Society for Chaos Theory in Psychology & Life Sciences
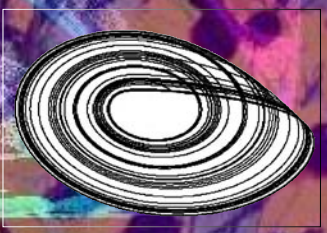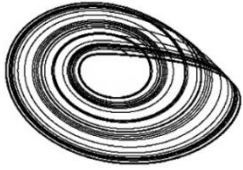
NEWSLETTER

Society for Chaos Theory in Psychology & Life Sciences

We are pleased to announce that

Robin Vallacher, PhD and Scott Kelso, PhD

will be our keynote speakers at the
25th Annual International Conference
29-31 July, 2015
University of Florida, Gainesville, FL, USA

Dynamical Social Psychology: Embracing (finally!) the Nonlinear Nature of Human Experience

by Robin Vallacher

For decades, the dominant paradigms in social psychology tried to impose tidy models of linear causality on the decidedly untidy and nonlinear dynamic processes of mind and action. True to the nature of nonlinear change, the traditional approach has become destabilized due to internal incoherence and is giving way to new paradigms that promise greater coherence, precision, and generalizability in capturing the nature of human experience. This phase transition is due in large part to the advent of sophisticated methods and tools (e.g., computer simulations, time series). I will highlight a tool developed in my lab that captures the internally generated ("intrinsic") patterns of psychological processes, and describe new insights into the dynamics of self-evaluation, social judgment, close relations, and intractable conflict revealed by this tool. I will conclude by proposing how the nonlinear dynamical systems approach may provide integration for the diverse subject matter of social psychology.

Robin Vallacher is a professor of Psychology, Florida Atlantic University, and a visiting scholar at University of Bern, Switzerland, and Max-Planck-Institute for Psychological Research in Munich, and the Center for Complex Systems, Warsaw University. Dr. Vallacher has investigated a wide variety of topics, from principles of social cognition, action identification, and self-concept, to issues in social justice, social change, and international conflict. His current work employs a dynamical systems framework to identify the invariant properties underlying these phenomena. Using experimentation and computer simulations, he and his colleagues have been investigating the dynamic underpinnings of self-regulation, social judgment, close relations, inter-group conflict, and the emergence of personality from social interaction. Dr. Vallacher has published several books, including two with Andrzej Nowak that develop the implications of dynamical systems for social psychology. His most recent opus is, *Attracted to Conflict: Dynamic Foundations of Destructive Social Relations* (Publ. Springer).

Night Thoughts of a Dynamicist: Key Concepts and Ideas behind Coordination Dynamics

by Scott Kelso, PhD

Richard Feynman once said something like "We would not know where we are stupid until we stick our necks out." In this talk I'll discuss some of the key concepts and ideas behind coordination dynamics, the science of coordination, where they came from and why they matter. This will include some historical aspects including early conferences and interactions with certain prominent scientists. Then I'll stick my neck out and make a linkage between consciousness and coordination. Rather than being a novel state of highly integrated information or matter, conscious agency will

be seen to emerge as a disorder-order transition of a coordination dynamics defined in an appropriate space of relevant variables.
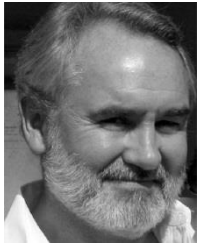
Scott Kelso holds the Glenwood and Martha Creech Eminent Scholar Chair in Science at Florida Atlantic University in Boca Raton where he is also Professor of Psychology and Neuroscience, Biological Sciences and Biomedical Sciences. He is the (Visiting) Professor of Computational Neuroscience at University of Ulster's Intelligent Systems Research Centre in Derry, N. Ireland where he guides a young team of researchers. From 1978 to 1985 Kelso was Senior Research Scientist at Yale University's Haskins Laboratories in New Haven, Connecticut. In 1985 he founded the first Center for Complex Systems and Brain Sciences in the US at Florida Atlantic and also led a NIH-funded National Training Program in this new interdisciplinary field. For most of his scientific career Kelso has been trying to understand how human beings (and human brains)—individually and together—coordinate behavior on multiple levels, all the way from cellular to cognitive and social behavior. He is considered an originator of Coordination Dynamics, a theoretical and empirical framework geared to understanding the functional coordination of living things. Kelso is the recipient of a number of awards including the MERIT, Senior Scientist and Director's Innovation Awards from NIH, the Distinguished Alumni Research Achievement Award from the University of Wisconsin, Docteur Honoris Causa from the Republic of France and the University of Toulouse (est. 1228). In 2007 he was honored to be chosen as Pierre de Fermat Laureate and in 2011 he received the Bernstein Prize. Kelso is a Fellow of AAAS, APA, APS and SEP. Trained in a specifically interdisciplinary setting, his PhD students and Postdocs have gone on to careers in some of the top academic and research institutions in the world.

