Commentary

Lost in *The Labyrinth of Time*

Michael Lockwood
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Lockwood's book is a all but complete guide to the concepts and theories that you have to understand in order not to get lost in the labyrinth of time. Many threads pass through the whole work. The first six chapters of the book are an introduction to Special and General Relativity, the revolutionary notion of time that emerges from them, and the cosmological hypothesis based on them. Chapter seven introduces the philosophical problems that the idea of time travel raises. Chapters eight to thirteen are focused on the problem of the arrow of time, entropy, and the emergence of order. The following three chapters deal with the problem of the interpretation of quantum physics. The final chapter is on the psychology of time perception. In this commentary, I will mainly focus on the issue of time travel, from the classical "paradoxes" to their approach in a quantum setting.

The ordinary notion of time seems to carry along the idea that time passes, and that the passage of time is something "out there" objectively in the world. However, in Special Relativity the temporal dimension can be separated from the three spatial ones only relative to a frame of reference. This situation gives rise not only to the counterintuitive notion of the relativity of simultaneity, but also to the idea that the reality of time is nothing over and above that of its unity with space in space-time. Within each frame of reference, temporal and a spatial distance between events are constant quantities, but normally only spatiotemporal intervals (a certain relation between the two) remain constant through variations of frame. If an objective time flow requires that the distance between events be frame independent, then nothing seems to be left of the idea that the passage of time is a genuine, or even essential, feature of reality.

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In General Relativity, space-time reveals further "disturbing" properties, with respect to our ordinary notions of (space and) time. The geometry of different regions of space-time varies depending on the distribution of matter and energy that we find in the corresponding region. Space-time is not flat – although locally we can consider it as flat – it is curved by matter and energy, i.e., matter and energy stretch and shrink space-time intervals. This allows us to interpret gravity not as a force, but as an effect of the curvature of space-time. Besides, how precisely to shape up the spatiotemporal metric within a frame of reference is by large a matter of practical convenience, given that the interesting physical quantities remain constant through modifications of the metric, that is many radically different metrics are indistinguishable with respect to the physical laws governing the interaction between energy-matter and space-time (the Einstein field equations). In particular, the space-time manifold can be foliated in many (reciprocally incompatible) ways into three-dimensional layers, and none of them has any physical or metaphysical significance over the other. If an objective flow of time requires a global and absolute succession of "now", again such a notion seems to receive a fatal blow form physics.

However, many cosmological models based on General Relativity – such as the Friedmann-Robertson-Walker models and the inflationary models – depict the universe as starting at a singularity, the Big Bang, and continuing in its life with distinct, successive, phases. It is therefore tempting to use certain cosmological characteristics, such as the mean distribution of matter and energy, or the constant curvature of certain hypersurfaces (i.e., three-dimensional "slices" of space-time) to signal out a preferred foliation and thus a *cosmic time* to be identified with the objective flow of time that we all experience.[1] This project, as Lockwood makes clear, has proved to be difficult to carry out in a convincing manner. Any way to spot a preferred foliation remains at bottom unjustified, and what is worst, General Relativity gives us reasons to doubt even the possibility of providing any global foliation such as required by a cosmic time. The Einstein field equations are compatible with the presence of closed time-like curves (CTC), that is path in space-time such that (1) can be followed by an object at a sub-luminal speed, and (2) with respect to

[1] See for instance Lucas 1999. For further critics to the project see Bourne 2006 who argues that even if the project were sound, cosmic time would not make do to play the part of tensed time – i.e., time with objective time flow.

reference frames anchored to objects that do *not* follow a CTC, an object that follows an almost complete CTC will arrive at a time that is earlier than its departure time. Thus, many space-time manifolds that contain CTC cannot be foliated on a global scale – although it is still possible to define locally a temporal order.[2] For instance, we can distinguish between the public time of ordinary people who do not follow CTC in living their lives, and the personal time of someone following a CTC, i.e., a "time traveller".

