Dynamics and Coevolution in Multi Level Strategic iNteraction Games

(CoNGas)

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CREATE-NET

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Abstract

Many real world systems possess a rich multi-level structure and exhibit complex dynamics that are the result of a **web of interwoven interactions among elements with autonomous decision-making capabilities**. CONGAS will develop new mathematical models and tools, rooted in game theory, for the analysis, prediction and control of dynamical processes in such complex systems.

CONGAS will provide a coherent theoretical framework for understanding the **emergence of structure and patterns in complex systems**, accounting for interactions spanning various scales in time and space, and acting at different structural and aggregation levels. This framework will be built around **game theoretical concepts**, in particular **evolutionary and multi-resolution games**, and will include also techniques drawn from **graph theory**, **statistical mechanics, control and optimization theory**. Specific attention will be devoted to systems that are prone to **intermittency and catastrophic events** due to the effect of collective dynamics.

The theory developed in the project will be validated by considering **three use cases**, one on the growth of the Internet, one on business ecosystems and one on viral marketing dynamics in Internet marketplaces.

The CONGAS Consortium comprises seven universities and research institution and includes leading scientists in game theory, evolutionary games, complex systems science, network science and data-driven analysis of socio-technical systems.

Factsheet

- CoNGas: STREP n. 317672
- Consortium has 7 EU partners
- Budget: 3.42 Meuro with 2.6 Meuro EU funding over 3 years period
- Coordination team:
  - ✓ Project Management: CREATE-NET (Francesco De Pellegrini)
  - ✓ Scientific Coordination: INRIA (Eitan Altman)

Consortium

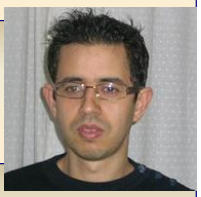
Organization	Country
CREATE-NET (Coordination)	Italy
I.N.R.I.A. (Scientific Coordination, Dissemination)	France
University of Avignon	France
Delft University of Technology	The Netherlands
Imperial College London	U.K.
University of Pisa	Italy
Technion	Israel

Key People

Francesco De Pellegrini (Coordinator – CN)

Eitan Altman (Scientific Coordinator – INRIA)

Rachid El Azouzi (UAPV)



Piet Van Mieghem (TEDELFTH)

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Motivation

1. **Target:** systems involving components performing actions based on **strategies** at several levels
   - Ex: human behavior impacts systems' structure at different levels
   - Agents **compete and cooperate** following **strategies that depend on the scale at which one looks at the systems** (e.g. (ir)rationality and/or utilities)
   - **Dynamics** and **equilibria** of multi-resolution games with complex ties between players
2. **Problem:** capture the right level of detail and **how agents' strategies couple the various scales** at which they operate; aim is better description and new **mechanism design** guidelines

Motivation (cont'd)

1. **Needed insight**: general mathematical laws that drive the dynamics of natural and artificial systems under strategies performed by competing and/or cooperating agents.
2. **Final descriptive requirements**: explain how agents' **strategies combine and emerge**

Example: in socio-technical systems imitation can drive massive coherent behaviors in a large fraction of certain population. Conversely, in a business ecosystem, a network of firms will follow precise strategic and rational market rules with the objective of maximizing a well-defined objective function.

General Objectives

1. **Obj 1**: development of new mathematical **models and tools, rooted in game theory**, for the analysis, prediction and control of dynamical processes in multi-level complex systems.
   - Relate **strategies** and games to the **emerging network structure**
   - Role of the **information flow** among different levels
   - Effects of different levels of **rationality at different scales**, **scale-dependent utilities**
2. **Obj 2**: perform **analysis of co-evolving complex systems** that are prone to **intermittency and abrupt dynamics** relating those to specific **configurations of agents' strategies**
   - Describe efficiency of **equilibrium and out-of-equilibrium conditions**
   - Study scale-dependent strategies and **emerging collective phenomena**

Scientific Objectives

1. Characterize the **impact of agents' strategies** and how the system's structure and **topology affects utilities**;
2. Model and analyze the interaction and competition among agents within each level, as well as among agents of different levels, through **cooperative and non-cooperative game-theoretic tools**
3. Model levels of **rationality** of agents depending on the different **levels they occupy**;
4. Develop a theory for **mathematical mechanism design** in Complex Systems;
5. Understand the impact of **information spreading processes on strategic decision making** in multi-level complex systems;
6. Model intermittency, out of equilibrium description and **early detection of risks**;
7. Methodologies rooted in **game theory** to characterize **evolving networks;**
8. Formalisms for **multi-resolution games** working at **different scales**.

