Cooperative behaviour under varying social conditions

Author: Clàudia Payrató Borràs and Advisor: Josep Perelló Palou
Facultat de Física, Universitat de Barcelona, Diagonal 645, 08028 Barcelona, Spain.

Abstract: The aim of this paper is to study human cooperative behaviour on a varying set of social games. Real data are analysed regarding persistent, mimetic and reciprocal strategies. Results assert that players did not act rationally but were affected by their immediate memory. In particular individual history rather than the environment has a significant influence on decision-making. Our findings suggest that human cooperation may emerge as a built-in trait.

I. INTRODUCTION

The concept of cooperation is one of the most powerful ideas of interdisciplinary research. From ant's social life [1] to self-organization of crystals [2], cooperative phenomena can be observed in almost any situation involving collective actions. Hence our struggle to understand nature demands nowadays a wider knowledge of the manner in which cooperation emerges.

Cooperation is not a new concept in physics, though. Thermodynamics has widely studied how in some phase transitions correlations between individual agents are so intense that the whole system behaves as one. Theories such as the Ising model can be understood in cooperative terms as well, where the particles can choose whether to cooperate (parallel spins) or defect (opposite spins) on the basis of a certain exchange potential. On the whole, any subject aiming to analyse how macroscopic phenomena arise from microscopic interactions will be eventually related to this idea.

The newly born interest in modelling systems that exhibit this sort of behaviour has extended tools and concepts traditionally belonging to physics to other fields such as biology, economy or sociology. Although contexts may be strikingly divergent, the methodology involved remains nearly the same. They all may require working with a big amount of variables, incomplete information on the way subjects interact or facing a significant reduction of the degrees of freedom.

This kind of interdisciplinar thinking is risky but prolific. Computing science, bioengineering or biophysics are some examples of promising research born in between different disciplines. Lately, some of these topics have been gathered together under the name of Complex Systems, a new area of knowledge which is rapidly gaining followers as well as scientific recognition. Game theory and so a big part of the notions we deal with on this text form part of this field.

Finally, comprehending human mind is undoubtedly a complex problem where many factors may be interlinked, requiring a delicate treatment. Sociophysics or neurophysics are some of the most recent attempts to approach this question from a physical point of view. With the research presented in this paper we aim to provide a deeper insight into how people cooperate through analysing their decisions when playing social games.

II. GAME THEORY

Game theory is one of the first serious endeavours to prescribe human behaviour through mathematical models. Although it was not fully applied to other sciences until 1970, its origins date back to 1928 when Jon Von Neumann published and article on how to *best* act when playing parlour games, namely poker [3]. The basic elements of his theory are hence the following: players (any subject making choices), decisions (called strategies) and payoffs (the result or consequence to a certain action, in general previously known by the players).

Despite game theory has evolved a great deal since 1928, its essential spirit is still the same. What makes poker peculiar against other broadly studied games like chess is that not all the information is available. Since other people's cards are carefully concealed, a unique logical answer cannot be achieved and thus participants feel obliged to behave strategically. This gives rise to a rich scenario where concepts such as cooperation come into scene. In special, we are concerned about games modelling social dilemmas.

A. Social Dilemmas

Social dilemmas are situations where individual interests are in conflict with the common good. In these games each player must make their decision alone (C or D) while ignoring the partner's choice, yet the eventual outcome depends on the global action as shown in Table I. Orthodox game theory expects people to behave *rationally*, that is to pursue uniquely their own profit [4]. In these terms, a dominant strategy is the one which maximizes the individual payoff. *Nash equilibria* is said to be achieved when all players behave rationally. Instead, *Pareto's optimality* accounts for commonweal, such that for any other set of strategies al least one player would do worse [5]. The presumable disagreement between the two equilibria is what gives rise to the dilemma.

Depending on the payoffs R, S, T and P players will be more predisposed to cooperate or rather tempted to defect (see Table I). For example, in Prisoner's Dilemma (PD, $T > R > P > S$) rational players are supposed to defect whereas Pareto's optimality appears when they both cooperate. In a Harmony Game (H, $R > S > P$ and $R > T > P$) Nash and Pareto's equilibria coincide and consequently cooperating is not only dominant but also a profitable strategy. In other games no dominant strategy exists. In particular in Stug Hunt (SH, $R > T > P > S$), also known as a coordination game, actors tend to cooperate or to defect simultaneiously. Similarly for Snow Drift (SD, $T > R > S > P$) players are expected to betray each other resulting in an anti-coordination game.