PRE-CONFERENCE WORKSHOPS

Benefit from the leading edge of a new SCTPLS workshop tradition that will get us all further ahead in nonlinear science with this collaborative "consulting group" approach to learning! This year's pre-conference workshops are modeled on the successful Nonlinear Datapalooza innovated by SCTPLS Past President David Pincus and co-sponsored by SCTPLS and Chapman University in early 2015. While these conference workshops are not for running your data analyses (save them for the next Datapalooza!), the safe-space collegiality and consultative atmosphere is a great setting to be met wherever you are and for you to get yourself further along in your nonlinear work!

July 29, 2015 morning
Workshop: So you want to get started or better equipped to use nonlinear thinking and methods?
Beginner to intermediate levels. This half-day workshop is for those of you who are in beginning or early stages of nonlinear thinking and of thinking about methods. In this workshop, you will learn or review basic concepts and be supported to apply them to your area of interest, to thinking about and interpreting results, beginning to look at methods, models and theory that may be best-fits for what you plan to, or already are, studying.

July 29, 2015 afternoon
Workshop: So you want to get further in applying nonlinear thinking and methods?
Intermediate to advanced levels. This half-day workshop is for those of you who have the basic foundations and some experience with nonlinear thinking and methods. In this workshop, you will get supportive attention for your particular domain of interest (a) to examine models and method choices more specifically and critically, (b) to work toward formalizing research designs for your plans and goals, and (c) to get insights to help you interpret and analyze results pertaining to participants' areas of interest.

Your 2015 Dynamic Duo Workshop Facilitator Team:

Stephen J. Merrill, Ph.D.
Dr. Merrill is Professor of Mathematics and Graduate Chair in Mathematics, Statistics, & Computer Science at Marquette University. His doctorate in mathematics is from University of Iowa. His major research interests include mathematical models in immunology utilizing a variety of methods including differential equations and stochastic techniques, the role of randomness in dynamical systems, creativity and dreaming, the mechanism of action of medicinal herbs, cardiac imaging, atrial fibrillation, thyroid disease, malaria control, nanotoxicology and the toxicology of novel compounds released from medical devices, and interactions of UV with HPV-associated cancer. He has

published over 50 scientific papers, and has held visiting Santa Fe Institute (Program in Theoretical Immunology), Center for Nonlinear Studies and Theoretical Biology and positions at Lefschetz Center for Dynamical Systems (Brown Biophysics (Los Alamos National Lab), and FDA, Center for Devices and Radiologic Health (Division of Biology).

Mark Shelhamer, Sc.D.

Dr. Shelhamer is on the faculty of Johns Hopkins where he started as a postdoctoral fellow in 1990. He has bachelor's and master's degrees in electrical engineering from Drexel University, and a doctoral degree in Biomedical Engineering from MIT. At MIT he worked on sensorimotor physiology and modeling, including the study of astronaut adaptation to space flight (Brown University), and continued, studying sensorimotor adaptation with an emphasis on the vestibular and oculomotor systems at Johns Hopkins. He has applied nonlinear dynamical analysis to the control of eye movements, including investigations of the functional implications of fractal activity in physiological behavior. He has had NASA's support to study sensorimotor adaptation to space flight, amassing a fair amount of parabolic flight ("weightless") experience in the process. He serves as an advisor to the commercial spaceflight industry on the research potential of suborbital space flight. He authored *Nonlinear Dynamics in Physiology: A State-Space Approach,* has published over 70 scientific papers, and has had research support from NIH, NSF, NASA, NSBRI, and the Whitaker Foundation.

He is currently on leave from his academic position to serve as NASA's Chief Scientist for human research at the Johnson Space Center.

Nonlinear Datapalooza:
A New Kind of Conference for a New Kind of Science

David Pincus, Ph.D,

By all appearances and measures thus far, it seems that our new kind of methods conference, the First Ever Nonlinear Datapalooza, worked out even better than expected. After nearly a year in which I wondering what was going to happen, from Wednesday January 28 to Friday January 30, I joined together with 25 colleagues here at Chapman University in Orange California to analyze data; A lot of analysis, and a lot of data. Except for one early evening out to dinner at a restaurant down the road, some great discussions at the hotel bar, and a couple of nice banquets at the start and end, that's pretty much all we did – sit in a big room together all day long and analyze a whole lot of data. Yet, it was by most accounts one of the best and most effective conference experiences any of us had ever had. I'd like to try to explain the story behind this unusual conference just a bit, because I think it might say something about how nonlinear science works, and how we can work together more effectively within it.