Impact

The foundational impact onto three specific methodological research lines.

1.Statistical Mechanics: new entanglement mathematical models

- New strategy-based multi-scale coupling model for a network of agents
- Mean field description combining strategies and characteristics

2.Evolutionary Dynamics: dynamics of complex networks using novel evolutionary game theory mathematical models;

- State-rich models for evolution
- A mathematics for networked agents.

3.Game Theory: emergence of cooperation and competition patterns and impact on dynamics and stability.

- diversity effects on topology and stability.
- phase transitions for strategies, emergence of collusions: a mechanism design to avoid them

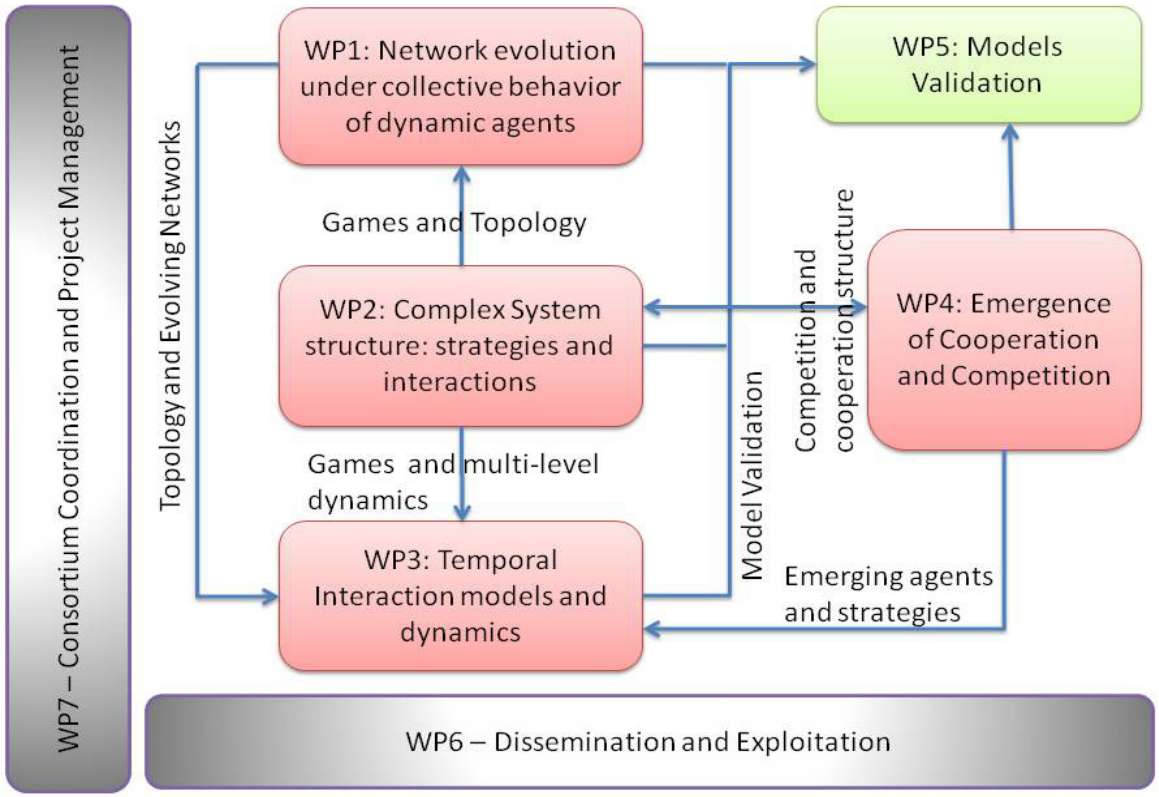
Advisory Board

1. Tamer Başar, Univ. of Illinois at Urbana Champaign, US
2. Jean Walrand, Univ. of California at Berkeley, US
3. Misako Takayasu, Tokyo Institute of Technology, Japan

