Society for Chaos Theory in Psychology & Life Sciences

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Society for Chaos Theory
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Alphabetical List of Authors & Conference Abstracts

Thomas Arnold, *Little Falls, MN*

A Propensity-Selection Threshold Model

Proposing a Propensity-Selection Threshold Model I want to propose a model for explaining measured outcomes such as crime rates, health costs, product sales, wealth distributions, and other similar measurements. My thesis is that it is advantageous to think of these rates as cumulative distributions that result from the intersection of normally distributed propensity and selection processes. Propensity and selection are constantly fluctuating due to high-dimensional chaos. As propensity and selection levels vary across the population, sometimes intersecting and sometimes not intersecting, we see a highly nonlinear distribution of outcomes where there are many zero values, which transition to a gradually increasing rate, and then transition again, culminating with small percentages of people who have extremely high rates. The explanations for these distributions have typically necessitated the use of two-part models. For example, the Zero-Inflated Power Law (Zipf-Pareto), Zero-Inflated Log-Normal Distribution, Hurdle Models, Compound Distributions (e.g., Compound Poisson-Gamma), and the Generalized Pareto Distribution (GPD) for the Tail. I will show how a propensity-selection threshold model provides a single model that explains the entire range of outcomes.

Aaron Clauset *University of Colorado, Boulder*

Nearly-Optimal Prediction of Missing Links in Networks

Networks are ubiquitous in real-world data applications, e.g., in social network analysis or biological modeling, but networks are also nearly always incompletely observed. Current algorithms for predicting missing links in the hard case of a network without node attributes exhibit wide variations in their accuracy, and we lack a general understanding of how algorithm performance depends on the input network's characteristics. In this talk, I'll describe a powerful meta-learning solution to this problem that makes nearly-optimal predictions by learning to combine or 'stack' many individual link prediction methods. Using synthetic data for which we can analytically calculate the optimal performance and a large corpus of 550 structurally diverse networks from social, biological, technological, information, economic, and transportation domains, we systematically evaluate more than 200 link prediction methods individually and in combined stacked models. Across most settings, we show that model stacking nearly always performs best and produces nearly-optimal performance on synthetic networks. Furthermore, compared to state-of-the-art graph neural network techniques, we find that model stacking is typically more computationally efficient and equally accurate on multiple measures of performance. Applied to real networks, we find that the difficulty of predicting missing links varies considerably across domains: it is easiest in social networks and hardest in economic and biological networks, but performance depends strongly on network characteristics like the degree distribution, triangle density, and degree variation. I'll close with some commentary on future work on the link prediction problem.

Stephen J. Guastello, *Marquette University*
Nicholas R. Peters, *Marquette University*
Anthony F. Peressini, *Marquette University, Milwaukee, WI*

Simultaneous Emergent Phenomena: Team Synchrony as a Control Variable in the Emergence of Team Leaders

Although emergent phenomena exhibit interesting and complex dynamics when considered individually, this presentation examines the intersection between two phenomena that could occur simultaneously in an intense group interaction: autonomic synchrony among team members and the emergence of team leaders. It was recently shown (Guastello, Peters, & Peressini, 2025) that the probability distribution of these self-organizing and emergent processes were similar with autonomic synchrony approaching the swallowtail catastrophe distribution that has become characteristic of leadership emergence. The objective of the present study was to examine the role of team synchrony as one of the three control parameters in the leadership emergence model. Research participants were 136 undergraduates who were organized into teams of three to five members playing the computer-game Counter-Strike while wearing GSR sensors to measure autonomic arousal. After approximately two hours of interaction, team members rated each other on leadership behaviors. Autonomic synchrony was analyzed as a driver-empath process that produced individual driver scores (the total influence of one person on the rest of the group) and empath scores (the total influence of the group on one person). Mathematical-statistical modeling was developed in three stages: (a) replicate a model obtained for a team effort in a similar setting involving dynamic decisions, (b) add variables other than synchrony that were logically associated with the control parameters, and (c) test synchrony and sync variability for its best fit as a control parameter. Results showed that synchrony made its best contribution as a bifurcation variable that brought individuals who were already in the zone of potential leaders into primary or secondary roles. Sync variability played the role of a bias variable that distinguished between primary and secondary leaders. Importantly, both sync variables pre-empted team performance as a control variable.

Yannick Hill, *Vrije Universiteit Amsterdam*
Adam W. Kiefer, *University of North Carolina at Chapel Hill*
David Pincus, *Chapman University, Orange CA*
Charles C. Benight, *Lyda Hill Institute for Human Resilience, University of Colorado, Colorado Springs*
Bernard Ricca, *Lyda Hill Institute for Human Resilience, University of Colorado, Colorado Springs*

Dynamical View on Resilience: Conceptualizations, Challenges, and Future Directions

