

# Complex Networks of Mindful Entities

– CoxNoME –

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# Summary

- In this course we want to understand and explain how some social collective behavior emerges from individuals agents' cognitive abilities, in communities where individuals are nodes of complex adaptive networks which self-organize as a result of the aforementioned individuals agents' cognition.
- We need to investigate which different cognitive abilities impinge on the emergence of population properties and, as a result, what are the cognitive capacities required to determine the emergence of a given collective social behavior.
- As such, the key innovation consists in the articulation of the two distinct levels of simulation, individual and societal, and in their combined dynamics. This must be achieved both at the modeling level and at the computational implementation levels.

# Complexity

- Complexity science refers to study of the emergence of collective properties in systems with many interdependent components.
- These components might be atoms or macromolecules in a physical or biological context, and people, machines or organisations in a socio-economic context.

# CoxNoME summary - 1

- 200 years after the birth of Darwin, and 150 after the “Origin of the Species”, several fundamental questions of evolution remain unanswered.
- The problem of the evolution of cooperation and emergence of collective action –traversing areas as diverse as Biology, Economics, Artificial Intelligence, Political Science, or Psychology– is one of the most interdisciplinary challenges science faces to-day.
- Understanding the evolutionary mechanisms that promote and maintain cooperative behavior is all the more complex the more intricate the intrinsic complexity of the participating individuals.

# CoxNoME summary - 2

- This complexity has been explored by our team in recent works, where it is shown, among several other properties, that the diversity associated with the interaction structures, learning and reproduction of a population is determinant in agents' choices and, in particular, for establishing cooperative actions.
- These studies were based on the framework provided by Evolutionary Game Theory (EGT), and Network Science theory, combining modeling tools of multi-agent systems and complex adaptive systems.

# CoxNoME summary - 3

- In this project we want to understand how collective action and cooperation emerge from the interplay between population dynamics and individuals' cognitive abilities.
- In communities where individuals are nodes of complex adaptive networks which self-organize as a result of the aforementioned individuals' cognition.

# CoxNoME - 1

- We combine unique expertise from Physics, Mathematics, Computer Science and Evolutionary Anthropology to investigate how different cognitive abilities impinge on the emergence of population properties and analyze the minimal cognitive capacities required to determine the emergence of specific, collective social behaviour.
- We construct network models equipping individual agents with embedded variable cognitive capacities, thereby giving them the possibility to sometimes opt for (costly) individual learning instead of keeping with simple-minded social learning by imitation, and explore how network adaptation moderates conflicts between individual and group interest.

# CoxNoME - 2

## Our aims are to:

- Provide new insights into the interplay between network and node dynamics, which may provide high-quality Computer Science and Mathematics results.
- **Contribute to Evolutionary Anthropology through models grasping rudimentary collective behaviour in primates —including humans.**

# CoxNoME - 3

and aim also to:

- Contribute to the field of AI, where design of intelligent agents and mechanisms for the organization and control of robot swarms are of great importance.
- We envisage incursions into the design of simple robots endowed with minimal cognitive capacities yet exhibiting desired emergent collective behaviour, from pre-defined rules.

# In a Nutshell

- The work involves integrating methods and principles that have witnessed a significant and independent development in as yet unrelated areas:
  - (1) The Physics of Complex Systems and Network Science
  - (2) Computational Logic
  - (3) Evolutionary Game Dynamics and Graph Theory
  - (4) Artificial Intelligence
- These will benefit from the precious input and experience from the Social-Anthropology of Primates and Humans.

# Motivation and detail - 1

- The main focus is characterized as the study of problems of emerging collective action, conflict resolution and self-organized behaviour.
- Self-organization is achieved in a population by individuals endowed with diverse cognitive capacities, allowing them to opt for distinct behaviours, based on local information provided by peers (horizontal transmission), or relatives (vertical transmission), who are neighbours in a social network of interaction whose links change in time.
- The evolutionary dynamics of the population and of the social web, influence and are influenced by the individuals' cognitive capacities and their neighbours' decisions.