Player 1 \ Player 2	Cooperates	Defects
Cooperates	(R,R)	(S,T)
Defects	(T,S)	(P,P)

TABLE I: Example of the usual matrix payoff for a symmetric non-zero sum game.

These four dilemmas are believed to be specially representative of any possible game. However, the *expected* behaviour does not necessarily have to match the *actual* behaviour. Testing this correspondence is crucial as long as game theory aims to deepen into reality and not stand as a mere entelechy. In the end, answering this question requires to analyse real data about social interaction.

B. DAU experiment set up

In this paper we examine the empirical information obtained from DAU experiment performed in Barcelona on 2014 [6]. Players faced a similar matrix to that represented in Table I with $R = 10$, $P = 5$, $4 < T < 16$ and $-1 < S < 11$ [7].

Players had to decide between two actions (C or D) for a certain number of rounds. Payoffs changed randomly as well as their opponent so that adaptive processes were maximally reduced. Participants would learn the final outcome at the end of each game, but the accumulated gain was not displayed in the screen. Neither it was the global ranking in order to avoid establishing a super game.

Results show a relevant deviation from the behaviour prescribed by orthodox rationalists, as can be observed in Fig. 1 and Table II. As some authors state [8], rational theory has proven to be incomplete or at least insufficient to account for the richness and diversity in decision-making, with fundamental queries still to be solved.

Several sophisticated expansions of traditional game theory have tried to provide plausible explanations to this fundamental disparity. Bounded rationality, evolutionary game theory or prospect theory are some examples of such kind of attempts. In light of some of their contributions we evaluate the data obtained in the DAU experiment, eventually aiming to fill the gap encountered between rational prescriptions and empirical results.

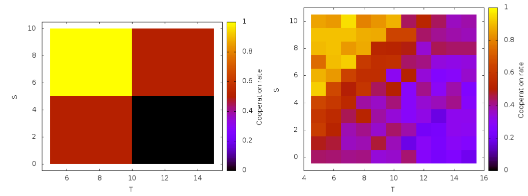

FIG. 1: Expected (left) and experimental (right) results on cooperative behaviour. The four games can be recognised as different areas of the plane: PD (bottom-right), H (upper-left), SH (bottom-left) and SD (upper-right). Cooperation emerges unexpectedly in PD while a notable increase of defectors appears for the coordination and anticoordination situations. In the H game cooperation rises for $S > 4$ and $T < 10$, because for such payoffs cooperating leads unvaryingly to the optimal outcome. In conclusion, although general tendencies are accomplished, dominant strategies are significantly different to the empirical data.

GAME	% of CC actions	% of CD/DC actions	% of DD actions
PD	9,45	37,15	53,40
H	61,57	31,24	7,19
SH	19,65	48,18	32,17
SD	16,85	44,83	38,32

TABLE II: Empirical percentage of each action over the total number of games. In the experiment 541 participants took part, thus resulting in a total number of actions of 8366. Data asserts that Nash equilibrium is not strictly fulfilled in any game, although general tendencies are as prescribed.

III. LIMITS OF RATIONAL THEORY

In our analysis we focus on those changing factors that may affect decision-making without being directly related to the matrix payoff. In short, we study the relationship between the previous scenario and the present selection by examining the influence of the own prior choice (persistence), of the opponent's choice (mimesis) and finally of the total choice (reciprocity). These three effects represent the player's social *memory* in terms of own history and environment.

It is noticeable that no relevance is given to the game in which the prior action takes place. Hence we consider the decision (C or D) itself. This assumption is justified by the fact that payoffs are continuously changing, so the impact of the matrix into the cooperation's importance is averaged over the (ST)-plane and therefore somewhat suppressed. In this sense, we consider that individuals are subject to volatile social conditions.

This investigation intends to reveal concealed mechanisms in decision-making that are beyond the limits of rationality. We believe that such strategies are intimately bounded to the emergence of cooperation in real life. Furthermore, this sort of ephemeral environments can be conceived as a more genuine representation of social interaction, when the meaningfulness of the matrix payoffs are not only diluted but also distorted by former experience.

A. Persistence

In this section we examine whether there is a connection between current and previous decisions of the same player. We present data as a $S - T$ function since this value is the maximum payoff difference in a symmetric matrix, thus being representative of each game. Results suggest that such correlation exists and is in fact significant. As shown in Fig. 2 a certain inertia is displayed so that players tend to persist in their strategies at least for two rounds.

