

Introduction



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Topics on non-equilibrium statistical mechanics and nonlinear physics (II)

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The research in non-equilibrium statistical mechanics and nonlinear physics is a scientific approach to the investigation of how relationships between parts give rise to the collective behaviour of a system, and how the system interacts and forms relationships with its environment. Such problems are tackled, mostly with new concepts and tools related to information theory, statistical mechanics and nonlinear dynamics. They aim at representing and understanding the organized albeit unpredictable behaviour of natural systems that are considered intrinsically complex. In fact, the exciting fields of complexity, chaos and nonlinear science have experienced impressive growth in recent decades.

Research topics not only include classical problems in statistical mechanics, fluids, pattern formation, chaos and dynamical systems (these have deserved a wealth of attention), but they have also given place to new interdisciplinary fields such as networks, social dynamics, econophysics, theoretical neuroscience and brain dynamics, granular media, biomathematics and data science, among others. The present issue of *Philosophical Transactions A*, 'Topics on non-equilibrium statistical mechanics and nonlinear physics (II)', constitutes the continuation of the previous volume that gathered selected, extended and enhanced papers presented at MEDYFINOL 2008 [1].

In particular, the contributions to this issue are due to the plenary speakers and a few invited talks, of XVIII MEDYFINOL 2014, that took place in Maceió, Brazil, 13–17 October 2014. MEDYFINOL is a

traditional and regular meeting of the statistical and nonlinear physics community in Latin America. The XVIII Conference followed a series of meetings that took place in Argentina, Brazil, Chile and Uruguay. The purposes of the MEDYFINOL meetings are to keep the scientific community updated on new developments and tendencies in the statistical mechanics and nonlinear dynamical fields, to spur collaborative international science programmes, and to identify and discuss the most relevant advances in the area. The success of the MEDYFINOL meetings can be attributed to the presence of eminent speakers, to the high-quality contributed papers, as well as to the significant participation of students.

The current issue gathers the contributions of leading scientists that delineate the state of the art in areas strongly influenced by non-equilibrium statistical mechanics and dynamical systems. The authors have made a special effort in writing high-level papers with an introduction general enough so as to reach a wide audience and introduce people outside their fields to their research.

In the first contribution, Descalzi & Brand [2] report interesting results for collisions between quasi-one-dimensional (line) solitons in the two-dimensional (2D) complex Ginzburg–Landau equation with cubic–quintic nonlinearity. Collisions of counter-propagating concentration waves during the catalytic oxidation of CO on a Pt(110) surface or collisions of arc-shaped multicellular structures of non-chemotactic mutants are examples of interactions of quasi-one-dimensional dissipative solitons. These objects, localized in one dimension and spatially extended in the other, exist due to a balance of nonlinearity, dispersion, gain and loss. Based on a simple dispersive–dissipative model, the cubic–quintic complex Ginzburg–Landau equation, the authors show in this article that the collision of quasi-one-dimensional dissipative solitons can lead to non-unique results for a large class of initial conditions which are not in their asymptotic state. The collisions are strongly affected by a modulation instability along the crest of the line solitons, which gives rise to a great variety of outcomes of the collisions.

In the next contribution, Cartes & Descalzi [3] describe a study about the transition from chaotic attractors to periodic explosive solitons on a generalized cubic–quintic complex Ginzburg–Landau equation that may model the propagation of pulses on a mode-locked fibre laser. These non-chaotic explosions appear when higher order nonlinear and dispersive effects are added to the complex cubic–quintic Ginzburg–Landau equation modelling soliton transmission lines. In particular, the authors have analysed the transition from periodic to non-periodic explosions (and vice versa) by bifurcation diagrams. This counter-intuitive phenomenon is the result of period-halving bifurcations leading to order (periodic explosions), followed by period-doubling bifurcations (or intermittency) leading to chaos (non-periodic explosions).

