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Structural Integrity, Flexibility, and Timing: Introduction to a Special Issue on Resilience

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Abstract: *This introduction to a special issue of* Nonlinear Dynamics, Psychology and Life Sciences *on the topic of resilience discusses the contributing articles in terms of their flexibility in methods, models, scale, and contexts combined with their integrity in shared theoretical understanding and generative knowledge. The ubiquity of resilience is discussed, a feature of potentially any living or non-living system and substance. This breadth calls for a flexible set of models and methods, along with the quest for integrative theory to make resilience science more resilient. Since resilience involves the ability of a substance or system to persist, to repair or recover, and to evolve, any common theory would consider structural integrity (the ability to hold together), flexibility (the ability to adjust and return), time and timing. Nonlinear dynamical systems theory is proposed as the only scientific perspective capable of building this sort of common knowledge of a ubiquitous process involving these specific features. The synopsis of each article's contribution to the issue includes an analysis of the flexibility the article adds in terms of models, methods, scale, and applied context, along with the theoretical integrity produced with respect to these common features of resilient processes: flexibility, integrity, time, and timing.*

Key Words: resilience, chaos, complexity, nonlinear dynamics, systems

What is resilience? A simple, yet challenging question. Perhaps defining resilience is a challenge because it is one of those ubiquitous and highly diverse processes that can be applied to both non-living material structures, like buildings, bridges, and machines, and across broad scales of living systems, from single cells to the global ecosystem. If we aim for the most general perspective possible, resilience may be described as a process of maintenance, of lasting, of withstanding, of self-repair, and potentially of self-improvement - increasing resilience through resilience. From this perspective, it becomes clear that resilience cannot be understood without time as time is the context in which maintaining, lasting, withstanding, repair, and improvement occurs. Time is as

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essential to resilience as it is to evolution. Along with time, structural integrity and flexibility may be essential aspects to consider when trying to understand any process of resilience. To be clear, *integrity* in the context of resilience does not connote any sort of religious or moral framework, as the common use of the term often does. Rather, *structural integrity* in the context of resilience describes the way in which the various elements within a system are arranged, connected, or configured. Integrity is meant to describe the relational strength of interactive parts of a system, their ability to hold onto one another, with a *relationship* defined by their material connections or exchange of energy or information. This scientifically grounded, and measurable sort of *integrity* may be simply another way to describe something that is capable of *lasting* or *withstanding*, and *flexibility* may be simply another way to describe something that is able to adjust and adapt, while maintaining global integrity. When defined as such, integrity and flexibility are not in opposition, but rather are complementary processes when a system is optimally resilient (Kiefer & Pincus, 2023).

The intention of this special issue on resilience is to contribute to the very resilience of this topic, with each article contained within this issue contributing to the integrity, the flexibility, and the advancement of knowledge on this important over time. This addresses the "why." As for "where," *Nonlinear Dynamics, Psychology and Life Sciences* is the ideal place. Within this issue lies a broad range of applications to the topic of resilience, ranging from personality to organizations. One will find varieties of models and methods, coming from a variety of disciplinary perspectives, and with a range of potential applications. Even with such variety, each of the contributions is interconnected to the others through a shared theoretical understanding of complex and potentially nonlinear change over time. This integrated knowledge and these flexible applications aim to discover incremental insights capable of building increasing knowledge through the processes of scientific challenge over time.

The first contribution, by Hill and Den Hartigh (2024) titled "Dynamical systems principles underlying resistance, resilience, and growth" tackles some of the broadest and most general theoretical considerations for researchers studying biopsychosocial resilience processes at multiple scales of size and time, including early warning signals for resilience loss and breakdowns. The authors aim to better understand how multi-scale interactions may contribute to the integrity, flexibility and growth processes, for example, from faster physiological changes to slower psychological changes. Importantly, Hill and Den Hartigh propose some specific models, methods, and hypotheses that may be applied to empirically study the various facets of resilience (i.e., resistance, resilience, and growth) as they co-occur at different scales.

The second article by Pincus (2024) titled "Romantic resilience: Fractal conflict dynamics and network flexibility predict dating satisfaction and commitment," is an empirical study that applies self-organization theory to better understand how romantic relationships persist or fall apart in response to conflict. The results of this study provide evidence for several new lines of knowledge, notably that conflict dynamics are fractal, with exponentially more small conflicts than large (i.e., fitting an inverse power-law distribution). Furthermore, daters with better fitting fractal dynamics, conveying a combination of structural integrity and flexibility, appear to have more resilient relationships, with higher satisfaction and commitment across the 30 days. Finally, the study also examined the coupling dynamics over time among conflict, satisfaction and commitment, discovering that more flexible network coupling, (not too tight, and not too loose) between conflict-satisfaction and conflict-commitment over time is associated with more integrated fractal conflict patterning over the 30 days. Consistent with Hill and Den Hartigh's proposition about the cross-scale interactions of fast and slow dynamics, this study provides evidence that flexibility in the regulatory functions of conflict at the scale of hours and days is associated with integrity in fractal conflict patterns at the monthly scale, functioning to maintain romantic resilience.

