

Big questions about small scales

Discrete or Continuous?

The Quest for Fundamental Length in Modern Physics

Amit Hagar
Cambridge U. Press, 2014. \$90.00
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Reviewed by Luis J. Garay

For Isaac Newton, space and time were independent, continuous entities. Albert Einstein unified the two into spacetime, again a continuous object. With the development of quantum field theory, however, physicists began to take seriously the idea that discreteness might be an essential component of our understanding of space and time. Amit Hagar's *Discrete or Continuous? The Quest for Fundamental Length in Modern Physics* takes the reader on an enjoyable journey—by turns historical, philosophical, and physical—in a quest to unravel many of the subtleties that underlie the concept of a minimum length in physics.

One central question explored in the book is whether the concept of spacetime can emerge solely from microscopic dynamics or whether, on the contrary, at least some primitive geometric notions are necessary. Also of paramount importance to the author—and also to me and, I dare say, many other physicists—are empirical data that support the existence of a minimum length in physical processes. That requirement has two aspects to it. On the one hand, the changes that a minimum length would introduce must agree with current experiments and observations within the accuracy of today's data. That is just a consistency check. On the other hand, any pet microscopic theory must make falsifiable predictions that entail deviations from continuum behavior. Without those two empirical points being satis-

fied, a theory of minimum length does not leave the realm of metaphysics. And although empirical confirmations or falsifications are common to most scientific quests, they (and in particular, the need to make predictions) were historically often left aside when dealing with the microscopic structure of spacetime. But that is not so anymore, and Hagar stresses the community's new attitude in his final chapter.

Aimed at theoretical physicists and philosophers of science, *Discrete or Continuous?* contains eight chapters and a coda, in the form of questions and answers, that superbly summarizes the main issues discussed in the body of the text. After the introduction, chapters 2 and 3 deal with the mathematical and philosophical aspects of spacetime discreteness, or minimum length. The author concludes that neither mathematics nor philosophy precludes spacetime having a discrete nature. He also points out that a minimum length may appear in two different forms. The first is ontological—a minimum size for the building blocks of a truly discrete spacetime. The second has an epistemological character, a limitation in our capability to acquire knowledge, without any implication concerning the nature of spacetime.

Chapters 4 and 5 present in great detail a plethora of early proposals for a minimum length. Those early ideas were generally in the context of quantum gravitational or semiclassical analyses—in which case the minimum length was the Planck length—or were suggested as a means to eliminate divergences in quantum field theories at small scales. Chapter 6 analyzes a possible dynamical origin for geometrical concepts, mainly based on correspondence between Albert Einstein and W. F. G. Swann in the 1940s. Together, those three chapters provide a wonderful and insightful historical presentation on many of the ideas entertained by the brightest minds in 20th-century theoretical physics. It is a section that no practitioner should do without.

Current attempts to quantize gravity are described in chapter 7. It offers a brief account of the most popular theories and approaches, although, in my opinion, a somewhat superficial one for the task at hand, at least in comparison with previous chapters. Included therein are discussions of string theory, loop quantum

gravity, emergent gravity, and other interesting proposals relevant to the discrete-versus-continuous debate. Throughout, Hagar emphasizes the primacy of geometry over dynamics.

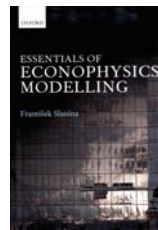
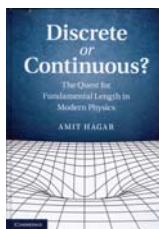
Chapter 8 is an account of the current situation of quantum gravitational theories in the empirical arena, and in particular it concerns four principles that have guided theoretical physics for years: locality, causality, unitarity, and local Lorentz invariance. The message of the chapter, and indeed of the whole book, is summarized in the last sentence: "If, like me, one requires more than mere consistency proofs, since it seems that only new predictions will be able to decide the issue and to convince supporters of the continuum to abandon their view, then, I am afraid, we still have a long way to go."

Essentials of Econophysics Modelling

František Šlanina
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(411 pp.). ISBN 978-0-19-929968-3

In *Essentials of Econophysics Modelling*, theoretical physicist František Šlanina presents a clear, concise, and in-depth treatise of this interdisciplinary field, which draws on methods and models originating in physics and applies them to the understanding of economic phenomena. The author argues that econophysics is "a quest for common principles, common tools, and common consequences found both in physics and economics."

The book, which attempts to bridge the two mathematical but distinct disciplines, should be accessible to readers from either community provided they have a fair knowledge of undergraduate-level mathematics. It successfully follows a tutorial style and includes exercises and problems at varying levels—from simple ones to short research projects. Concepts and techniques that require significant but elementary explanation are presented in boxes that the advanced reader can skip and the beginner can consult.



Luis Garay is a professor of physics at the Complutense University of Madrid in Spain. He conducts research at the interface of gravity and quantum theory, including black holes and studies of a minimum length in gravitational physics.