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Short Note

The road ahead for Rosennean Complexity

Patricia A. Lane

Department of Biology, Dalhousie University, 1459 Oxford Street, Halifax, Nova Scotia B3H 4R2, Canada

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1. Introduction

To end the Special Issue (SI), it is useful to recall that its original purpose was to "call attention to this 'fork in the road' (Frost, 1916) and to suggest that the less travelled road of Rosennean Complexity (RC) deserves more exploration, especially by ecologists. My objectives in this paper are twofold: first, to point out that Rosen's legacy is revolutionary, much larger than complexity theory *per se,* and indicative of his character and scientific integrity. This SI is being published on the 20th anniversary of Rosen's death, which evokes an added historical perspective on his legacy and the remarkable man behind that legacy (See Section 2). He was a good friend and colleague for more than 20 years and I include some personal observations in this section. Second, I summarize some of the key suggestions, examples, criticisms, and applications of Rosennean Complexity (RC) discussed in the Special Issue that together constitute some useful advice for the Road Ahead for ecologists (See Section 3). Contributing authors were invited to provide a range of disciplinary viewpoints of the applicability of RC to ecology.[1] The breadth of approaches of the 23 contributors reinforces Rosen's applicability to many areas of interest to ecologists. The authors suggest how ecologists might build bridges between Rosen's work and these other areas both explicitly and by example. While it is impossible to get 23 people to agree on anything, agreement was not the goal. No two of the papers are similar. Therefore, the SI does not read like a textbook by a single author who systematically expounds a thesis from first principles, but rather as a collection of diverse and even conflicting ideas, which is consistent with the original vision. Every paper, however, gives encouragement to ecologists to venture down the 'less travelled road'.

The journey to the destination of ecological complexity will not end with this SI; in fact, there is much road ahead. If anything, the SI has raised even more questions about how ecologists could best venture down the 'less travelled road' if they chose to pursue RC. Some of the questions are difficult and do not have easy answers, but the 'asking' cannot be avoided. Asking the right questions in science is half the battle – perhaps the more important half, and difficult questions without apparent answers can motivate creativity and progress. Rosen was a master at asking the right question even when he was criticized for asking questions that no one cared about (Rosen, 2006). To be sure, he also did not shy away from asking extremely difficult questions, starting with "what is life?" He termed this the central question of biology (Rosen, 2000) and of his career, so much so that he called it his "Imperative" (Rosen, 2006).[2] He realized that to ask this question was, "to find oneself standing essentially alone" (Rosen, 1991).

'What is life?' is such a difficult question that most introductory biology textbooks avoid answering it entirely; for example, in Campbell Biology (Reece et al., 2014), the eleven authors described the 'living' using over 1500 verbose pages, but they did not attempt to define life. Instead, they provided only a list of non-unique features of living systems. Rosen did not believe such lists are very helpful. He said: "despite the profound differences between those materials systems that are alive and those that are not, these differences have never been expressible in the form of a list – an explicit set of conditions that formally demarcate those materials systems that are organisms from those that are not. Without such a list, Schrödinger's question, and biology itself, becomes unanswerable at best, meaningless at worse so we must probe more deeply into what the quest for such a list actually connotes. No such list means there is no algorithm, no decision procedure, where we can find organisms in a presumably larger universe of inorganic systems. It has, of course, never been demonstrated that there is no such list. But no one

E-mail address: Patricia.Lane@Dal.Ca.

[1] When Special Issue (SI) papers are referenced in this paper, the citation appears as follows: (Author, 2018, this issue).

[2] Rosen always capitalized 'Imperative'.

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has ever found one. I take seriously the possibility that there is no list, no algorithm, no decision procedure that finds us the organisms in a presumptively larger universe of inorganic systems. This possibility is already a kind of non-computability assertion, one that asserts that the world of lists and algorithms is too small to deal with the problem, too non-generic" (Rosen, 2000).

Curiously, it seems we discourage biology students from asking this central question at their earliest stage of professional development. When Rosen would lecture to my classes, the students became entranced as he outlined the shortcomings of measurement, the richness of complexity theory, the virtue of qualitative relationships, the vice of preoccupation with 'matter', and the meaning of life. His ideas were completely foreign to their whole nascent academic experience of quantification and reductionism. He summed this up in Rosen (2000) as follows: "I am always asked by experimentalists why I do not propose explicit experiments for them to perform, and subject my approaches to verification at their hands. I do not do so because, in my view, the basic questions of biology are not empirical questions at all, but, rather, conceptual ones…" Yet, biology professors teach that experiment, measurement, and statistical testing are the most essential ways to 'do science'.

In summary, it is difficult to pick up a single thread of Rosen's work like RC and to discuss it as if it was an isolated concept because it is fully embedded into a much larger conceptual framework that is beyond the scope of the Special Issue, but of all the threads, complexity is a good one to start with, however, it is not the whole answer to what is life. Rosen said that "for a material system to be alive, there is a necessary condition that it be complex, but this is not a sufficient condition" (Rosen, 2000). The best way to understand his total framework is to study his publications and some suggestions are given in Section 4. I have not found any shortcut to this understanding.