The topic 'resilience' has grown in popularity among researchers over the last few decades. However, this increased popularity of the term has clouded its meaning with many different views, conceptualizations, and approaches to studying it emerging over time. A potential unifying framework that may help integrate these scattered ideas into one coherent approach may be offered by dynamical systems (see the special issue on resilience in *Nonlinear Dynamics, Psychology, and Life Sciences,* 2024). Therefore, the aim of this panel discussion is to provide insight into how resilience is understood in different domains, what challenges currently are present for researchers, and what future directions may be fruitful. This panel discussion will also provide plenty of room for questions from and discussion with the audience for an engaging and fruitful exchange. The panel: Yannick Hill (chair/discussant) is an Assistant Professor of Sports and Performance Psychology at the Vrije Universiteit Amsterdam. His work is mainly focused on understanding individual stressor response dynamics in athletes, first responders, and armed forces to develop tailored training programs, particularly for performing under pressure. Adam Kiefer (discussant) is an Assistant Professor of Exercise and Sport Science at the University of North Carolina at Chapel Hill. He utilizes a dynamical systems approach for measuring, modeling and analyzing the complexity of healthy and pathological human performance to enhance both performance enhancement and injury prevention in sport. David Pincus (discussant) is a Professor of Clinical Psychology at Chapman University. In line with his application of nonlinear dynamics in psychotherapy, he has produced numerous studies investigating the function of fractal patterns that underlie interpersonal processes, personality, behavior, cognition and emotion. Charles Benight (discussant) is a Professor of Psychology and Executive Director of the Lyda Hill Institute for Human Resilience (UCCS). His main interest focuses on the adaptation to traumatic events including the recovery from natural disasters, man-made disasters, motor vehicle accident trauma, sexual abuse, domestic violence, and bereavement using a social cognitive approach. Bernard Ricca (discussant) is an associate professor of statistics at the Lyda Hill Institute for Human Resilience (UCCS). He is currently translating is expertise in physics to time series analyses in behavioral sciences, specifically for clinical (e.g., psychological trauma) applications.

Yannick Hill, *Vrije Universiteit Amsterdam*
Paula Carmona, *Vrije Universiteit Amsterdam*
Michael L. Dolezal, *University of Washington, School of Medicine, Seattle*
Ruud J.R. Den Hartigh, *University of Groningen*
Raoul R.D. Oudejans, *Vrije Universiteit Amsterdam*
Adam Kiefer, *University of North Carolina, Chapel Hill*

Functional Dynamics and Training Load in Sport Science

In the domain of sport science, the functional dynamics between training load and physical development have been well established for many years. For example, to stimulate muscle growth, training load should not be too small to provide sufficient stimulation, but also not too large to avoid injuries. This pattern also follows classical psychological theories on the stimulative effects of arousal doses like the inverted-U hypothesis or the individual zones of optimal functioning. However, these theories lack rigorous empirical testing. Therefore, the first aim of this study was to establish so-called dose-response profiles to assess the relationship between training load and psychological states (i.e., self-efficacy, perceived performance, and mood). Given that training progression necessitates changes in training load, the second aim was to examine whether these dynamics remain stable or change over the course of a season. To test these aims, we collected data from 10 players of the U23 team of a Dutch elite soccer club over the course of one full season. Players completed a daily questionnaire before and after each training session and match, rating their perceived exertion (RPE) and responding to single-question items for each psychological variable. We calculated the internal load (RPE x duration) for each session and created personalized 3D dose-response profiles by mapping each psychological variable as a function of internal load and time. The 3D dose-response profiles were divided into four periods of equal duration across the season, allowing us to identify critical windows where the stimulative effects of training load on psychological states change. Our results show that each player exhibits unique stimulative patterns, and these patterns change over the course of the season. The 3D dose-response profiles reveal that the same training load can have different effects on different players and at different times, highlighting the importance of considering individual differences and temporal dynamics in training program design. To conclude, the findings suggest that a one-size-fits-all approach to training may not be effective in optimizing psychological development. Instead, coaches should consider using personalized and dynamic training programs that account for individual differences and temporal changes in psychological states. Michael Dolezal will discuss understanding and evaluating the longitudinal dynamics of resilience, especially following events that are both physically and psychologically traumatic as well as in global mental health contexts. I will discuss both theoretical and applied challenges to evaluating resilience dynamics within these populations, current approaches to addressing these challenges, and how these approaches can generalize to other populations. I will also discuss how understanding the dynamics of resilience can be used to inform primary and secondary prevention interventions for depression and PTSD, especially in rehabilitation and global mental health contexts.

Adam Kiefer, *University of North Carolina, Chapel Hill*
Stephen Guastello, *Marquette University, Marquette University, Milwaukee, WI*
David Pincus, *Chapman University, Orange CA*

The Dynamics of Experiential Balance: An Exploration of Nonlinear Methods for Modeling Resilience and Self-Organization in Mental Health

This 90-minute symposium will present innovative applications of nonlinear dynamics to high-frequency experience sampling data, offering a window into the emergent patterns of psychological and interpersonal life as they unfold in real time. With a focus on self-organization, flexibility, and resilience, the symposium will explore how different analytical lenses reveal the hidden order within dynamic processes relevant to mental health and adaptive psycho-social functioning. The session will begin with a theoretical and methodological overview by Dr. David Pincus (15 minutes), introducing a dataset comprising three weeks of high-density experience sampling from 200 individuals (63 time points per person). The data include affective states, coping behaviors, self and relational appraisals, and narrative stressor descriptions, as well as baseline and follow-up measures of psychopathology and personality. Dr. Pincus will outline foundational concepts from self-organization theory and nonlinear systems science' such as metaflexibility, structural integrity, and coupling' and propose how these can guide the identification of empirical markers of resilience and transformation in interpersonal relationships. The second presentation by Dr. Stephen Guastello will provide a distinct analytic perspective on the same dataset (20 minutes). Drawing from nonlinear statistical modeling, Dr. Guastello will explore how constructs of synchrony in time series are relevant to the understanding of within-person patterns over time. New questions that arise include (a) whether the variables of interest are hierarchically organized, and what does that do for our understanding of synchrony between people; and (b) what could be the best strategies for organizing the data analysis relative to the goals of defining results and interpreting them. The presentation includes results from SyncCalc applied to the experience sampling data. In the third presentation, Dr. Adam Kiefer will apply multidimensional recurrence quantification analysis (mRQA) to investigate shared dynamics across multiple variables simultaneously (20 minutes). This approach captures the richness of recurring temporal structures in high-dimensional state spaces, offering insights into how systems return to or diverge from familiar configurations. Dr. Kiefer will demonstrate how mRQA can be used to characterize the structure and variability of participants' dynamic profiles and explore how these patterns may reflect differences in regulatory processes or adaptive capacity. In the final presentation, Dr. Pincus (20 minutes) will introduce a third method, Orbital Decomposition (OD), employed to identify nominal patterns of experience, to quantify the complexity of those patterns, and to examine individual differences in these patterns and their complexity. Together, the symposium aims to illustrate how different nonlinear dynamical systems tools can be applied to the same rich dataset, each shedding light on complementary aspects of human psycho-social functioning. A concluding discussion (15 minutes) will engage the audience in a broader reflection on the promise and challenges of bringing nonlinear dynamics into psychological science' particularly in relation to modeling resilience, mental health, and the self-organizing nature of human experience.

