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Editorial

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The path of complexity

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"*I think the [21st] century will be the century of complexity*" - Stephen Hawking

Complexity science studies systems where large numbers of components or subsystems, at times of a different nature, combine to produce surprising emergent phenomena apparent at multiple scales. It is these phenomena, hidden behind the often deceptively simple rules that govern individual components, that best define complex systems. Since these behaviors of interest arise from interactions between parts, complex systems are not counterparts to simple systems but rather to separable ones. Their study therefore often requires a collaborative approach to science, studying a problem across scales and disciplinary domains. However, this approach introduces challenges into the ways collaborations function across traditionally-siloed disciplines, and in the publication of complexity science, which often does not fall cleanly into disciplinary journals. In this editorial, we provide our view of the current state of complex systems research and explain how this new journal will fill an important niche for researchers working on these ideas.

A brief history of complexity

The idea of complexity as a transdisciplinary look at systems is itself an emergent phenomenon as it cannot be traced back to a single individual, study, or event, but instead emerged slowly across fields. In its broadest definition, complexity is a perspective that embraces uncertainty and the need for multidisciplinarity in the face of large interconnected systems. This idea has a long history throughout the world, from classical Eastern philosophy to pivotal figures in western science. In the final work of René Descartes, "The Passions of the Soul" from 1649, human life itself is described as many parts of a different nature interacting creating networks with emergent properties where local effects can have surprising global consequences. These concepts were not formalized then, but were used as a framework to try and wrestle complex ideas that defy reductionist descriptions.

The formalization of complexity occurred across fields in the last century. In 1962, Herbert Simon laid a road map for the study of complex systems in "The architecture of complexity"[1]. Herbert Simon himself was a political scientist who eventually turned to organization and artificial intelligence research. A decade later, the physicist Philip W. Anderson addressed how this philosophy clashes with the standard reductionist hypothesis in 1972 in "More Is Different: Broken symmetry and the nature of the hierarchical structure of science"[2]. In this essay, Anderson argues the need for multiple perspectives since "*the ability to reduce everything to simple fundamental laws does not imply the ability to start from those laws and reconstruct the universe.*" The deeper we go in fundamentals, the less relevant they appear to be to global human-scale problems. Similar ideas also emerged in philosophy with the transdisciplinary work of Edgar Morin and his critiques of reductionist or system theory[3]. Morin's formal work on the topic arguably starts in 1978 with "Human Unity" and culminates in 1990 with "Introduction à la pensée complexe." In his foreword to the latter[4], Alfonso Montuori summarizes the paradigm of complexity as "*a way of thinking that does not mutilate life... not disembodied and abstract, but rich in feeling, intuition and connection to the larger social and historical context.*"

Curiosity about the remarkable complexity of living systems inspired critical developments spread across several disciplines. Having made fundamental insights in the field of quantum mechanics, Erwin Schrödinger turned to developing theory on self-replication and heritable information. In doing so, he remarked that fully understanding living systems will likely require new laws of physics[5]. At the same time, John von Neumann and Stanisław Ulam were developing theoretical machines (which became foundational to the future field of computer science) that could build functional copies of themselves with hopes they would eventually evolve ever-increasing levels of *biological* complexity[6,7]. Attempting to explain the origin of biological complexity, Per Bak and Stuart Kauffman both arrived at structuralist arguments centering on self-organization, but each followed a distinct intellectual path; Kauffman analyzed coarse-grained models of genetic regulatory networks[8], while Bak developed the iconic sandpile model that exhibits self-organized criticality[9]. The success of this community reminds us that life, like any other complex system, is best studied wholly and from many perspectives. This process of intellectual progress through dialogues between fields was repeated in other disciplines. Networks of all kinds are now analyzed using theories from social sciences as well as models from physics and mathematics[10]. As we explore in our inaugural collection, the study of epidemics and misinformation are increasingly turning to a unified toolbox for contagions of a biological or social nature. This dialogue across disciplines and this search for unified models and theories became the ethos of complexity science over the next few decades.

Complexity as a community

Complexity might not be a science per se, arguably having no specific set of shared systems of interests or methodological tools, but it certainly is a community with a shared approach to science. With members from many disciplines, complexity is a community driven by intellectual curiosity and an openness to engage with new problems and disciplines.

