Becoming, relativity and locality

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Abstract

It is a central aspect of our ordinary concept of time that history unfolds and events come into being. It is only natural to take this seriously. However, it is notoriously difficult to explain further what this 'becoming' consists in, or even to show that the notion is consistent at all.

In this article I first argue that the idea of a *global* temporal ordering, involving a succession of cosmic nows, is not indispensable for our concept of time. Our experience does not support the existence of global simultaneity and arguments from modern physics further support the conclusion that time should not be seen as a succession of cosmic nows. Accordingly, I propose that if we want to make sense of becoming we should attempt to interpret it as something purely local. Second, I address the question of what this local becoming consists in. I maintain that processes of becoming are nothing but the successive happening of events, and that this happening of events consists entirely in the occurring of these events at their own spacetime locations. This leads to a consistent view of becoming, which is applicable even to rather pathological spacetimes.

1 Simultaneity and the Now

Untutored intuition sees an inextricable bond between time and global simultaneity: time is a succession of cosmic nows. Each such 'now' extends over the whole universe, connecting simultaneous events. Part of this intuition is the supposed self-evidence of the meaning of statements about distant simultaneity. However, in 1905 Einstein famously subjected this intuitive picture to a drastic epistemological critique. He started by conceding [8] that there cannot be any dispute about whether *coinciding* events are simultaneous. But, Einstein pointed out, for events that do not spatiotemporally coincide the meaning of simultaneity is not so obvious. The reason is that we do not have immediate empirical access to the temporal relations between events that take place at a distance from each other—at least, not in the cases in which these events are outside each other's sphere of causal influence. We ourselves are more or less spatially localized and this, together with the fact that information cannot travel faster than light, implies that at any instant in our lives there are events that can be influenced by us (in the future lightcone), events that can influence us (in the past lightcone), but many more events that are not within causal reach at all. Events in the future and past lightcones are unambiguously temporally ordered with respect to the event at their apex (indeed, we could have veridical memories of all past lightcone events, and there could be memories of the apex event everywhere in the future lightcone); but what about all the other events, outside the two cones? Notoriously, Einstein concluded that in the case of such distant events their temporal order with respect to us, and in particular simultaneity, must be established *by definition*. His concrete proposal for establishing simultaneity was that two clocks that rest with respect to each other can be taken to be in synchrony if a light signal that leaves clock A at time t_0 (as indicated on A) and is reflected at clock B when B's hands indicate t_1, arrives back at A at local A-time $2t_1 - t_0$. In other words, the event at A halfway between the emission of the signal and its return is taken to be simultaneous with the reflection of the light at B. The arbitrary aspect typical of definitions, according to Einstein, is that it has to be *stipulated* that light going from A to B and back again needs equal amounts of time in the two directions (in other words, that the speed of light is direction independent). This definition is equivalent to taking $\epsilon = 1/2$ in Reichenbach's famous formula $t_1 = t_0 + \epsilon(t_2 - t_0)$ [19].

In the spirit of Einstein's 1905 discussion, Reichenbach and many others after him have argued that this value of ϵ, and therefore which events are regarded as being simultaneous, is purely a matter of convention. The justification of this view is that the consistent use of any other value of ϵ (with $0 < \epsilon < 1$) leads to a description that is empirically equivalent to the standard one ($\epsilon = 1/2$). Indeed, distant simultaneous events, whatever the value of ϵ that is taken for the definition of simultaneity (as long as $0 < \epsilon < 1$), have spacelike separation with respect to us, so that we cannot reach them by signals and cannot be reached from them. In other words, the definition of simultaneity only pertains to what lies outside our past and future lightcones and can therefore have no influence on the content of our observations. Relativistic theories (in which the speed of light is the maximum speed of information transfer) are therefore empirically equivalent to their variants with $\epsilon \neq 1/2$.

It is important to note that there are *two* ingredients in this epistemological critique of the relevance of simultaneity. First, there is the assumption that there is no action at a distance: signals cannot propagate faster than with the speed of light c. Second, it is assumed that observation is a *local* process. The whole conventionality argument is based on the presumption that the observation event can be represented by the apex of a lightcone, i.e., a spacetime point.