Conference Emergence

It's safe to admit at this point that I really wasn't quite sure what to expect from this conference. In 2013 I applied for a small grant from my school, Chapman University, to cover a more traditional methods training conference. I was hoping to cover travel costs for five or six methods experts to do a fairly typical, mostly didactic methods workshop. I had several of my own personal incentives for wanting to do this: service to the organization as outgoing past-president, bringing a high quality workshop to my university, and being able to get some good methods training without having to travel (I've still got young kids at home and enjoy sleeping in my own bed).

However, when my grant application was funded at half of what I had budgeted I honestly wasn't sure what to do. Fortunately, creativity outshined demoralization. Over time, I began to think about some way to do a methods conference that would be about half as expensive, which led to the idea of removing the distinction between expert and novice, between organizer and attendee, and eventually to reconsider many of the norms and assumptions that surround the common notions of what makes a professional conference.

I realized that most conferences are designed for presentations of completed or near-complete scientific work. The goals for attending center around: dissemination, increasing citations, and obtaining critical feedback on one's work. Secondary goals are networking, hearing about other approaches, and gathering citations to other's work. Traditional conferences are hierarchical, with experts presenting "keynote" and "plenary" talks and workshops typically in a didactic format – the roles are relatively prescribed and static.

I started to wonder if everyone's incentives could be better met by turning the process upside-down: getting rid of hierarchy and presentations of completed work could we remove boundaries to forming new collaborations, increasing productivity, and learning new methods? As someone who is a decent generalist in nonlinear science, with one foot in the practical world (a licensed psychologist and professor with a high teaching load) and one foot in the methods world – I

figured my role could be to act as a sort of bridge, bringing methods people and data people together in a collaborative environment.

I know what methods experts enjoy analyzing good data. Further, their professional incentive is to disseminate their methods in the most efficient ways possible. On the other side, people with time-series and other good potentially nonlinear data want help analyzing their data, with the professional incentives to break new ground in their areas and to learn a method well enough that they can use it right away. I happened to know many people in this situation as well.

I have found that the usual conference experience is not terribly efficient at serving the needs of either group. Like others, I usually leave a conference with a large list of articles to look up, methods to try to learn, and people I'd like to stay in touch with. I've got years of these lists at this point in my career. At the larger scale, our society, SCTPLS, needs to be positioned at the nexus of each of these processes, moving the scientific progress along, because most broadly, one of the greatest barriers to scientific progress is the slow speed at which new methods get disseminated.

The Conference Process

Building the conference then became a process of getting the right ingredients together and then creating a loose structure in which data analysis in collaborative teams could emerge, based on individual incentives, from the bottom up. This process started with three methods experts who were willing to volunteer to be conference organizers – Stephen J. Guastello, from Marquette University; Jonathan Butner, from University of Utah , and Adam Kiefer, from the University of Cincinnati. I already knew that these three had diverse methods expertise, were great to work with, and each is an outstanding teacher capable of consultation and facilitation. With their generous agreement to serve as "Team Leaders," for three eight-person max analysis groups, the foundation was set.

The second necessary ingredient was good data. I was honestly shocked by the response to the call for data to analyze at the Datapalooza, especially with the unusual conference description and name. We were full more than a week prior to deadline, and I had to turn away several good entries before prematurely closing the call for participation. A range of individuals signed up to bring data, including brand new members as well as "old-timers;" students, professors, and non-academicians; local and international travelers. The various disciplines represented beyond psychology included animal behavior, physical therapy, computational science, social work, nursing, complementary and alternative medicine, public health, and bio-mechanics. The data participants were: Lisa Taylor-Swanson (University of Washington), Mary Koithan (Arizona Arizona State University), and Lisa Conboy (New England School of Acupuncture); Keith

Warren (The Ohio State University); Vincent Berardi (San Diego State University/Claremont Graduate University); Brianne Beisner and Kelly Finn (University of California, Davis); Shayna Henry (Kaiser Permanente Southern California); Marybeth Grant-Beuttler and Richard Beuttler (Chapman University); Ruth Bush (University of San Diego); Oto Cadsky (Forensic Psychiatrist); David Marra (Marquette University); and Ken Ware (International NeuroPhysics Functional Performance Institute, Robina, Gold Coast, Australia).

Finally, we picked up a handful of additional methods experts, who ended up being indispensable, allowing for more hands and heads to assist with the various analyses that were needed as we got into the "work" of the workshop. These participants were: Jennifer Yentes (University of Nebraska at Omaha); Joshua L Haworth (The Johns Hopkins University); Alexander Wong (Florida Atlantic University).

