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# *Time Reborn: From the Crisis in Physics to the Future of the Universe* FREE

Steven Carlip



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# The Maxwell demon is in the details

## Life's Ratchet
### How Molecular Machines Extract Order from Chaos

Peter M. Hoffmann
Basic Books, 2012. $27.99 (278 pp.).
ISBN 978-0-465-02253-3

*Reviewed by R. Dean Astumian*

In the microscopic world, molecular machines carry out tasks, including transport, pumping, and assembly, that are associated with machines in the macroscopic world. In the past those remarkable molecules have been found only in living systems, but recent advances in chemistry have made it possible to take the first, halting steps toward synthetic molecular machines.

In *Life's Ratchet: How Molecular Machines Extract Order from Chaos*, Peter Hoffmann offers a fascinating glimpse into recent research on molecular-machines, research that lies at the intersection of biology, chemistry, and physics. He explains the unexpected ways that machine-like functions are accomplished by molecules and discusses conceptual similarities between how molecular machines operate and the mechanisms by which biological organisms evolve.

The book starts out with the early Greek natural philosophers and the beginnings of the tension between deterministic and statistical explanations of matter. It covers the development of probability theory as a mathematical discipline. That theory is at the heart of recent descriptions of molecular machines according to which thermally driven molecular motion combines aspects of deterministic mechanics with ineluctable probabilistic fluctuations due to the thermal environment.

An overarching motif of the book is a comparison between evolution and the Brownian motion of molecular machines. Evolution works by locking in only those random changes to a species that confer a competitive advantage; Brownian-motor mechanisms use chemical energy to lock in the fluctuations—driven by random thermal noise—that move the molecular machine forward. A key idea is the interplay between chance, due to ineluctable thermal noise, and necessity, as described by the deterministic laws of classical physics.

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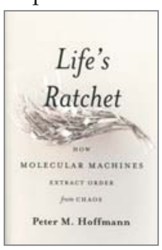
Unfortunately, in chapter 3 Hoffmann makes a serious, but understandable, error in discussing the second law of thermodynamics. He offers a straw man by restating the second law as follows: "There can be no process whose only result is to convert high-entropy (randomly distributed) energy into low-entropy (simply distributed, or concentrated) energy" (page 78).

The primary literature is replete with similar formulations of the second law, but the statement above is not correct. Many processes result only in the conversion of random energy into ordered energy. Take as a simple example a small particle suspended in water. If the particle (say a micron in diameter) is denser than the surrounding water, gravity will on average pull it down toward the bottom of the container. In any short time interval, however, there is a reasonable chance that, because of thermal noise, the particle will move up. During that time, the only thing happening is that random thermal energy from the water is converted into "concentrated" potential energy in the particle. As the author points out later in chapter 5, precise statements of the second law focus not on single events but on the impossibility of cyclic or repeatable processes that convert random energy into concentrated energy.




The instant we recognize that processes converting high-entropy energy into low-entropy energy in fact happen all the time in single molecules, just less frequently than the microscopically reverse processes, we are led to the possibility that a molecular machine could work by capturing the relatively rare free-energy-increasing fluctuations. And that is where the thought experiments of Maxwell's demon and Smoluchowski's trapdoor come in. An individual particle fluctuates up and down, though on average it moves down. If the fluctuations could be observed by an external being—a demon—who traps the upward fluctuations, the particle could be caused to move continually upward against gravity and thereby store energy. One-way devices such as a trapdoor, or the ratchet and pawl famously discussed by Richard Feynman, could accomplish the same goal, but without the need for intervention by an intelligent being.

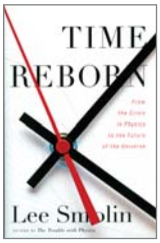
Of course, no one-way devices can operate at the molecular scale without input energy, nor are there real demons to control molecular events. However, the work of a Maxwell's demon can be accomplished by allosteric interactions. That well-known macromolecular phenomenon is a way by which the binding between a ligand and a molecular machine is controlled by the state of the machine. Allosteric interaction with a single ligand provides a mechanism for a switch and hence for regulation of molecular processes, but it does not provide a mechanism for powering a machine—unless the ligand can be catalytically converted to a different form as, for example, in adenosine triphosphate hydrolysis. When allosteric interactions discriminate between reactant and product, energy released by the nonequilibrium chemical reaction can be used to power the machine. An important take-home message is that in coupling a chemical reaction to drive motion, molecular recognition is more important than the mechanics of the machine's conformational changes.

