rounds, but never with the same partner twice, being direct retaliation unfeasible. By helping another individual, a given player may increase (or not) its reputation, which may change the pre-disposition of others to help her in future interactions. However, its new reputation depends on the social norm used by her peers to assess her action as a donor. Previous studies of reputation-based models of cooperation, reviewed recently [10] indicate that cooperation outweighs defection whenever, among other factors, assessment of actions is based on norms which require considerable cognitive capacities [10,12,13]. Such high cognitive capacity contrasts with technology-based interactions, such as e-trade, which also rely on reputation-based mechanisms of cooperation [18,19,20]. Despite the success and high levels of cooperation observed in e-trade, it has been found [18] that publicizing a detailed account of the seller's feedback history does not improve cooperation, as compared to publicizing only the seller's most recent rating. In other words, practice shows that simple reputation-based mechanisms are capable of promoting high levels of cooperation. In view of the previous discussion, it is hard to explain the success of e-trade on the basis of the results obtained so-far for reputation-based cooperation in the context of indirect reciprocity.

2 Evolving Social Norms

Let us consider a world in black and white consisting of a set of tribes, such that each tribe lives under the influence of a single norm, common to all individuals. Each individual engages once in the indirect reciprocity game (cf. section 7) with all other tribe inhabitants. Its action as a donor will depend on its individual strategy, which dictates whether it will provide help or refuse to do it. Reputations are public: this means that the result of every interaction is made available to every one through the *indirect observation model* introduced in [13] (see also [15]). This requires a way to spread the information (even with errors) to the entire population (communication/language). Consistently, language seems to be an important cooperation promoter [21] although recent mechanisms of reputation spreading rely on electronic databases (e.g., in e-trade, where reputation of sellers is centralized). If you consider that each individual action is determined by both donor and receptor's reputations, and since reputations are either *GOOD* or *BAD*, there are $2^4 = 16$ possible strategies. On the other hand, the number of possible norms used to assess each individual's action depends on their associated order. The simplest are the so-called first order norms, in which all that matters is the action taken by the donor. In second order norms the reputation of one of the players (donor or recipient) also contributes to decide the

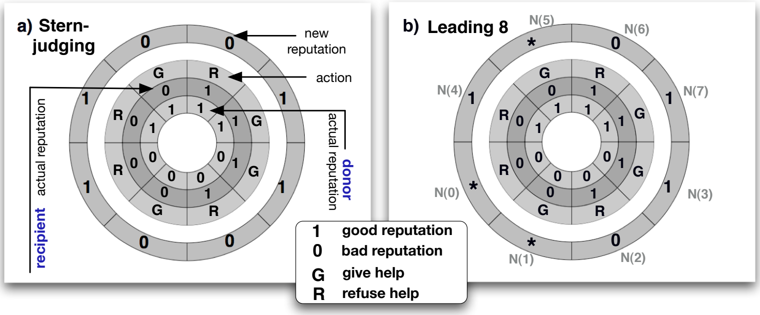

Fig. 1. The higher the order (and complexity) of a norm, the more inner layers it acquires. The outer layer stipulates the donor's new reputation based on the 3 different reputation/action combinations aligned radially layer by layer: Inwards, the first layer identifies the action of the donor. The second identifies the reputation of the recipient; the third the reputation of the donor. Out of the 2^8 possible norms, the forth represents one social norm. In a) we show the most successful norm, *stern-judging*. Stern-judging renders the inner layer (donor reputation) irrelevant in determining the new reputation of donor. This can be trivially confirmed by the symmetry of the figure with respect to the equatorial plane (not taking the inner layer into account, of course). All norms of second order will exhibit this symmetry, although the combinations of 1 and 0 bits will be, in general different. b) The *Leading 8* Norms of Ohtsuki and Iwasa, identifying with $*$ those *slices* in the final norm which can be associated with either *GOOD* (1) or *BAD* (0) reputations.

new reputation of the donor. And so on, in increasing layers of complexity and associated requirements of cognitive capacities from individuals. Any individual in the tribe shares the same norm, which in turn raises the question of how each inhabitant acquired it. We do not address this issue here. However, inasmuch as indirect reciprocity is associated with *community enforcement* [6,9] one may assume, for simplicity, that norms are acquired through an educational process. Moreover, it is likely that a common norm contributes to the overall cohesiveness and identity of a tribe. It is noteworthy, however, that if norms where different for different individuals, the *indirect observation model* would not be valid, as it requires trust in judgments made by co-inhabitants. For a norm of order n there are 2^{2^n} possible norms, each associated with a binary string of length 2^n . Here, we consider third order norms (8 bits). In assessing a donor's new reputation, the observer has to make a contextual judgment involving the donor's action and the reputation of the donor and the receiver (see Figure 1).