Finally with a couple of volunteer Chapman University students, Katy Wann (Psychology) and Justin Huft (Marriage and Family Therapy – I had more than my own two hands and one head to keep the conference flowing. In terms of the numbers, the final group of 25 participants were 29% students, 12% post-docs, 12% independent scientists, and 47% were academic scientists.

The Joy of Good Work

Once confirmed, each participant selected or data group selected the team leader with whom they wanted to work, in some cases starting in one group and then switching on day two for secondary analysis with an alternative method. The result was three roughly equal teams comprised of a team leader, an additional methods expert, and three or four data sets to analyze. The initial results that were produced are far too numerous to list here. Indeed, one change that will need to be made at future "Datapaloozas" will be to streamline the presentation of results at the closing banquet – which could easily have gone on for many more hours had the catering and AV staff not forced us to shut things down.

A few of the more memorable results for me, from a participant's perspective, included: assisting my undergraduate students in measuring fractal structures in monkey social hierarchies; seeing shifts in attractor dynamics for stress and fatigue for women across the menopausal transition; and seeing some robust and clinically relevant increases in the complexity of ECG dynamics in response to a simple physical training program for individuals with spinal cord injury. Furthermore, I saw the joy in participants eyes as they learned hands-on an array of nonlinear techniques including: fractal analyses, nonlinear regression, recurrence analyses, and the analyses of state-space trajectories using hierarchical regression and structural equ ation modeling.

This "joy" is well reflected in our post-conference survey results. Every participant (100%) found the conference to be "very much" or "exceptionally" more interdisciplinary and innovative compared with other conferences they have attended, and 94% found it to be "very much" or "exceptionally" more tailored to participant needs. When asked to rate the conference in its relative effectiveness in different areas, 90% found it to be more effective in teaching new methods and facilitating professional networking. While in terms of increasing people's productivity, 100% of participants expect that the Datapalooza will be more effective than the typical conference toward the goal of increasing their productivity in publications and conference presentations, and 79% expect a significantly better increase in grant applications.

The Future

We will continue to track the outcomes of the Datapalooza over time: particularly the actual impact of the conference on attendee's productivity, ongoing collaborations and use of nonlinear methods. This data will help us to improve the process in order to better serve attendees at the next Datapalooza, tentatively planned for 2017. We are further planning to seek additional funding from the National Science Foundation or other sources for the next conference. Additional funding would be nice in order to assist in supplementing lodging and other costs for attendees, to increase scholarships and travel support for student attendees, and perhaps even to give just a little support to our outstanding team leaders next time around.

We certainly have improvements to make for future meetings. We will need to do a better job of giving everyone the time and encouragement to get a fuller understanding of everyone's data, especially given the breadth of disciplines and approaches that were present. We need to try to find better ways to serve those who attend with the goal of learning techniques without bringing data, and hopefully expand so that more people can bring data. Yet, it is deeply encouraging that the most frequent suggestion for improvement was to add an additional day. While for those who indicated that they would like me to do a better job of getting the groups to stop working during the scheduled breaks, all I can say is - I really tried!

I am deeply satisfied with our organization's ability to pull off this sort of experiment with the small seed funding obtained from Chapman University. The openness, support and hard work of our Executive Committee really made the whole thing possible.

The needs of the various stakeholders are not likely to change much over time. Methodologists will continue to want to spread the good news; researchers will continue to need new methods and will want to learn hands-on using their own data; and each of us wants to learn and network with good colleagues in a more experiential and hands-on conference environment.

Our organization, the Society for Chaos Theory in Psychology and Life Sciences, will be here over the next 25 years and beyond, as nonlinear and dynamical methods continue to gradually evolve to become the most commonly used approaches within the social and behavioral sciences. Our organization will provide the context for this evolution over these years to come, a home base from which innovation in nonlinear science may continue to spread, grow and flourish.

David Pincus, Ph.D., Past President, SCTPLS
Associate Professor, Psychology
Chapman University

WE WANT TO HEAR ABOUT YOUR WORK, TOO!

CALL FOR ABSTRACTS OF PAPERS, SYMPOSIA, AND POSTERS

Submissions deadline is April 30, 2015.