If observations instead are taken to correspond to extended regions in spacetime, it could legitimately be asked whether simultaneity plays a role in determining the outcome of the observation *within* such regions; in which case simultaneity on this local level would not be conventional. It seems more plausible to suppose that an observation is a process of finite spatiotemporal extension that does *not* depend on simultaneity within the region of observation (so that the content of the observation supervenes directly on the collection of events within the spacetime region of the observation). However this is taken to be, the fact remains that the 'observation spacetime region' is of very limited extent—its spatial dimensions should certainly not exceed that of the human body. Our perceptual apparatus, memory, etc., are all more or less localized. So regardless of the status of local simultaneity, in the very small, the way simultaneity is assigned *outside* this limited region of observation plays no role for the content of observation. The representation of an observation by a point-event is therefore a justified approximation, especially in the context of the cosmological considerations we shall be concerned with in this article. In the arguments we shall put forward, this (quasi-)local character of observation will play an important role.

In spite of the argumentation about the irrelevance of simultaneity for what we observe, the claim that simultaneity in special relativity is merely conventional is controversial. The reason is that the conventionality thesis is epistemologically inspired, and therefore more or less automatically suspicious from a realist point of view. Especially after Malament's proof [13] that the $\epsilon = 1/2$ relation is the only plausible equivalence relation between events that can be defined from the 4-geometry of Minkowski spacetime and a given inertial worldline, the tide seems to have turned against Reichenbach and his followers. I will later come back to Malament's argument, which is ontological rather than epistemological. But whatever one's attitude with respect to the conventionality thesis, it has to be admitted that its two premises, namely that there is a maximum signal speed and that observation is local, lead to the conclusion that choosing $\epsilon \neq 1/2$ makes no difference for observational results. This conclusion stands, whether or not one accepts it as a good argument for the conventionality thesis. Local observations—the experiences of localized observers—are invariant under different choices of the value of ϵ in the same way as they are invariant under different choices of coordinate systems. In particular, *it follows that those human experiences that suggest that time flows are invariant under different choices of* ϵ.

This observation undermines the idea that our direct experiences of time, passage, and becoming provide support for the idea that there are cosmic nows, whose succession determines the flow of time. We do not need a succession of a definite set of global simultaneity hyperplanes in order to accommodate our experience. For it follows from what was just said not only that completely different choices of such hyperplanes lead to the same local experiences,[1] but even that we do not have to bother about global simultaneity *at all*. If we decided to scrap the term 'simultaneity' from our theoretical vocabulary, no problem would arise for doing justice to our observations. This ties in with the fact that relativistic theories can be given completely local formulations—simultaneity plays no role in the dynamical laws of relativity theory. Clearly then, our direct time experience does not provide epistemological warrant for the existence of a global now and global becoming. This line of reasoning parallels Einstein's 1905 argument that our local experience does not support the classical notion of absolute simultaneity.

[1] We could also take ϵ position and direction dependent without observational differences, in which case simultaneity would not correspond to a set of hyper*planes* but to curved hypersurfaces.

2 Rotating frames

So, if arguments based on our direct awareness of the flow of time were the only ones at our disposal, we might already now deny the relevance of global simultaneity for our conceptions of time and becoming. However, it would be too quick to think that limitations of our means of observation, in this case the fact that we are restricted to the observation of local events, imply strict bounds for our conceptions about the structure of the world. There may be good theoretical reasons for assuming the existence of things or structures we do not have direct observational access to. Indeed, the fact that our observations take place in a restricted spacetime region have not prevented us from theorizing about spacetime as a whole—like Minkowski spacetime in special relativity. Now, in the context of Minkowski spacetime there is a well-known theoretical argument designed to show that there exists exactly *one* global equivalence relation that meets natural requirements to be imposed on the concept of simultaneity relative to an observer, namely the relation of Minkowski orthogonality with respect to the worldline of this observer [13]. This simultaneity relation is built into Minkowski spacetime, in the sense that it is completely definable from the Minkowski metric (plus the specification of the worldline in question). If one takes a realist stance with respect to Minkowski spacetime—and we do not want to argue against such a realist position here—this global simultaneity therefore appears to have a clear ontological grounding. Is it not natural to assume that this particular simultaneity relation fixes the successive instants in the history of the world, which come into being one after another?