Coleson Kovacs, *Palmer Ridge High School, Colorado Springs, CO*

Xin Yee, *University of Colorado, Colorado Springs*

Analysis of Dutch Marine Heart Rate Data using Sliding Window Hankel Dynamic Mode Decomposition to Understand Human Resilience

This study identifies key characteristics of human resilience through biometric data analysis using Sliding Window Hankel Dynamic Mode Decomposition (SW-HDMD). We applied this technique to heart rate data collected from 23 Dutch Marines during an intensive 30-day training period to predict training completion or dropout based solely on extracted dynamic features. Heart rate measurements over time reveal both short-term and long-term stress response dynamics among participants. Our SW-HDMD methodology segments each Marine's heart rate data using pre-defined time windows with 20% overlap between consecutive windows. We then apply Hankel DMD to each segment to extract HDMD modes and eigenvalues representing heart rate dynamics. These eigenvalues indicate how rapidly HDMD modes decay and oscillate temporally. After aggregating all eigenvalues across time-windowed segments for each Marine, we classify them as either "slow" or "fast" based on a user-defined threshold' eigenvalues above the threshold are designated as fast, while those below are considered slow. Using a one-day sliding time window and a threshold of 0.01, we discovered that the average value of slow eigenvalues significantly differentiates Marines who completed training from those who dropped out. This research represents the first application of a dynamic mode decomposition variant to analyze biometric data for understanding human resilience.

Stanley Krippner, *CIIS, Carmichael CA*
Ahmed Setti, *psychiatrist, Morrocco*

Nonlinear Non-equilibrium Psychology

In this presentation, Ahmed Setti and I will be introducing the concept of a nonlinear, non-equilibrium psychology -- one reflecting the work of Ilya Prigogine and Elizbeth Stegner. This approach sees the psychotherapist's task to serve as a guide who helps a client create order out of disorder, a guide who sees crises as salutary, leading to resilience and growth. This approach sees the brain as a dynamic self-organizing system that can best be fathomed in a transdisciplinary manner, drawing upon mathematical models and quantum physics. Special attention is paid to immigrants, the millions of displaced people around the world. Their struggle to exist in an unfamiliar cultural setting can be an opportunity to create order out of chaos, emerging stronger and more resilient than before they began their journey. Setti had drawn upon his work with hundreds of clients using this framework with notable success, especially immigrants he has treated, and realizing the unpredictability of this intervention. On my part, my research into nighttime dreams, creative insights, traumatic reactions, psychedelic experiences, and anomalous phenomena were not adequately explained by linear, equilibrium-based models. However, Setti's non-equilibrium psychology has provided investigative tools absent from conventional linear models.

Cortney Armitano-Lago, *University of North Carolina, Chapel Hill*
Elaine Reiche, *University of North Carolina, Chapel Hill*
Bernard Ricca, *University of Colorado, Colorado Springs*
Dominic Willoughby, *University of North Carolina, Chapel Hill*
Adam Kiefer, University of North Carolina, Chapel Hill

Topological approach to profiling on-court maladaptive gait dynamics following anterior cruciate ligament reconstruction

Following anterior cruciate ligament reconstruction (ACLR), patients often exhibit a more rigid (i.e., less adaptable) gait pattern. This reduced adaptability during walking has been associated with changes in knee cartilage composition, potentially contributing to early knee osteoarthritis (KOA). These gait alterations likely stem from disruptions in the neuromechanical interactions that support healthy, adaptable movement. Traditionally, researchers have used nonlinear models to analyze individual features of gait dynamics after ACLR. However, this approach overlooks the interplay among neuromechanical components that are critical for joint health and adaptability. This study applies a topological data analysis (TDA) framework to quantify the complex, multimodal neuromechanical interactions underlying gait adaptability following ACLR. We conducted a cross-sectional study involving 10 individuals with ACLR and 10 uninjured controls. Each participant completed a single study visit, performing a functional reaction time task in a virtual environment. Participants were instructed to run as quickly as possible toward a designated target that appeared randomly within the environment. To capture muscle activation patterns, participants wore eight surface electromyography (EMG) sensors. Muscle activity was recorded across 32 trials per participant. We will construct multiscale topological profiles of gait adaptability for each group to identify distinguishing features. To characterize muscle activation coordination dynamics, we will apply cross-recurrence quantification analysis (CRQA). Finally, general linear mixed models (GLMMs) will compare coordination metrics across groups. This is the first application of TDA to characterize gait coordination dynamics following ACLR, offering a more comprehensive alternative to traditional univariate analyses by capturing dynamic interdependencies among neuromechanical signals.

