NONLINEARITY:

THE HISTORY AND PHILOSOPHY OF THE SCIENCE

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Abstract:

This article provides for a concise history of nonlinearity from the context of the changing assumptions in science throughout the turn of the twentieth century. Concerned with the development of an ethics of technology in higher education, it establishes a background for ongoing research on quantitative methods in the social sciences. The history expands knowledge of the philosophy of nonlinear science and complex systems.

1. Introduction

Why nonlinear science? Given the classical assumptions in nearly every academic discipline from social to hard scientific thought, linearity dominates our everyday lives. However, classical thinking applies linear methods to what is without question a nonlinear world. To understand nonlinearity and the justification of nonlinear methods, this paper details a brief history of ideas from the emergence of realities that questioned classical assumptions. The history underscores the importance of advances in science from the twentieth century work in relativity and quantum mechanics, the development of nonlinear methods in mathematics and statistics, and then the advancement of dynamical systems theory in quantitative research methods for the social sciences. The work provides a background for ongoing research in nonlinear statistics and the development of an applied ethics for postsecondary education. In conclusion, acknowledging the limits of nonlinear science, an argument is made for the importance of advancing nonlinear analysis in the social sciences by challenging but not entirely undermining the logic of conventional linearity – then noting the implications for, and bridging a dialogue with qualitative research methods.

1.1. *History of the Science*

Linearity is a convention of classical science. Newton's laws of physics based themselves on the concept of a constant and static universe. Time and space remained linear concepts; a mere backdrop upon which events occur, they were separate and independent measures with no beginning or end. In the late nineteenth century, the deterministic and absolute system of knowledge that was grounded in Newtonian mechanics and Euclidean geometry to describe the physical world began to unravel. Hendrick Lorentz believed himself to be well on the way to answering the final questions of physics before Einstein's relativity complicated matters that arose from questions that developed over atomic structure and behavior. First proposed by Maxwell in electromagnetism and thermodynamics and Plank's work in electrodynamics, the questions and problems with classical science suggested by these early scientists prove to be the foundations for a history of nonlinear science, dynamics, and complexity.

Alongside the classical mechanical metaphor for mind and nature, scientists that held structures universal and absolute began to expose the dynamic properties of the atom as assumptions in electrodynamics, established by Hans Oersted and Michel Faraday, were deconstructed. Following Plank's turn of the century work on the subject, by 1915, Einstein formulated the General Theory of Relativity. Relativity itself revealed that space and time are interwoven and relative to the observer. Moreover, adding a fourth dimension to the spatial dimensions of classical science, space-time is not flat and constant, but rather a dynamic non-Euclidean geometry. As Bohr, Heisenberg, Schrödinger, Dirac and others in quantum physics continued to question classical assumptions, physicists faced questions akin to the Greek philosophers that pondered atomic structure and scratched their chins over the nature of knowledge. With the obstacles to measurement encountered by Heisenberg, the complex and dynamic patterns of the natural world then unraveled. [1][2]

John von Neumann directly identified the discoveries in quantum physics as a problem of linearity. Neumann put forth methods that attempted to provide early solutions to the problems of measurement and worked on the implications of quantum theory for classical linear logic throughout the 1930s. Paul Dirac first accounted for the spin of the particle consistent with general relativity, illustrating the interdependence between quantum theory and relativity. Erwin Schrödinger provided solutions for measurement with remarkable accuracy by measuring the change in the wave function of a particle with respects to time. The work eventually indicated the problem of entanglement between elementary particles in the fabric of time and space, thus revealing more and more the dynamic and complex topography that remains unsolved today. From Schrödinger, the many contradictions and disagreements with relativity arose.

Einstein labored in search of unity through field theory. Formulated with Hermann Minkowsky, field theory involved measurements through world lines, based on the assumption that the laws of physics are Lorentz invariant [3]; an assumption, from debate over the contradiction with the quantum theories at the time, eventually proven to be incorrect. The work of John Bell and David Bohm in quantum physics brought into question field theory, which led to the recognition that relativity is incomplete. While Einstein continued his work, Richard Feynman did much to account for the probabilistic nature of quantum theory by calculating the interactions between particles and antiparticles in entanglement through a method commonly known as sum over the histories.

No fundamental answers were discovered until new directions began when Roger Penrose and Stephen Hawking awakened realities in relativity, black holes, and singularities. The collaboration overthrew Newton's assumption of a universe with no beginning as their work implicated that it began at a specific point in space-time. Into the 1970s, debates concerned themselves with measurement of the wave function of a particle and relativity, which continued at the same time that dynamics catalyst from nonlinear math, the work of Edward Norton Lorenz, and the complex patterns of the Lorenz Attractor.

Physics need provide explanations where the linear calculation of world lines in Minkowski space-time through Einstein's field theory cannot be reconciled with matrix mechanics [4]. Given the dynamic topography, debate remains over whether a Euclidean metric can be adjusted to solve the contradictions between relativity and quantum theory, or if a nonlinear quantum physics through string theory is necessary [5]. Nonlinear mathematics paralleled the recent advances in physics and today a new research methodology begins.

1.2. *Nonlinear Mathematics and Dynamics*

The assumptions of classical science have been foundational to the social sciences since the publication of Newton's *Principia*. From political science and economics in the eighteenth century to the early use of quantitative methods in psychology throughout the nineteenth century, academic knowledge grounded itself in physics – rather, the interpretation of physics – as the unifying science of all the sciences. Henri Poincaré, often noted as the founder of nonlinearity, anticipated the problems of linear methods to explain a nonlinear world as early as 1903. Thinkers such as C.S. Peirce in the nineteenth century questioned classical logic [6] and interdisciplinary scholars throughout the turn of the century, such as C. West Churchman, other systems thinkers, and even the educational psychologist Jean Piaget worked with cognizance of the implications of the changing assumptions in science for logic, learning, and social organization [7][8]. The realities of the advances in physics and the profound philosophical consequences for the "real world" were voiced by some and then ignored by others, or classical science simply remained unquestioned.