Actually, it is misleading to state that the above argument leads to a simultaneity relation that is built into Minkowski spacetime and therefore must be assumed to exist as soon as the existence of Minkowski spacetime itself is accepted. As already mentioned, the relation in question is defined with respect to worldlines. Now, it may be maintained that as a mathematical fact all possible worldlines (also curved ones) exist in Minkowski spacetime, together with the associated orthogonality hyperplanes at each of their points. This, however, clearly does not lead to one definite notion of simultaneity. Instead it is a vast *collection* of simultaneities whose existence is warranted by the existence of Minkowski spacetime, and this collection does not yield one sensible notion of global temporal succession. We must apparently specify which worldlines are privileged and relevant for simultaneity. This is tantamount to augmenting the structure of Minkowski spacetime.

Our own worldlines seem prime candidates for the required additional structure. After all, we are the ones who come up with these intuitions about global becoming and successive cosmic nows, so it appears reasonable to suppose that the simultaneity that is involved is simultaneity relative to us. However, our worldlines are complicated: we take part in the annual and daily motion of the Earth and are therefore not moving inertially. Our situation is very nearly that of inhabitants of a rotating system in Minkowski spacetime. The study of the properties of time in rotating systems is therefore relevant for the question of whether the simultaneity related to actual observers leads to a global now.

The study of rotating frames of reference played an important role in Einstein's discovery of general relativity [24]. Time in these frames exhibits a structure that is also important from a modern foundational point of view [3, 5]. The most significant point for our present discussion is that local Einstein synchrony ($\epsilon = 1/2$) in a rotating system *does not extend to a consistent global definition of simultaneity.* Each observer on a rotating disc can locally apply the Einstein definition, but the so-defined local nows do not combine into one hypersurface. Therefore, orthogonality with respect to rotating worldlines cannot serve the purpose of defining a succession of global Nows.

This can be seen easily by considering observers who are positioned along the edge of a rotating disc (and who are at rest with respect to the disc). Synchronizing along the edge with $\epsilon = 1/2$ leads to a discrepancy, a time gap, upon returning to the initial position. For imagine the circle that forms the edge to be folded out into a straight line. The spacetime diagram of Fig. 1 represents the uniformly moving observers sitting along this line, together with their local $\epsilon = 1/2$ synchrony hyperplanes. It is evident that the initial and final events cannot coincide when the line is folded back into a circle: there is a time gap. More generally, local Einstein simultaneity with respect to worldlines with accelerations that involve rotations cannot lead to a global equal time hypersurface (this is a consequence of Frobenius's theorem [25, Appendix B.3]).

So, if we accept that Einstein simultaneity with respect to worldlines enjoys a special status and is the candidate *par excellence* for grounding an objective Now, we face the disappointing result that this notion cannot define a global now in the case of our own worldlines of rotating Earthlings, or the worldlines of arbitrary other rotating systems. However, in view of the omnipresence of forces and fields, we can only expect that actual observers

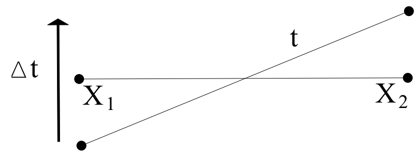

Figure 1: Standard synchrony along a rotating circle ($x_1 = x_2$), folded out into a line.

and other actually existing physical systems are in a state of acceleration that involves rotation. That means that Einstein simultaneity with respect to actually materialized worldlines will quite generally not lead to a global definition of simultaneity.

Therefore, nows of global becoming cannot be fixed by Einstein simultaneity with respect to worldlines in Minkowski spacetime that are realistic representations of actual material worldlines.[2] Special relativistic cosmic nows must clearly be related to a particular choice of *non-materialized* parallel timelike geodesics (actually, a continuous set of them that completely fills up spacetime, i.e., a congruence). Such a congruence defines a frame of reference and the unique Einstein simultaneity associated with it. But which congruence of inertial worldlines should be chosen? The spatiotemporal structure of Minkowski spacetime does not single out any set of parallel geodesics from the infinitely many defined in it—this is one way of formulating the relativity postulate, which says that all frames are equivalent. So if we are not going to refer to the actual material worldlines in the universe, but only to the spacetime structure itself, we have insufficient resources to fix a unique set of global nows. If we do attempt to rely on the actual material worldlines, however, we will not succeed in defining global nows at all.