Jay Lee, *New Mexico Highlands University, Rociada NM*

Reversal Theory: A Grand, Systems Theory of Psychology

Reversal theory (RT) is a grand theory of psychology rooted firmly in principles of systems theory and nonlinear dynamics. RT was designed by an early cyberneticist, Michael Apter (Apter, 1966, 1969, 1970; Smith & Apter, 1975; Visvader, 1977). As another example of the systems foundation of RT, Apter's 1970 book, 'The Computer Simulation of Behaviour,' was re-released in 2018 as one of the first books on artificial intelligence. RT is a state-focused, theory of psychology bounded by rules and propositions (Apter, 2001) defining a first-person, phenomenological landscape. RT rejects homeostasis and instead formulates a multidimensional theory for modeling psychological change. The term 'reversal' was and is representative of the bistable nature of psychological change (e.g., Apter, 1981, 1989, 1992, 1993, 2001). However, most psychologists with interests in using RT for psychological research have applied classical or normative, psychometric approaches more suited for psychological, trait-based theories rather than a theory based on nonlinear dynamic change. A comprehensive theory of psychology, especially one that uses a systems perspective, is by definition more complex and multidimensional, and such a theory requires rigorous methodology. It is proposed to briefly outline the phenomenological landscape of RT with examples illustrating some of the constructs, mechanisms, and propositions including nonlinear analogs. Finally, some measurement challenges using accepted nonlinear and systems techniques, a sample of different theoretical considerations arising from this perspective, and suggestions for future research directions will conclude this presentation.

Sam Leven, *TPI, Boca Raton, FL*
Fred Abraham, *Silliman University, Philippines*

Toward Biologically Plausible Quantum Neural Networks

Work by Kurian and his group confirms the visions of Pribram and Penrose which claims that the brains' remarkable speed and intensity of thought and self-regulation are facilitated by quantum processing. While Werbos and Pribram have considered the implications of quantum effects, the task of modeling the complex dynamics involved requires a breathtaking leap. But the apparent presence of quantum processing requires reframing of our theories and, hence, our models and experiments. The observed mechanism Kurian, et al., established should prompt us 'at all levels' to reimagine the dynamics of behavior and belief. Arshavsky's argument for multi-state and -texture neural complexity has been enhanced by findings of synaptic memory storage 'enhancing' local processing capacity. The extended 'bidirectional' processing in organs and local nervous clusters advances the span and depth of ' brain' control. Deco et al.'s work on massively parallel long-range cooperative motor and affect dynamics further increases the depth and speed of neural systems. Still, Penrose and Hameroff's theory demands addressing. We offer a model that considers the integration of simultaneous emergent renderings of experience. We follow the Multiple Selves literature to demonstrate the many-sided convergences of sensory, motivational, and cognitive impressions of self and environment in planning and evaluating experience. The QART model suggests that the brain leverages quantum superposition to hold multiple possibilities in parallel. ART mechanisms then guide evolution and eventual 'collapse' of the superposition into a coherent conscious experiences ' the parallel streams as competitive-cooperative 'selves' framed by internal milieu and intention emergent. The model is largely based on Grossberg's ART [LaminART] architecture, but also considers Werbos and Davis' Cycles vision. The notion is that multiple images of Pribram compete and cooperate 'yielding the sense of continuity as waves of processes converge and collapse. The model we offer is not the last word; arguably, as a toy referent, it is not even the first. Instead, its goal is to demonstrate how impoverished our imaginations have been. Its purpose is to emphasize how suboptimal our ignorance remains; its obvious imperfection invites fault-finding, criticism, and smarter beginnings. Inside this global representation of consciousness, lies the neural network that follows.

Vikas O'Reilly-Shah, *University of Washington, Seattle*

Delay Coordinate Embedding as Neuronally Implemented Information Processing: The State Space Theory of Consciousness

Despite intensive effort, a satisfactory scientific theory of consciousness remains elusive. This paper introduces the State Space Theory, aiming to meet key criteria for a theory of consciousness while providing a satisfactory framework consistent with neurobiological and philosophical considerations. The theory posits that the cortex processes information through delay coordinate embedding within recurrent neural networks. These networks create state space representations of reality, forming hierarchical, pseudo-hierarchical, and parallel pathways. Under this theory, consciousness is posited to arise at the highest-order engines in this hierarchy, with complex behavioral options competing within these engines. The theory emphasizes that consciousness is a dynamic process, not representable within a static neuronal state, and develops uniquely in each individual due to history-dependent development of the processing engines. Neuronally, these delay coordinate embedding engines are posited to form recurrent networks that process information by integrating current and past data to reconstruct models of reality, leveraging the power of Takens' Theorem. These engines would themselves exhibit nonlinear dynamics sensitive to initial conditions. This mechanism aligns with the subjective and emergent properties of consciousness, explaining phenomena like binocular rivalry and ambiguous figures. The theory also addresses cortical plasticity and the heuristic nature of cortical processing, aligning with neurobiological evidence supporting the idea that the cortex's information processing is generic rather than specialized. The State Space Theory aligns with and expands upon major theories like Higher-Order Theories, Global Workspace Theories, Integrated Information Theory, and Predictive Processing Theories by providing a computational mechanism for hierarchical integration and recurrent processing. Philosophically, it reconciles dualist intuitions with a monist perspective, positing that consciousness emerges from dynamic brain processes rather than static states. The theory addresses the unity of consciousness and the privacy of subjective experiences, offering a new framework to understand free will within deterministic systems. Future work will refine this theory, exploring its neural mechanisms and validating its predictions, advancing our understanding of consciousness.

