Epilog

Four weeks before his death, Albert Einstein wrote in a letter of condolence to the family of his life-long friend Michael Besso (Dukas and Hoffman 1979):[5] "For us believing physicists, the division into past, present and future has merely the meaning of an albeit obstinate illusion." There is no doubt that Einstein meant this remark seriously. Evidently, it refers to the four-dimensional ('static') spacetime picture of a 'block universe' that his theory of relativity uses so efficiently. This picture seems to be at variance with the experience of a *present passing through time* (the 'flow' or 'passage of time'). In contrast, the relativistic spacetime framework contains only a concept of *local events* (points in spacetime), which may be regarded as a continuum of dynamically related *here-and-nows*. Because of these dynamical relations, characterized by time-symmetric local laws, a *local present* can be viewed as 'moving' along the world line of an observer. His personal history is a succession of strongly correlated (local clusters of) events, dynamically controlled by proper time, while a global dynamical state would depend on an arbitrary foliation of the spacetime that is characterized by its invariant metric structure.

In Hermann Weyl's words: "The objective world simply *is*; it does not happen. Only to the gaze of my *consciousness, crawling upward* along the life line of my body, does a section of this world come to life as a fleeting image in space that continuously changes in time" (my italics). Any objective (classical) description of the locally experienced world must therefore treat space and time on an equal footing: it does not contain the concept of an *objective global present*. For this reason, Huw Price (1996) chose the subtitle 'A View from Nowhen' for his book on time's arrow. However, whether the objective world 'simply is', or rather 'comes into being', seems nonetheless to be a pure matter of words. Weyl's 'is' (the block universe picture) does not exclude a dynamical evolution (see Sect. 5.4).

[5] "*Für uns gläubige Physiker hat die Scheidung zwischen Vergangenheit, Gegenwart und Zukunft nur die Bedeutung einer wenn auch hartnäckigen Illusion.*"

The four- (or higher-) dimensional ‘static’ *view* is by no means specific to the theory of relativity. It does not even require deterministic laws, as it was already used by St. Augustine in his *Confessiones*. He regarded it as a divine world view – presumably since he understood it as including all details – not merely as a conceptual framework. A mortal physicist may at least *conceive of* the future history of the world (though with less confidence in the details than in those of the past). Even Laplace could not have expected his model world to be determinable *in practice* (see Sect. 3.3); he had to assume an extra-physical demon of unlimited capacities for this purpose. The argument that even the *macroscopic* future cannot in general be known to physical systems, such as humans or computers, should not be confused with a conceivable indeterminism of the dynamical laws (as is often done in the theory of chaos – see the lucid article by Bricmont 1996).

The peculiarity of the subjective present, often mistaken as part of an objective ‘structure of time’, was emphasized by Einstein in a conversation with Carnap. According to Carnap (1963), “Einstein said that the problem of the Now worried him seriously. He explained that the experience of the Now means something special for man, something essentially different from the past and the future, but that this important difference does not and cannot occur within physics. That this experience cannot be grasped by science seemed to him a matter of painful but inevitable resignation.” So he concluded “that there is something essential about the Now which is just outside the realm of science.”

Carnap emphasized, however, that Einstein agreed with him (in contrast to Bergson and other philosophers) that this situation does *not* indicate a *defect of the physical concept of time*. (The non-confirmation of a prejudice is easily viewed as a defect!) The situation should rather be understood as reflecting the undefined role of the observer, that must characterize the fundamental and underivable here-and-now of *subjective* reality in the form of a local psycho-physical parallelism, for example. Objective reality (the ‘divine world picture’ of a block universe) must instead always remain a hypothesis – but this successful (‘heuristic’) fiction[6] describes an empirically founded *asymmetry* in time that does *not* require the concept of a present which flows in time.

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[6] This notion of a ‘fiction’ is quite compatible with that of reality, even though it emphasizes the impossibility of *proving* the existence of a real world. For example, Einstein’s *gläubiger Physiker* (believing physicist) may express the *belief* in an objective reality (in Einstein’s case preferentially a local one) to be described by the physical formalism. As an admirer of Hume (but not of Kant – see Franck 1949) Einstein was clearly aware of this hypothetical character of reality. The evidence that Nature appears comprehensible was regarded by Einstein as “the most incomprehensible thing about Nature”. One should here recall that Descartes and Hume raised their doubts and criticism, which essentially forces us into fictionalism, against attempts to obtain absolute *certainty* in the empirical sciences – not against any *conceivable* reality – see also d’Espagnat (1995).