This could be accounted by a several number of hypothesis such as the manifestation of transitory states of mind (like euphoria or disappointment) or the existence of a certain degree of automatization in decision-making (namely a scarcity of conscious reflection).

Indeed, bounded rationality postulates that purely rational thinking is sometimes substituted by a set of alternative strategies, that might be gathered into the following: trial and error, imitation, obeying an authority or tradition, habit, thoughtless impulse and hunch [9].

In particular, it has been proved [10] that humans tend to follow made-up rules that, though not completely reliable, speed up decision-making and function well for a sufficient number of times. Some authors [8] propose as an example the association *stay–win change–lose*, which perfectly elucidates here the obtained results. On these terms, persistence could be understood as a sort of primitive criteria that imposes when no better reasoning is attained, as an efficient strategy or plainly as a spontaneous first reaction.

B. Mimesis

We now evaluate whether the partner's decision has an impact on the player's behaviour. It could be imagined that tendencies such as copying the opponent's strategy may be significant.

Nevertheless, results decline mimesis as a determining strategy, as can be concluded from Fig. 3. It has been claimed that imitation arises as a need for economising decision-making resources [11]. This mechanism is technically similar to that described to depict persistence, despite the opposite implications on the final choice. Therefore it is remarkable that both strategies do not emerge symmetrically but instead persistence dominates (see Table III). In conclusion, this finding suggests that the actual processes encouraging persistence and mimesis may not be equivalent.

C. Reciprocity

It is a plausible assumption that players will not only be affected by their own choice (persistence) or their opponent's decision (mimesis) but also by the *entire* action. Although game's design is conceived as to avoid adaptation, fleeting responses are still to be expected.

Results demonstrate a decisive impact of the prior occurrence into the present game, as can be concluded from Fig. 4, Fig. 5 and Fig. 6. However, we can not disregard the fact that persistent tendencies manifest as well, making it difficult to distinguish between the two contributions (see Table III). That's why we place a particular attention on those bias which can not be acknowledged

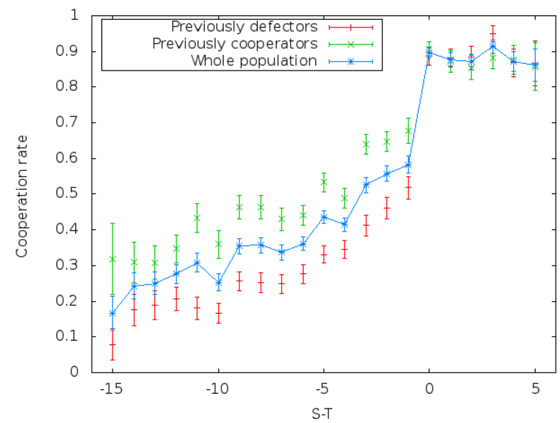

FIG. 2: Persistent behaviours. Data (in several colours) shows that those who have cooperated in the previous round exhibit a certain tendency to cooperate again, whereas those who have defected tilt to defect again. Both strategies are relevant when compared to the average population. For S–T >0 (H triangle) the system collapses and no discrepancy is observed between the two groups.

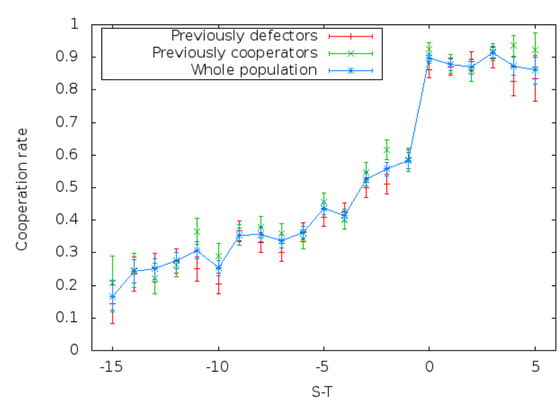

FIG. 3: Analysis of mimesis. Although a slight bias may be noticed, data (in several colours) indicates that mimesis can not be asserted as a meaningful effect.

by persistent behaviours (for instance the drop on cooperation by deceived cooperators in the H game).

Evolutionary game theory claims that in social interaction humans experience a natural tendency to reward generosity as well as to punish opportunism [12]. This statement clarifies the observed reactions after successful cooperation, but fails to explain the fact that deceived cooperators choose to cooperate again. In addition, for reciprocity to become a stable strategy, we would need to establish a mechanism to recognise cooperators and defectors in advance.