In the context of Minkowski spacetime the project of defining a global notion of becoming is therefore hopeless. We could of course just *choose* some foliation of Minkowski spacetime and declare it to realize universal

[2]One may object that it does not make sense at all to represent the actual universe by means of special relativity. However, Minkowski spacetime provides an approximation to general relativistic spacetimes that is quite good even for large spatiotemporal regions. But see the next section for an assessment of the situation in general relativity.

nows. But these nows would not play any role in our time experience, since our experience is local and does not depend on stipulations about the time coordinates to be assigned to space-like separated events. Moreover, such a global now would not play any role in the formulation of physical theory. Finally, it would not be definable from Minkowski spacetime structure without the addition of arbitrary elements. It would be bad metaphysics to opt for something as gratuitous as that.

But there may be a way out. The best available theory of our actual universe is not special relativity with its highly symmetrical flat Minkowski spacetime but *general* relativity. Perhaps this theory offers better prospects for global becoming.

3 Non-rotating universes

In completely generic general-relativistic spacetimes the situation is worse rather than better. There are solutions of the Einstein field equations that cannot be sliced up at all by means of spacelike hypersurfaces. This feature of general relativity, and its possible consequences for the theory of time, have become notorious since Gödel's seminal work [9, 10]. Gödel found solutions of the field equations in which there are closed timelike curves (it is characteristic of these Gödel spacetimes that the matter in them possesses a net rotation). It is clear that there can be no linear ordering of global Nows and therefore no global linear flow in universes in which worldlines bend back into their past. So if we take the view that the essential features of time are those that are solely determined by the Einstein equations—in other words, that the essential features of time are those that are present in all models of the theory—it follows that global linear flow cannot be such a feature: there are solutions of the Einstein equations without it.[3]

In his 'Reply to Criticisms' Einstein remarked about the Gödel universes: "It will be interesting to weigh whether these are not to be excluded on

[3] I take it that Gödel's argumentation is directed against the idea that it is an essential characteristic of time that it *flows linearly*; that becoming in this sense exists. Although Gödel's formulation is not quite unambiguous, I think that this is the only way his argument makes sense (compare [7, pp. 194-200]). The form of Gödel's argument as I understand it then is: Time is usually said to be different from space because it *flows* from the distant past to the distant future; but in some solutions there is time without such flow being possible; flow can therefore not be an essential, defining characteristic of time.

physical grounds" [23, p. 688]. In other words, Einstein suggested that not all mathematically correct solutions of the general relativistic field equations may represent physically possible worlds. If the class of possible worlds is indeed taken to be smaller than the full set of mathematical models satisfying the general relativistic field equations, then in this smaller set of 'physical solutions' the shared properties of time might include the total ordering that is needed for Gödel's global becoming.[4]

The proposal not to take into account Gödel type solutions of the Einstein equations may seem *ad hoc*. However, on second thought it is perhaps not implausible. First of all, observational evidence indicates that our own universe is not rotating[22]. Other possible general relativistic worlds, in which strange Gödelian things happen, exist as far as we know only on paper. That by itself, however, is no obstacle for considering them relevant for an analysis of the concept of time based on our best physical theory. But it should be noted that general relativity with its usual scope may not be the only contender here. Already in the case of classical particle mechanics there is a serious rival for Newtonian mechanics in the case of non-rotating universes, and the situation seems similar in relativity theory. For those solutions of the classical Newtonian equations of particle motion in which there is no net particle rotation, it is possible to formulate a completely relational, Leibnizean particle mechanics that is empirically equivalent (for these cases with no net rotation) to Newtonian classical mechanics [11]. In this relational classical theory only mutual distances and relative orientations of the particles occur—there is no need for absolute space. As just mentioned, our universe actually appears to be non-rotating. So, as a piece of counterfactual

[4]This suggestion could alternatively be couched in terms of essential versus contingent properties of time. As just mentioned, Gödel's argument for the 'ideality' of time, as he puts it, relies on the idea that if time 'objectively lapses' (if there is objective becoming), this should be an *essential* property of time, instantiated in all possible worlds. The Gödel universes are then relevant as counterexamples. If the set of possible worlds is restricted so as to exclude Gödel universes, objective passage may regain its status as an essential attribute of time. As a limiting situation we could consider taking only our own universe as possible: then everything existing in our world would exist necessarily. The actual characteristics of time in our world would thus by definition also be essential. This seems a too drastic curtailment of the scope of physical theory and a trivialization of the distinction between the essential and the contingent, however. Even if we are convinced that there is actually only one universe and if we are strict empiricists, it makes sense to conceptually distinguish between the merely contingent and the essential, on the basis of the properties of (a set of) models of our theories.