Gomez *et al.* [4] present a novel way of Polarimetric Synthetic Aperture Radar (PolSAR) images classification. PolSAR sensors provide useful information about the Earth and other celestial bodies: texture, dielectric constant and distance. Because they illuminate the scene with microwaves, they operate at any time (independently of the sunlight) and almost independently of adverse weather conditions. Each pixel of a fully PolSAR image carries a Hermitian matrix which follows a complex Wishart distribution. It is difficult to turn these data into valuable information using classification algorithms. The authors propose a new classification technique which uses stochastic distances, optimized weights and a dynamics governed by a diffusion–reaction system. These three elements interact in a nonlinear complex manner, smoothing the data while avoiding the deletion of small significant details, and evolving towards a classification with good global properties. Two experiments were carried out, through real and simulated images, to prove the method effectiveness. Promising results were shown and one could consider they will be very important study for remote sensing.

In the following contribution, Paiva *et al.* [5] deal with drainage of high viscous fluid (oil) by means of injection a less viscous fluid (water). The authors show numerical evidence that the amount of displaced oil is very sensitive to the porosity of the medium. By solving the Navier–Stokes equation numerically, the authors are able to quantify the dependence of the fraction of retained oil as a function of the injection rate. Further, they investigate how the quantity of retained oil changes with respect to the geometric aspect of the region defined as porous. The paper has numerical results about an interesting subject related to the oil displacement inside a

porous medium, which is a common procedure used in the field of oil exploration. They present results showing how the fraction of retained oil changes as a function of different data that control the displacement mechanism such is the capillary number and the ratio between viscous force and capillary force. Also they investigated how the fraction changes for different configurations of the packing generation. They used the Apollonius packing, changing the number of circles and their diameters in a controlled way.

Cortés-Domínguez *et al.* [6] compare two systems with rotational symmetry. The first is a Bénard–Marangoni experiment, where a fluid layer is destabilized by buoyancy and surface tension forces created by temperature gradients. The second system consists on a large drop of liquid metal destabilized using oscillating magnetic fields, through radial Lorentz forces. Although there are important differences between both configurations, the results are similar: the patterns break the rotational symmetry, with different azimuthal and radial wavenumbers. Such patterns are stationary in most cases, but they can exhibit various dynamical behaviours: rotations, slow transitions or cyclic connections between different patterns. This is a valuable contribution considering that few experimental works have been carried on instabilities in fluids under the influence of external magnetic fields, especially for low-frequency ranges.

Non-equilibrium systems, as opposite to equilibrium ones, are very rich in its behaviour, or, to state it in a less positive sentence, are full of complications. The dynamics of a granular set of particles presents very exciting phenomena like the one addressed in the contribution of Cordero *et al.* [7], segregation, but it also strongly depends on the type of energy injection in the system, making the results less universal than for equilibrium systems. The authors deal with the influence on segregation of the type of vibration that the container suffers, and they are able to show that the coexistence of dense gas phases moves in the phase diagram for different types of vibrations. The vibrations are not symmetric: the time the box is moving up is, in general, different to the time it is moving down. Increasing the asymmetry, the size in phase space of the chaotic regions grows. When many grains are placed in the box, the phase separation between dense solid-like regions coexisting with fluid-like regions takes place at smaller global densities for asymmetric vibration profiles.

In a very interesting paper, Thiel *et al.* [8] study the effect of amino acid starvation on protein synthesis rate. The synthesis of proteins, which is crucial to life, is a complicated process where ribosomes process along the mRNA sequence, attracting tRNAs charged with amino acids corresponding to each codon and thus assembling the protein amino acid chain. Because ribosomes follow each other and can create traffic jams which hinder yield, especially as different codons are processed at different speeds (existence of slow codons), higher initiation rates, ribosome or amino acid availability does not translate necessarily into higher protein synthesis rates. Here the authors focus on how these rates depend on amino acid availability. The authors show how different protein sequences give rise to different behaviours depending on how slow codons are distributed along the sequence, and they identify different classes of mRNA sequences. Most interestingly, they show how two mRNAs of different types which share a common pool of amino acids may interact in such a way that the synthesis rate of one of the proteins is actually increased as amino acid availability is reduced, as a result of resource allocation. This is a very interesting result which confirms that community based effects are a key ingredient in cellular function and that they can have the same regulating effect as more complicated interaction networks. Moreover, this is the first time that such an effect is demonstrated for amino acid starvation, corresponding to situations of nutritional stress.

