The future of social experimenting

Dirk Helbing[1] and Wenjian Yu
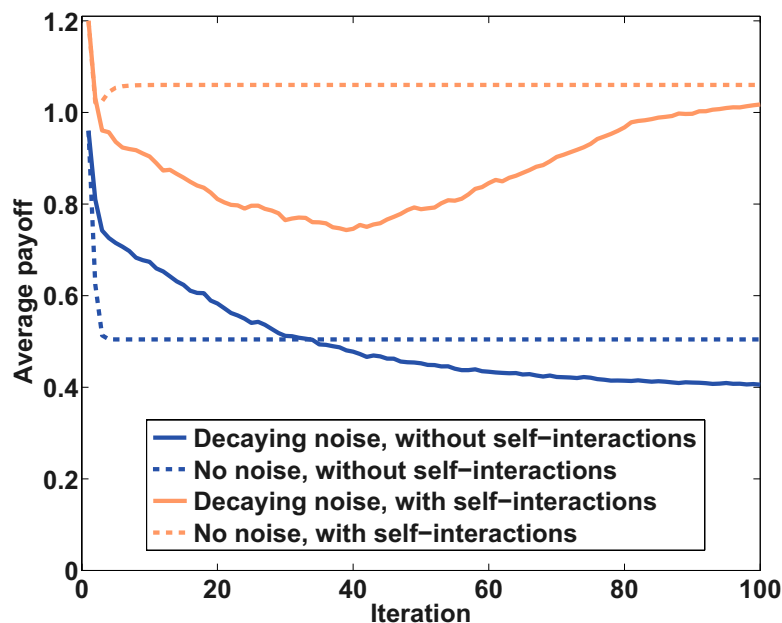*ETH Zurich, 8092 Zurich, Switzerland*

Recent laboratory experiments by Traulsen et al. (1) for the spatial prisoner's dilemma suggest that exploratory behavior of human subjects prevents cooperation through neighborhood interactions over experimentally accessible time spans. This indicates that new theoretical and experimental efforts are needed to explore the mechanisms underlying a number of famous puzzles in the social sciences.

Cooperation is the essence that keeps societies together. It is the basis of solidarity and social order. When humans stop cooperating, a war of everybody against everybody can result. Understanding why and under what conditions humans cooperate is, therefore, one of the grand challenges of science (2), particularly in social dilemma situations (where collective cooperation would be beneficial, but individual free-riding is the most profitable strategy).

When humans have social dilemma-type interactions with randomly changing partners, a "tragedy of the commons" (3), i.e., massive free-riding, is expected to occur. But how are humans then able to create public goods (such as a shared culture or a public infrastructure) and build functioning social benefit systems despite their self-interest? Under what conditions will they be able to fight global warming collectively? To answer related research questions, scientists have experimentally studied, among other factors, the influence of spatial and network interactions on the level of cooperation in various games, including nondilemmatic ones (4–6).

In their laboratory experiments, Traulsen et al. (1) have now implemented Nowak's and May's prisoner's dilemma in two-dimensional space (7), where the size of the two-dimensional spatial grid, the number of interaction partners, and the payoff parameters are modified for experimental reasons. The prisoner's dilemma describes interactions between pairs of individuals, where free-riding is tempting, and cooperation is risky. Therefore, if individuals interact with different people each time (as in the case of well-mixed interactions), everybody is predicted to end up free-riding. If the world were really like this, social systems would not work.

However, in computer simulations of the spatial prisoner's dilemma (7), cooperative (altruistic) behavior is able to survive through spatial clustering of similar strategies. This finding, which can dramatically change the outcome of the system, is also called network reciprocity (8). When individuals have neighborhood interactions and imitate better-performing neighbors unconditionally, this can create correlations between the behaviors of neighboring individuals. Such spatiotemporal pattern formation facilitates a coevolution of the behaviors and spatial organization of individuals, generating configurations that can promote cooperative behavior. In fact, some long-standing puzzles in the social sciences find a natural solution when spatial interactions are taken into account. This includes the higher-than-expected level of cooperation in social dilemma situations and the spreading of costly punishment (9). The question is whether these theoretical findings are also supported by experimental data.

