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Preface

PNLD 2019, the sixth of the Perspectives in Nonlinear Dynamics conferences, was held in São Paulo, Brazil from July 16 to July 19, 2019 as a satellite to STATPHYS 27 that was held the preceding week in Buenos Aires, Argentina. The venue for the meeting was ICTP-SAIFR, the South American Institute for Fundamental Research of the ICTP which is housed on the campus of the São Paulo State University (UNESP) at the Instituto de Física Teórica (IFT-UNESP).

The meeting was supported by the ICTP-SAIFR, and had about 45 talks (both invited and contributed) with about 60 poster presentations - more or less the same as at earlier versions of PNLD. In all, there were about 110 participants at the conference and given the synergy with STATPHYS, the participants came from over fifteen countries, with, not unexpectedly, considerable representation from South American nations. We present here a brief report on the meeting, as well as a summary of the proceedings. We should add that some of the contributions here were not presented at the conference; some of the invitees were not able to travel at the time. In addition to the editors of the Proceedings, the Conference was organized by Silvina Ponce Dawson and Gabriel Mindlin of the Universidad de Buenos Aires, Argentina, and Roberto Kraenkel of the IFT-UNESP and Ricardo Viana from the Universidade Federal do Paraná (UFPR), Brazil. A new feature of this PNLD is that all the talks were video-recorded and are available for viewing on the website, https://www.ictp-saifr.org/conference-on-perspectives-in-nonlinear-dynamics/.

As we mentioned in the report on the last several PNLDs, much of the initial impetus to study nonlinear dynamical systems arose from considerations of statistical physics. The connection between PNLD and STATPHYS has helped to focus our attention on important issues in nonlinear science studies in a sustained manner. The continuity embodied in the PNLD programmes has been gratifying. Several of the invited speakers at the 2019 meeting had attended earlier PNLD conferences, and at least five of the participants in São Paulo had been there at the start, in Chennai in 2004.

The topics at this meeting included a discussion on recent developments in nonlinear dynamical systems (conservative and dissipative dynamics, noise and stochastic effects), spatiotemporal order and chaos, synchronization, control of chaos, nonlinearity in biological, socio-economic and technological systems, social networks, dynamics on networks, urban computing, ergodicity, mixing, turbulence and transport in passive scalar and active reacting flows, computational neuroscience, and climate dynamics. The diversity of talks at the meeting captured the breadth and interdisciplinarity of the field of nonlinear dynamics and complex systems. Of particular note was the invited talk by Paulo Artaxo of the University of São Paulo, on the scientific challenges in studying regional and global climate change. This is an area where different aspects of nonlinear science come together to contribute to an issue of great significance, both globally and locally.

Keeping the importance of addressing contemporary problems in mind, we have expanded the scope of the Proceedings somewhat, to include a round-table discussion on the application of nonlinear models in the mathematical modelling of the SARS-CoV-2 pandemic that is currently devastating the world. The rapidity with which the disease has overtaken humanity, especially when there was confidence that methods of science could tame nature, has been humbling. Especially as we realize, that there are other sources of nonlinearity in the manner in which societies tackle this disease. The noise and insecurity that different cultures and interests introduce into the basic nonlinear epidemiological model are not negligible, and each country is experiencing the pandemic in a different way. We believe that this is a fitting moment in time when the scientific community needs to speak unequivocally in support of the use of reliable modelling tools in addressing problems of current social importance. For this we have invited several opinions from experts working in the area, even though several (most) of them did not attend the PNLD conference.

In addition to Artaxo, several talks at the meeting discussed climate modelling and analysis, including the inaugural talk by Jürgen Kurths on a complex network approach to look at the global pattern of extreme-rainfall patterns. Neelima Gupte and colleagues presented an analysis of microtransitions in hierarchical networks with applications to climate, and Elena Surovyatkina of the Potsdam Institute for Climate Impact

Research presented her results on forecasting monsoon onset and withdrawal, based on methods of nonlinear dynamics.