Other models incorporating the influence of feelings can shed some light on the question. It has been suggested [13] that emotional reactions interfere into cognitive evaluation causing a distortion in the perception of the payoffs. Thus, responses like thankfulness or vindictiveness may profoundly affect the player's decision. In consequence, tendencies after consensus could be encouraged by reward and apathy while cheated players' behaviour in H game might have been motivated by revenge. All in all, former's cooperative perseverance in the rest of the games as well as cheater's insistence on defecting are better explained by persistence.

IV. CONCLUSIONS

Results demonstrate that memory plays an essential role in decision-making for people facing a changing set of games under varying social conditions. Participants on the experiment have been found to display two significant strategies: persistence and reciprocity. Anyhow, some of our latter results can only be interpreted by means of persistent behaviour.

Theories such as bounded rationality roughly account for most of our findings. However, the fact that imitation is not a significant factor and that persistence prevails as a dominant strategy even when the opponent cheats suggests that some *intrinsic* features of the players should

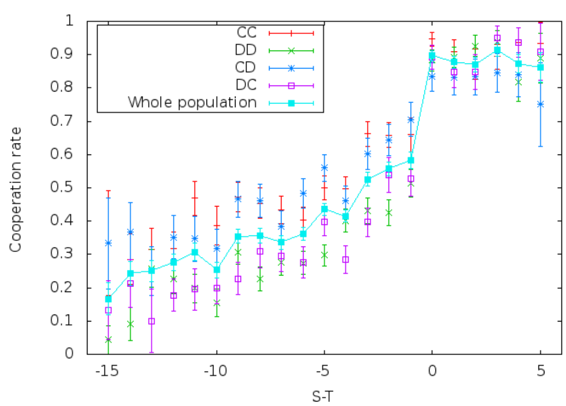

FIG. 4: Reciprocal behaviours. All strategies are proved to be significant when compared to the average population. In general terms CC and CD seem to encourage cooperation, while after DD and DC a trend to defect again is manifested. It is remarkable that for the H triangle CD actions lead to a dramatic decrease in cooperation. It can not be stated which action is the main contribution to each bias.

Average	p(C)=48,2%±1,7%
Persistence	$p(C_i\|C_i)$=55,5% $p(C_i\|D_i)$=39,4%
Mimesis	$p(C_i\|C_j)$=49,0% $p(C_i\|D_j)$=45,8%
Reciprocity	$p(C_i\|C_iC_j)$=55,4% $p(C_i\|C_iD_j)$=55,0% $p(C_i\|D_iD_j)$=40,5% $p(C_i\|D_iC_j)$=42,2%

TABLE III: Conditioned probabilities for the three effects. The conditioning decision always refers to the previous action. i and j stand for the players ($i \neq j$). Those values differing from the average more than a 1,7% can be said to be significantly different with a 99,7% of confidence (see Appendix).

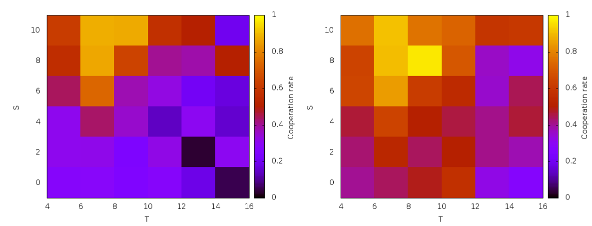

FIG. 5: Cooperation after consensus. Unproductive coordination (DD, left) increases defection except for the H triangle which is not found significant. For the coordination and anti-coordination games only about the 20 % of the players are cooperative. Successful cooperation (CC, right) results in a rise of cooperative actions (about half the population cooperates in the weak PD). In this case cooperation conforms around the 40% of actions in the SD and SH. Error analysis in the Appendix.

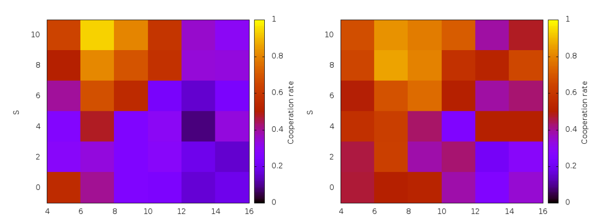

FIG. 6: Cooperation after frustration. Cheating (left) decreases cooperation to a 20% in all games except for the strong H. Surprisingly, being deceived (right) stimulates cooperation for PD, SD and SH arriving to around a 50% of cooperative actions. However, for the H triangle about only the 80 % of the players cooperate, which is an outstanding drop (see Appendix).

be acknowledged. In this sense, the main phenomenological conclusion is that participants played cooperatively or defectively almost independently of the environment. Therefore, although some outstanding reactions to being deceived have been analysed, altogether people behaved persistently.