history, we could speculate about what the history of mechanics would have been if Newton had proposed this relational theory instead of his actual theory involving absolute space. In the relational version of particle mechanics it is a built-in and law-like feature that there is no net rotation (there is no background with respect to which such a global rotation could even be defined). Only non-rotating universes are therefore possible according to this theory. In other words, the lack of rotation is essential and necessary within this theoretical framework. In our counterfactual history, this feature could then have been carried over to the conceptual framework of an alternative version of general relativity theory. Indeed, it can be shown that general relativity accommodates Leibnizean and Machian desiderata if one restricts the set of allowed solutions to non-rotating closed universes [12]. So one can imagine an alternative course of history in which the notion of a net rotation of the matter in the universe would never have made sense as a physical possibility. Such an absence of rotation is conducive to the existence of global nows, as we already saw, and it excludes Gödel universes. If we go on to exclude exotic possibilities like wormholes in spacetime that give access to the past, this could lead to spacetimes that allow global foliations as the only physical possibilities.

Let us go along with this line of reasoning, and assume that physically possible universes (of which our universe is one) do not rotate on an astronomical scale and do not contain closed timelike worldlines. This allows [14] the introduction of a foliation of spacetime into a linearly ordered set of three-dimensional spaces, each space being orthogonal to the worldlines representing the mean motion of matter.[5] At first sight this possibility seems to decide the issue: in all physically possible universes it could be said "that reality consists of an infinity of layers of 'now' which come into existence successively" [9].

However, Gödel himself already expressed reservations about this way

[5] There may also exist other ways of defining a global time. In particular, in spatially homogeneous cosmologies three-dimensional spaces of constant mass density may foliate the spacetime. Often this does not yield something new, because these homogeneity spaces are in many models orthogonal to the worldlines as well; but there exist also cosmological models in which the homogeneity condition and the orthogonality condition lead to different foliations [1, Sec.3.3]. We focus on the orthogonality criterion because it matches the special relativistic notion of simultaneity, which appears a natural requirement in view of the indistinguishability between special and general relativity on the local scale. But the arguments against global becoming to be put forward below will also work against the homogeneity definition.

of constructing a Now (without pressing the point). He observed "that the procedure described above gives only an approximate definition of an absolute time. No doubt it is possible to refine the procedure so as to obtain a precise definition, but perhaps only by introducing more or less arbitrary elements (such as, e.g., the size of the regions or the weight function to be used in the computation of the mean motion of matter). It is doubtful whether there exists a precise definition which has so great merits, that there would be sufficient reason to consider exactly the time thus obtained as the true one."

Consider, to make Gödel's worry clear, the Robertson-Walker solutions of the field equations. These are the solutions that are found if spatial homogeneity and isotropy are imposed. It is possible to define a global time t in them (t is the argument of the scale factor occurring in the standard way of writing the solutions). The equal-t hypersurfaces are orthogonal to the worldlines of matter—matter is at rest in these hypersurfaces (in which the matter density is constant). The total spacetime can thus be represented as a stack of equal-time hypersurfaces, a succession of three-dimensional spaces each of which belongs to one value of t. This cosmic time t thus seems very well suited to make the notion of global becoming more precise.

