



**ERCIM "ALAIN  
BENSOUSSAN"  
FELLOWSHIP  
PROGRAMME**



## Scientific Report

First name / Family name

Luis Alberto Martínez Vaquero

Nationality

Spanish

Name of the *Host Organisation*

National Research Council of Italy (ISTC-CNR)

First Name / family name  
of the *Scientific Coordinator*

Vito Trianni

Period of the fellowship

01/09/16 to 31/08/18

### **I - SCIENTIFIC ACTIVITY DURING YOUR FELLOWSHIP**

The main line of research was developed with my scientific coordinator at the LARAL group of the host institution and partially in collaboration with the local scientific coordinator of the REP. Making use of methods from evolutionary game theory and collective behaviour, we have studied the co-evolution of signalling and reciprocity as mechanisms to promote cooperation in social groups. We have shown how signalling, even when it is costly, is much more prone to favour cooperation, whereas reciprocity tends to be more opportunistic. Reciprocity is also less likely to evolutionarily emerge, and when it does, it is usually together with signalling. We have continued this work extending our study to systems with multiple options with different values and pairwise signalling interactions among individuals, allowing us to see the emergence of behaviours shown in nature, like recruitment or cross-inhibition, which are fundamental for collective decision making and division of labour.

A secondary line of research was initiated with the LABSS group, also belonging to the host institution. We set up a stylised model of recruitment processes in organised crime and terrorist networks making use of evolutionary game theory. For this purpose we supervised a master student, Valerio Dolci, from Tor Vergata University.

During the last months, I have also co-supervised the visiting master student Aurélien Brouillaud from École Polytechnique, Paris, France. With him, we started to study the emergence of leadership in social groups with different distributions of individual strength. We plan to continue this work in the near future.

In parallel with these projects, I have continued on-going collaborations closely related with the scientific problems studied under the fellowship. Special mention should receive the work on long memory strategies in direct reciprocity carried out with researchers from IST Austria and Harvard University.

## II - PUBLICATION(S) DURING YOUR FELLOWSHIP

- Co-evolution of signalling and reciprocity in collective games

*Martinez-Vaquero, L. A.; Santos, F. C.; Trianni, V.*

*Pending*

Many biological systems –as well as human societies– show significant levels of collective action, forming cooperative groups of non-related individuals. To guarantee that free riders do not exploit cooperators, mechanisms need to be in place. Several of these mechanisms have been proposed as suitable promoters of cooperation, yet they have been mostly studied independently, such that their interplay remains largely unexplored. For instance, direct reciprocity relies on the fact that individuals interact more than once, and are capable of reciprocating past actions. Also, collective action may be driven by signals and quorum dynamics that evolve side by side with individual's actions. Here we combine these two mechanisms to analyse the conditions in which evolution selects for direct reciprocity, signalling, or their combination. We find that successful strategies in the realm of direct reciprocity are not selected in the presence of signalling. In most cases, individuals do better by solely resorting to signalling, even when signals are costly. In light of these results, it may not be so surprising that direct reciprocity has been observed only in a limited number of cases among non-humans, whereas signalling is widespread at all levels of complexity.

- Recruitment to organized crime and terrorist networks under an evolutionary perspective

*Martinez-Vaquero, L. A.; Dolci, V.; Trianni, V.*

*Pending*

Crime is pervasive into modern societies, although with different levels of diffusion across regions. Its diffusion and dynamics are dependent on various socio-economic factors that make the overall picture particularly complex. While several theories have been proposed to account for the establishment of criminal behaviour, from a modelling perspective organised crime and terrorist networks received much less attention. In particular, the dynamics of recruitment into such organisations deserves specific considerations, as recruitment is the mechanism that makes crime and terror proliferate. We propose a framework able to model recruitment processes in both organised crime and terrorist networks from an evolutionary game theoretical perspective. Through this stylised model, we are able to study a variety of different circumstances and factors influencing the growth or decline of criminal organisations, and observe the convolute dynamics between agents that decide to get associated into criminal organisations, criminals that prefer to act on their own, and the rest of the civil society.

- Evolution of pairwise signalling mechanisms in collective decision problems

*Martinez-Vaquero, L. A.; Santos, F. C.; Trianni, V.*

*In preparation*

- Memory-n strategies of direct reciprocity.