We introduce the following evolutionary dynamics inside each tribe: During one generation all individuals interact once with each other via the indirect reciprocity game. When individuals reproduce they replace their strategy by that of another individual from the same tribe, chosen proportional to her accumulated payoff [12]. The most successful individuals in each tribe have a higher reproductive success. Since different tribes are *under the influence* of different norms, the overall fitness of each tribe will vary from tribe to tribe, as well as the plethora of successful strategies which thrive in each tribe. This describes individual selection in each tribe. At a higher level, tribes also engage in pairwise conflicts with a small probability, associated with selection between tribes. We consider different forms of conflict between tribes, which reflect different types of inter-tribe selection mechanisms based on the average global payoff of each tribe [5,22,23,24,25], involving different selection processes and intensities of selection: imitation dynamics, a Moran-like process, the pairwise comparison process and a war of attrition (see section 7 for details). We perform extensive computer simulations of evolutionary dynamics of sets of 64 tribes, each with 64 inhabitants. Once a stationary regime is reached, we collect information for subsequent statistical analysis. We compute the frequency of occurrence of bits 1 and 0 in each of the 8 bit locations. A bit is said to fixate if its frequency of occurrence exceeds or equals 98%. Otherwise, no fixation occurs, which we denote by X, instead of 1 or 0. We analyze 500 simulations for the same value of b, subsequently computing the frequency of occurrence ϕ_1, ϕ_0 and ϕ_X of the bits 1, 0 and X, respectively. If $\phi_1 > \phi_0 + \phi_X$ the final bit is 1; if $\phi_0 > \phi_1 + \phi_X$ the final bit is 0; otherwise we assume it is indeterminate, and denote it by $*$. It is noteworthy that our bit-by-bit selection/transmission procedure, though artificial, provides a simple means of mimicking biological evolution, where genes are interconnected by complex networks and yet evolve independently. Certainly, a co-evolutionary process would be more appropriate (and more complex), and this will be explored in future work.

3 Emergence of an Unique Social Norm

The results, for different values of b are given in Table 1, showing that a unique, ubiquitous social norm emerges from these extensive numerical simulations. This norm is of second-order, which means that all that matters is the action of the donor and the reputation of the receiver. In other words, even when individuals are equipped with higher cognitive capacities, they rely on a simple norm as a key for evolutionary success. In a nutshell, helping a good individual or refusing help to a bad individual leads to a good reputation, whereas refusing help to a good individual or helping a bad one leads to a bad reputation. Moreover, we find that the final norm is independent of the specifics of the second level selection mechanism, i.e., different second level selection mechanisms will alter the rate of convergence, but not the equilibrium state. In this sense, we conjecture that more realistic procedures will lead to the same dominant norm.

The success and simplicity of this norm relies on never being morally dubious: To each type of encounter, there is one *GOOD* move and a *BAD* one. Moreover, it is always possible for anyone to be promoted to the best standard possible in a single move. Conversely, one bad move will be readily punished [26,27] with the reduction of the player's score. This prompt forgiving and implacable punishment leads us to call this norm *stern-judging*. Long before the seminal work of Nowak and Sigmund [6] several social norms have been proposed as a means

Table 1. For each value of the benefit b (c=1), each column displays the eight-bit norm emerging from the analysis of 500 simulations employing the selection method between tribes indicated as column headers. Irrespective of the type of selection, the resulting norm which emerges is always compatible with *stern-judging.* For the pairwise comparison rule, the inverse temperature used was $\beta = 10^5$ (strong selection, see Sections 4 and 7).

b	Imitation dynamics	Moran	Pairwise Comparison	War of Attrition
2	10011001	1*011001	10011001	********
≥ 3	10011001	10011001	10011001	10011001