The role of time is very different in quantum theory because of the latter's probabilistic appearance. The 'openness of the future' has even been regarded as its most fundamental novel aspect (von Weizsäcker 1982), although its origin and meaning remain controversial. Heisenberg spoke of the trajectory of a particle 'coming into being by human observations' (see the end of the Introduction), while the later Niels Bohr seems to have regarded *objective* quantum events as occurring 'out of the blue' in the measurement device (see Ulfbeck and Bohr 2001). Similar ideas about a fundamental concept of *becoming* in Nature were upheld for somewhat different (though also questionable) reasons by Prigogine (1980).

It is evident that these various opinions are based on different interpretations of quantum theory (see Sect. 4.6). For example, the wave function has been regarded as representing mere 'potentiality' or some novel fundamental concept of information ('it from bit' – see Wheeler 1994). These concepts would then asymmetrically apply only to the future, while the past is presumed to be given. Some of them may in fact represent no more than words (see Tegmark 1998). In particular, if quantum theory were just a stochastic theory, the block universe picture would still apply to the 'divine world view', as mentioned above, while quantum theory is in conflict with *any* local reality.

If the wave function (or some more general concept of superpositions) is the correct kinematical concept of quantum theory (complete, in particular, to define entropy as a measure of irreversibility), its dynamics must be essential and sufficient to analyze the objective arrow of time – regardless of any further interpretation. This dynamics is deterministic as far as the Schrödinger equation holds, but probabilistic whenever a collapse of the wave function has to be taken into account. Although the collapse probabilities have been claimed to be time-symmetric (Aharonov, Bergmann and Lebowitz 1964), since $|\langle a|b\rangle| = |\langle b|a\rangle|$ for any two states a and b, the structure of initial and final states of a probabilistic event is usually very different – see (4.56) and footnote 2 of Chap. 5. A generic collapse would *reduce* the entanglement between subsystems, as it projects onto definite 'pointer states', while it is usually preceded by a much larger *increase* of entanglement (decoherence). This latter asymmetry can be explained by means of an appropriate initial condition for the universal wave function (the absence of initial entanglement). In the case of a collapse, symmetry could be restored only if this collapse were allowed also to 'create' nonlocal entanglement in an acausal manner in order to reverse (4.56).

Could the subjective experience of a present that seems to flow in turn induce an *apparent* time asymmetry that had no counterpart in the real world? Einstein's above-quoted remark is often interpreted as supporting this idea of an arrow of time as an illusion. It is, therefore, often mentioned by the fundamental information-theoretical school of statistical mechanics (Sect. 3.3.1), or in favor of an *extra-physical* concept of (growing) 'human knowledge' – corresponding to Heisenberg's 'idealistic' interpretation of the wave function.

I have tried to explain in various chapters of the book that the concept of entropy is in fact observer-related by means of a *relevance concept*. This observer-relatedness of the macroscopic description (which includes ‘pointer states’ of measurement devices) is particularly important in quantum theory, and – as it turns out – even for the emergence of a classical concept of time from a timeless quantum world. However, the observed time-asymmetry could always be traced back (at least in principle) to the asymmetric structure of an objective physical reality, that according to present knowledge is represented by a nonlocal quantum world.

Memories, in particular, have to be stored in physical form, and are then correlated with sources in their past (they are ‘retarded’). This drastic asymmetry may be sufficient to explain the *apparent* flow of time once there is a psycho-physical parallelism based on a presumed local *moment of awareness*. Only this (*not* necessarily asymmetric) concept of a local present is fundamentally subjective, while the asymmetry between past and future directions is part of objective reality. What we usually call the preserved *identity* of a person (who changes considerably during his lifetime) is ‘in reality’ nothing but a particularly strong and robust ‘causal’ correlation between *different* local physical states which represent the individual carriers of a subjective present. As pointed out by Einstein and Carnap, it is the *here-and-now* subjectivity as the center of all awareness that goes beyond objective reality, while it must severely affect our perception of the ‘real world’.

The essential novel aspect of quantum theory is its nonlocality. The dislocalization of superpositions with increasing time forces certain causal chains, which may also represent observers, to exist only in dynamically autonomous *components* of the global quantum state. Since these components then branch in our asymmetric quantum world, the quasi-classical world *appears* indeterministic to these branching observers. Entanglement entropy of ‘systems’ may appear to be an objective quantity that is defined by the global wave function, but locality (essential to characterize systems) already represents a non-trivial relevance concept that can be justified only by the locality of the observer, which is *facilitated* by the locality of dynamics.