Though the Robertson-Walker metric is often used as a representation of our own universe, our universe is obviously not homogeneous and isotropic. It is only when we average over very large spatial regions that the distribution of matter in the actual universe appears to approximate homogeneity and isotropy. That means that only if we leave small scale details out of consideration, our universe can be approximated by a model of the Robertson-Walker type. Now, we could define equal-t hypersurfaces in our actual universe as surfaces that are orthogonal to the average mass distribution that we can calculate by coarse graining over large volumes. But the result of this procedure depends on the details of the averaging process and the size of the regions considered. One would expect that the conformity to a Robertson-Walker spacetime becomes better when the sizes of the regions over which the averaging takes place become bigger (though it is not really certain that the homogeneity and isotropy assumption will be satisfied in a limiting situation, or even that there is a well-defined limiting situation), but as long as the averages are taken over finite regions homogeneity will not be complete and will vary with the sizes of the volumes. Accordingly, the equal-t hypersurface that is found will be different depending on the choices we make for the averaging procedure. So there is arbitrariness in the definition of the global time t, comparable to the arbitrariness in choosing one set of parallel inertial worldlines over another in Minkowski spacetime. However, if we concentrate not on the imaginary worldlines of smeared out matter but go to the detailed scale of real, actually existing worldlines, we encounter the same problems as when we attempted to do this in Minkowski spacetime: in general these actual worldlines will be rotating and there will be no global simultaneity hyperplane orthogonal to even a small subset of them (like our own worldlines on Earth). It is obvious that the above-mentioned empirical fact of a vanishing rotation in our universe can only refer to the net rotation, found by averaging on a cosmic scale: on a small scale, rotation is present everywhere around us.

As Gödel stated, in order to arrive at a notion that has a chance of representing *objective* global time flow one should first of all provide an unambiguous definition of global time. What we have just seen is that it is impossible to arrive at such a definition if we attempt to extend special relativistic local simultaneity defined with respect to actual worldlines in our universe. Only in very special highly symmetrical cosmologies do hypersurfaces exist that can plausibly be considered to realize such uniquely determined cosmic instants. As soon as we turn to realistic, asymmetrical, cosmological models the definition of such hypersurfaces comes to depend on statistical considerations and is no longer unique.

More generally, even if we forget about the orthogonality condition, in asymmetrical spacetimes[6] that admit foliation at all no unique foliations can be singled out on the basis of the spacetime geometry [1, pp. 264-265]. Many slicings of spacetime are generally possible, none of them deserving the label 'fundamental'.

However, what we would like, in Gödel's words, is a definition that "has so great merits, that there would be sufficient reason to consider exactly the time thus obtained as the true one". It will not do to just stipulate that one or another way of cutting up spacetime in a series of non-overlapping three-dimensional spaces furnishes a succession of nows. In particular, what we would like to have is a foliation of spacetime that does explanatory work with respect to our experience of time and our intuition of time flow. That, however, appears an unattainable goal. The arbitrariness of foliations just discussed basically derives from the fact that the physical laws have a local character and do not need a notion of simultaneity for their formulation at all. That is the reason that we were driven to consider contingent, fact-

[6]Spacetimes without symmetry actually lie dense in the total space of solutions

like circumstances as a basis for possible definitions. But such contingent circumstances, pertaining as they do to far-away conditions in the universe at large, are completely irrelevant to our local experience. We can conclude that global time plays no role at all in our time experience.

This general diagnosis is not changed by the various proposals that have been made to use foliations that lead to simplifications of the equations in the constrained Hamiltonian formalism of GRT, like those that take the mean extrinsic curvature of hyperplanes as the time parameter. The constrained Hamiltonian formalism itself characterizes these choices as choices of a particular gauge [25, Appendix E], which is tantamount to saying that nothing observable depends on the selection of one possibility over another.

The bottom line is that cosmic time on any proposal is defined via a global description that has no bearing on what happens on a small scale. But it is exactly the processes on the small scale (like the time experiences of human observers and the evolution of localized systems) that lie at the basis of the idea that there *is* objective becoming. The rate of these local processes is determined by the amount of *proper time* between events, and not by differences in cosmic time. For consider local observers in arbitrary motion with respect to each other and starting from one spacetime point: proper time differences along their worldlines will not conform to contour levels of any cosmic time function, due to the non-integrability of proper time. As a consequence, discrepancies will generally occur in the time lapses recorded by observers that meet again after having traversed different paths between two events, as illustrated by the twin effect. However, during their respective journeys such twins will be able to use the same physics; one twin ages as fast as the other, as judged by his own clocks. They have the same time experiences. This empirically verified democracy would be broken once we started measuring the rate of processes by some 'true' global time. Accordingly, global time—if it can be defined at all—is unrelated to our experience of becoming. Proper times are the quantities we use in daily life in our local environment. Cosmic time plays no role on a mundane level.