The recent findings by Traulsen et al. (1) do not indicate a significant effect of spatial neighborhood interactions on the level of cooperation, because their experimental subjects did not show an unconditional imitation of neighbors with a higher payoff, as it is assumed in many game-theoretical models. In fact, it is known that certain game-theoretical results are sensitive to details of the model, such as the number of interaction partners, the inclusion of self-interactions, and significant levels of randomness (10) (Fig. 1). Moreover, people have proposed a considerable number of different strategy update rules that matter as well. Besides unconditional imitation, these include the best response rule (11),

Fig. 1. Average payoff of all individuals in the spatial prisoner's dilemma with and without self-interactions, displayed over the number of iterations. It is clearly visible that the initial payoff drops quickly. In the noiseless case, the average payoff does not change anymore after a few iterations (see broken lines) because the spatial configuration freezes. In contrast, in the case of decaying noise, the average payoff keeps changing (see solid lines). It is interesting that the average payoff, when no self-interactions are taken into account, is higher in the noisy case than in the noiseless one over the time period of the laboratory experiment by Traulsen et al. (1), covering 25 iterations (see blue lines). The better performance in the presence of strategy mutations could be a possible reason for the high level of strategy mutations observed. If self-interactions are considered (see orange lines), the average payoff recovers after about 40 iterations, which correlates with an increase in the level of cooperation. To see this effect, experiments should be run over at least 60 iterations, or the payoff parameters should be changed in such a way that the average payoff recovers earlier. It is conceivable, however, that experimental subjects would show a lower level of strategy mutations under conditions where noise does not pay off (in contrast to the experimental setting without self-interactions).

multistage strategies such as tit for tat (12), win-stay-lose shift rules (13), and aspiration-dependent rules (14), as well as probabilistic rules such as the proportional imitation rule (15), the Fermi rule (16), and the unconditional imitation rule with a superimposed randomness ("noise"). In addition, there are voter (17) and opinion dynamics models (18) of various kinds, which assume social influence. According to these, individuals would imitate behavioral strategies that are more frequent in their neighborhood. So, how do individuals really alter their behavioral strategies?

Traulsen et al. (1) find that the probability of cooperation increases with the number of cooperative neighbors, as expected from the Asch experiment (19). Moreover, the probability of strategy changes increases with the payoff difference in a way that can be approximated by the Fermi rule (16). In the case of two behavioral strategies only, it corresponds to the well-known multinomial logit model of decision theory (20). However, there is a discontinuity in the data, when the payoff difference turns from positive to negative values, which may be an effect of risk aversion (21). To describe the time-dependent level of cooperation, it is sufficient to assume unconditional imitation with a certain probability and strategy mutations otherwise, where the mutation rate is surprisingly large in the beginning and exponentially decaying over time.

Understanding the origin of this "noise" would be important to control it experimentally and to reveal effects that would otherwise be hidden in the randomness of the data. Do people make mistakes or do they choose to behave in a noisy way? As figure 2 of ref. 1 shows, rather than quickly destroying cooperation, randomness leads to more cooperation in the experiment of Traulsen et al. than the unconditional imitation rule predicts. This goes along with a significantly higher average payoff than for the unconditional imitation rule (Fig. 1). In other words, the random component of the strategy update is profitable for the experimental subjects. This suggests that randomness in social systems may play a functional role.

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Given that Traulsen et al. (1) do not find effects of spatial interactions, do we have to say goodbye to network reciprocity in social systems, despite the nice explanations it offers? Probably not. The empirically confirmed spreading of obesity, smoking, happiness, and cooperation in social networks (22) indicates that effects of imitating neighbors (also friends or colleagues) are relevant, but probably over longer time periods than 25 interactions. In fact, according to equation 3 of Traulsen et al. (1), cooperation could spread after about 40 iterations, when the mutation rate has decreased to low-enough values. Such an effect should occur when self-interactions are taken into account (Fig. 1). To make it observable experimentally, however, one would have to reduce the necessary number of iterations by varying the experimental conditions.

