SURF Proposals, IFISC 2020

1. Twitter as a proxy for sociolinguistic variation

Advisor: David Sánchez

Online microblogging platforms such as Twitter generate massive amounts of data that contain a wealth of information on language usage. It is well known that spelling, lexical and syntactic variation of this usage is correlated with the speakers' socioeconomic status. Our aim is to employ a database of UK geolocated tweets to quantify, with statistical methods, the influence of income and educational levels on standard and non-standard spoken English. The SURF fellow will benefit from learning big data techniques to analyze human behavior phenomena in today's society.

2. Game theory and the evolution of cancer

Advisor: Tobias Galla

Populations of cancerous cells can be described using ideas from evolutionary game theory. For example, mutants may emerge and compete with ‘wild type’ (normal) cells for resources. This determines the fitness of the different types of cells, and how quickly they reproduce. In game theory one is interested in the interaction between co-operators (who contribute to a common resource) and defectors (who use the resource but do not contribute). The dynamics of such systems can be described mathematically by stochastic models of so-called birth-death processes. In this project you will use ideas from non-equilibrium statistical physics to investigate evolutionary games (e.g. public good games) and/or populations of cells in the context of cancer modelling. For example, we might focus on the probability with which mutants can invade and take over an existing population. Ideally the project will combine computational work and analytical calculations. Interested students will need to be proficient in a computer language such as C++ or Fortran (Matlab will not be sufficient), and they need to have a solid interest in the theory of stochastic processes. Prior knowledge of techniques from statistical physics (e.g. master equations, stochastic differential equations) would be welcome.

3. Time-dependent analysis of traffic incidents using recurrent neural networks

Advisors: Apostolos Argyris and Jose Javier Ramasco

In the context of the current research, the patterns of congestions that emerge from various traffic incidents within a city grid will be analyzed. These incidents may originate from occasional or scheduled/expected intraday traffic events. Data sets from actual traffic recordings will be used, feeding various machine learning structures, mainly focusing on recurrent neural networks. Aim of this investigation is to identify the dependence between the time duration of the traffic incidents, the time extension of the generated congestion and its dissipation within the investigated road infrastructure.
Required skills and knowledge: Programming, knowledge in time-series analysis and machine learning techniques

4. Detecting covert communication networks
Advisor: Tobias Galla

In this project we will imagine a situation in which there is a covert communication network, consisting of a set of receiving and transmitting units. We are unable to detect the units themselves, but we can send around a probe which can intercept the communication lines. From this, information about the possible number of communication units and their locations can be inferred. We will ask the question: what is the optimal search path for such a probe? To address this problem we might first study search paths which can be described by a small set of parameters. Analytical solutions might then exist. Time permitting we will explore Bayesian approaches, in which beliefs about the locations of the units are continuously updated based on observations made. The project will require the student to carry out computational work and analytical calculations. This project requires the student to have advanced computational skills. In particular you will need to be proficient and experience in a computer language such as C++ or Fortran (Matlab will not be appropriate). Students with prior experience in visualisation would be particularly welcome. A solid interest in probability theory would also be a plus.

5. Renewable energy sources and power grid stability.
Advisors: Pere Colet and Damià Gomila

The power grid is, arguably, the largest socio-technical system in the world. Stable operation requires the synchronization of the power plants and a precise balance between generation and consumption. The balance is not easy to achieve due to the random character of (part of) the load and the increasing use of renewable sources which are subject to uncontrollable factors, such as wind or sunlight. In this project we will study the synchronization and stability of a prototypical power grid when a large fraction of the generation comes from renewable sources, as well as the effect of including battery storage systems.

6. Coherent Maxwell Demons @ the Nanoscale
Advisor: Rosa López

In 1867 J. C Maxwell introduced the idea of an intelligent agent (called demon by Lord Kelvin) capable of separating hot and cold particles of a gas without performing work and then, violating the second law of thermodynamics. The paradox was solved in the context of Information Theory. The entropy decrease by the demon is compensated by the entropy increase of the act of deleting information whenever the demon resets the setup to the initial state. These days, the action of the demon is view as a clever feedback mechanism in which useful work can be extracted. At the nanoscale we can profit from this idea of building motors or refrigerators based on the demon action. In the nano world the quantum coherence is a fundamental characteristic that can either help or not to the demon to perform his task. We propose to implement a coherent demon to a quantum device, i.e., a single quantum dot coupled to topological matter. In the project we will explore how coherence modifies or not the efficiency of the quantum engine. For this goal we will apply proper tools developed in quantum information theory and quantum transport theory. Our results will impact in the development of the Quantum Technologies.

7. Quantum machine learning for real world tasks
Advisors: Miguel C. Soriano and Roberta Zambrini

Reservoir computing is a special machine learning paradigm to process time varying data. We have recently started a research line generalizing it into the quantum regime, considering for instance spin networks. The aim of this project is to establish the performance of this scheme for real world tasks such as human speech recognition.

8. Mining atmospheric information from aircraft trajectory data
Advisor: Massimiliano Zanin

Air transport generates huge quantities of data, e.g. about aircraft trajectories and weather conditions, which are seldom exploited. These data may nevertheless be used to extract information about the airspace with an unprecedented resolution and reliability. In this research project we will explore how ADS-B reports (i.e. position reports sent by aircraft during the flight) can be used to infer the atmospheric pressure, specifically comparing the reported barometric and geographical altitudes. This will require develop models to assess the reliability of the information, by comparing the results from different flights in the same region; and this could, in turn, be used to assess the reliability of the trajectory information. The student must have a good knowledge of Python; previous experience in modeling and data analysis will also be positively evaluated.