Overall, *Life's Ratchet* does an excellent job of conveying the tension between mechanical descriptions of molecular machines, in which input energy causes "forward" motion, and the chemical perspective, in which input energy prevents "backward" motion and in which forward motion is caused by thermal noise. Although written primarily for a lay audience, with not a single equation in the text, I highly recommend this book to scientists in the fields of biophysics and nanoscience as a readable introduction to a broad variety of topics in those areas.

## Time Reborn
### From the Crisis in Physics to the Future of the Universe

Lee Smolin
Houghton Mifflin Harcourt, 2013. $28.00 (352 pp.). ISBN 978-0-547-51172-6

Lee Smolin is a very good popularizer of science, a provocative thinker, and a




skilled polemicist. His latest popularization, *Time Reborn: From the Crisis in Physics to the Future of the Universe*, displays an uneasy mix of those abilities. It is a clear, well-written description of the physics of time and timelessness, an introduction to some intriguing new ideas, and a carefully crafted argument for a highly controversial viewpoint. Unfortunately, that last element is presented in a way that will confuse lay readers who lack the background to distinguish among standard physics, open questions, and the highly speculative notions that are largely Smolin's own.

Smolin's first thesis is that physics has fallen into a trap in which time and novelty have been systematically devalued. He describes a series of steps in this "expulsion of time" from physics—from the description of dynamical processes as timeless curves in configuration space to the discovery of the relativity of simultaneity to the notorious frozen formalism of quantum cosmology. I was impressed. I know of no other popular physics book that succeeds in explaining such diverse concepts as configuration space, the Wheeler–DeWitt equation, effective field theory, and the block universe. I was also intrigued by the connections Smolin draws among the disparate roles of time in physics.

The author's second thesis is that this expulsion of time arises from a basic fallacy: the mistaken attempt to extend to the universe as a whole an approach that works for subsystems—the "Newtonian paradigm." Here, I find the argument far less persuasive. Certainly the universe is a unique system, and we cannot control initial conditions, so tests of physical laws must be different. But the far more sweeping claim upon which Smolin's thesis rests seems to be largely a statement of philosophical prejudice.

Smolin is ambitious, indeed. He wants a theory in which the laws of physics are themselves determined, and argues that this is only possible if the laws evolve in time, presumably along with the meta laws that govern their evolution. He wants to replace quantum mechanics with a highly nonlocal hidden-variable theory, and to replace the standard probabilistic interpretation with one in which probabilities are determined by actual outcomes of past measurements. His notion of time requires that we abandon the relativity of simultaneity, and for that, he likes shape dynamics, a recent reformulation of general relativity in which time reparameterization invariance is traded for local scale invariance.

I like shape dynamics, too. I'm working on a paper on the subject right now. But it is far too early to consider it anything more than an interesting new avenue to explore. Smolin's treatment of this topic is, unfortunately, typical: His book does a poor job of distinguishing established results, speculative ideas, and personal opinions. Expert readers will have no trouble seeing the broader perspective. But few of the intended readers of *Time Reborn* will know that its claim that quantum mechanics requires an isolated system with an outside observer is not the only interpretation. Fewer still will know that the book's depiction of timelessness in the Wheeler–DeWitt equation is just one interpretation among many, or that Poincaré recurrence occurs only for quantum systems with discrete energy spectra, or that "quantum graphity" has yet to reproduce any known physics.

My biggest reservation about this book, though, is its lack of humility.

Smolin, a critic of the more extravagant pronouncements of string theorists, now declares that his view of time is "the key to the meaning of quantum theory and its eventual unification with space, time, gravity, and cosmology." He claims to show—not argue or contend, but show—that "no extension of the Newtonian paradigm can yield an acceptable theory of the universe as a whole.'' He asserts that "the only way to avoid the fallacy and the paradox of an improbable universe is to base our explanation … on time-asymmetric physics." In the book's last chapter, he finally steps back and confesses that he is merely "try[ing] to construct reasoned arguments." But that's too little, too late.

Again, experts will discount the hyperbole. But lay readers are liable to conclude that Smolin is clearly right and that other physicists are just being pigheaded in not following his lead, or, worse, that correctness in physics is essentially a matter of opinion.

