Théorie des jeux et contrats sociaux

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Introduction

Among biological populations, mankind stands out for the magnitude of its impact on the environment it lives in. The feedback between individual-level behavior and its environmental context is often mediated by the structure of human societies, so that the consequences at the individual level heavily depend on what the others do. Such a scenario can be formalized by public goods games that represent fundamental subjects of theoretical and applied investigations in fields that span from mathematics, to biology, to economy.

The prototypical example of a 'public good', whose advantages are available to every person irrespective of the fact that it contributed or not to its establishment, is the reduction of anthropogenic changes of the Earth climate. As the control of carbon dioxide emissions can only be achieved by the coordinated effort of billions of people -or hundreds of nations-, the main problem faced by global governance policies is to achieve such a coordinated effort. However, in deciding whether to contribute to a public good, individual entities are faced with a conflict between individual and collective interests. Indeed, whereas the consequences of global warming -at least in the long term- are likely to affect everybody to some more or less severe degree, there is an immediate personal cost to the unilateral choice of dropping the emission level. As a consequence, the individuals may refrain from their contribution, thus giving rise to the so-called 'Tragedy of the commons' where everybody is eventually worse off.

Game theory provides a formal description of how competition between individual strategies constrains the sustainability of public goods. In this abstract setting, one can test different hypotheses on the interaction rule between individuals, and in particular the possibility that rational selfish agents chose to contribute to the global well being.

Although this framing has primarily lead to theoretical results, both by analytical and numerical means, it is increasingly used also for applications, and notably for modeling real-world scenarios. In this respect, experiments inquiring human and non-human behavior in controlled settings have allowed to explore to which extent certain simplifying assumptions occur in actual biological societies and how far can the mathematical results be informative of general processes.

The interaction between a well-established theoretical corpus and the applications to real sociobiological situations is a particularly promising interface between mathematics on the one side, economy, behavioral ecology and social sciences on other. The search for general principles that rule the dynamics of collective enterprises moreover reaches out disciplines such as evolutionary biology, statistical physics and informatics, whose methods start being profitably imported in the game-theoretical framework, and that have a long tradition of interfacing with experimental investigation.

In the following two sections we will resume the main points discussed during the "journée IHP" of the ARP MathsInTerre, and then provide guidelines about what implementation is desirable to foster the interaction between mathematics and the other sciences on the subject of social games.

Mathematics and social games: the state of the art and future challenges

Game theory is an instrument to understand social processes in biological populations. Its applications to mankind are particularly challenging because of the extreme complexity of human behaviors and interactions. Indeed, even if humans evidently share a common good -the Earth- they need to preserve, the collective outcome of their choices is affected, other than by individual motivations, by the structure of societies and institutions that shape connectivity, provide a hierarchical organization and affect the time scales over which objectives can be attained.

On the other hand, simple mathematical models, and in particular game theory, explain some regularities that can be detected in human societies throughout the world, such as sense of fairness in ultimatum games, as well as the outcome of experiments in controlled settings, as the promotion of cooperation through punishment, optional participation and reputation.

Although theoretical approaches unveiled general processes that are in play in human societies, and more widely in biological populations, a number of challenges lie ahead, both in terms of extending current theoretical framework to more realistic -thus more complex- settings, and in terms of modeling actual scenarios to foster applications.

Theoretical challenges include the broadening of the current game theoretical framework to various topologies of individual interaction networks. The effect of a multiplicity of strategies and of heterogeneity - at the individual as well as the collective level- has also been little explored compared to the fundamental role that differences of status appear to play in negotiations for global governance. Moreover, climate-change game models require to introduce features, such as finite time frames for achieving a result, the nonlinearities that underlie different kind of gradual versus abrupt changes in the collective gain, the fluctuations in the environmental parameters, the coexistence of multiple time scales associated with different social aggregates, that would benefit of a theoretical framing akin to what was developed for two-players games.

When moving towards its applications to real-world societies, game theory needs to interface with controlled experiments on the one side, and with collected data on the other. In order for this interaction to improve both the mathematical theory and its implementation, it is necessary to support the development of mechanistic models upon which to base the representation of individual motivations, of decision-making at the individual and societal level, of the nature and structure of interactions, and finally of the effect of policies and norms on human behavior.
Interfacing theory with experiments both in human and non-human populations can help identifying general rules that may be exploited to guide global policies.
The interaction with other disciplines, notably Earth sciences, experimental economics, psychology, evolutionary biology, statistical physics and complex systems science can prove extremely useful for the establishment and the test of models.

In spite of the fact that game theory is still quite far away from permitting quantitative account and inference on human societies, it provides a sound theoretical framework that not only frames social conflicts in human societies, but constitutes a shared language between different disciplines.
The development of novel mathematical approaches, as well as the strengthening of the interface with experimental results may contribute, if not to the establishment of rules for global governance, at least to slowing down the anthropogenic environmental degradation, until new technological solutions will reduce the level of conflict related to fossil fuels-based energy production.

Recommendations to the ANR

- Most challenging problems in relation with game theory and Earth sciences:
    - Mechanistic modeling of the structure and dynamics of human interactions
    - Including ecology and demography in game theoretical descriptions
    - Emergence and evolution of institutions, role of institutions in helping/hindering the establishment of social behavior.
    - Response to stochastic environmental changes and strategies to reduce risk
    - Understating the role of communication
- Mathematical tools that should be improved or developed for the fundamental understanding of these

problems:
- Investigating possible designs for implementing cooperation. Ex : through institutional sanctioning (punishment, incentives)
- Social behavior in different topologies, such as networks and spatially heterogeneous populations. Ex: problem of congestion.
- Framing the problem of public goods in order for the solution to appear more accessible. Ex: establishing intermediate goals.
- Mathematical modeling of climate change behavior both at the individual and the institutional level.
- Modeling the response to stochastic environmental change and control of risk.

- Applications to be pursued:
  - Determining the essential ingredients of human behavior that should be introduced in models and theory.
  - Comparison of models for behavioral choices in climate change scenarios with behavioral experiments and data on the actual application of climate change policies.
  - Test models and theories with experimental evolutionary studies, including those with simple organisms.

- Most promising interactions with other disciplines:
  - Experimental economics: allows quantitative comparison with game theoretical models
  - Psychology & cognitive biology: inform the modeling of human decision-making
  - Evolutionary biology: transfer of concepts/tools from the studies on evolutionary transitions, parallelism between cultural and genetic evolution (Baldwin effect), accidental pre-adaptations.
  - Statistical physics: models allowing a multiplicity of possible scenarios and stochastic effects.
  - Complex systems sciences: dynamics on networks and multi-agents models
  - Earth sciences: establishing the form and nature of social dilemmas at the global scale