The third contribution by Guastello (2024) titled "Elasticity, rigidity, and resilience in occupational contexts," is an integrative theoretical review of an extensive line of empirical study examining elasticity versus rigidity as a resilience-making factor for both individual workers and occupational teams. Guastello includes a rich variety of factors operating at different scales, such as moment by moment affect, coping, communication, coordination, and synchronization; the gradual accumulation of efficacy beliefs constructed from the experience of ongoing successes or failures; and the more stable traits and abilities that the workers bring to bear in various situational contexts. The review also includes a wide variety of nonlinear indices in addition to elasticity-rigidity, including chaotic hysteresis, bifurcations, and various other features that can be examined within the topology of a cusp catastrophe model. Altogether, this piece of work provides great breadth to the collection in its applied significance for occupational resilience, models, and measures. Yet, there is also a good deal of overlap in the common scientific knowledge it provides with respect to understanding the multi-scale, multi-factorial processes that combine to produce resilience via elasticity-rigidity, and potentially prevent catastrophic breakdowns.

Next is an empirical article by Guastello, Hombsch, Schaid, and McGuigan (2024) titled "Who syncs? Elasticity-rigidity in a dynamic decision team." This contribution is part of a series of studies that was carried out in a game-paradigm (i.e., *Counter-Strike*), and examined the putative resilience-related process of physiological synchronization among team members (i.e., physiological arousal measured through galvanic skin response). Interestingly, the focus of the study was to examine which of many personality or cognitive variables, hypothetically reflecting elasticity-rigidity, would predict physiological synchronizing with other players during the games. A couple of the most notable results indicate that physiological synchronization tends to emerge over time, with repeated team experiences, and that several of the elasticity-rigidity variables predicted an empathic sync response (i.e., the tendency to be driven up and down in physiological arousal by the changing states of team members). The empirical context (e.g., team performance) and theoretical focus (e.g., elasticity-rigidity) provide a helpful empirical exemplar of how ongoing replications can continue to build knowledge in occupational team performance following from the prior review article by Guastello. Additionally, one may note the multi-level, fast and slow variables included in the detailed analyses of the study (from physiological to personality), along with the common theoretical focus on elasticity-rigidity as a bifurcation parameter on a cusp model.

The final contribution to the special issue by García-Díaz (2024) is titled "Resilience as Anticipation in Organizational Systems: An Agent-based Computational Approach." This computational study aims to understand resilience at the broadest scale, organizations comprised of many individuals, using agent-based modeling, which is ideally suited to theory building in this sort of context where empirical study can be resource intensive and limited in terms of available methods and measurements. This study focused on a relative gap in the literature on organizational decision making concerning the anticipation of shocks to the system (i.e., sudden perturbations). In addition to the resilience-making processes of communication, decision-making and responding to such shocks, it would make sense that the ability of a system to anticipate a shock could be critical in preparing to resist the impact of the shock, increasing resilient responses post-shock, and potentially making longer-term adaptations. This modeling approach is unique among the articles in this issue in its focus on network connectivity. In doing so, the results contribute further to the integrative knowledge of resilience. Specifically, the results suggest that more flexible network connectivity, observed as sparse or clustered networks of agents, are better able to anticipate and respond to shocks. By contrast, full connectivity may tend to reduce diversity and independence in responses, increasing the chances of rigidity and breakdown. Importantly, however, rigidity and flexibility are complementary, not either-or propositions. The results of this investigation suggest that the optimal structural configuration among agents' responses involves a balance between the two. Again, despite the different scale, setting, and methods of this study, one may find that the results reflect the theoretical importance of integrity (network connectivity), flexibility (sparseness and independence), and timing (anticipation and various types of shocks) in these results.

Integrity, flexibility, and time may be applied to the processes of science as well. Incremental gains in scientific knowledge about resilience should have integrity over time, lasting, and withstanding challenges over time. Scientific knowledge about resilience should also be flexible, applicable to as many applied contexts as possible, and capable of correction and improvement over time. Given that the concept of resilience may be applied to the process of science itself, one may logically consider what the key challenges are to integrity, flexibility and growth within the scientific study of resilience. One factor may be disciplinary boundaries. Even if one constrains the topic of resilience to psychology and the life sciences, one will find a massive array of fields across biology (from cells to ecosystems), as well as the psychological areas ranging in scale and topic from neurons to (social) neighborhoods and beyond. Furthermore, within each discipline, one will find theoretical divergence and even scientific allegiances to specific frameworks, models and methods.

Divergencies within and between various fields studying resilience may pose significant challenges to the integrity of resilience science. In fact, the greatest challenge to flexibility in the science of resilience may arise from the narrow application of reductionism and linear models. In contrast, flexibility is inherently a nonlinear process, while integrity is an emergent property of a system with well-connected elements and operationally definable boundaries that render the system a *whole*. Flexibility, integrity, challenges, and potential for growth are all inherently sensitive to time and timing, characteristic of nonlinear dynamical systems.

Speaking on behalf of the editors and contributors to this special issue, we hope that the great variety of contexts, models and methods convey the versatility of nonlinear dynamical systems theory applied to resilience science. At the same time, we hope that readers can appreciate that nonlinear dynamical systems approaches also allow for vast theoretical integration and for common processes to be applied across this great variety of scales in time and in size. From individual trauma and romantic resilience, to teams, and even large-scale organizations, resilience may show up as resistance against the onset of a perturbation, repair following the perturbation, and adaptations that allow for evolution against future perturbations. It is also important to note that, while nonlinear dynamical systems methods can be challenging at first, the underlying concepts are intuitively practical and theoretically sound. In the context of resilience, key processes such as integrity, flexibility and timing are crucial for understanding how systems withstand, respond, and adapt over time in a variety of situations. We hope that the various articles here provide good resources and serve to generate new ideas for those who would like to join in and contribute to the collective effort to contribute to the resilience of resilience science.

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