Lorenz brought the obscure and abstract, underlying ramifications of relativity and quantum science to the forefront of mathematics. Where "classical approximation is justified and quantum mechanical indeterminacy is correspondingly ignored," with Lorenz's attention to dynamical systems in meteorology, nonlinearity began to "strike close to home" [9]. From a flaw in computer models for forecasting, the uncertainties of linearity led the scientist to publish a first mathematical model of nonlinear phenomena, the Lorenz Attractor that became foundational to dynamical systems and a symbol for "chaos theory" throughout the 1960s. The culture of the 60s and nonlinear fads frequently led the unconventional scientists of an unconventional science to not be taken seriously. With Lorenz's work on paper confirmed by an experiment using a water wheel test to generate the fluid dynamical properties (not at all unlike an experiment suggested by Newton), nonlinearity gained legitimacy.

When the mathematician struggled with conventional statistics while working with economic data, Benoit Mandelbrot equally discovered theoretical geometries of nature, which cannot be achieved through classical Euclidean dimensions in time and space. While nonlinear dynamics struggled to develop much of an applied discipline, with difficulties even for physics but success in areas like fluid dynamics and light, the emergent mathematical discipline of theoretical dynamics flourished. However, nonlinear science and dynamics, in Karl Popper's terms, primarily described a world of purely theoretical mathematical forms. Despite the obstacles, Thomas Kuhn's history and philosophy of science supported the work of the early abstract mathematicians as biologists and ecologists took an active interest in nonlinearity. [9][10]

Today, scientists utilizing nonlinear approaches often maintain that linear methods prove simply indefensible. Nevertheless, in language defined by Penrose, nonlinear science still does not fully bridge the "Platonic" world of ideal mathematical forms in theory with empirical observation in the physical world [11]. While there is growing acceptance that linear social systems are largely nonexistent – with the limitations of linear statistics recognized and attempts to provide factorial and multivariate techniques throughout the 1950s to early 1960s [12] – the same conventional linear methods first developed in the nineteenth century remain deeply ingrained in social scientific methods. Formulated in 1984 by David Kenny and Carl Judd, nonlinear Structural Equation Modeling (SEM) became a catalyst for a breakthrough in statistics.

1.3. *Structural Equation Modeling (SEM)*

Kenny and Judd initiated a change in perceptions regarding linear assumptions in quantitative methodology. For example, in psychology, noted by Bertenthal [13], nonlinear analysis and dynamics gain recognition as an undeniable means "for understanding human behavior." Shumacker and Marcoulides, et al. [14] and Boker and Wegner, et al. [15] offer a glimpse of the models that evolved to quantify dynamic and complex social systems. While the SEM toolbox cannot claim infallibility, as the theorists do recognize, it reliably analyzes complicated relationships not possible with conventional techniques.

Although fallible, including that "the model is still a tedious, complex undertaking," [16] SEM provides the tools to analyze relationships, and their nonlinear interactions. Inasmuch as nonlinear methods remain a relatively emergent area, pragmatic approaches to linearity still need be developed in the same way that quantitative methods do not replace the need for qualitative studies. Moreover, the same as with engaging in the history and philosophy of the science, opening a dialogue on research methodology with qualitative researchers and methods proves pertinent and relevant. In this context, research concerns itself with an exploration of these themes, including dynamics [12], specifically in order to develop ideation for a case based ethics of technology.

2. Toward an Ethics of Technology

Although methodologies only recently began to be advanced, the fact that technological change dramatically alters the landscape of postsecondary education is commonly underestimated without foresight and the analytical tools to effectively problem solve the complex, rapid social changes underway. The debates at the horizons of the Information Age with globalization concern broad social and political implications, the potential misuse of technology, and how it will affect academic knowledge. In general, scholars have called for an ethics within the philosophy of technology [16][17] while others address specific issues for areas such as engineering education and the computer sciences.

The promise and challenge for higher education include the way in which technology will change the nature of knowledge, the process of teaching and learning, and its social organization [18]. Additional concerns address the unclear role of technology [19] linkages to changes in governance and public policy [20][21], and issues related to globalization, immigration, rising social and economic inequality, knowledge economy, and culture [22]. Industrial Age thinking and philosophy, in an Information Age that requires an ethics for twenty-first century technologies, remains an obstacle to be problem-solved.

Nonlinear methods provide directions to address the obstacles with the logic of linear assumptions. However, neither can they be undermined. Computational theory, modern mathematics and the hard sciences do not replace the need for induction, qualitative judgment, and practical reason. Continuing work on these issues aims to develop mixed-methods where qualitative research and legal logic contribute to the development of the framework for an ethics of technology.

3. Conclusion

The most justifiable rationale to answer the question of why nonlinear methods need be advanced is the reality that if linear methods have proven problematic in the natural and hard sciences, then linear methods evidently cannot claim infallibility within the social sciences. The advances in the physical sciences at the turn of the twentieth century revealed an infinitely more dynamic and complex world than previously known to classical scientists. Mathematicians advanced dynamical models, but applied disciplines face obstacles, and we might expect that the challenges parallel problems with measurement in physics and the physical sciences. The limitations of nonlinear methods remain alongside the confines of linearity. From a shift in perceptions, considered through the philosophy of science in the development of an ethics of technology, continued research approaches needs in order to advance applied nonlinear methods with changing assumptions in a rapidly changing world.

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