In fact, over the last decade, complexity science has grown in waves, always reaching new disciplines. With roots in philosophy, economics and physics, complexity was originally a community based on abstract thought experiments and models[11]. Computer scientists and statisticians joined to help with computational modeling and processing of big data. Ecologists, anthropologists, or political scientists also joined with the complex systems they had been studying for decades; food web data, social support networks, governance systems, or even communication networks of trees! Neuroscientists and biomedical scientists came in and proposed that complexity science could help us better understand ourselves through complex models of our brain, microbiome, and immune systems, among others.

One driver of this growth is that the core message that "more is different" resonates with many scientists[12]. Across disciplines, moving from one ideal system studied in isolation to an interacting open population is extremely hard. That is how many academic fields are born after all: population biology, ecology, statistical physics. Complexity science grows by recognizing that there are lessons to be learned from all of these efforts. That message was echoed over the last decades to form the complexity community of today. Especially in recent years, as we celebrated the Nobel prize of Giorgio Parisi which highlighted the importance of letting curiosity and real-world serendipity guide even theoretical and fundamental scientific inquiry[13].

Interdisciplinary, not any-disciplinary

Research that transcends disciplinary borders faces unique challenges in the traditional publishing system, which is built on disciplinary foundations. The goal of *npj Complexity* is therefore to publish work contributing to dialogues occurring at the edges of disciplines. Our editorial team is well aware of the traditional challenges in this space and aims to embrace new, *weird*, and creative perspectives. This will hopefully result in a curated venue where members of our community, regardless of fields, can listen to emerging voices or discover new ideas and fields of study.

Currently, research in complexity often has to choose between two imperfect options. Studies can be published in disciplinary venues, from physical, biological, or social sciences, which requires tailoring the project and the text to a specific disciplinary audience at the risk of losing part of the identity of the research. Alternatively, studies can aim for multidisciplinary journals, which more often than not are large journals that publish from *any* disciplines, rather than journals focused specifically on *interdisciplinary* work. Offering a home for research that transcends disciplines or build bridges across them is at the core of the mission of *npj Complexity*. It is not designed to be the journal of the future. It is after all founded in partnership with a traditional publisher and relies on the current open-access standards. Yet, the journal aims to help fill a longstanding and important gap in the publishing venues for interdisciplinary work.

As a community, including the newcomers interested enough to read this, we aim to push knowledge in new directions at the edge and intersections of many disciplines. This goal means that we at times solve big problems with a unique perspective, and at times reinvent the wheel in a new setting. To distinguish the two, it is critical for complexity scientists to surround themselves with a diversity of experts and listen to knowledge from new disciplines. Failing to do so, complexity science risks becoming yet another discipline with a funny name, with its own jargon and problems. It is thus a core requirement of *npj Complexity* that manuscripts published by the journal be readable to its broad target audience in order for pre- and post-publication peer review to transcend disciplinary boundary.

To quote the great Murray Gell-Mann, physicist turned complexity scientist[14], at his 1969 Nobel Prize speech: *We are driven by the usual insatiable curiosity of the scientist, and our work is a delightful game.* At *npj Complexity*, research needs to engage with scientists from any discipline by appealing to the inherent curiosity of complexity scientists. It is a difficult and subjective goal, but one that is at the heart of complexity science.

The path of complexity

Complexity science is at times described as weird and unique, but it has many cousins, such as systems theory, cybernetics, ecology, political science, and any other fields interested in systems composed of many parts interacting at multiple scales or through diverse mechanisms. The value of using the term "complexity" is in part to embrace the openness of the community through the vagueness of the term. It is therefore hard to formulate a concrete mission statement for the journal. Yet there is a dire need for a holistic approach to complexity research: From theory, to experiments, to applications, including the philosophy and ethics thereof.

And *npj Complexity* aims to be such a home for complex systems, including but not limited to:

- network science,
- artificial life,
- computational social science,
- systems biology,
- data science,
- ecology & evolution,
- dynamical systems,
- economics & finance,
- and social complexity.

Spanning across these domains and more, we find that the most pressing problems facing humanity are cross-disciplinary in nature: emerging pandemics, misinformation, climate change, rising global inequality, human right movements, adaptations to new technologies and the nonlinear interactions that arise among all of these challenges. None of these problems can be tackled in isolation, they require complex thinking and disciplines working in unison. Research along this path can be challenging for standard peer review practices as it involve dialogues across fields and expertise, or new language and perspectives. Efforts to rise to these global challenges while embracing their complexity deserve their own venues.

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