Submit your abstract(s) electronically at

http://www.societyforchaostheory.org/conf/2015/cfp

NEURAL CODE & POWER LAWS

The road from spike frequency to mental states is paved with intermediate energetic steps which can be defined and quantified

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ABSTRACT

The brain electric activity exhibits a power law distribution which appears as a straight line when plotted on logarithmic scales in a log power versus log frequency plot. The slope of the line is given by a single constant, the power law exponent. Since a variation in slope may occur during different functional states, the brain currents are said to be multifractal, i.e. characterized by a spectrum of multiple possible exponents. A role for such non-stationary scaling properties in neural coding has scarcely been taken into account. Here we show that changes in fractal slopes and in the message content are correlated. Taking into account arguments concerning entropy, we illustrate that modifications in power law exponents are associated with variations in the Rényi's entropy, which is a generalization of Shannon's entropy. Changes in Rényi's entropy, in turn, are able to modify the information transmitted by spikes. Our results point up that multifractal systems lead to different probability outcomes based solely on increases or decreases of the fractal exponents. We offer new insights in the characterization of the forces required for transcranial stimulation, where doubts still exist about the parameters of the waveforms to employ. We indeed anticipate our essay to be a starting point for testing psychological correlates of the brain activity - such as sensations - under currents equipped with different power law slopes.

INTRODUCTION

The brain activity observed at many spatiotemporal scales exhibits fluctuations with complex scaling behavior (Newman, 2005), including not only cortical electric oscillations, but also membrane potentials and neurotransmitter release (Milstein et al., 2009; Linkenkaer-Hansen, et al., 2001). In particular, the frequency spectrum of cerebral electric activity displays a scale-invariant behaviour $S(f) = 1/f^n$, where $S(f)$ is the power spectrum, f is the frequency and n is an exponent that equals the negative slope of the line in a log power versus log frequency plot (Van de Ville et al. 2010; Pritchard, 1992). Pink noise can be regarded as an intrinsic property of the brain characterizing a large class of neuronal processes (de Arcangelis and Herrmann, 2010); moreover, power law distributions contain information about how large-scale physiological and pathological outcomes (Jirsa et al., 2014) arise from the interactions of many small-scale processes. It must be emphasized that the fractal slope is not invariant in brain, but is rather characterized by multiple possible exponents (He et al., 2010), summarized in a single value, the "generalized fractal dimension" **α**. It has been demonstrated that different functional states - spontaneous fluctuations, task-evoked, perceptual and motor activity (Buszaki and Watson, 2012), cognitive demands (Fetterhoff et al., 2014), ageing (Suckling et al, 2008) - account for variations in power law exponents across cortical regions (Tinker and Velazquez, 2014; Wink et al, 2008). Accordingly, we may view the multifractal cortex as an ensemble of intertwined (mono)fractals, each with its own dimension and scaling slope: the brain is thus regarded as a system of fractal geometry with a complex spectrum of self-exact similarity breakdown, in which scaling exponents mark dynamical transitions between different response regimes (Papo, 2014).

The aim of our paper was to evaluate, via a geometrical/mathematical model of synthetic power law oscillations, the relationships among brain scaling slopes, energy/ Rényi's entropy and psychological states. Do cortical fluctuations in power law exponents modify the energy of the system? The answer is positive. The metabolic activity of the brain is high, accounting for 20% of the energy consumed. Much of the brain's vast energy budget is reserved for spontaneous neuronal activity, but perceptual and motor activity, task performance and cognitive demands account for an additional energy consumption of 5%, often confined to small cortical areas (Sengupta et al., 2013). Indeed, local boosts in spike frequency (in particular beta and gamma waves) cause a transitory increase of energy

consumption and free energy production, with a metabolic cost of 6.5 μmol/ATP/gr/min for each spike (Attwell and Laughlin, 2001). Throughout the increases in free energy, the $1/f^n$ exponent varies across brain regions. Recent papers start to uncover connections between the exponent of a fractal scaling in escape paths from energy basins and the activation free energy (Perkins et al., 2014). The ongoing fluctuations with complex scale-free properties can thus be absorbed into a free energy framework (Friston, 2010): the critical slowing implicit in power law scaling of dynamics is mandated by any system that minimizes its energetic expenditure.

It has been shown that the entropy is also linked with different psychological and cognitive states. As an example, analysis performed on emotionally online dialogues demonstrated the tendency towards a growing entropy (Sienkiewicz et al, 2013). Further, ensemble of supervised maximum entropy classifiers can accurately detect and identify sentiments expressed in notes (Wicentowski and Sydes, 2012), perceptual functions are correlated with thermodynamical entropy and free energy (Freeman et al., 2011) and Shannon's entropy is able to predict task performance (Guastello et al., 2013). Finally, the entropy has been recently proposed as a measure of semantic and syntactic information of multidimensional discrete phenomena (Štys et al., 2015). Our task was to evaluate if increases or decreases in the $1/f^n$ power slope in multifractal systems, besides the above mentioned impact on energy efficiency, might play a role in information processing and emotions, or, in other words, if are we allowed to link probability outcomes with psychological states.