Table 2. Emergence of *stern-judging* for different intensities of selection. We carried out the bit-fixation analysis described in main text for the evolution of social norms under the pairwise comparison rule (see section 4), for different values of the intensity of selection β. Intensity of selection decreases from left to right. Whereas for strong selection all norm bits fixate for $b \geq 2$, fixation becomes more difficult for b=2 as β decreases. Yet, in no case did we obtain fixation of a digit incompatible with *stern-judging.*

b	$\beta = 10^5$	$\beta = 10^4$	$\beta = 10^3$	$\beta = 10^2$	$\beta = 10^1$	$\beta = 10^0$
2	10011001	1*011001	1*01100*	1*01100*	1*01100*	********
≥ 3	10011001	10011001	10011001	10011001	10011001	10011001

to promote (economic) cooperation. Notable examples are the standing norm, proposed by Sugden [8] and the norm proposed by Kandori [9] as a means to allow community enforcement of cooperation. When translated into the present formulation, standing constitutes a third-order norm, whereas a fixed-order reduction of the social norm proposed by Kandori (of variable order, dependent on the benefit to cost ratio of cooperation) would correspond to *stern-judging.* Indeed, in the context of community enforcement, one can restate *stern-judging* as : *Help good people and refuse help otherwise, and we shall be nice to you; otherwise, you will be punished.* It is therefore, most interesting that the exhaustive search carried out by Ohtsuki and Iwasa [13,15] in the space of up to third-order norms found that these two previously proposed norms were part of the so-called *leading-eight* norms of cooperation.

4 Norm Evolution for Different Intensities of Selection

The pairwise comparison rule [28], one of the evolutionary mechanisms used in the previous section (see also section 7), provides a convenient framework to study how the intensity of selection between tribes affects the emergence of *stern-judging.* It corresponds to introduce the following dynamics: Given two tribes chosen for a conflict, say A and B, with average payoffs P_A and P_B, respectively, then norm of tribe B will replace that of A with a probability given by $p = (1 + e^{-\beta.(P_B - P_A)})^{-1}$, whereas the inverse process will occur with probability $(1 - p)$. In physics this function corresponds to the well-known

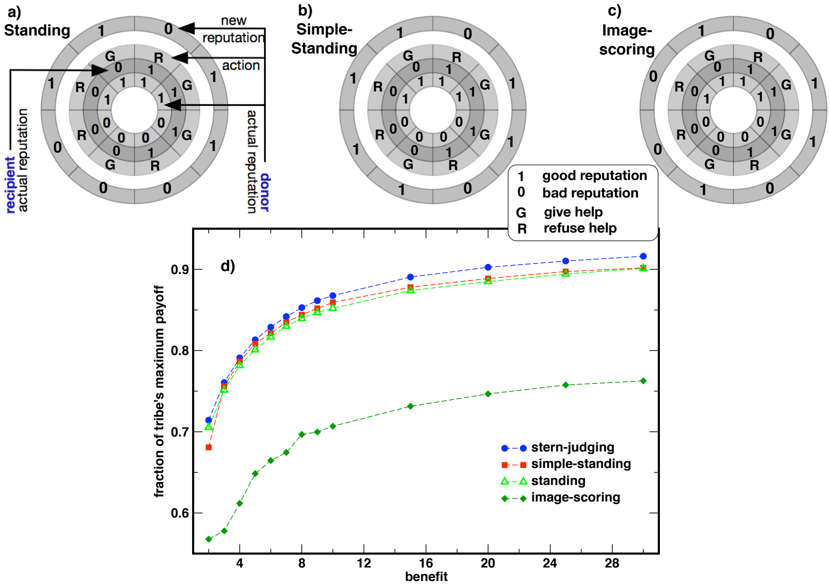

Fig. 2. We depict the three norms (besides *stern-judging* - Fig.1-a), the performance of which we analysed. Both *stern-judging*, *simple-standing* and *image-scoring* are symmetric with respect with the equatorial plane, and as such are second order norms. As for standing, it clearly breaks this symmetry, constituting a third order norm. In d), we plot the ratio between the average payoff attained by each tribe under the influence of a single, fixed norm, and the maximum value possible, given the population size (64), the benefit from cooperation (b) and the cost of cooperation ($c = 1$).