Vikas O'Reilly-Shah, *University of Washington, Seattle*

Leveraging Large Language Models to Enhance Research Workflows in Nonlinear Dynamical Systems: Guidance, Case Studies, and Best Practices

Nonlinear dynamical systems (NDS) involve complex behaviors requiring specialized analytical frameworks, posing unique challenges in hypothesis generation, computational workflows, result interpretation, and researcher training. Large language models (LLMs) present novel opportunities to augment these research processes. This article explores how researchers can effectively interact with LLMs to facilitate NDS research. We utilize two case studies: first, determining embedding parameters for the Lorenz attractor, a canonical chaotic system, to demonstrate how LLMs can assist in generating tailored hypotheses, producing and debugging specialized code, enhancing the interpretability of results, and providing real-time computational and instructional support, particularly for researchers new to NDS methods. Second, we use an empirical dataset – electroencephalographic (EEG) data from human subjects - to illustrate how LLMs can accelerate the use of traditional NDS analytical techniques via coding suggestions while providing guidance on assessing data characteristics comprehensively. This work emphasizes LLMs as tools to augment researcher capabilities rather than as primary analytical engines. Expert oversight remains critical for ensuring accuracy and appropriate application; at the same time, strategically integrated LLMs can substantially lower technical barriers and accelerate research progress in NDS. We conclude by discussing limitations, best practices for integrating AI-powered tools with rigorous scientific oversight, and future directions for hybrid AI-human workflows in nonlinear dynamical research.

Bernard Ricca, *Lyda Hill Institute for Human Resilience, University of Colorado, Colorado Springs*

Presidential Address: The Nonlinear Limbo: How Low Can You Go?

Many of the tools used in nonlinear dynamical systems have their roots in the physical sciences and engineering, and hence, were developed with certain assumptions about the data on which they would be used. However, as NDS tools have found their way into the behavioral, life, economic, social, and health (BLESH) sciences, they often get used with data that do not meet those assumptions. To date, however, there has been very little work done to identify the degradation of the results that comes from the violation of assumptions. Furthermore, rarely do BLESH researchers report bootstrapped confidence interval measures that would allow for inferential conclusions to be drawn. In this talk, I will demonstrate some behaviors of some NDS tools when they are used with small and very small datasets, and explore what that could mean for NDS BLESH research, especially regarding sample sizes and sampling frequencies.

Alessandro Maria Selvitella, *Purdue University Fort Wayne, IN*

On the Effectiveness of Sparse Identification Methods to Detect Nonlinear Models of Oscillatory Dynamics in the Life Sciences

The classical perspective in applied mathematics and nonlinear analysis is to build models describing reality from first principles. This approach has been challenged in recent years due to the increasing interest in complex phenomena. Data science leverages the availability of large datasets and computational power to address such challenges, particularly when little scientific knowledge of the biology or physics of the phenomenon is available. A combination of applied mathematics and data science tools is crucial when some data is available, but we have only a partial understanding of the phenomenon under study. In this context, methods such as Sparse Identification of Nonlinear Dynamics (SINDy) have emerged. SINDy is a data-driven technique designed to discover nonlinear dynamical systems from empirical data. By analyzing multivariate time series, SINDy identifies the most sparse governing ordinary differential equations (ODEs) or partial differential equations (PDEs) using regularization methods, such as LASSO. SINDy capitalizes on the observation that many natural phenomena can be described by systems with only a few nonlinear terms, yielding interpretable models. In this talk, we will discuss the effectiveness of SINDy in accurately determining the nonlinear dynamics of systems such as the van der Pol equation and the Kuramoto model, along with some extensions and comparisons with simpler, linear models. The van der Pol equation and the Kuramoto model emerge in many fields of the life sciences, including biomechanics and psychiatry; they are major benchmark examples for testing new methods for identification of systems with rich dynamics, also when chaotic behaviour of solutions and synchronization are possible. In this presentation, we will also describe in detail how to implement these methods and discuss several examples for illustration.

Narges Shakerian, *University of Nebraska, Omaha*
Jorge Zuniga, *University of Nebraska, Omaha*
Aaron Likens, *University of Nebraska, Omaha*

Driving Conditions Modulate Persistence and Predictability in Steering Wheel Control Dynamics

Driving is an essential daily activity with continuous steering adjustments to control a vehicle safely. It is crucial to understand how different driving conditions, such as speed, steering wheel condition, and road shape, impact steering control, particularly the persistence (consistency of steering adjustments over time) and predictability (anticipating future steering movements from previous ones). To investigate this, a study recruited thirty healthy drivers (15 females; ages 19-36). The participants performed simulated driving tasks under varying driving speed (slow vs. fast), steering wheel condition (standard vs. mirror-reversed), and road direction (straight, left curve, right curve). Steering wheel angle was recorded and measured using two nonlinear metrics: Detrended Fluctuation Analysis (DFA) and Sample Entropy (SampEn) for persistence and predictability, respectively. Results revealed that DFA short-range scaling exponents (α) were significantly affected by steering wheel condition ($F(1,318.14)=25.76$, $p<0.001$, $\eta p2=0.22$) and speed ($F(1,318.03)=15.26$, $p<0.001$, $\eta p2=0.60$), with an interaction between these factors ($F(1,318.03)=5.61$, $p=0.018$). Long-range scaling exponents (α) were significantly influenced by the interaction between direction and steering wheel condition ($F(2,318.14)=3.59$, $p=0.029$, $\eta p2=0.78$), and direction and speed ($F(2,318.14)=3.45$, $p=0.033$, $\eta p2=0.77$). SampEn analysis indicated significant effects of direction ($F(2,318.01) = 23.46$, $p < 0.001$, $\eta^2 = 0.072$) and steering wheel condition ($F(1,318.02) = 32.36$, $p < 0.001$, $\eta^2 = 0.092$), along with an interaction of these two factors ($F(2,318.01) = 5.96$, $p = 0.003$, $\eta^2 = 0.027$). These findings highlight how steering wheel control adapts to environmental factors, with variations in predictability and persistence shaping individual driving patterns.