CTC figures prominently in Gödel's argument that General Relativity, by allowing CTC, forces us to renounce to an objective notion of "lapse of time" and even to embrace an idealistic view of time to the effect that temporal order is not objective. Lockwood grants to Gödel that the physical possibility alone of CTC menaces the objectivity of the temporal passage and order[3], but he rightly maintains that simple compatibility with Einstein field equations does not necessarily boil down to physical possibility.

The possibility of having CTC in a spatiotemporal manifold clearly is related to the possibility of having time travel. However, as also Gödel seemed to think, one can accept CTC in a manifold while refusing the possibility that such CTC could be followed by ordinary object or persons long enough to allow a time travel situation. The grandfather "paradox" is the standard objection to the possibility of time travel. Suppose that time travel is possible and that twenty years old Tim embarks on a time machine for the fifties. It seems as Tim could reach his grandfather and kill him before he generates Tim's father, thus preventing his conception to happen. Since it is not possible that both Tim is and he is not born, we have to give up the hypothesis that time travel is possible. Philosophers have questioned this line of reasoning in various ways, after the seminal articles by Harrison 1971, Lewis 1976 (and Horwich 1975, who is more critical towards the idea though). The "standard" view, which in the first part of this chapter Lockwood provisionally defends, is that self-consistent time travel does not require miracles or extraordinary forces to prevent paradoxes, but only unusual (for non-time travellers) coincidences. The situation is not substantially different from cases of

[2] CTC does not imply that the manifold possessing them cannot be globally foliated. If a spacetime is closed by possessing a "cylindrical" topology, then it both possesses CTC and can be globally foliated.

[3] This is not the most common attitude; see Dorato 2002, Bourne 2006. Even the defence of Gödel's argument in Yourgrau 1999 seems to suppose that the main objection to Gödel's argument lies there. See also Calosi 2009.

foreknowledge. If a infallible foreteller predicts that I will not go to Mongolia within the next five years, then no matter how hard I try to reach Mongolia in the meanwhile, each time I try to go to Mongolia something will happen preventing me to reach it: the plane is compelled to land somewhere before Ulan Bator, the train derails before getting to the border, a snow storm stops my expedition from Siberia to the Gobi Desert, and so forth and so on.

Self-consistent time travel requires that any attempt by a time traveller to prevent her or his own birth is bound to fail – as in general any "bilking attempt", i.e., any attempt to change the past or prevent an unavoidable event. The particular reason why it is going to fail can be very different from one time to another, but what is the general and deep reason for there being *each time* a failure? If we discharge miracles and other non-ordinary forces, the only answer seems to be that there is a *conspiracy* in nature that prevent the initial conditions of any bilking attempt to be such to lead to contradiction. In insisting that this situation is unacceptable, both for common sense and for standard scientific practices, Lockwood parts company with the standard view on the issue. It is important to notice that the constraints on the initial conditions that are imposed by many time travel scenarios arise even in absence of free will agency. In order to show it, Lockwood provides an intriguing example (akin to a example in Earman 1972). Consider a train track that leads to a "wormhole" tunnel with the following characteristics: if a train enters it at a certain time, it exits from it ten minutes before it has entered it. Now, a computer that controls a train T can be programmed in a way that if a train exits from the tunnel at a certain time, then T stays at rest in the station, while if no train exits from the tunnel, then T enters the tunnel. Assuming there is only one train around, this situation leads us to a paradox – a "purified form" of the grandfather paradox, freed of any reference to human free agency.

If conspiracies on the initial conditions are required in order to avoid contradictory situations of this kind, then time travel – although not contradictory – seems to imply a violation of what Deutsch has called the Autonomy Principle.[4] It is a matter both of common sense and of ordinary scientific practice to assume that if *locally* the laws of physics admit of a certain configuration of matter, then the *global* situation of the universe cannot constraint the possibility of such a configuration of matter. If we can construct

[4] For a critique of the idea that those cases are substantially different from cases implying free agency, see Sider 1997.

a train and a computer with the physical properties that we have just described, then we should be able to do it even in the proximity of a "wormhole" tunnel. Global consistency, however, seems to require that this will not be possible unless external factors interfere with the train or the computer: a meteorite hitting the train before it enters the tunnel, or a electromagnetic field interfering with the computer, say.