The next three contributions show that information theory provides novel effective tools to investigate important multi-disciplinary problems such as the characterization of neuronal activity, the determination of anticipated and delayed synchronization in neuronal circuits, and the behaviour of Libor interest rates. Such analyses are performed evaluating quantifiers like the Shannon entropy, the generalized statistical complexity and the Fisher information over probability distribution functions which take into account the temporal causality.

Neurons tend to fire a spike when they are near a bifurcation from the resting state to spiking activity. The phase diagram is determined by a delicate balance between noise, dynamic currents

and initial conditions. Montani *et al.* [9] present a novel methodology to characterize the dynamics of this system that takes into account the fine temporal ‘structures’ of the complex neuronal signals. This allows the authors to accurately distinguish the most fundamental properties of neurophysiological neurons that were previously described by Izhikevich applying nonlinear dynamic theory, and its classification depending on bifurcation and resting state. The authors propose a versatile method to quantify the 20 most fundamental neurocomputational features of oscillatory patterns of biological neurons considering subtle measures accounting for the causal information: Shannon permutation entropy, Fisher permutation information and generalized permutation statistical complexity. Their approach allows to estimate the ‘clustering properties’ of these different neuronal structures, quantifying the causality of the signal and inferring the emergent dynamical properties of the system through a two- and three-dimensional time causal space representation.

Montani *et al.* [10] employ numerical and experimental data to assess the time delay between the activities of two brain areas using Bandt–Pompe permutation quantifiers in a special plane, called multiscale entropy-complexity causality plane (for which one of the axes is the permutation Shannon entropy and the other is the generalized permutation statistical complexity). They are able to show that the anticipated synchronization/delays one dynamics between different areas can be confidently characterized by the above-mentioned information theory quantifiers. Anticipated synchronization becomes a function of the embedding delay, a parameter of the Bandt–Pompe technique. Scale considerations are explicitly incorporated in their approach by changing this embedding delay. The location in the entropy-complexity plane of the ‘relative synchronization time’ allows the authors to extract fruitful information concerning the underlying dynamics of the complex local field potential’s time series, and to characterize the concomitant dynamics. The associated numerical and experimental results confirm that the author’s tools yield a conceptually simple yet computationally efficient algorithm for characterizing the complex time series involved in describing brain circuits. The confirmed existence of anticipated synchronization mediated opens up several venues for investigating synchronized activity in the brain.

In the sequence, Fernández Bariviera *et al.* [11] analysed Libor interest rates in British Pounds, Euros, Swiss Francs and Japanese Yens for seven different maturities (overnight, one week, one, two, three, six and 12 months) during 2001–2015. A novel information theory approach was devised for the purpose of detecting changes in the stochastic underlying dynamics of the Libor time series: the causal Shannon–Fisher Plane. The authors identified a significant reduction of the informational efficiency for the British, Swiss and Japanese markets during the years 2007–2012. The authors conjecture that this inefficient behaviour is consistent with the Libor manipulation that was uncovered by financial authorities. Besides, they found that the behaviour of the Libor for all currencies and for maturities one, two and three months follows a different dynamics than the one associated with the other maturities. In particular, the authors conclude that the methodology is a pertinent tool for unveiling changes in the stochastic structure of data. Thus, it can be used as a market overseeing instrument.

The last two contributions consider up-to-date problems in the field of complex networks.

Our current vision of the world has integrated the concept of networks: man-made networks as, for example, electrical networks, airport networks or the World Wide Web come easily to our minds. But many of us are not aware that in the natural world there are many interesting complex networks as is the case of metabolic networks or the network of social relationships. Complex networks can show organization or structure, an order grouping selectively sets of nodes. Such sets of nodes are the support of community-based functionalities. In the context of metabolism, it means that a group of nodes are functionally relevant: their workings are useful for the resulting organism existence. Detecting communities in networks is a main problem in network science. Alvarez *et al.* [12] propose a new way of developing such a task based on a generalization of the dissimilarities/distance between nodes to be implemented in hierarchical clustering algorithms. To this aim, the authors propose the use of convex combinations of usual and novel dissimilarities measures, and show their performance on two real networks:

the metabolic network of *Caenorhabditis elegans* and a network of social relationships (the Zachary Karate Club Network).