In conclusion, cooperation can arise in social interaction as a built-in trait. Hence, payoffs are not as decisive as traditional game theory have stated. Nevertheless, if this phenomenon emerges as depicted by bounded rationality or responds to the existence of a cooperative phenotype is something that must be investigated. Other decisive questions may include analysing whether memory stands for more than two rounds or if it can be modelled in terms of a Markov Chain.

Eventually, this would lead us to further research. The explanations provided up to now are known to be merely descriptive and rather *ad hoc*, yet they arise from the necessity to confront experimental results with the orthodox theory. Once data has provided us with suitable hypothesis, the next step would be postulating a predictive model. Similar processes have occurred in physics before and led to exceptional results. In our case, the complexity of the human mind should not be seen as a discouraging obstacle but rather as an inspiring challenge.

V. APPENDIX: ERROR ANALYSIS

The error for a binomial process is calculated following Eq.(1).

$$err = z\sqrt{\frac{p(1-p)}{N}} \tag{1}$$

For the S–T plots, errorbars are computed with $z = 1$ and all strategies are compared to the behaviour of the average (whole population without the first round of players, since they do not have memory yet). We consider data to be relevant if its errorbars do not interfere with the average's ones. Significance for Fig. 7 and Fig. 8 is computed dividing the discrepancy between the strategy and the error of the average with $z = 2$, thus data can be said to be significant with a 95,45% of confidence in almost all points. Finally, for Table III the error has been calculated with with $z = 3$.

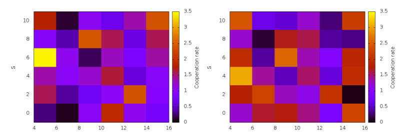

FIG. 7: Significance for consensus: successful cooperators (left) and unproductive concorders (right).

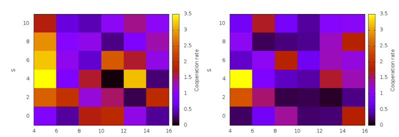

FIG. 8: Significance for frustrated cooperation: cheaters (left) and deceived players (right).

ACKNOWLEDGMENTS

I want to say thanks specially to my advisor Josep Perelló, without whose guidance and advice any of this would have been possible. Also to Mario Gutiérrez Roig and Isabelle Bonhoure, for their helpful ideas. To Carlota Segura, who patiently listened during the meetings. And infinite thanks to my family and friends, for being always there.

[1] Heinze, Jrgen, B. Hlldobler, and C. Peeters. *Conflict and cooperation in ant societies.* Naturwissenschaften 81.11 (1994): 489–497.

[2] Firouzi, Ali, et al. *Cooperative organization of inorganic-surfactant and biomimetic assemblies.* Science 267.5201 (1995): 1138–1143.

[3] Neumann, J. V. *Zur theorie der gesellschaftsspiele.* Mathematische Annalen 100.1 (1928): 295–320.

[4] Osborne, Martin J., and Ariel Rubinstein. *A course in game theory.* MIT press (1994)

[5] Rosenthal, Edward C. *The Complete Idiot's Guide to Game Theory.* New York, NY: Alpha (2011)

[6] Press release: `http://www.barcelonalab.cat/ca/noticies/mes-500-persones-participen-lrsquoexperiment-collectiu-brain/`

[7] Webpage to play the game: `http://161.116.80.44/`

[8] Colman, Andrew M. *Cooperation, psychological game theory, and limitations of rationality in social interaction.* Behavioral and brain sciences 26.02 (2003): 139–153.

[9] Simon, Herbert A. *Theories of bounded rationality.* Decision and organization 1.1 (1972): 161–176.

[10] Coleman, James S. *Foundations of social theory.* Harvard university press, 1994.

[11] Pingle, Mark. *Imitation versus rationality: An experimental perspective on decision making.* The Journal of Socio-Economics 24.2 (1995): 281–315.

[12] Sethi, Rajiv and Somanathan, Eswaran. *Understanding reciprocity*, Journal of Economic Behavior & Organization, 50, 1, pp 1—27, (2003)

[13] Loewenstein, George F., et al. *Risk as feelings.* Psychological bulletin 127.2 (2001): 267.