However, physicist Kip Thorne and his collaborators[5] has shown that, if the laws governing a system are continuous, then it is possible – in presence of CTC – to find out consistent continuations of initial conditions that do not require conspiracy. Indeed, the problem turned out to be quite the opposite. Many initial conditions show the following feature: there is more than one consistent evolution of the system, and none of them is more likely to happen. Imagine a billiard table in which the two central holes have the following feature: whatever enters in the right hole exits from the left hole three seconds before it has entered in the right hole. Now, roll a ball between the two holes: what is going to happen? A consistent continuation of the initial conditions (the launch of the ball in a straight trajectory between the two holes) is that the ball passes between the two holes as it would on a normal billiard table. However, it is also perfectly consistent to suppose that while the ball passes through the holes it is hit by a ball emerging from the left hole, which deviates it in such a way that it enters the right hole with a momentum such that it exits from the left hole three seconds before and hits *itself* as it did. Many other continuations are all possible and none of them is more probable than any other to happen. In this example, as in many other settings, they are *infinite*! Even a Laplacian demon possessing a perfect knowledge of all natural laws and all former states of the universe would not be in a position to know what lies in the future if it contains CTC, or to tell what is more likely to happen.

Lockwood does not discuss the issue whether this solution to the problem can be generalized, and thus time travel never requires conspiracy on initial conditions, or there are physically plausible cases that would require a failure of the Autonomy Principle.[6] However, he does take into account the failure of determinism at a macroscopic level implied by time travel, and acknowledges

[5] See, for instance Echeverria et al. (1991). Their work follows previous seminal investigations by Feyman and Wheeler 1949.

[6] For a discussion of this problem see Artzenius and Maudlin 2002, and also Earman and Wuthrich 2004.

that such a failure of determinism is more dramatic than that due to probabilistic causation of quantum phenomena, in which we can usually weight the probability that an effect is brought about against that of other effects. Indeed, the solution he proposes to avoid failure of the Autonomy Principle is intended to apply also to the underdetermined cases.

Lockwood introduces his many minds interpretation of quantum mechanics with a lengthy and intriguing discussion of the measurement problem, focusing on Einstein and Schrödinger criticism of the Copenhagen interpretation and the failure of the local hidden variables solution provided by the Bell theorem. While Einstein was mainly concerned with the lack of determinism, Schrödinger was more concerned with the lack of continuity implied by the quantization of the states of quantum systems. The Schrödinger equation, indeed, describes in a continuous manner the evolution of the wave function of micro-physical systems, by attributing to them superposed states. Now, how should we construe the superposed states of a system that the continuous Schrödinger equation implies – given that attributing them simultaneously to the same system is clearly contradictory? According to Schrödinger, measurement does not collapse the wave function, turning the evolution of the system into a discontinuous process, but only makes the macro-system of the measurer entangled with the micro-system of the observer. The idea of construing superposed quantum states as *alternatives* comes from a particle interpretation of the reality that quantum theory is talking about, and from the fact that when we measure we only observe one of these states. But in a way this interpretation is just a consequence of our limited point of view, due to our being entangled with the measured system.