Validation domains

1. **Business Ecosystem:** companies compete and cooperate, while respecting procedures and laws aimed at ensuring a fair and sustainable economy
    1. detect early signs of collusion;
    2. instability risks of the ecosystem as a whole.
2. **Internet growth:** agents are access/service providers, content providers, infrastructure providers and users/subscribers.
    - evolution of the Internet topology at the AS level;
    - interwoven effects of economics and technological metrics acting on multiple scales.
3. **Viral Marketing Dynamics in Internet Marketplaces**:
    - predicting the evolution over time of a given advertisement;
    - effective viral marketing strategies.

WP structure of CONGAS



Contacts

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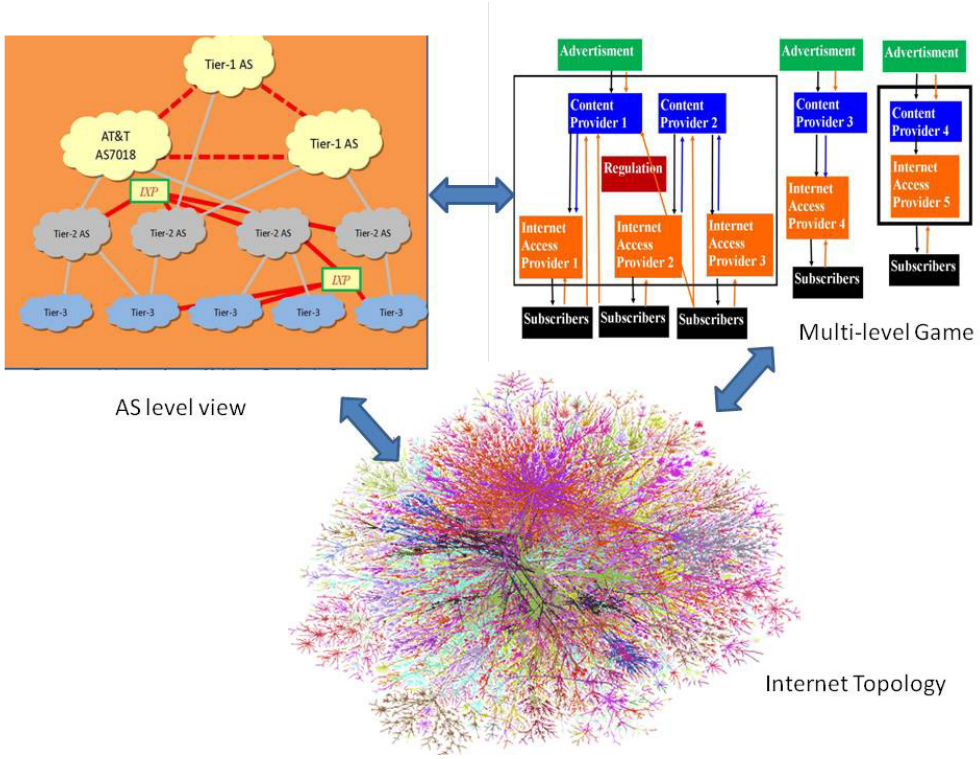
Additional slides

Internet growth

1. Agents: access/service providers, content providers, infrastructure providers and users/subscribers.
2. Interactions are ruled by economic dependencies (e.g., traffic fares)
3. More detailed structure of strategies and interactions is needed
4. Datasets: CAIDA, DIMES, RIPE/RIS, RouteViews ISOLARIO (www.isolario.it).



Viral marketing scenario

1. Models for viral marketing: epidemics and players dynamics do interact
2. Depending on the scale, agents behave differently (e.g., *replicators, competitors or cooperators*)
3. Intermittent or abrupt changes in the dynamics are possible (e.g., driven by content popularity)
4. Impact: viral marketing datasets