METHODS

Because our model relies on the so called "Rényi's entropy", we need to explain why this underrated construct is useful in the portrayal of multifractal systems. Indeed, the basic thermodynamic properties of multifractal systems may be discussed by extending the notion of the information Shannon's entropy into the more general framework of the Rényi's entropy. The Rényi's entropy of order β is defined to be (Baez, 2011):

$$H_\beta(X) = (1/1-\beta) \ln\Sigma_i\, p_i^\beta$$

Where $0 \leq \beta < \infty$. The term X is a random variable with n possible outcomes and and $p_i = P(X=i)$, for $i = 1, 2, 3, ...n$, is a probability distribution on a finite set.

The Rényi's entropy approaches the Shannon's entropy as β approaches 1, so that β=1 (i.e., the limit for β→1) is defined to be the Shannon's entropy:

$$\lim_{\beta \to 1} H_\beta = -\Sigma_i\, p_i\, \ln p_i$$

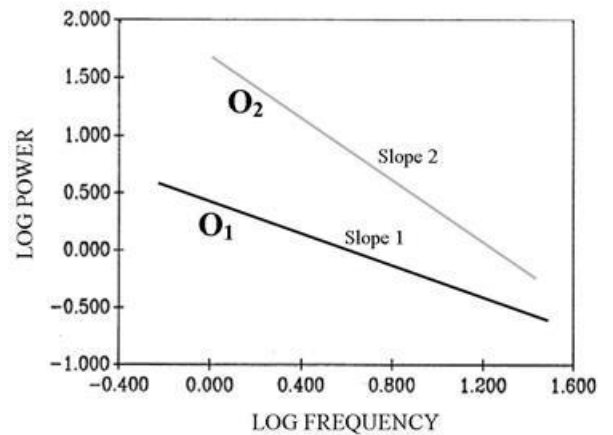The Rényi's entropy is also closely related to the

Fig. 1. Two series of free scale oscillations O1 and O2 with different power law exponents and slopes. See text for further details.

thermodynamical Gibbs' entropy and the free energy F, through the formula: $F = (1 - T) H_\beta$ in which T is the temperature. Mathematically, it is expressed as follows: the Rényi's entropy of a system is minus the "1/β-derivative" of its free energy with respect to a quantity. Because of its build–in predisposition to account for self–similar systems, the Rényi's entropy is an effective tool to describe multifractal systems (Jizba and Korbel, 2015). It has been demonstrated that the Rényi's entropy and the generalized fractal dimension **α** are interchangeable: the Rényi's parameter β is connected via a Legendre transformation with the multifractal singularity spectrum **α** (Jizba and Arimitsu, 2001). It means that, from the maximum entropy point of view, the power law exponent n and Rényi's parameter β exhibit a straight relation, therefore changes in n lead to changes in β (Słomczynski et al, 2000).

Here follows the procedure we carried out. We generated, in a log amplitude versus log frequency scatter plot, an artificial model of multifractal system (Figure 1), obtaining two series of free scale oscillations **O₁** and **O₂** with different power law exponents and slopes - slope 1 and slope 2, respectively - (Milstein et al. 2009; Pritchard, 1992).

Taking into account the two oscillations **O₁** and **O₂**, we build, in touch with Shannon (1948), a system equipped with the random variable p in the case of two possibilities with probabilities p and $(1-p)$ and calculated on the X-axis the values of Rényi's entropy (with β=1 corresponding to the slope 1 and β=2 corresponding to the slope 2), plotted as a function of p on the Y-axis (Figure 2A). In order to connect the probability p with psychological correlates, we plotted on the X-axis a diagram (Figure 2A) which summarized the emotions associated with the delivery of reward or punishment or a stimulus associated with them, or with the omission of a reward or punishment (Rolls).

In our simulation, the two possibilities with probabilities p=0 and p=1 were the utmost sensations of

terror and ecstasy, while the intermediate steps stood for the in-between emotions from the first to the second: fear, apprehension, relief, pleasure - each one characterized by its probability p -. The use of the Rolls' diagrams was just a proof of concept: other diagrams with different mental states (sensations, perceptions, cognitive abilities) could be tested instead. Furthermore, the difference Δp between the curves $\beta=2$ and $\beta=1$ was plotted against a range of values of Rényi's entropy (Figure 2B).