Nicolas Stergiou, *University of Nebraska, Omaha*

A large body of research demonstrates the existence of an optimal level of variability which enables us to interact adaptively and safely to a continuously changing environment, where often our movements must be adjusted in a matter of milliseconds. Decrease or loss of this optimal level due to neurodegenerative and physiological disorders makes the system more rigid and less adaptable to different perturbations. Increase makes the system noisier and more unstable. Stable behavior is a rich behavioral state with high complexity, where complexity is defined as highly variable fluctuations in physiological processes resembling mathematical chaos and fractals thus being more nature based. In this keynote, I present updates of this field of research regarding the innovative "next step" that goes beyond the many descriptive studies that characterize levels of variability in various populations. This research aims to eventually devise novel interventions and technologies that will harness the existing knowledge on variability and create new possibilities for those in need to improve performance and/or restore their decreased physical abilities.

Alexander Stover, *Lyda Hill Institute for Human Resilience, University of Colorado, Colorado Springs*
Jenna Happe, *Lyda Hill Institute for Human Resilience, University of Colorado, Colorado Springs*
Bernard Ricca, *Lyda Hill Institute for Human Resilience, University of Colorado, Colorado Springs*
Charles Benight, *Lyda Hill Institute for Human Resilience, University of Colorado, Colorado Springs*

Inverse Power Law Distributions in HRV: Indicators of Psychological Adaptability Post-Trauma

Self-organization' a process in which systems develop order or structure without direct external control' emerges from the interplay between the parts of the system. In living systems, self-organization underlies physiological and psychological functions, which enable systems to exhibit rigid to flexible responses to environmental pressures. Inverse power law (IPL) distributions frequently emerge in self-organizing systems. Heart rate variability (HRV), an index of autonomic nervous system functioning, is a marker of psychological adaptability. Lower HRV is typically associated with affective dysregulation. The present study hypothesized that the distribution of HRV follows an IPL distribution, and that the properties of that distribution may bring further insight into the relationship between HRV and affective dysregulation. IPL analyses produce metrics of structural integrity (goodness of fit; a system's coherence) and flexibility (shape parameter; a system's ability to adapt to perturbations while maintaining identity). Moreover, optimal functioning may occur within a critical zone, where flexibility is balanced (e.g., neither excessively rigid nor excessively diffuse). Outside of this zone, systems may become more vulnerable to dysregulation. Similarly, lack of coherence may affect the ability to function, with small goodness of fit values being more prone to dysregulation. Consequently, we propose that trauma survivors whose cardiovascular systems operate within the optimal zone of flexibility and sufficient coherence would exhibit greater positive affect and reduced negative affect (measured using the Positive and Negative Affect Scale) over time. Structural integrity and flexibility will be evaluated for the hour before a participant completes the PANAS twice daily for 6 weeks.

Heather Thompson, *University of Central Oklahoma, Edmund*
Jake Yost, *University of Central Oklahoma, Edmund*
Tabitha Thompson, *University of Central Oklahoma, Edmund*
Mickie Vanhoy, *University of Central Oklahoma, Edmund*

Multifractal Analysis Reveals Hidden Temporal Dynamics in Task Complexity

Task complexity is a well-established factor influencing response times and movement variability across perceptual, cognitive, and motor tasks. We revisit Fitts' law, as the difficulty of a movement increases -- by manipulating target distance or size -- movement speed decreases and variability increases. Similarly, Donders' experiments showed that increasing the number of stimulus-response alternatives or the complexity of decision-making steps systematically slows response times. These observations form a foundational framework for understanding performance in speeded response tasks. Standard analyses of task complexity focus on mean response times and error rates, often employing ANOVA to compare performance across conditions but such aggregate measures can obscure the fine-grained temporal dynamics and variability inherent in behavioral data. For example, movement preparation time, not just execution, is a critical determinant of movement variability, revealing the importance of analyzing temporal structure in performance. Multifractal Detrended Fluctuation Analysis (MFDFA) – a nonlinear time series method – can be applied to response times collected from a speeded response task with systematically varied complexity levels. MFDFA enables the quantification of complex, scale-invariant fluctuations in behavioral time-series, not captured by traditional spectral analysis or summary statistics. While MFDFA has been used to classify cognitive states from EEG data during attentional and visuo-motor tasks, its application to behavioral response times is a less common method for peering into the temporal organization of performance under different task demands. Undergraduate participants completed a series of speeded tasks with systematically manipulated complexity. We hypothesized that increasing task complexity would be reflected not only in longer mean response times, as predicted by standard methods, but also distinct multifractal signatures in the temporal structure of response times. We expected broader multifractal spectra for more complex tasks, indicating increased temporal variability like EEG-based studies of cognitive state classification. This project is another example of multifractal analysis providing a more nuanced picture of behavior beyond what is revealed by mean-based metrics alone. This approach continues to inform future research in perception, cognitive ergonomics, human-computer interaction, and the neuro-dynamics of complex task performance.

