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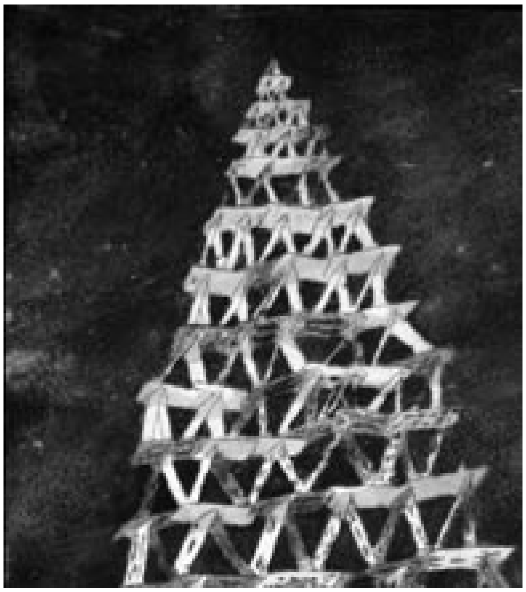
Nonlinear Dynamics, Psychology, and Life Sciences



Special Issue: Brain Dynamics

Brain Dynamics and Conscious Sequencing

Robert A M. Gregson and **Sifis Micheloyannis**, *Guest Editors*

An EEG Study of Brain Connectivity Dynamics at the Resting State

Stavros I. Dimitriadis, *University of Patras, Greece & Aristotle University, Thessaloniki, Greece;* **Nikolaos A. Laskaris**, *Aristotle University, Thessaloniki, Greece;* **Vasso Tsirka**, *University of Crete, Greece;* **Michael Vourkas**, *Technical High School of Crete, Greece;* **Sifis Micheloyannis**, *University of Crete, Greece*

We investigated the dynamical behavior of resting state functional connectivity using EEG signals. Employing a recently introduced methodology that considers the time variations of phase coupling among signals from different channels, a sequence of functional connectivity graphs (FCGs) was constructed for different frequency bands and analyzed based on graph theoretic tools. In the first stage of analysis, hubs were detected in the FCGs based on local and global efficiency. The probability of each node to be identified as a hub was estimated. This defined a topographic function that showed widespread distribution with prominence over the frontal brain regions for both local and global efficiency. Hubs consistent across time were identified via a summarization technique and found to locate over forehead. In the second stage of analysis, the modular structure of each single FCG was delineated. The derived time-dependent signatures of functional structure were compared in a systematic way revealing fluctuations modulated by frequency. Interestingly, the evolution of functional connectivity can be described via abrupt transitions between states, best described as short-lasting bimodal functional segregations. Based on a distance function that compares clusterings, we discovered that these segregations are recurrent. Entropic measures further revealed that the apparent fluctuations are subject to intrinsic constraints and that order emerges from spatially extended interactions.

Cognitive Aspects of Chaos in Random Networks

Gaetano L. Aiello, *Universita' di Palermo, Italy*

A special case of deterministic chaos that is independent of the architecture of the connections has been observed in a computer model of a purely excitatory neuronal network. Chaos onsets when the level of connectivity is critically low. The results indicate a typical period-doubling route to chaos as the connectivity decreases. A cognitive interpretation of such type of chaos, based on information theory and phase-transitions, is proposed.

Understanding Neuromotor Strategy During Functional Upper Extremity Tasks Using Symbolic Dynamics

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The ability to model and quantify brain activation patterns that pertain to natural neuromotor strategy of the upper extremities during functional task performance is critical to the development of therapeutic interventions such as neuroprosthetic devices. The mechanisms of information flow, activation sequence and patterns, and the interaction between anatomical regions of the brain that are specific to movement planning, intention and execution of voluntary upper extremity motor tasks were investigated here. This paper presents a novel method using symbolic dynamics (orbital decomposition) and nonlinear dynamic tools of entropy, self-organization and chaos to describe the underlying structure of activation shifts in regions of the brain that are involved with the cognitive aspects of functional upper extremity task performance. Several questions were addressed: (a) How is it possible to distinguish deterministic or causal

patterns of activity in brain fMRI from those that are really random or non-contributory to the neuromotor control process? (b) Can the complexity of activation patterns over time be quantified? (c) What are the optimal ways of organizing fMRI data to preserve patterns of activation, activation levels, and extract meaningful temporal patterns as they evolve over time? Analysis was performed using data from a custom developed time resolved fMRI paradigm involving human subjects (N=18) who performed functional upper extremity motor tasks with varying time delays between the onset of intention and onset of actual movements. The results indicate that there is structure in the data that can be quantified through entropy and dimensional complexity metrics and statistical inference, and furthermore, orbital decomposition is sensitive in capturing the transition of states that correlate with the cognitive aspects of functional task performance.