2. Rosen's revolutionary legacy

2.1. Scientific Revolutions

Science has had a long history with revolution when the First Scientific Revolution began with Copernicus' 1543 publication on "The Revolutions of the Heavenly Spheres", which eventually led to the Newtonian Paradigm. The latter has permeated most of human endeavors, even beyond science itself, from the Enlightenment to Modernity and Postmodernity. The Newtonian Paradigm, while successfully applied to physical systems, has failed in biology (Kitto and Kortschak, 2013). Some, like Rosen, have proposed a Second Scientific Revolution that will emanate from biology in the 21st Century. It can be termed the Biological Revolution or the Biological Complexity Revolution (BCR). Rosen advanced the notion that biology would become the central trunk of the generic tree of science, with other sciences like chemistry and physics serving as non-generic branches of the tree. He pointed out: "At present, the fact is that there is still no inferential chain which leads from anything important in physics to anything important in biology" (Rosen, 2012). He spent a great deal of time imagining the future, especially his vision for the future of science.

Scientific revolutions begin after tiny cracks appear in the prevailing paradigm, which eventually turn into large fissures (Kuhn, 1970). Rosen consciously accelerated this process and he did this with meticulous integrity. At every opportunity, he took his intellectual sledgehammer to the Newtonian Paradigm that portrayed biological systems as machines and he cracked it in as many places as possible. He was a prime mover in this current scientific paradigm shift and his work will undoubtedly continue to illuminate the way throughout this century. The BCR has the maturing of complexity theory at its center especially for biological systems. This is our present. I cannot identify the exact day the first hairline fracture blemished the Newtonian Paradigm in the past, nor can I predict when its replacement will fully manifest in the future, but I do know that Rosen's vision continues to take hold, increase in momentum, and gain adherents. Paradigm shift is never easy. It is extremely difficult for a scientist who has so much invested in a prevailing paradigm to shift their conceptual foundation, and even identity, to embrace a new one. Kuhn (1970) concluded that most paradigm shifts in science come about as the believers in the old paradigm die out. It appears that scientists, like everyone else, wrap themselves in their paradigms like protective shrouds, smug and threadbare to the end. Nothing is more comforting, until that comfort is no longer required. Thus, paradigm shifts tend to be generational. They can encompass all of science like Rosen's proposal or have a smaller scope.

No one knows what science will be like in 2100, but the cracks in the old scientific paradigm seem too large and irreversible to end the 21st century with biology under physics. The latter could assume a reduced role for simple systems as its proponents expire or cease trying to treat open biological systems as if they are closed. Science, however, has taken many enigmatic turns in the past, and it is a far more subjective and social undertaking than most of us would like to admit. Progress is rarely an upward linear trajectory, and in the limit, there is no absolute truth. Science is always flawed and imperfect, always seeking the next truth, however transitory. The exhilaration of the search, however, can be addicting.

Scientific revolutions in the making can also have adverse consequences for the scientists who promote them. The First Scientific Revolution was certainly dangerous for its participants as the Roman Catholic Church sought to quell it. For example, Galileo stood trial for heresy in 1633 and ordered[3] "to abandon his doctrine, not to teach it to others, not to defend it, and not to treat of it". He was not officially exonerated by the Church until 1992 when Pope John Paul II concluded, "Thanks to his intuition as a brilliant physicist and by relying on different arguments, Galileo, who practically invented the experimental method, understood why only the sun could function as the center of the world, as it was then known, that is to say, as a planetary system. The error of the theologians of the time, when they maintained the centrality of the Earth, was to think that our understanding of the physical world's structure was, in some way, imposed by the literal sense of Sacred Scripture…" (Pope John Paul II, Ibid). Clearly, it takes more than a match to burn down a nascent paradigm or a belated apology to absolve one. Similar to Galileo, Rosen focused upon moving the center of science from physics to biology by demoting the former to be the keeper of the specific and simple, while anointing the latter as the true center of science and the keeper of the general and complex.

To initiate a revolution is neither a blasé endeavor nor a random happenstance; it takes purpose and planning to change the culture of communal wisdom permanently. Some of our best scientists throughout history have been ardent revolutionaries,[4] and Robert Rosen is no exception. Revolution is clearly not for milquetoasts, and most share an incredible passion to change science for the better. They usually exhibit a remarkable focus in pursuing their mission, and clearly, Rosen's mission was to ensure that living systems were no longer to be considered as machines. He wanted to explain what makes one bit of matter alive and another inanimate. While scientists no longer fear incarceration or burning at the stake as occurred in the First Scientific Revolution, current scientific adversity can take many forms: unfair criticism, ostracism, funding and publishing constraints, unethical peer review, administrative interference, research center closure, job loss, etc. Rosen certainly had to work in some very disagreeable academic conditions at least three times in his career often with little appreciation, and even when these adverse conditions defeated some of his colleagues (Nadim, 2012). Despite the hardships, Rosen was unwavering in his right to pursue his revolution.

[3] Pope John Paul II, L'Osservatore Romano N. 44 (1264)–November 4, 1992.

[4] Lynn Margulis and Jane Jacobs are two other revolutionary scientists mentioned previously (Lane 2018b, this issue).