RESULTS

The curves in Figure 2A illustrate the two cases of Rényi's entropy with exponents $\beta=1$ and $\beta=2$. The curve $\beta=1$ stands for the Shannon's entropy (under ergodic conditions). Note that, at a given value of p, a passage from the exponent $\beta=2$ to $\beta=1$ leads to an increase in Rényi's entropy, and vice versa. Furthermore, at a given value of Rényi's entropy, a variation in β exponent leads to a different probability distribution: as an example, the left right arrow shows the difference in p between the curves $\beta=2$ and $\beta=1$, at the fixed point of Rényi's entropy=.55. Figure 2B points up that different rates of Rényi's entropy are correlated with a wide spectrum of probabilities p: at each given value of entropy, the shift of the exponent from $\beta=2$ to $\beta=1$ causes different changes in Δp. In other words, at each given value of Rénji entropy, a simple variation in power law exponent n from 2 to 1 modifies the value of p, and thus the content of the message.

In order to evaluate if changes in β exponent could be correlated with the occurrence of different emotions, we plotted the emotions described by Rolls on the X-axis of the probabilities and found that, in our model, a modification of the β exponent leads to different psychological states. In the above mentioned example, at the fixed value of Rényi's entropy=0.55, the variation in Rényi's exponent from 2 to 1 modifies the emotions from fear to terror (Figure 2A).

CONCLUSIONS

Our analysis led to an unexpected conclusion: the road from spike frequency to mental states is paved with intermediate energetic steps which can be defined and quantified. In order to optimize perceptions and thoughts, the brain is equipped with an intrinsic mechanism of fluctuations with complex temporal and spatial scaling properties: in this framework, changes in power law exponents play a crucial role in information processing, leading to variations not only in entropy and probability, but also in basic emotions.

The relation between stimulus, spike trains and transmitted inputs forms the neural code, the crucial tool by which neurons recognize and store the data. But where is the neural code? A range of different theories
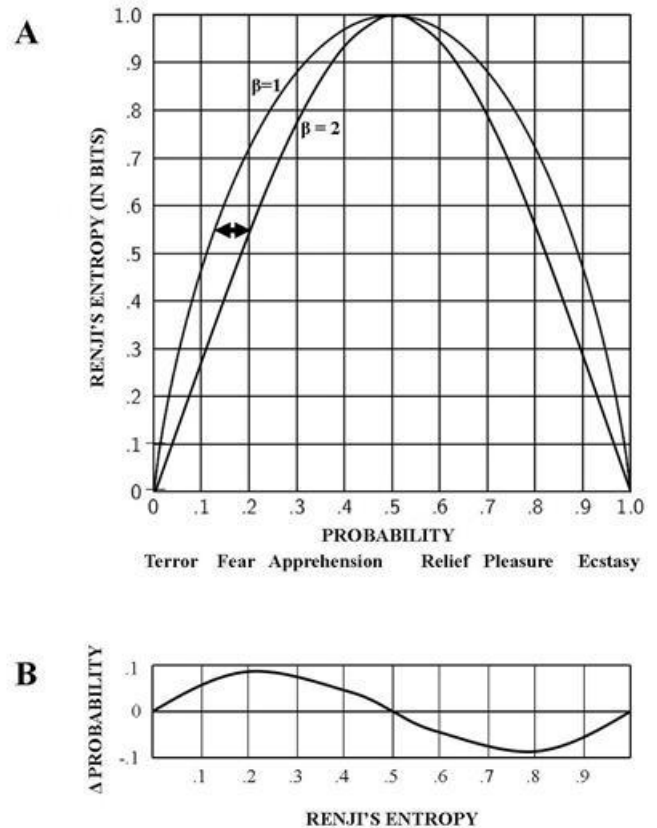

Fig. 2 A: Two cases of Rényi's entropy with exponents $\beta=1$ and $\beta=2$.

Fig. 2 B : Difference Δp between the curves $\beta=1$ and $\beta=2$ plotted against a range of values of Rényi's entropy. See text for further details.

has been offered over the years: rate or temporal codes, latency, relational, synchrony codes, mixtures of them (Gollisch, 2009). We hypothesize that another underrated mechanism might play a role in neural communication: the power law exponent. Based on the above mentioned energetic constraints, we indeed propose that variations in brain fractal slopes are correlated with changes in the content of the message. In such a framework, complex scale-free statistics are fixed points of a renormalization flow and can be understood as asymptotic behaviors emerging as the system is rescaled (Fraiman and Chialvo, 2012), while cognitive tasks are modulated by the $1/f^{n}$ exponents of the brain fluctuation probability function, leading to a shrinking of multifractal spectrum and/or transitions from mono- to multi-fractal distributions (Popivanov et al., 2006).