*Hilbe, C. \*; Martinez-Vaquero, L. A. \*; Chatterjee, K.; Nowak, M. A.*

*Proc. Natl. Acad. Sci. USA, 114 (18), 4715-4720 (2017).*

\* C.H. and L.A.M.-V. contributed equally to this work

Humans routinely use conditionally cooperative strategies when interacting in repeated social dilemmas. They are more likely to cooperate if others cooperated before, and are ready to retaliate if others defected. To capture the emergence of reciprocity, most previous models consider subjects who can only choose from a restricted set of representative strategies, or who react to the outcome of the very last round only. As players memorize more rounds, the dimension of the strategy space increases exponentially. This increasing computational complexity renders simulations for individuals with higher cognitive abilities infeasible, especially if multiplayer interactions are taken into account. Here, we take an axiomatic approach instead. We propose several properties that a robust cooperative strategy for a repeated multiplayer dilemma should have. These properties naturally lead to a unique class of cooperative strategies, which contains the classical Win–Stay Lose–Shift rule as a special case. A comprehensive numerical analysis for the prisoner’s dilemma and for the public goods game suggests that strategies of this class readily evolve across various memory- $n$  spaces. Our results reveal that successful strategies depend not only on how cooperative others were in the past but also on the respective context of cooperation.

- When agreement accepting free-riders are a necessary evil for the evolution of cooperation

*Martinez-Vaquero, L. A.; Han, T. A.; Pereira, L. M.; Lenaerts, T. Sci. Rep. 7, 2478 (2017).*

Agreements and commitments have provided a novel mechanism to promote cooperation in social dilemmas in both one-shot and repeated games. Individuals requesting others to commit to cooperate (proposers) incur a cost, while their co-players are not necessarily required to pay any, allowing them to free-ride on the proposal investment cost (acceptors). Although there is a clear complementarity in these behaviours, no dynamic evidence is currently available that proves that they coexist in different forms of commitment creation. Using a stochastic evolutionary model allowing for mixed population states, we identify non-trivial roles of acceptors as well as the importance of intention recognition in commitments. In the one-shot prisoner’s dilemma, alliances between proposers and acceptors are necessary to isolate defectors when proposers do not know the acceptance intentions of the others. However, when the intentions are clear beforehand, the proposers can emerge by themselves. In repeated games with noise, the incapacity of proposers and acceptors to set up alliances makes the emergence of the first harder whenever the latter are present. As a result, acceptors will exploit proposers and take over the population when an apology-forgiveness mechanism with too low apology cost is introduced, and hence reduce the overall cooperation level.

### III - ATTENDED SEMINARS, WORKSHOPS, CONFERENCES

#### Invited seminars

- *Moral codes, commitments, and signals: explaining the emergence of cooperation through evolutionary game theory*  
20/12/2017. PUC-Rio, Brazil
- *Mechanisms to understand the evolution of cooperation at different levels of complexity in social and biological systems.*  
07/08/2018. University of Campinas, Brazil.

- *Cooperative agreements and the role of forgiveness under the eye of evolutionary game theory*  
15/08/2018. Fundação Getúlio Vargas, Brazil

### **Communications to conferences**

- *Emergence of cooperation in self-organising social systems: An evolutionary game theoretical approach.*  
Behaviour 2017. 30/07/2017 – 04/08/2017. Estoril, Portugal
- *Evolution of signalling and memory for consensus decisions in public good games.*  
BIFI International Conference 2018. 06/02/2018 – 08/02/2018, Zaragoza, Spain
- *Value-sensitive collective decision making under an evolutionary game theory perspective*  
IUSSI 2018 Congress. 05/08/2017 – 10/08/2018 Guarujá, Brazil

### **Organisation and participation in workshops and conferences**

- Winter Whorkshop on Complex Systems 2017 (WWCS2017)  
Steering Committee member and attendee.  
06/02/2017 – 10/02/2017. Petnica Science Center, Serbia
- Conference on Complex Systems 2017 (CCS2017)  
Program Committee member.  
17/09/2017 – 22/09/2017. Cancun, Mexico
- Winter Whorkshop on Complex Systems 2018 (WWCS2018)  
Steering Committee member and attendee.  
28/01/2018 – 03/02/2018. Utrecht University, The Netherlands
- International Conference on Complex Systems 2018 (ICCS2018)  
Program Committee member.  
22/07/2018 – 27/07/2018. Cambridge, USA

## **IV - RESEARCH EXCHANGE PROGRAMME (REP)**

Instituto Superior Técnico (IST), University of Lisbon, Portugal)

Local scientific coordinator: Francisco C. Santos

Dates: 23/05/2017 – 06/06/2017

The REP was a great opportunity to begin a collaboration with Francisco Santos and his group. During the time spent in Lisbon, we begun working on the co-evolution of signalling and reciprocity. The vast experience of Francisco Santos in evolutionary game theory and complex systems was key to provide the project with a strong and decisive scientific impact. We will publish this work soon, and we are planning to continue our collaboration beyond it.