Mickie Vanhoy, *University of Central Oklahoma, Edmund*
Tabitha Thompson, *University of Central Oklahoma, Edmund*
Jake Yost, *University of Central Oklahoma, Edmund*
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Competing Models and Classic Paradigms Viewed from a Complex Systems Perspective

The classic Sternberg paradigm can help compare competing models of short-term memory phenomena if we analyze response time (RT) series with multifractal detrended fluctuation analysis (MFDFA). There are several hypotheses: (1) the classic serial exhaustive search model, (2) resource-based or dynamic state models, and (3) parallel or subsystem models. Each model makes distinct predictions for summary RT measures and the multifractal spectra of RT time series. If the serial exhaustive model is correct, then mean RT will increase linearly with set size, and the multifractal spectra will be narrow, reflecting uniform, stationary processing with limited temporal variability across trials. If resource-based or dynamic state models are correct, then mean RT may still increase with set size, but multifractal spectra will broaden as set size increases, reflecting greater intermittency and dynamic allocation of cognitive resources--visible as increased variability and scaling structure in the RT series. If parallel or subsystem models are correct, then multifractal spectra may show moderate broadening and potentially distinct patterns for different task components, reflecting interacting but partially independent processes. By directly comparing these predictions, our experiment provides a crucial test: If we observe only narrow spectra consistent across set sizes, the serial exhaustive model is supported. If, instead, we find broader, more complex spectra that scale with task demands, this could challenge the strict serial model and support modern, dynamic views of short-term memory. Thus, the multifractal properties of RT series may serve as a decisive outcome, distinguishing between classic and contemporary theories of cognitive processing.

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Athlete Acceleration Dynamics during a Target Pursuit Task in Virtual Reality: A preliminary analysis

Athletes rely on perceptual information to guide behavior, particularly in tasks requiring continuous interaction with moving targets. Heading adjustments are often considered a primary control variable; however, strategies may shift under speed and time pressure constraints. Analyses of overt trajectories may overlook the nested temporal structure of behavior. This study examines the dynamics of acceleration' a fast-evolving control-relevant signal' during an overground virtual reality (VR) target pursuit task (TPT), using auto-recurrence quantification analysis (aRQA) to assess how acceleration fluctuations reflect control and coupling to informational structure. Forty-seven athletes performed a VR-TPT with humanoid targets moving at 50%, 66.3%, 83.3%, and 100% of each athlete's maximum speed. Position data (x, z) were recorded at 60Hz, smoothed with a 30% LOESS filter, and used to compute acceleration. aRQA was conducted using optimized parameters (dimension=3, delay=10, and radius=0.95 m/s²). Linear mixed-effects models tested effects of speed on diagonal (%DET, MnL, MaxL) and vertical (%LAM, TT, VMax) aRQA measures, with participant as a random effect. As speed increased, acceleration became less predictable: mean %DET=93.41% at 50% speed, decreasing by 1.18% (p=.001, 95% CI [-1.90, -0.30]), 2.09% (p<.001, 95% CI [-2.81, -1.38]), and 2.39% (p<.001, 95% CI [-1.23, -0.30]) at 66.3%, 83.3%, and 100% speeds, respectively. VMax (normalized to trial length) decreased from 9.18% (50% speed) by 0.91% (p=.010, 95% CI [-1.60, -0.22]), 0.95% (p=.007, 95% CI [-1.63, -0.26]) and 1.47% (p<.001, 95% CI [-2.15, -0.79]) at the higher speeds. These results suggest shifting control dynamics with speed, potentially reflecting strategic adaptation through acceleration-based regulation.

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Bio-behavioral Team Dynamics Measurement System (BioTDMS) for Objective Team Training Assessment

The DARPA OP TEMPO program aims to accelerate warfighter readiness by providing instructors with objective, automatic assessments of team performance during simulation training. To that end, we created the Bio-behavioral Team Dynamics Measurement System (BioTDMS), a multimodal sensing and analytics pipeline that discovers bio-behavioral signatures emanating from within the human body and through team member interactions that predict team performance. BioTDMS employs a layered symbolic dynamics model that converts time-aligned neural, cardio-respiratory, kinematic, and verbal data, collected using a multimodal sensor suite. Moving-window entropy and mutual information computed across the symbolic sensor space yields real-time metrics that quantify team adaptability following training perturbations and distribution of team-member influence across bio and behavioral subsystems. These features feed a multi-task, multi-kernel machine learning model that refines individual and team performance prediction while preserving explainability through team construct mapping and command-line user interface. We present preliminary results from field testing a full physical-computational implementation of BioTDMS during Fire Support Team (FiST) training exercises at U.S. Marine Corps Air-Ground Combat Center, CA. An onsite team instrumented five-person FiST crews with multimodal sensor suites. Sensor data was processed by BioTDMS for real-time and post-hoc analytics. BioTDMS currently accounts for 67% of variance in a subjective team performance assessment made by instructors, with improvements expected upon further refinements of BioTDMS modeling components. These findings demonstrate BioTDMS s potential as an operational tool for automatic, objective team assessments. Future OP TEMPO use cases, including multi-ship aviation combat and human autonomy teaming, will test the generalizability of BioTDMS.