The Dynamic Matching of Neural and Cognitive Growth Cycles

Annemarie Peltzer-Karpf, *University of Graz, Austria*

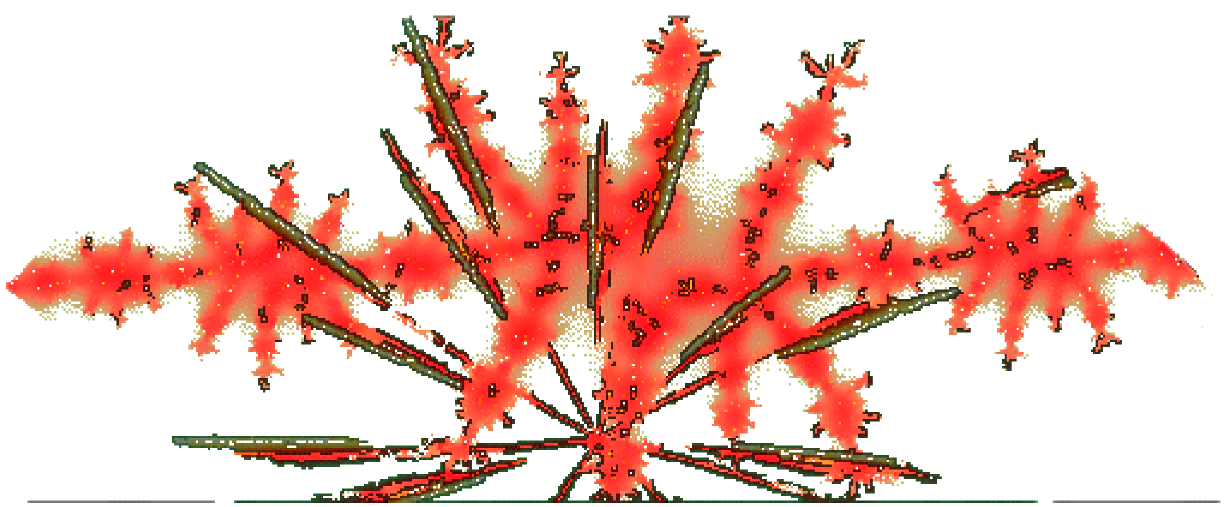
In recent years complex systems biology has developed detailed numerical models mimicking the establishment, modulation, and fine-tuning of neural networks. Current research within the framework of Dynamic Systems Theory (DST) emphasizes the nexus between dynamic cycles in the brain and cognitive development which unfold in a nonlinear way and allow for individual variation. Careful observations over multiple timescales and levels of organization suggest a link to system-specific developmental changes in the central nervous system with more functional specialization opening up more efficient information processing. This can be seen in spurts of EEG energy and altered cortical coherence. Data of age- and experience-related changes in synaptic density and metabolism, shifts in blood flow and improvement of (sub)cortical connections are projected on a dynamic trajectory of cognition moving from diffuse to more refined constructions in the various subsystems, each of which exhibiting its own developmental path. Pending questions are the generation of rules amidst diversity and fluctuation, and the correlation of growth rate and critical mass in developmental dynamics and interaction.

Network Analysis and the Connectopathies: Current Research and Future Approaches

Graeme Martin, *University of Birmingham, Edgbaston, UK*

Complex network analysis has been applied to capture the structure and functional dynamics of the brain. These studies have revealed normal and abnormal network topologies. Network differences are observed in conditions such as Alzheimer's disease, Schizophrenia, Depression and ADHD. Such findings suggest that a number of different pathologies have sufficiently similar features that the term "connectopathies" has been introduced to describe these common topological characteristics. This paper examines the evidence for network properties and failures found in certain disorders, concluding with a brief discussion of maps and the Human Connectome Project's value to understanding brain disorders and dynamics.

Cover image: "The Voice of Air" *by Susan Lowdermilk.* The annual art feature article, which appears in the January issue of *NDPLS*, explains the cover artists' theses for combining imagery from nonlinear dynamics with concepts from psychology and the life sciences. The Fractal Fern (below), which has become an icon for *NDPLS,* is part of the Fractal of the Day collection by J. C. Sprott.



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