# Motivation and detail - 2

- Such complex social atoms evolving through the social web have never been studied before, and presumably provide the most sophisticated “*in silico*” experiments of social behaviour.
- In this way, we believe to be able to uncover some features of social behaviour in the upper primates, as well as perhaps shed light on the evolutionary origins of modern social behaviour, in light of anthropological evidence.
- Moreover, these insights can then be transformed into mechanisms to organize and control swarms of robotic agents.

# Motivation and detail - 3

- The study of emergent properties of complex networked populations has yet to look inside the kernel of each of the social atoms.
- Rather than just a fixed set of situation-action rules inducing automatic reactive behaviour, one would like to additionally impart a node with more sophisticated cognitive abilities, e.g.
  - goal directed reasoning and planning
  - hypotheses making under uncertainty
  - looking ahead into possible futures
  - respecting norms, be they regulative or moral-like
  - recognizing intentions in others through their actions

# Motivation and detail - 4

- Given the plethora of possibilities of how to model cognitive abilities, we must identify the intrinsic features providing, *per se*, the most prominent individual behaviour leading to emerging, unanticipated collective behaviour.
- Their choice is guided by questions relevant to Evolutionary Anthropology.
- We take care to delimit the number of available parameters, in order to render our study tractable, also making it possible to engineer future robot implementations.

# Motivation and detail - 5

- That the individuals in a networked population afford more cognitive abilities, and dynamically choose their rules of behaviour, rather than act from a fixed pre-compiled set, gives the system a much richer and realistic dynamics, which is worth to explore.
- Under such a new paradigm, individuals should be able to hypothesize, look into possible futures, probabilistically prefer, deliberate, signal and respond to signals, take history and trust into account, form coalitions, adopt and hone game strategies.

# Motivation and detail - 6

- We consider different types of individual and social dynamics of cooperation, both deterministic and stochastic, and we shall make use of N-person interactions modeled in terms of games that constitute metaphors of social dilemmas of cooperation.
- We develop models where population dynamics will be implemented using the tools of Evolutionary Game Theory, where individuals consider:
  - past actions (history); hypothetical futures (prospection); indirect forms of signaling (reputations); assessment of actions (social norms); and punishment (regulation)in their contributions to collective endeavors.

# Motivation and detail - 7

- In addition, the project allows us to understand the role played by the mechanisms above in the self-organization and emergence of specialization, often at the core of several population-based AI studies.
- We are interested in the impact of the interplay between individual cognition and population dynamics in the emergence of important socio-politic concepts common to upper primates and Humans:
  - direct and indirect reciprocity; the evolution of hierarchical structures, norms and institutions; the formation of coalitions and in-group favoritism, including the creation of modular or segregated social networks.

# Motivation and detail - 8

- Since individual capacities are now made explicit, one also has to examine the dynamics of how these intricate behaviours will be passed along, be it by learning from peers or by genetic inheritance.
- There is here an important opportunity to combine, in an unprecedented manner, the mathematical tool of computational logic with the analytical and computational methods of the physics of complex systems and network science, and the mathematics of evolutionary processes.

# Motivation and detail - 9

- Finally, we shall develop a new computational tool to provide an experimental platform for the development of concrete lab experiments replicating, in a controlled setup, social dilemmas of cooperation.
- We believe these topics represent some of the most exciting interdisciplinary challenges of our time, opening new research tracks in Complex Adaptive Systems.
- Game theory constitutes a common language shared by a broad collection of apparently unrelated research fields in social and natural sciences, and promotes training of young scientists with a truly multi-disciplinary background.

# Added Value

- In equipping individuals with enhanced cognitive abilities, we open a new dimension in the investigation of collective behaviour in complex networks.
- The availability of anthropological data and models will inspire the reconstruction of primate behaviour in a computational framework. This, in turn, enables us to anticipate their emergent collective behaviour, in preparation for fieldwork.
- Moreover, the framework can be employed to design intended collective action of robots.

**Thank you!**

**Questions?**