LIST OF POSSIBLE PROJECTS: COMPLEX-SYSTEMS GROUP

1. Critical signature of wind distribution at different scales

2. Statistics and Modeling of Animal and Human Communication

3. Statistics and Modeling of Human Populations

1. Critical signature of wind distribution at different scales

Any flow in the regime of Fully Developed Turbulence (FDT) develops a scale-invariant hierarchy which is multifractal. The global circulation pattern of wind is of multifractal character, as can be assessed by means of the singularity analysis of the wind field. But the distribution of singularities is not uniform across the Earth, particularly when transient, critical phenomena take place, such as hurricanes (that is, tropical cyclones). These are processes which are far from stationarity and from bidimensionality, with a strong feedback loop of deep convection. It is then expected that its singular signature will be different than that of the normal wind regime.

In this work we intend to characterize the normal distribution of wind as a multifractal system according to FDT. We expect to develop appropriate techniques to distinguish the role of hurricanes and other extreme events, and to characterize the specificities of the singularity statistics. The structure of singularities on hurricanes should provide some information about the role of convection and on the power of dissipation on hurricanes; a good knowledge of critical systems would be required to solve this inverse problem.

The candidate (mathematicians, physicists…) should have a good academic profile, solid background in functional analysis or in the physics of critical phenomena, and a strong motivation to work in complex-systems science in general and in geophysics in particular.

[1] A. Turiel et al. *Microcanonical Multifractal Formalism: a geometrical approach to multifractal systems. Part I: Singularity Analysis.* Journal of Physics A **41**, 015501 (2008).

Supervisors: Álvaro Corral (CRM) and Antonio Turiel (Institut de Ciències del Mar).

2. Statistics and Modeling of Animal and Human Communication

Language is one of the most complex products of both the human brain and cultural evolution. But comparative research is revealing striking similarities between human language and the communication of other species [1]. The present project aims to, first, extract patterns and statistical regularities in these data and to compare them with those present in human language; and second, apply different sorts of models to find the most plausible representation and explanation of the data. The research will focus on databases on monkeys, cetaceans, birds and also on children.

Specific models have been proposed for particular trends of human language, such as the Zipf's law, but no unified model exist; in fact, not even a well accepted model exists for a single observable. The extension of the models to animals is even more unclear. Some approaches are random-typing models, variations of the rich-get-rich or preferential-attachment rule proposed by Simon, Polya urns, and the least-effort principle. All of them have been criticized following an intense debate [2]. The crudest versions of these models allow for analytical treatment, mainly through stochastic processes theory, but the more refined versions will be necessarily studied by means of computer simulations.

The application of strict model selection procedures will be indispensable, balancing goodness-of-fit and the parsimonious character of the models. Both frequentist and Bayesian approaches will be compared, and, in addition to simplicity, physical (i.e., linguistic or cognitive) plausibility will be contemplated. Other sequences conveying information content, such as the genome, and other Zipf-like systems, like ecosystems, will be considered, for comparative reasons.

The potential candidates (mathematicians, physicists, statisticians, computer scientists…) should have a good academic record and very high motivation to do research and learn new things in a cross-disciplinary environment. Programming skills are necessary from the beginning or should be developed on the fly.

[1] R. Ferrer-i-Cancho et al. *Compression as a universal principle of animal behavior.* Cognitive Science 37(8), 1565-1578 (2013).

[2] M. Mitzenmacher. *A brief history of generative models for power laws and lognormal distributions.* Internet Mathematics 1, 226 (2004).

Supervisors: Álvaro Corral (CRM) and Ramon Ferrer-i-Cancho (Departament de Llenguatges i Sistemes Informàtics, UPC).

3. Statistics and Modeling of Human Populations

The statistical pattern known as Zipf's law has been proposed to hold for many different social systems. One just needs to count the number of elements of some bigger entities, as for instance, the number of employees of companies, believers of different religions, visitors of web pages, daily telephone calls to users, etc.. But sometimes it is not easy to identify clearly either the elements or the entities. This happens when the entities are cities, which are usually defined in terms of obsolete administrative conventions that do not reflect the real patterns of human population.

In this project we propose to study high resolution, human demographic big data in order to unveil the real patterns of human settlements. Related studies have been performed for the spatial distribution of language speakers, and it has been found that the Zipf's law is not the best statistical model, being outperformed by the lognormal distribution. Then, the application of strict model selection procedures will be indispensable, balancing goodness-of-fit and the parsimonious character of the models. Both frequentist and Bayesian approaches will be compared, and, in addition to simplicity, physical (i.e., social) plausibility will be contemplated. Other Zipf-like systems, like ecosystems, will be considered, for comparative reasons. Another important branch of the project will be the development and simulation of agent-based models.

The potential candidates should have a good academic record and very high motivation to do research and learn new things in a cross-disciplinary environment. Programming skills are necessary from the beginning or should be developed on the fly.

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