It is clear for everyone that we live in a connected world. We communicate and transfer information with a huge number of acquaintances by means of online platforms available through mobile devices. Gómez-Gardeñes *et al.* [13] model how these platforms compete as a product of the actions of users within the underlying social networks. In particular, the authors analyse the transition from the dominance of a single platform to the coexistence of multiple communication means used by a set of social actors. This is a very interesting work on competition between layers as a possible model of social network interaction. Based on a very simple Ising-like model, the authors propose a Hamiltonian that takes into account the interaction among users of the same social network and the competition between different applications due to splitting of resources.

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References

1. Descalzi O, Martí AC, Masoller C, Rosso OA. 2009 Topics on non-equilibrium statistical mechanics and nonlinear physics. *Phil. Trans. R. Soc. A* **367**, 3151–3156. (doi:10.1098/rsta.2009.0101)
2. Descalzi O, Brand HR. 2015 Non-unique results of collisions of quasi-one-dimensional dissipative solitons. *Phil. Trans. R. Soc. A* **373**, 20150115. (doi:10.1098/rsta.2015.0115)
3. Cartes C, Descalzi O. 2015 Transition from non-periodic to periodic explosions. *Phil. Trans. R. Soc. A* **373**, 20150114. (doi:10.1098/rsta.2015.0114)
4. Gomez L, Alvarez L, Mazorra L, Frery AC. 2015 Classification of complex Wishart matrices with a diffusion–reaction system guided by stochastic distances. *Phil. Trans. R. Soc. A* **373**, 20150118. (doi:10.1098/rsta.2015.0118)
5. Paiva ASS, Oliveira RS, Andrade RFS. 2015 Two-phase fluid flow in geometric packing. *Phil. Trans. R. Soc. A* **373**, 20150111. (doi:10.1098/rsta.2015.0111)
6. Cortés-Domínguez I, Burguete J, Mancini HL. 2015 Experimental dynamics in magnetic field-driven flows compared to thermoconvective convection. *Phil. Trans. R. Soc. A* **373**, 20150113. (doi:10.1098/rsta.2015.0113)
7. Cordero P, Risso D, Soto R. 2015 Effect of the vibration profile on shallow granular systems. *Phil. Trans. R. Soc. A* **373**, 20150116. (doi:10.1098/rsta.2015.0116)
8. Heldt FS, Brackley CA, Grebogi C, Thiel M. 2015 Community control in cellular protein production: consequences for amino acid starvation. *Phil. Trans. R. Soc. A* **373**, 20150107. (doi:10.1098/rsta.2015.0107)
9. Montani F, Baravalle R, Montangie L, Rosso OA. 2015 Causal information quantification of prominent dynamical features of biological neurons. *Phil. Trans. R. Soc. A* **373**, 20150109. (doi:10.1098/rsta.2015.0109)
10. Montani F, Rosso OA, Matias FS, Bressler SL, Mirasso CR. 2015 A symbolic information approach to determine anticipated and delayed synchronization in neuronal circuit models. *Phil. Trans. R. Soc. A* **373**, 20150110. (doi:10.1098/rsta.2015.0110)
11. Bariviera AF, Guercio MB, Martinez LB, Rosso OA. 2015 A permutation information theory tour through different interest rate maturities: the Libor case. *Phil. Trans. R. Soc. A* **373**, 20150119. (doi:10.1098/rsta.2015.0119)
12. Alvarez AJ, Sanz-Rodríguez CE, Cabrera JL. 2015 Weighting dissimilarities to detect communities in networks. *Phil. Trans. R. Soc. A* **373**, 20150108. (doi:10.1098/rsta.2015.0108)
13. Gómez-Gardeñes J, de Domenico M, Gutiérrez G, Arenas A, Gómez S. 2015 Layer–layer competition in multiplex complex networks. *Phil. Trans. R. Soc. A* **373**, 20150117. (doi:10.1098/rsta.2015.0117)