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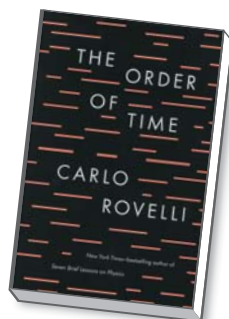
Is the future as real as the present?

Carlo Rovelli has written a lovely, thoughtful, and poetic book about the nature of time. A topic as old as thought itself, it is occasionally consigned to the category of “too philosophical for serious physicists.” But, as Rovelli so lucidly explains, a fundamental change in the understanding of time was both an ingredient and a result first of special relativity and then of general relativity, and further rethinking may be required to understand quantum gravity and fundamental open questions in cosmology. His book also highlights how central time, along with the closely related quantities of energy and entropy, is to essentially every aspect of our experience and understanding of the physical world.

Rovelli, a professor at the Center for Theoretical Physics in Marseille, France, has thought long, hard, and unusually deeply about time—not just in the context of his central field, quantum gravity, but also in statistical mechanics, quan-

The Order of Time

Carlo Rovelli
Riverhead Books,
2018. \$20.00



tum foundations, and even evolutionary theory. That lifetime of thinking comes through in *The Order of Time*. Although compact, approachable, and clear, the book is dense with ideas and insights. It's appropriate for a broad readership, from those who want just a taste of what could (or should) reconfigure their intuitions about time to researchers who will enjoy Rovelli's framing of important issues, the links to questions outside of physics, and his provocative theses.

The Order of Time is organized into four sections. The first recounts the developments in physics that refute our intuitive understanding of time as a smooth, unidirectional, rigid, and universal flow

from past to future. Time is not universal (special relativity), or rigid (general relativity), or continuous (quantum theory), or fundamentally unidirectional (classical versus statistical mechanics). Physicists generally know those arguments well, but Rovelli gives some beautifully clear metaphors, such as genealogy for the partial time ordering of events, and a useful and careful framing of the major scientific issues surrounding our understanding of time.

The book's second part discusses how we should conceptualize time in modern physics, especially in anticipation of further advances in fields such as quantum gravity. Rovelli contends that “the world is made of events, not things.” That should be taken with a grain of salt—“things” are quite useful to think about—but he is clearly right that human bias tends toward “thingification.” For fundamental physics, events such as particle interactions, quantum measurements, or signal receipts are often of much greater interest.

The block-universe view of time holds that all events are laid out through spacetime with “equal reality,” with future events just as fixed and immutable as those in the past. Rovelli's treatment of that conception in the third section is interesting and subtle. He enthusiastically accepts the lack of a preferred direction for cosmic time and acknowledges that the basic equations connecting times are all deterministic and time reversible. But he rejects the implications that the future and the present are equally real and that “nothing happens” because everything has in a sense already happened. Our understandings of past, present, future, and “real” are all local approximations, he argues, and should not be extrapolated to reality as a whole.

It was a bit unclear to me whether Rovelli's view on the block universe would hold equally true in a universe that was purely classical or governed by a deterministically evolving “wave-function of the universe,” or if instead it relies on his “timeless” formulation of quantum gravity and cosmology. But his discussion shows how enormously subtle—and unresolved in physics—the relationship is between different notions of time.

The final portion confronts, and attempts to bridge, the description of time

in fundamental physics with our experience of time as situated, thinking, acting observers embedded in a particular physical universe. The section covers several aspects, from the rather technical to the deeply humanistic. Primarily, the discussions are both enlightening and, I'd hold, the right way to think about those issues, although a few topics, such as thermal time, occupy a frustrating ground between too technical and not technical enough.

I was intrigued but unconvinced by Rovelli's scheme to avoid the so-called "past hypothesis," which defines the early universe as one occupying an extraordinarily low-entropy state. Entropy growth underlies time, which, as Rovelli eloquently expresses, underlies everything we experience. Moreover, the entropy gap implied by the past hypothesis is a cosmic store of information and order that provided the raw material out of which all chemical, gravitational, biological, and other forms of order in our universe ultimately derive. But, Rovelli argues, it isn't necessary for the universe to have had a low-entropy state; it just needed to be low entropy *from a particular point of view*.