If we reject the idea of altering the continuous dynamic of the Schrödinger equation (as in collapse-Copenhagen, De Broglie-Bohm, GRW interpretations), then the only alternative seems to be that of accepting that superposed quantum states all simultaneously exist *in parallel realities*. Schrödinger was the first who realized that if we take quantum theory at face value, it predicts the existence of parallel realities, not only at the micro, but also at a macro level. However, he also never managed to come to terms with this conclusion, which is the core idea of Everett's interpretation of quantum mechanics. Lockwood is quite careful in linking his position to that hinted at in Schrödinger's last lessons, rather than to the many-worlds interpretation that Everett's work pioneered. Every interpretation of quantum mechanics that accepts that superposed states all simultaneously exist has to reshaping our concept of the macroscopic world so as to accommodate the idea of parallel realities. The idea behind the many mind interpretation is that there is no objective division of parallel realities. Rather, our minds – which are subsystems of our brains – form, along with all the states that are possible object of detection by them, the basis for such a division. Therefore, speaking of parallel worlds – composing what is sometime called a *multiverse* – although harmless in many occasions may be misleading with respect to such interpretation.

The fact that the division between the many distinct realities is "subjective" in this sense does not mean that according to Lockwood what exists depends on the subjects. The main point of Lockwood here is that what in classical relativity is thought to be a space-time manifold is indeed a *space-time-actuality* manifold. Time, even more than space, «paves the way for diversity in unity», but «space-time [may not be] the only arena within which Nature is able to spread herself» (p. 314). If the actual state of the world is simply the state in which we happen to be in, then we can think at the dimension of actuality as a dimension comprising simultaneous diversity within reality. If the hypothesis of the space-time-actuality manifold is correct, then we can have diversity in unity not only along the temporal dimension (today I have coffee as breakfast, tomorrow I have tea), and along the spatial dimension (my head is warm, my toes are chilled), but also along the dimension of actuality (today, in the kitchen, in a superposed state, I am drinking coffee, in another state I am drinking tea).

If the arena of reality is that of a space-time-actuality manifold, then it seems that the problems raised by the possibility of time travel can be solved without renouncing to the Autonomy Principle. Consider again the case of the "paradoxical" train. According to this interpretation of quantum mechanics, the train ends up in a mixed state encompassing two states (with equal weights[7]). Both such states exist in two parallel realities: in one the train enters never to be seen around, while in the other it emerges from the tunnel although it never entered it. The same goes for underdetermined cases. Keeping the previous example of the billiard balls in mind: in one reality the launched ball goes through the holes, in another it is hit by a previous self, and so on. In

[7] How do we make sense of states possessing different weights, as often happens in quantum mechanics? According to Lockwood, the weight of a state *s* corresponds to the size of the regions of actuality in which we find *s*.

general, objects and persons, by moving through the dimension of actuality, can go back in time and reach, indeed "create" in a sense, different realities from the one they come form.

Lockwood does not seem to be worried by a philosophical problem that has been raised for the multiverse solution to the grandfather paradox, and which still seems to stand for his interpretation.[8] Is travelling through a space-time-actuality manifold a genuine case of *time* travel? Consider the grandfather paradox again. By entering a parallel universe, Tim can indeed achieve his murderous purposes and kill his grandfather. However, did he really manage to reach the past? A first problem here is that speaking of "the past" in a space-time-actuality manifold is ambiguous: the term can refer either to that area of actuality from which Tim comes from (the reality from which he comes from) or to that that he reaches after his travel (the reality in which he arrives). Of course, if he had reached the past in the first sense, he could not have managed to kill his grandfather, and thus he has reached the past only in the second sense. But then in so far as in a space-time-actuality manifold is also possible to reach the past in the first sense, should not we regard as "genuine" time travel only the first kind of travel?

A supporter of the space-time-actuality manifold here could simply answer that in so far as Tim has also travelled backwards along the time dimension, and not only "sideways" through actuality, this is as good as time travel as we can demand. Actually, she can even insist that the objection rests on a confusion with respect to the core problem here. Forget about the grandfather paradox and the idea of time travel. If the whole point with CTCs was that they seem to lead to a violation of the Autonomy Principle (and to underdetermined cases of causation), then, regardless of how we label the strategy, it does work. By moving in a space-time-actuality manifold, Tim would not be constrained by conspiracies to fail in carrying out his project to kill his own grandfather. This response would be, I maintain, a good piece of reasoning. However, there is a more substantial philosophical problem with the space-time-actuality approach, which cannot be so easily dismissed.