Fermi distribution function, in which the inverse temperature β determines the sharpness of transition from $p = 0$, whenever $P_B < P_A$, to $p = 1$, whenever $P_A < P_B$. Indeed, in the limit $\beta \to +\infty$, we obtain imitation dynamics (strong selection), whereas whenever $\beta \to 0$, B replaces A with the same probability that A replaces B. As we change β between these two extreme limits, we can infer the role of selection intensity on the emergence of *stern-judging*. In Table 2 we show results for different values of β, which testify for the robustness of *stern-judging*. In other words, in spite of the fact that, with decreasing β (decreasing selection intensity), it becomes increasingly difficult for all 8 bits to fixate whenever $b = 2$, in no case do we get results which deviate from *stern-judging* as the emerging social norm. These results reinforce the conclusion that *stern-judging* is robust and ubiquitous.

5 Cooperation Under a Selected Social Norm

Among the *leading-eight* norms discovered by Ohtsuki and Iwasa [13,15] (Fig. 1-b), only *stern-judging* [6] and the so-called simple-standing [29] constitute second-order norms. Our present results clearly indicate that *stern-judging* is favored compared to all other norms. Nonetheless, in line with the model considered here, the performance of each of these norms may be evaluated by investigating how each norm performs individually, taking into account all 16 strategies simultaneously. We compare the performance of *stern-judging* with the popular norms standing and *image-scoring*, as well as with the other second-order norm which incorporates the *leading-eight*, coined *strict-standing* [29]. We shall maintain mutation errors in strategy update, as well as errors of implementation. As a result, and given a fixed (immutable) norm, selection and mutation dictates the simultaneous evolution of all the 16 strategies in a given tribe. In Fig. 1-b we depict the *leading-eight* norms. The *slices* identified by $*$ correspond to places where both *GOOD* (1) or *BAD* (0) reputations can be freely assigned, the remaining norm being on of the *leading-eight.* Since a second order norm, in this representation, is simply a norm which exhibits a mirror symmetry with respect to the equatorial plane, it is obvious that there are only two second order norms which incorporate the *leading-eight*: Besides *stern-judging* (see Fig. 1-a), also simple-standing (Fig. 2-a) belongs to the *leading-eight. Image-scoring* and *standing*, the original norm proposed by Sugden, complete the set of norms of Fig. 2.

In Fig. 2-d we show results for the ratio between the average payoff reached in each tribe and the maximum average payoff attainable in that tribe, given the tribe size and the benefit (keeping cost=1). This quantity is plotted as a function of the benefit from cooperation, b. The results in Fig. 2-d show that *stern-judging* performs better than any of the other norms. Both standing and simple-standing lead to very similar performance, which reinforces the idea that second order norms are enough to promote cooperation under indirect reciprocity. Finally, *image-scoring* performs poorly compared to any of the other norms, a feature which is also related to the fact that the present analysis was carried out in the presence of errors [16,7,17,12].

6 Conclusion

Analyzing the approaches in the previous sections, we should note the results obtained in sections 3 and 4 are stronger than the analysis carried out with fixed social norms, since *stern-judging* emerges as the most successful norm surviving selection and mutation with other norms, irrespective of the selection mechanism. In other words, *stern-judging*'s simplicity and robustness to errors may contribute to its evolutionary success, since other well-performing strategies may succumb to invasion of individuals from other tribes who bring along strategies which may affect the overall performance of a given tribe. In this sense, robustness plays a key role when evolutionary success is at stake. We believe that *stern-judging* is the most robust norm promoting cooperation.

The present result correlates nicely with the recent findings in e-trade, where simple reputation-based mechanisms ensure high levels of cooperation. Indeed, *stern-judging* involves a straightforward and unambiguous reputation assessment, decisions of the donor being contingent only on the previous reputation of the receiver. We argue that the absence of constraining environments acting upon the potential customers in e-trade, for whom the decision of buying or not buying is free from further ado, facilitates the adoption of a *stern-judging* assessment rule. Indeed, recent experiments [30] have shown that humans are very sensitive to the presence of subtle psychologically constraining cues, their generosity depending strongly on the presence or absence of such cues. Furthermore, under simple unambiguous norms humans may escape the additional costs of conscious deliberation [31].

As conjectured by Ohtsuki and Iwasa [13] (cf. also [5,22]), group selection might constitute the key-element in establishing cooperation as a viable trait. The present results show that even when more sophisticated selection mechanisms operate between tribes, the outcome of evolution still favors *stern-judging* as the most successful norm under which cooperative strategies may flourish.