Our results pave the way for innovative therapeutic strategies. We conjecture that the electric fractal-like structures - setting aside their supposed relationships with self organized criticality (Bak et al., 1987), nonequilibrium steady-state dynamics or second order phase transitions (Papo, 2014) - could be modulated

through the superimposition of an external electric currents characterized by carefully chosen power law exponents. We suggest that the techniques of transcranial electrical stimulation need to take into account not only the amplitude and frequency of the applied waveforms (Reato et al., 2013), but also their scaling slope. A tenable field of application are the diseases that have been linked to disturbance of brain networks - Alzheimer's disease, depression, attention deficit hyperactivity disorder, autism (Fox and Raichle, 2007) -, meaning that they could be ameliorated, or even removed, by appropriate artificial fields - e.g., via selective application of electric waves of specific power law exponent on target micro-areas - able to "recovery" and restore the physiological brain activity (Sunderam et al., 2009).

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Nonlinear Dynamical Bookshelf

Baofu, P. (2007). The Future of Complexity: Conceiving a Better Way to Understand Order and Chaos. Singapore: World Scientific. ISBN: 978-981-270-898-4. Contrary to the conventional wisdom held by many contemporaries in our time, the popularity of studying complexity is fast becoming a new fad in the intellectual scene. However, can the study of complex phenomena truly reveal recognizable patterns (with predictable outcomes) to enhance our understanding of reality, especially when it is embedded within the messy web of complexity? If so, what then are the limits? This book strives to demolish some of the myths surrounding the nature of complexity and, in the process, to provide an original theory to understand it in this world and beyond. It introduces the author's dialectic theory of complexity, together with the theoretical debate in the literature. It expounds on the concept of complexity from various perspectives, including chemistry, micro- and macro-physics, biology and psychology. It also examines the nature of complexity from societal and cultural perspectives. This book presents a broad view on the nature of complexity, adequately introducing the reader to this emerging field.

Ivancevic, V. G., & Reid, D. J. (2014). Complexity and control: Towards a rigorous behavioral theory of complex dynamical systems. Singapore: World Scientific. ISBN: 978-981-4635-86-8. The book Complexity and Control: Towards a Rigorous Behavioral Theory of Complex Dynamical Systems is a graduate-level monographic textbook, intended to be a novel and rigorous contribution to modern Complexity Theory. This book contains 11 chapters and is designed as a one-semester course for engineers, applied and pure mathematicians, theoretical and experimental physicists, computer and economic scientists, theoretical chemists and biologists, as well as all mathematically educated scientists and students, both in industry and academia, interested in predicting and controlling complex dynamical systems of arbitrary nature.

Stefański, A. (2009). Determining Thresholds of Complete Synchronization, and Application. Singapore: World Scientific. ISBN: 978-981-283-766-0. This book is devoted to the phenomenon of synchronization and its application for determining the values of Lyapunov exponents. In recent years, the idea of synchronization has become an object of great interest in many areas of science, e.g., biology, communication or laser physics. Over the last decade, new types of synchronization have been identified and some interesting new ideas concerning the synchronization have also appeared. This book presents the complete synchronization problem rather than just results from the research. The problem is demonstrated in relation to a kind of coupling applied between dynamical systems, whereby a unique classification of possible couplings is introduced. Another novel feature is the connection presented between synchronization and the problem of determining the Lyapunov exponents, especially for non-differentiable systems. A detailed proposal of such an estimation method and examples of its application are included.
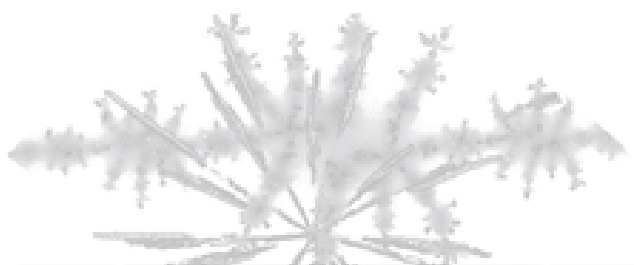
Coming Soon from NDPLS

Special Issue Scheduled for 2015: Optimum Variability. It is now well known that healthy heart rate variability is chaotic and not rigidly oscillating. The principle of healthy variability has extended to other biomedical and psychological phenomena. What is the status of the research in any of the application areas? To elaborate further, some thought has been given to the idea that optimum variability results from a combination of the minimum entropy or free energy principle that pushes in a downward direction, and Ashby's Law of Requisite Variety that pushes in an upward direction. As a result, NDPLS would like to expand the scope of this particular topic into a special issue. Certain aspects of this topic area have been well subscribed already, and manuscripts by several author groups are in progress. Articles that we would like to present next include: new empirical studies that expand our understanding of one or more applications of the optimum variability principle; review studies that are specific to applications of the optimum variability principles in social psychology, abnormal psychology, organizational behavior, and economics; and empirical studies in the areas described above.

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