Biological problems were central to another set of talks. These included a study by Ricardo Martínez-Garcia on patterns that emerged in populations with density-dependent movement, a model of brain tumour, by Kelly Iarosz, network-based tools for retina image classification by Cristina Masoller, and Ricardo Gutiérrez' study of the dynamics of ecological networks. José Luis Herrera Diestra presented a study of the viral disease dengue in Venezuela using methods of network analysis. Computational neuroscience was also one of the themes, with an exploration of phase synchronization in Hodgkin–Huxley-type networks by Bruno Boaretto, phase synchronization and intermittency in healthy and Alzheimer affected human brains, by Roberto Neto, the effect of neural variability on the phase synchronization of neural networks by Kalel Rossi, and Fernando da Silva Borges's study of firing patterns in networks of exponential integrate-and-fire neuron model that also had adaptive properties.

Bruno Eckhardt, who had also attended the first PNLD meeting in Chennai in 2004 returned to speak on individual and collective bacterial motions. It is a matter of great sorrow that he passed away a few weeks after this meeting. This was very unexpected and it has been a big loss to our community. We will greatly miss him for his deep insights, his patience, and his gentle humor.

Three talks focussed specially on turbulence. Samriddhi Ray spoke on non-intermittent turbulence, while José Soares de Andrade discussed self-organization and anomalous scaling in non-Newtonian turbulence. Pablo Mininni presented his results on stratified turbulence, focussing on low-dimensional dynamics and invariant manifolds.

Two topics that continue to be of considerable current interest are the study of synchronization and the study of networks, often in conjunction with each other. Tiago Pereira spoke on the ability of external stochastic driving at network hubs to induce coherence resonance and synchronization, using the network motif of a star to make the point. Fabiano Ferrari discussed the suppression of synchronization due to time-delay feedback in neural networks, while Ulrike Feudel also looked at loss of synchrony and transient chaos in networked systems. Adilson Motter discussed the contrast between the symmetry of the dynamical state and the symmetry of the system and the role of heterogeneity in network dynamics.

The notion of frustrated synchrony in complex networks was the topic of Ginestra Bianconi's talk. Nicolás Rubido discussed the topological factors that affect network inference. Using machine learning to infer the structure and dynamics of networks was the topic of Francisco Rodrigues' presentation, and using machine learning and neural networks to extend the usual atomistic simulations to infer properties of liquids formed the focus of Alexandre Rocha's presentation.

Over the past decade, there has been an upsurge in applications of nonlinear dynamics and (particularly) network science in areas of economics and social sciences. Several talks at the conference had these foci. Nivedita Deo analysed the evolution and dynamics of currencies, Ricardo Ruiz examined the case of inequality in random markets, while Babatunde Idowu studied chaotic dynamics in finance. Camilo Rodrigues Neto presented a model for laws of scale in urban systems. Network theory was used in a number of contexts, Javier Buldú studied connections, Murilo Baptista used these to analyse the spatial signatures of causality to understand social crisis in Brazil, and Silvio da Costa Ferreira showed how information spreading over political communication networks can be quantified.

Issues of transport in chaotic systems was the focus of a few talks, from Ricardo Viana, who spoke on fractal structures in open Hamiltonian systems in the context of plasma physics, Ricardo Egydio de Carvalho on barriers to transport when there are shearless atractors, and Iberé Caldas on shearless invariants in a class of symplectic mappings.

In addition to these, there were a few talks that fell outside the general themes enumerated above. Americo Barbosa da Cunha Jr presented a bifurcation analysis of a bistable system that describes the physics of piezoelectric energy harvesting, Zoltan Toroczkai discussed aspects of computational complexity, Pedro Pessoa spoke on entropic dynamics on statistical manifolds and Mario Chávez suggested a new procedure for ordering and ranking complex high-dimensional data, Andre Gusso presented results on robust chaos induced by external driving with two frequencies, Emanuel Fernandes de Lima discussed non-chaotic transitions in classical systems, Alejandro López Castillo described Turing patterns that were modulated by a chemical concentration gradient, and Raul de Palma Aristides spoke on nonlocal coupling between oscillators. The final talk of the conference was by Stefano Boccaletti, who gave a panoramic overview of the behavior of networked phase oscillators which can show explosive synchronization and Bellerophon (as opposed to chimera) states.

This Proceedings consists of twenty papers which expand on the conference themes. Five articles are by participants at earlier PNLDs who were not at this meeting in person. We are grateful to them for enthusiastically contributing to the Proceedings. Both Somdatta Sinha and Sudeshna Sinha were at several of the PNLDs and played a major role in organizing PNLD 2013 in Hyderabad. P. Muruganandam and K. Murali have been at several earlier PNLDs, as have Awadhesh Prasad and Manish Shrimali. Finally, K.R. Sreenivasan – who, as it happens, gave the first talk at the first PNLD! – has also contributed to the proceedings.

