The March of Time. Evolving Conceptions of Time in the Light of Scientific Discoveries, by Friedel Weinert: Dordrecht, Springer, 2013, 284 pp.
ISBN: 978-3-642-35346-8

Friedel Weinert's *The March of Time* is an extremely dense and rich text, which carefully discusses scientific investigations and results that are relevant for our understanding of the temporal aspects of reality. The author often goes well beyond an elegant exposition of history of ideas, by entering into philosophical debates and touching upon important theoretical issues in contemporary philosophy of time.

The material is divided into three large sections. The first focuses on cosmology, it starts with a historical overview and finishes with considerations about the importance of measurement for the conception of time in science. The second one is about the opposition between the view that the fundamental level of reality is irreducibly dynamic, and the "reductionist" take on the flux of time of the so-called "Block Universe" view. Here the theoretical discussion focuses on the two issues of relationism vs. substantivist about time, and of the metaphysical consequences of relativistic physics. The third section is about the problem of fundamental asymmetry of the laws of nature. The discussion pertains not only to the role of entropic asymmetries in the directionality of time, but also to quantum cosmology and the idea of an "emergent" temporal reality.

Although, in general, the parts that concern history of science precede the one centred on theoretical considerations, sometimes the discussion starts with the philosophical background, while other times it starts with the results of science. Every part is basically self-contained, and this creates some repetitions, which may be useful for readers who are not into the topic, and are never too large for more expert readers. In general, the writing is both precise and elegant.

One of the main threads within the whole text is – as it may be expected – the issue of the reality of time. The author elaborates on a distinction between what he calls *physical time* and *psychological time* to discuss different stances towards the dynamism of the world as we experience it and its seemingly irreversible temporal order. Several points of interests are raised; for instance, from a cosmological point of view, the global topological properties of the universe that we inhabit do not affect our local experience of a temporal passage, and yet they have consequences for the problem of whether temporal relations have an intrinsic directionality.

There are two mains families of science-based arguments against an objective flow of time, as it is suggested by our naïve, pre-theoretical experience, and somehow reinforced by our measurement practices in science, which – as the author notices – are based on the assumption of the regularity and invariance of what is measured. The first come from Special Theory of Relativity (STR) and the "Block-universe view", which Minkowski's geometric formulation of it suggests. As is well-known, the spacetime of Special Relativity seems to vindicate a form of B-theory of time. McTaggart famously distinguished between a temporal A-series, which is grounded in the tensed determinations of events – their beginning either past, present or future – and hence irreducible dynamic, and a temporal B-series, whose basic elements are the invariant temporal relations between the events (earlier/later-than and simultaneity). In contemporary metaphysics, the distinction between the two series, which McTaggart exploited in an argument to the conclusion that time itself is unreal, underpins two main conceptions of time: the dynamic "A-theoretic" view and the static "B-theoretic" view of time. Although STR cannot be embedded in a framework in which the relations of earlier/later-than and simultaneity are absolute, its formulation in a frame-of-reference relative version of B-theory, which gives rise to a physical interpretation of a fourdimensional Mikowskian manifold, is straightforward. The grand picture of time that such a formulation suggests is the so-called "Block Universe view", in which the universe is not understood as a succession of three-dimensional snapshots unfolding one after the other, but rather as a tenseless structure in which physical events are located.

The block view is not a logical consequence of Special Relativity: it can be derived neither deductively from its principle, nor inductively from its empirical predictions. As Weinert puts it, we should rather talk about a "conceptual" entailment from the Minkowski *formulation* of STR to the block view. Besides, temporal reality, as depicted by Minkowski Space-time is not entirely "Kantian", namely not all temporal features are radically sensitive to the frame of reference we are considering. Causal connectibility, space-time interval, and the speed of light are all invariants of the theory, and they are all connected to measurable quantities. Hence, even if time "runs differently" for observers in different frames of references relative to each other, each observer can always calculate other observers' ticking rate of clock.

More interestingly, alternative formulations of STR have different conceptual entailments. In particular, the author focuses on the "axiomatic" formulations, pioneered by Alfred Robb (1914), Constantin Carathéodory (1924) and Hans Reichenbach (1924), and which attracted the attention of Einstein himself during the last years of his life. Those formulations take into account the thermodynamic aspects of light propagation and thereby "offer [...] the conceptual possibility of a dynamic space-time model, which is nevertheless rooted in the B-series" (p. 141). The underlying idea is that, by formulating STR within the framework of a light geometry, we are pushed to consider space-time not as a block that simply *is*, but rather as the unfolding outcome of fundamental facts about the propagation of light signals between successive instants in space-time. As noted by the Author, such a view bears several similarities with what is called the "Growing block" view in the philosophical literature. Although the irreducible relativity of simultaneity in STR doesn't allow us to recover a global temporal flow, considerations about the spreading of thermodynamic states allows the individuation of invariant relationships grounded in physical quantities (such as entropy, pressure, and perhaps temperature), which open up the possibility of defining a frame-invariant clock, and put flesh on the idea of becoming as an objective and measurable phenomenon, rather than a mental construction.

The General Theory of Relativity (GTR) complicates the picture in two opposing directions. On the one hand, not only the tensed aspect of time, but also the "B-theoretic" temporal structure seems to become frame-relative in GTR. On those grounds, Kurt Gödel attempted to demonstrate the "idealistic" theory of time, and more recently, John Earman has provided a McTaggart-style argument to the same conclusion. On the other hand, the cosmological considerations in GTR can be used to define a global time scale, which may turn out to have interesting connection with the thermodynamic "arrow of time".

The second family of science-based arguments against an objective flow of time consists in arguments from the time symmetry of the fundamental laws of physics. If at the fundamental level the structure of reality does not distinguish between a future-oriented and a past-oriented direction – i.e., it does not show temporal anisotropy – then it is difficult to see how the whole picture of a dynamic reality, as suggested by our ordinary experience, can be taken as reflecting some deep feature of our universe.

Now, not all scientific enterprises rely on temporal symmetric principles. Biology and psychology, for instance, seems to be sensitive to temporal anisotropy, but also – and more relevantly for the topic of the book – thermodynamics and quantum mechanics. However, the statistic definition of the second law of thermodynamics makes it a poor candidate for a fundamental law, and temporal asymmetry may be an emergent feature due to decoherence, that is the transition from quantum to classical level. Yet, entropic asymmetries are to be found both at a local level and at the global level of quantum cosmology, and thus – even if they have a *de facto* rather than a *de jure* status (i.e., even if they are empirical generalizations, rather than law-like facts)– they may be an indicator of an irreducibly anisotropy at the fundamental level.

The last section of the book elaborates on this idea. It starts with discussions on various formulations of the second laws of thermodynamics and the attempts to construe it as encoding the cosmological arrow of time. As it is known, without taking into account the initial condition of the universe, and privileging them over the final ones in the definition of the asymmetry, no individuation of the asymmetry of thermodynamic processes with an arrow of time that goes beyond what is *typical* to human experiences can take off the ground. The issue of whether the boundary conditions of the universe are symmetric or not leads the section to a detailed discussion of central problems in quantum cosmology. The book finishes with an interesting discussion of the topic of time travel.

(Reviewed by Giuliano Torrengo
– Department of Philosophy, University of Milan
giuliano.torrengo@gmail.com)