Would I recommend the book? To a colleague, yes: While portions are irritating, it is valuable to have to think about the issues it raises, even if only to clarify one's disagreements. To a lay reader, only hesitantly: perhaps as part of a reading list that could also include Sean Carroll's *From Eternity to Here: The Quest for the Ultimate Theory of Time* (Dutton, 2010; reviewed in PHYSICS TODAY, April 2010, page 54); Julian Barbour's more difficult *The End of Time: The Next Revolution in Physics* (Oxford University Press, 1999); and, for an ambitious reader, Robert Geroch's wonderful *General Relativity from A to B* (The University of Chicago Press, 1978; reviewed in PHYSICS TODAY, May 1979, page 71).

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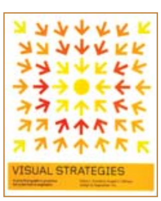
## Visual Strategies
### A Practical Guide to Graphics for Scientists and Engineers

Felice C. Frankel and
Angela H. DePace
Yale U. Press, 2012. $35.00 (160 pp.).
ISBN 978-0-300-17644-5




The production of figures, which have always been essential in physics publications, has undergone a revolution. A figure used to be an *x-y* plot, drawn by a draftsman, graphically showing the behavior of data. Now, figures illustrate so much more; *x-y* plots are supplemented by a plethora of figure types whose variety is driven by the increasing sophistication of computer graphics software and fed by ever-expanding data sets. For example, what used to be simple *x-y* plots are now in color or in three dimensions, and descriptions of experiments are now frequently supplemented by sophisticated "how-to" schematics. The design and production of computer graphics is much more complex and challenging than in days past.

Science photographer Felice Frankel and systems biologist Angela DePace offer a wonderful solution to the problem. *Visual Strategies: A Practical Guide to Graphics for Scientists and Engineers* is a how-to book on effectively utilizing modern computer graphics. Both authors have extensive experience in presenting complex data.

The book is focused on the use of drawings to illustrate structure and process, primarily in the life sciences, but the authors also give some attention to the physical sciences. Data sets are now so complex, the authors state, that they are better presented with structure-and-process drawings than with traditional *x-y* plots. And indeed, the most useful types of figures today are the ones that have benefited the most from advances in computer graphics. It is in introducing those that the book really shines.

*Visual Strategies* is intended to be a useful tool for scientists in their day-to-day graphics preparation. It is divided into sections with indented tabs for easy access. Rather than present a discussion of a theme or topic, the book instead is a compendium of specific examples chosen from the literature. In each case, the authors dissect a published graphic and make suggestions as to how it could be improved.

That approach is effective in getting specific about how graphics can be best presented, but it is less convenient for finding specific ideas for graphics than a more expository presentation would be. For that reason, the book is better suited to scientists already well-versed in data presentation who want to improve their skills—a target audience that probably includes the majority of scientists.

The presentation of basic concepts in the first three chapters reflects the authors' views on the goals and purposes of graphics. Chapter one covers form and structure. It is a primer on how to present such data as the shapes of complex biomolecules or atoms on a surface probed with a scanning tunneling microscope. The authors point out that shape information is like complex data structures, which, unlike simple *x-y* plots, involve more than two number sets.

Chapter two describes figures that represent the time evolution of a process; they can include a sequence of images from a movie or a depiction of how some process evolves, or a sequence of figures describing the how-to of an experiment. Because such figures are often essential and are becoming increasingly sophisticated, the authors' suggestions about them are of particular value.

Chapter three covers the comparing and contrasting of data sets, an essential step of organizing complex data. The key task addressed is how to take data subject to multiple interpretations and present them so that the author's conclusion comes through clearly. The fourth chapter is a collection of specific case studies that combine the material of the earlier chapters and offer additional concrete realizations of the strategies the authors have presented. The fifth chapter discusses computer graphics that allow viewers to interact with the data; those graphics are restricted to online papers.

Perhaps the best way to judge this how-to book is to ask whether it can actually help you. Indeed, one example was chosen from a paper by my research group, which presented data that were quite difficult to convey. The postdoc who did that work is quite artistic and made what I thought was a good figure. Still, *Visual Strategies* made excellent suggestions that would have greatly improved our figure.

I think others will find similar value in this excellent book.

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## Simple Brownian Diffusion
### An Introduction to the Standard Theoretical Models

Daniel T. Gillespie and
Effrosyni Seitaridou
Oxford U. Press, 2013. $84.99
(273 pp.). ISBN 978-0-19-966450-4

*Diffundere*, the Latin origin of the word "diffusion," means "to spread out." Diffusion is practically ubiquitous and takes place in solids, liquids, and gases.