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Multifractal and Recurrent Features of Behavior in the Presence of Colored Background Noise

People must function in environments that contain extraneous or unwanted sounds. Noise can obscure more informative sounds (signals). Noise may influence how well people perform visual tasks, but all noise is not the same. The environment can include background sounds like music, ambient noise, or noise with specific spectral features. Results are mixed about whether background noise can enhance performance. One way to analyze the influence of noise on performance is to measure the observer's sensitivity (d') to the signal independent of their response bias (β). Those are summary statistics that can describe the observer's overall accuracy and strategy but they do not capture the rich source of information in behavioral variability over time. Multifractal Detrended Fluctuation Analysis (MFDFA) can quantify the complexity and long-range correlations in eye movement patterns to distinguish between cognitive states. Recurrence Quantification Analysis (RQA) can reveal the temporal structure in the data, tracking how often and in what way the system revisits previous states or patterns. It can capture features like stability, predictability, and the presence clustered behaviors in eye movements and response times, not directly measurable by multifractal analysis. In a quiet lab, with standard computer work-stations, undergraduate participants completed random-ized blocks of trials where they pressed the keyboard spacebar when they noticed a visible change in the orientation of a moving Gabor patch stimulus traveling from left to right across the display. Noise-canceling headphones simultaneously played audible background noise with specific spectral features. Each block of trials contained one type of colored noise: pink, white, gray, blue, violet, or brown. We hypothesized that pink noise, which shares structural similarities with many natural signals, could potentially enhance detection performance and promote stable, adaptive responding (seen as broader multifractal spectra and more structured recurrence). The high-frequency energy of violet noise might disrupt vigilance more severely if it disrupts rhythms critical for sustained attention. Low-frequency-dominant brown noise might destabilize performance dynamics if it overwhelms sensory processing. The results show how background noise may reshape behavior states, with implications for designing environments that support sustained visual attention.

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Processing of Vibration and Temperature Data Using Mathematical Modeling of Collective Intelligence Decision Making

Optimization of preventive maintenance is often based on information about vibration and temperature of structures. But such data may contain significant noise. Therefore, enhancement of forward-looking information in such situations presents some features of interest. Before developing any new systems, it is always useful to check if there are objects, which can be used as their prototypes. In particular, it is possible to apply knowledge about living organism transform engines of data. Whatsoever, increasing interest in artificial systems capable of high quality of operational behavior under uncertainty and indeterminism clearly demonstrates necessity of infusion of adjustment mechanism from biology for improvement of functioning of required system. Wherein, experience in developing neuro-computers shows that it is not necessary to simulate all features of a real biological object for effective operation of the electronic brain. For example, a real neuron is a lot more complicated than its model used in neurocomputing, but such approach may be very effective. In real life, decisions are often made by groups of professionals. In other words, collective intelligence decision making takes place, and simulation such process may be considered an effective approach to solve many significant challenges. Upon that, functions being used for mathematical modeling in situation of this kind should adequately cover all aspects of emulated procedure. For instance, simulator of estimation of avalanche risk described in consists of functions, each of which knowingly has semantic charge, and their combination may be considered as a theory of predicting this slope process by a group of experts. For purpose of analysis of situation with the help of temperature and vibration data, values of temperature and vibration plus their time changes are used. Each of these parameters is edited with the help of function simulating of work of a separated professional, which opinion is apprized with an element of fuzzy set related to certain decision about a problem of preventive main-tenance, wherein membership degree shows level of accepting such decision. Then, taking into account cooperation of group members, levels of their consent with the decision may be changed if each of them makes allowance for opinions of other experts. At the third step, the team leader fuses of opinions of experts together and makes decision. Forms of functions being used and their parameters are selected with the help of Monte Carlo technique so as results of analysis are as near as possible to known data obtained from experience. Utilizing this approach permits to avoid both downtime because of failure of equipment and unnecessary preventive main-tenance, which increase effectiveness of production. Operation of equipment with relatively high temperature and vibrations is repeatedly observed. At the same time, dangerous combination of predictors has led to failure in many cases.

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Results of Using Mathematical Modeling of Collective Intelligence Decision Making for Dangerous Phenomena Forecast

Improving accuracy of forecasting various dangerous phenomena is very important to prevent fatalities and material losses as well as to avoid false alarms, which may result in a heavy financial cost. Therefore, it presents some features of interest. The collective behaves in ways that are not possible for the individual agents which form the collective. Its dynamics are not a simple scaling-up or extrapolation from the dynamics of the agents. Whereby, collective intelligence systems possess a level of complexity in their dynamics which far exceeds that of simple Newtonian objects. Quite often in real life, decisions are made on the ground of conclusion of experts' council, wherein its chief need to be able to take final decision, accounting for as well his or her opinion as estimation of other professionals. Under due building such group, its operation can be very effective even though challenging and questionable situation takes place. On the basis of mathematical modeling of making collective intelligence decision by such group, some simulators of estimation of risk are developed. They consist of functions, each of which knowingly has semantic charge to increase effectiveness of operation. Such systems are tested both in real time and in look back study. Acceptable results have been obtained, wherein in many complicated cases known statistical technology demonstrates under-performance. For example, mathematical support for avalanche forecast prepared with the help of such approach shows adequate effectiveness in Kamchatka. At the same time, other methodologies have not been in a position to predict risk correctly in this region. In addition, regulatory guide of 'Avalanche Risk Forecast' has been utilized in Russia since 2000. Unforetold avalanches are absent, and although overestimation of risk takes place, its value is acceptable. Therewith, application of other techniques has not enabled to predict avalanches under certain circumstances. The similar mathematical support and software are used to forecast mudflow in Tyrnyauz area of North Caucasus. Unpredicted torrents are not observed. Post-event analysis of the earthquake focus preliminary to some earthquakes shows satisfactory results too. Therefore, developed mathematical support can be used for forecasting various dangerous phenomena. It permits to perform both real time analysis and long-range estimate, which considerably increase level of safety and prevent material losses.