The particular value of the work by Traulsen et al. (1) is that it facilitates realistic computer simulations and, thereby, also allows one to determine payoff values and other model parameters, which are expected to produce interesting effects after an experimentally accessible number of iterations.

Because of nonlinear feedback effects, social interactions can have a variety of different outcomes that are hard to predict without extensive computer simulations scanning the parameter space. Such parameter dependencies could, in fact, explain some of the apparent inconsistencies between empirical observations of social behavior in different areas of the world (23), at least when framing effects such as the expected level of reciprocity and their impact on the effective payoffs (8) are taken into account. The progress in the social sciences by understanding the parameter dependence of system behaviors would be enormous. Given that the effort to determine them experimentally is prohibitive, one could still check computationally predicted, parameter-dependent outcomes by targeted experiments. Hence, the future of social experimenting lies in the combination of computational and experimental approaches, where computer simulations optimize the experimental setting and experiments are used to verify, falsify, or improve the underlying model assumptions.

1. Traulsen A, et al. (2010) Human strategy updating in evolutionary games. *Proc Natl Acad Sci USA* 107: 2962–2966.
2. Pennisi E (2005) How did cooperative behavior evolve? *Science* 309:93.
3. Hardin G (1968) The tragedy of the commons. *Science* 162:1243–1248.
4. Selten R, Apesteguia J (2005) Experimentally observed imitation and cooperation in price competition on the circle. *Games Econ Behav* 51:171–192.
5. Cassar A (2007) Coordination and cooperation in local, random and small world networks: Experimental evidence. *Games Econ Behav* 58:209–230.
6. Kirchkamp O, Nagel R (2007) Naive learning and cooperation in network experiments. *Games Econ Behav* 58: 269–292.
7. Nowak MA, May RM (1992) Evolutionary games and spatial chaos. *Nature* 359:826–829.

8. Nowak MA (2006) Five rules for the evolution of cooperation. *Science* 314:1560–1563.
9. Gürerk Ö, Irlenbusch B, Rockenbach B (2006) The competitive advantage of sanctioning institutions. *Science* 312:108–111.
10. Szabó G, Fáth G (2007) Evolutionary games on graphs. *Phys Rep* 446:97–216.
11. Matsui A (1992) Best response dynamics and socially stable strategies. *J Econ Theory* 57:343–362.
12. Axelrod R (1984) *The Evolution of Cooperation* (Basic Books, New York).
13. Nowak M, Sigmund K (1993) A strategy of win-stay, lose-shift that outperforms tit-for-tat in the Prisoner's Dilemma game. *Nature* 364:56–58.
14. Macy MW, Flache A (2002) Learning dynamics in social dilemmas. *Proc Natl Acad Sci USA* 99 (Suppl. 3):7229–7236.
15. Helbing D (1992) *Economic Evolution and Demographic Change*, eds Haag G, Mueller U, Troitzsch KG (Springer, Berlin), pp 330–348.

16. Szabó G, Tőke C (1998) Evolutionary prisoner's dilemma game on a square lattice. *Phys Rev E Stat* 58:69–73.
17. Dornic I, Chaté H, Chave J, Hinrichsen H (2001) Critical coarsening without surface tension: The universality class of the voter model. *Phys Rev Lett* 87:045701.
18. Sznajd-Weron K, Sznajd J (2000) Opinion evolution in closed community. *Int J Mod Phys C* 11:1157–1165.
19. Asch SE (1956) Studies of independence and conformity: A minority of one against a unanimous majority. *Psychol Monogr* 70:1–70.
20. McFadden D (1974) *Frontiers of Econometrics*, ed Zarembka P (Academic, New York), pp 105–142.
21. Kahnemann D, Tversky A (1979) Prospect theory: An analysis of decision under risk. *Econometrica* 47:263–291.
22. Smith KP, Christakis NA (2008) Social networks and health. *Annu Rev Sociol* 34:405–429.
23. Herrmann B, Thöni C, Gächter S (2008) Antisocial punishment across societies. *Science* 319:1362–1367.