7 Simulations

Individual Interactions. We considered sets of 64 tribes, each tribe with 64 inhabitants. Each individual engages in a single round of the following indirect reciprocity game [6] with every other tribe inhabitant, assuming with equal probability the role of donor or recipient. The donor decides it provides help to the recipient, following her individual strategy that regards its own reputation and the reputation of the receiver. This results in a total of 16 strategies, encoded in a string of four bits. If it helps, donor's payoff decreases by $c = 1$, while the recipient's payoff increases by $b > 1$. In case of defection, the payoffs remain. This action will be witnessed by a third-party individual who, based on the tribe's social norm, will ascribe (subject to some small error probability $\mu = 0.001$) a new reputation to the donor. Moreover, individuals may fail to do what their strategy compels then to do, with a small execution error probability $\mu_c = 0.001$. After all interactions take place, one generation has passed, simultaneously for all tribes. Individual strategies in each tribe replicate to the next generation in the following way: For every individual A in the population we select an individual B proportional to fitness (including A) [12]. The strategy of B replaces that of A, apart from bit mutations occurring with a small probability $\mu_s = 0.01$.

Conflicts Among Tribes. With probability $p_{conflict} = 0.01$, all pairs of tribes may engage in a conflict, in which each tribe acts as an individual unit. Different types of conflicts between tribes have been considered which, besides the pairwise interaction rule introduced in section 4, we describe in the following. *Imitation Selection*: we compare the average payoffs P_A and P_B of the two conflicting tribes A and B, the winner being the tribe with highest score; *Moran Process*: In this case the selection method between tribes mimics that used between individuals in each tribe; one tribe B is chosen at random, and its norm is replaced by that of another tribe A chosen proportional to fitness ; *War of attrition*: We choose at random two tribes A and B with average payoffs P_A and P_B. We assume that each tribe can display for a time which is larger the larger its average payoff. To this end we draw two random numbers R_A and R_B each following an exponential probability distribution given by $\frac{e^{-t/P_A}}{P_A}$ and $\frac{e^{-t/P_B}}{P_B}$, respectively. The larger of the two numbers identifies the winning tribe. As a result of inter-tribe conflict (an additional conflict is discussed in [14]), the norm of the loosing tribe (B) is shifted in the direction of the victor norm (A). After the conflict, each bit of the A's norm will replace the corresponding bit of norm of tribe B with probability $p = \frac{\eta P_A}{\eta P_A + (1-\eta) P_B}$ which ensures good convergence whenever $\eta < 0.2$, independently of the type of conflict (a bit-mutation probability $\mu_N = 0.0001$ has been used). Furthermore, a small fraction of the population of tribe A replaces a corresponding random fraction of tribe B: Each individual of tribe A replaces a corresponding individual of tribe B with a probability $\mu_{migration} = 0.005$. Indeed, if no migration takes place, a tribe's population may get trapped in less cooperative strategies, compromising the global convergence of the evolutionary process.

Parameters. Each simulation runs for 9000 generations, starting from randomly assigned strategies and norms, in order to let the system reach a stationary situation, typically characterized by all tribes having maximized their average payoff, for a given benefit $b > c = 1$. The subsequent 1000 generations are then used to collect information on the strategies used in each tribe and the norms ruling the tribes in the stationary regime. As a cross validation, results did not change if instead we ran simulations for 14000 generations, accumulating information over the subsequent 1000 generations. This indicates that a steady state has been reached. We ran 500 evolutions for each value of b, subsequently performing a statistical analysis of the bits which encode each norm, as detailed before. In our simulations, we adopted the following values: $\eta = 0.1$, $\mu_N = 0.0001$, $\mu_S = 0.01$ and $\mu_a = \mu_e = 0.001$. The benefit b varied from $b = 2$ to $b = 36$. Our conclusions are robust to reasonable changes of these parameters. Moreover, results presented are qualitatively invariant to variations of the different mutation rates introduced above, as well as to variation of population size and number of tribes. Furthermore, reducing the threshold from 98% to 95% does not introduce any changes in the results shown. Finally, in Fig. 2-d we ran 500 simulations for each tribe with 64 inhabitants, and used the last 1000 generations from a total of 10000.

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