Soutenances de Thèses 2024

Matteo Butano

Vendredi 30 aout 2024, Petit amphithéâtre Bâtiment Pascal n°530 **Soutenance de thèse**

Mean-Field Games Applied to Pedestrian Dynamics

This thesis explores pedestrian dynamics through experimental observations and simulations, focusing on the operational layer of pedestrian movement. Experiments involving a controlled crowd and a moving cylindrical obstacle, reveal that pedestrians exhibit anticipatory behaviors that deviate from granular behavior. The thesis challenges two existing pedestrian dynamics models, of different complexity showing their limitations in capturing the observed anticipatory behaviors. These models are found to be too myopic, focusing on short-term decisions without adequately accounting for long-term anticipations. To address these shortcomings, this work proposes a model based on the theory of Mean-Field Games (MFG). MFG models, which combine optimal control and game theory, describe interactions among a large number of agents via their average density, simplifying the mathematical framework. The MFG model successfully predicts the experimental anticipation patterns by incorporating a discount factor that adjusts the weight of future events in the optimization process. Additionally, the thesis presents two corollary projects. The first has the goal to integrate MFG with agent-based microscopic models to handle scenarios requiring detailed individual interactions, such as evacuations. The second explores using Physics Informed Neural Networks to solve MFG equations.

Jury : Cécile Appert-Rolland (directrice de thèse), Thierry Gobron (rapporteur), Bertrand Maury, Antoine Tordeux, Denis Ullmo (directeur de thèse), Marie-Therese Wolfram (rapporteure)

Jules Givois

Lundi 30 septembre 2024, Petit amphithéâtre Bâtiment Pascal n°530 **Soutenance de thèse**

Binding of fermionic mixtures in low dimensions

In this thesis, we study the problem of binding in ultra-cold fermionic mixtures composed of N_h identical heavy fermions interacting with N_l light fermions through a zero-range attractive potential in low-dimensional geometries. The binding phenomenon depends on the space dimension and on the heavy-light mass ratio and results from a subtle competition between the repulsive Pauli pressure of identical fermions and the heavy-light attraction. In one dimension, by using an exact few-body analysis, we establish and characterize states of a single light atom bound with up to five heavy atoms. Then, using a mean-field approach valid for large N_h, we find that such N_h+1 clusters are bound for any N_h as long as the mass ratio exceeds

a threshold which scales as N_h^3. Extending this mean-field method to N_l>1, we show that N+1-type clusters can attract each other and form self-bound chains resembling charge-density waves in the thermodynamic limit. We also extend this mean-field theory to the two-dimensional N_h+N_l problem and find that N_h+1 clusters can form for arbitrarily large N_h in two dimensions as well. However, the mass-ratio threshold for binding scales as N_h^2. In order to find the energy and size of the clusters we take into account beyond-mean-field effects as the two-dimensional mean-field theory is scale invariant. Finally, we present numerical evidence that two two-dimensional N+1-type clusters always repel each other and form no self-bound state, contrary to the one-dimensional case.

Jury : I. Bouchoule, H.-W. Hammer (rapporteur), P. Massignan (rapporteur), C. Mora, D. Petrov (directeur de thèse)

Louis Bremaud

Lundi 16 décembre 2024, Petit amphithéâtre Bâtiment Pascal n°530 **Soutenance de thèse**

Mean Field Game description of virus propagation

This thesis investigates the role of human behavior in epidemic modeling. Epidemics are influenced by both individuals' spontaneous responses and government-imposed measures, creating a feedback loop that shapes the outbreak's progression. However, many existing models treat human behavior as an external factor, limiting their realism. To address this gap, the thesis applies the Mean Field Game (MFG) framework, a theoretical tool for incorporating individual decision-making into epidemic models.

The first part of the thesis applies the MFG approach to an SIR (Susceptible-Infected-Recovered) model with a social structure. Individuals balance infection risk against the social and economic costs of reducing contact. Numerical simulations with realistic parameters identify a Nash equilibrium, reflecting self-interested behavior, and we compare it to the social optimum, which minimizes overall societal costs. The gap between these scenarios is narrowed through constrained Nash equilibria, which include government interventions. The analysis also reveals that changes in population size or model duration can lead to phase transitions in optimal strategies, emphasizing the need for adaptive policies.

In the second part, the MFG framework is extended to complex networks, where individuals differ in connectivity. Using pairwise approximation, we derive epidemic dynamics and integrate MFG principles. Simulations on realistic contact networks highlight how variations in social cost structures influence individual behavior, with significant differences observed based on connectivity levels. A related project provides new analytical insights into the SIR model on regular networks.

Jury : Alain Barrat (examinateur), Marc Barthelemy (président du Jury), Laura di Domenico (examinatrice), Olivier Giraud (co-directeur de thèse), Sergio Gomez (rapporteur), Gabriel Turinici (rapporteur), Denis Ullmo (directeur de thèse)

Giorgio Ciliberto

Jeudi 19 décembre 2024, Petit amphithéâtre Bâtiment Pascal n°530 **Soutenance de thèse**

Non-locality and Back-reaction in Acoustic Black Holes and Non-linearity in Quantum Fluid Dynamics

This thesis is mainly about quantum correlations and non-linear fluctuations in quantum fluids. It focuses especially on collective quantum fluctuations, i.e. sound waves, in the stationary flow of a 1D Bose-Einstein quasi- condensate which exhibits an acoustic horizon, i.e. a transition from subsonic to supersonic flow. Quantum phenomena generated by the presence of the horizon are investigated. The thesis also presents a brief excursus on two- dimensional turbulence in a quantum fluid. We study quantum non-separability, non- locality and back-reaction of the acoustic Hawking radiation emitted by an analog black hole. The entanglement and nonlocal correlations within the tripartite system of quasi-particles emitted from the acoustic horizon are first investigated. Back-reaction equations govern- ing the effect of such acoustic radiation on the inhomogeneous background are derived and stationary solutions are considered. Finally, a phenomenological theory based on topological constraints for vortex creation and annihilation is effectively applied to experimental data, thus accounting for the growth and decay of turbulence.

Jury : Jacqueline Bloch, Andreas Buchleitner (co-directeur de thèse), Marek Kus, Nicolas Pavloff (directeur de thèse), Heidi Rzehak, Augusto Smerzi