I don't really see how that can work. Although one could identify subsystems with respect to which the universe appears low entropy, I can't see how it would continue to be low entropy despite the progression of time either forward or backward. I'm not sure that Rovelli really sees how it works, either—he as much as admits that it is a desperate measure to avoid the past hypothesis. But there may be a core of an idea here that could be made to work, perhaps with additional ingredients, such as cosmological inflation.

Those scientific issues, however, should not detract from what is so delightful about this book. It is infused with wisdom, warmth, and intelligence. A reader looking for a more detailed understanding of issues of time in physics would do well with a weightier work like Sean Carroll's excellent *From Eternity to Here: The Quest for the Ultimate Theory of Time* (2010). But although low in mass, Rovelli's book is heavy with insight and will give all readers a taste of the mysteries of time. It will lead nearly any reader to consider many things in a new light.

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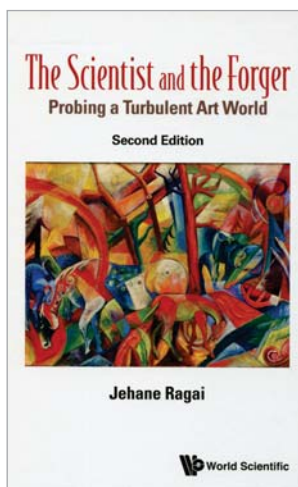
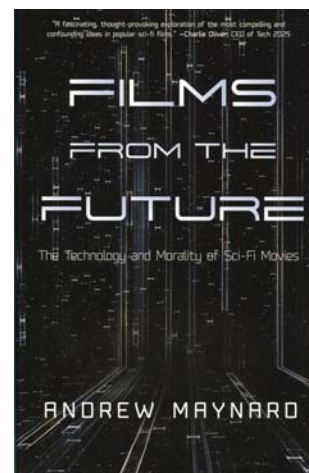
NEW BOOKS & MEDIA

Films from the Future

The Technology and Morality of Sci-Fi Movies

Andrew Maynard
Mango, 2018. \$27.99

From resurrection biology and human cloning to artificial intelligence and genetic manipulation, imagined technologies form the backbone of science fiction. In *Films from the Future*, physicist Andrew Maynard discusses the promises and potential pitfalls of technologies from 12 of his favorite movies—some blockbusters, like *Jurassic Park* (1993), and some more obscure, like *The Man in the White Suit* (1951). Part cautionary tale, part message of hope, Maynard's narrative is both entertaining and thought-provoking. —CC



The Scientist and the Forger

Probing a Turbulent Art World

Jehane Ragai
World Scientific, 2018 (2nd ed.). \$68.00

Jehane Ragai, an emeritus professor of chemistry at the American University in Cairo, Egypt, takes the reader on a tour through the fascinating world of art forgery in the second edition of *The Scientist and the Forger*. Ragai covers the science of forgery detection but also emphasizes other signs that a piece of art might be fraudulent, such as the lack of a paper trail establishing ownership. The chapters string together anecdotes about different forgers and forgeries in a way that can sometimes feel disjointed, but readers interested in art will find much to intrigue them. The book's beautiful color images add another level of appeal. —MB

King of the Dinosaur Hunters

The Life of John Bell Hatcher and the Discoveries That Shaped Paleontology

Lowell Dings
Pegasus Books, 2018. \$35.00

John Bell Hatcher was a prolific 19th-century collector of prehistoric fossils and bones, including the first *Triceratops* skeleton. In *King of the Dinosaur Hunters*, paleontologist Lowell Dings concentrates on Hatcher's professional life. He delves into Hatcher's extensive travels, fossil collecting, and all the minutiae associated with those activities, including letters to employers, expenses, and conflicts with his fellow paleontologists. The book provides little detail about Hatcher's personal life and is aimed primarily at paleontology devotees interested in knowing more about the challenges of early fossil hunting. —CC