Recent developments in nonlinear systems is represented by the work of Rosetto and Schelin on Wada boundaries in pp-wave spacetimes and by the work of Dixit, Asir, Prasad, Kuznetsov and Shrimali on spatial feedback control on multistability in hidden attractors, Gutiérrez, Cabeza and Rubido discuss spatio-temporal order and chaos and bifurcations and hysteresis in experimentally coupled logistic maps. The section on nonlinearity in biological, socio-economic and technological systems has found good contributions by Aravind, Murali and Sinha on logic gates with memristor circuits, drug resistance in cancer research from Trobia *et al.*, and an interesting approach to computational cancer modelling from Silva and Ferreir. Complex networks are represented by an analysis of chimera states on multiplex networks by Batista, Viana and Batista. The ergodicity, mixing, turbulence and transport in passive scalar and active reacting fluids section finds two contributions: one on the statistics of heavy inertial particles by Maity and Ray, and the other on the quantum computation of fluid dynamics, an unusual topic by Bharadwaj and K.R. Sreenivasan. The analysis of neuroscience by the methods of nonlinear dynamics is becoming widespread these days, and finds its place in this volume via the study of inhibitory synapses in neuronal networks and their effect on criticality by Borges *et al.* and also the analysis of noise induced transitions in neuronal inter-spike intervals.

Biological systems repeat again in the study of the effects of density dependent growth on metapopulations, as well that of population redistribution under the Allee effect. Climate studies, an area where the techniques of nonlinear dynamics increasingly find applications, is represented by studies of fractality and complexity in sea surface temperature by Ogunjo and Fuwape, and of signatures of cyclones and El Niño and La Niña phenomena in climate networks by Sonone, Saha and Gupte. Complex networks recur again in another form in the work of Bhadola, Saichaemchan, and Deo who carry out a spectral analysis of financial threshold networks. Finally, both fractal structures and semi-quantum chaos make their appearance in an unusual context in a pair of Schwarzchild black holes, in the work of Souza Filho, Mathias, Caldas and Viana, and in SU(2) nonlinear dynamics in the work of Sarris, Hansen and Plastino.

The volume ends with a set of articles which were specially invited for a virtual round-table discussion in the context of the current pandemic. Most current efforts to understand the spread of diseases such as COVID-19 are based on nonlinear SIR (susceptible-infected-recovered) models that trace their origins back to Kermack and McKendrick (*Proc. R. Soc. Lond.* **A 115**, 700–721 (1927)). The dynamical systems and statistical physics communities have been active in this area, and so it seemed appropriate to ask for a candid appraisal of the value of such efforts at this time. These are collected in a section entitled **COVID-19 round table**. There has been enthusiastic participation from India and South America, both of which have been hit hard by the SARS-Cov-2 virus.

The four articles by Mindlin, Kraenkel, Menon, and Nandy *et al.* concentrate on the challenges posed by the modelling of COVID-19. There is overall agreement that while the basic model evolution equations are well understood, predictions are difficult due to local factors, such as varying degrees of virulence and infection rates in the virus itself, and effects of factors such as population density, migration factors, frequency of injection of infection, age dependent factors, and others. The three articles by Herrera Diestra and Velásquez-Rojas, Bera and Das, and Pereira, specifically examine the effect of external interventions such as immunization strategies, lockdown and other mitigation measures. These articles discuss similar intervention strategies in vastly differing geographical contexts, and should be juxtaposed against each other for comparison. In contrast the article of Gómez-Gardeñez, Buldú and Aguirre, Sinha, and Dhar, discuss classic mathematical models of epidemiology and their relevance in the current scenario.

These eleven articles were written a few months into the pandemic when little was known about the structure and role of the contact network on the spread of infection. Even today, there is insufficient data in most parts of the world where the public health services are inadequate, although in some locations painstaking and methodical work, especially on the part of health workers, has made such data available. Future modelling efforts will no doubt incorporate these features. An ideal outcome would be one in which these studies could feed in directly into effective public health policies; this would underscore the utility and importance of modelling studies in our

discipline. Having said this, it should be admitted that we are presently far from this ideal outcome, but it is also clear that there is hope for the future.

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