What is right about the "feeling" that a movement in space-time-actuality is *not* a genuine case of time travel, even if it follows a CTC with respect to the temporal dimension[9], is that it is not clear what the relation between the

[8] See, for instance, Abruzzese 2001.

[9] In a space-time-actuality a CTC is a line whose projection on the space-time hypersurface is

individuals that we find along the dimension of actuality is. Lockwood seems to defend the idea that individuals located in different region of actuality can be strictly identical to each other. At one point he says:

> [t]he idea is that, just as you can be in different states at different *times* (relative to your current motion), so also you can be in different states at the *same* time at different points in *actuality*. (p. 316)

Speaking of *you* being at the same time in different point of actuality suggests that individuals can move through actuality as they move in space. Indeed, the strict identity with respect to the participants of the various superposed states could be seen as another point of distinction between the many minds interpretation of quantum mechanics and the many worlds one.[10]

However, the strict identity thesis between individuals located in different region of actuality is problematic. The problems bear similarities to that of identification of individuals through possible worlds in modal logic. Although no discussion of such topic is to be found in Lockwood's book, the consequences of not accepting a strict identity thesis for the solution to the problem of the apparent violation of the Autonomy Principle that the many minds interpretation of quantum mechanics purports to give can be seen even without entering a sophisticated discussion. Consider the paradoxical train case, and assume that there is not strict identity between the train that enters the tunnel in the region of actuality in which the computer detects no previous train entering the tunnel and the train that emerges from the tunnel in the region of actuality in which the computer detects it. In the reality in which a train arrives from a CTC that partly lies in other region of actuality, the Autonomy Principle is not violated. However, in the reality in which the train, following the command of the computer governing it, enters the tunnel and disappears the Autonomy Principle does seem to be violated. That the train literally goes nowhere is as good a constraint on the behaviour of the system programmed to behave in a certain way and positioned near a CTC as an

closed. Therefore, it may not be topologically closed.

[10] Lockwood does not stick to a strict identity vocabulary across the board, and often speaks of "copies" of oneself as dwelling different zones of actuality (e.g., p. 325). Indeed, he seems to acknowledge that a refusal of the strict identity thesis has psychological plausibility: «But whereas memory gives you access to your own states at other times, there is no counterpart of memory that gives you access to your own states at other location in actuality: states that you can think of as belonging to your alter egos» (p. 316).

asteroid arriving from a far region of space hitting the computer and destroying it for good.

A possible solution of this predicament could be endorsing a rather non standard view on the individuation of individuals, modelled after the view that individuals persist in time by having temporal parts that are located at different points in time. Individuals moving through space-time-actuality may be identified with entities possessing not just spatial and temporal parts, but also "modal" parts.[11] There would be, thus, strict identity of an individual that is spread through different regions of actuality, while its modal parts would not be identical with each other. Whether Lockwood idea of a space-time-actuality manifold can indeed be put to use to solve such problems as the Autonomy Principle failure, then, can be judged only on the background of a more detailed analysis of identity within such a manifold.

In starting this note I have claimed that Lockwood's book is a almost complete guide of what it takes to understand the most distinctive aspects of time that our scientific theories allow us to discover. I have finished it by pointing out something that Lockwood seems not to have taken fully into account. It may seem that I have changed my mind along the way, but this impression should be dismissed. Because Lockwood's book provides us with a deep, interesting and fully worked out insight in the different aspects of time that emerges from contemporary physics, it is also apt to prompt new discussions on the "pure" philosophical side. And this is a characteristic that good books, irrespective of whether they deserve the "all but complete" label or not, have.

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[11] Varzi 2001 fiddles with the idea in a more traditional possible worlds context.

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