In summary, what follows from these considerations is that we do not really need to engage in meditations about other universes. Both according to special and general relativity, applied to our *actual* universe, a plausible global time cannot be defined by reference to what happens on the small scale of human experience and local physical experiments. Such a global time *can* probably be defined through theoretical considerations on the cosmic scale, but such definitions involve an unavoidable element of arbitrariness, and the resulting t is irrelevant to our time experience and the description of local processes.

4 The block universe and becoming

A global time function, if it exists at all, thus appears to be a theoretical expedient. It is a helpful tool in the theoretical treatment of spacetimes with a certain amount of symmetry and is a useful concept in, e.g., the constrained Hamiltonian formulation of GRT. In the latter context it is comparable to the choice of a particular gauge in electrodynamics. It does not have consequences on the level of observation (which is local) and a fortiori is not relevant for our time experience.

However, according to traditional doctrine the existence of a unique series of global nows is indispensable for what this doctrine considers the essential difference between space and time, namely that time is 'dynamic' whereas space is 'static'. The basic idea behind this is that time is objectively *progressing* from the past to the future. The history of the universe is unfolding itself, and this process consists in the successive coming into being of global nows. This was exactly the notion of time targeted in Gödel's attack. Accordingly, after Gödel had argued that time *cannot* be flowing this way, he concluded that it must be 'ideal', by which he meant that our feeling of becoming does not reflect an objective process of becoming that exists in physical reality itself, independently of us. Time flow and the associated difference between space and time must be mind-dependent if there are no global nows, according to this argument.

This way of reasoning is not at all peculiar to Gödel's analysis. That the absence of a unique succession of universal nows entails that there is no essential difference between space and time is in fact the basis of a notorious argument within special relativity. The core of this argument is that without a unique series of nows all events must have their places in spacetime in the same way as the objects on my desk possess their spatial positions. All events in the history of the universe should be there 'together', 'at once'. Put differently, we live in a 'block universe' in which all events—past, present and future—'exist jointly'. Allegedly, this block view would imply that the universe is 'static', without change and becoming and without fundamental differences between past, present and future. It is sometimes added that this blatantly conflicts with our direct experience of temporal change, and that this experience must therefore be an illusion. Several versions of this argument exist in the context of special relativity (compare [18, 20, 15, 16, 17]), but as we have seen it can be adapted to the situation in general relativity as well.

There is something deeply puzzling about this argumentation, especially about any possible 'illusion part' of it. As emphasized in the preceding sections, our time experience—local as it is—does not depend on the concept of global time. So how then could the denial of the objective existence of global time lead to a picture that is in conflict with our direct experience? If there indeed is a mismatch between the block universe and our experience it must surely come from some other source, not from the absence of global simultaneity. So let us try to find out whether there actually is something in the block universe that is at odds with our time experience and whether it is true that our intuitive notion of time is in conflict with what the block picture tells us.

This project is hopeless from the outset. It is the purpose of the four-dimensional spacetime picture, which the block universe is, to represent *all* events that actually take place in the universe, complete with *all their properties and mutual relations*. An adequate block universe representation therefore also contains all events in the lives of individual human beings, with all the impressions and experiences that (partly) constitute these events. For example, that I now remember past events and do not yet know much about what is to come is part of my experience at this instant of my life and should be part of the four-dimensional picture; the same applies to my conviction that exactly *now* it is now. All actual events, experiences and intuitions must be there in the block representation, exactly at the spacetime position where they actually occur. So there cannot be any conflict between experience and the block universe. More generally, since all actual events in the history of the universe are faithfully represented, with all their characteristics and mutual relations, there cannot be anything missing in the four-dimensional picture at all.

This latter conclusion is of course independent of whether or not global simultaneity exists. If objective global time does exist, this can and should be represented in the block representation. If it does not exist, it is not represented in the block. In both cases the block representation does not need to leave anything out of consideration. But the question of course remains whether the absence of global simultaneity implies anything for the difference between space and time, and for the viability of the notion of becoming.

Since everything that we experienced, are experiencing and will experience is represented in the four-dimensional block, quite independently of whether or not there is global simultaneity, all experiential differences between space and time are also there. Is there any reason to maintain that in the case of lacking global simultaneity these experienced differences must have the status of illusions whereas they may refer to something real if there is global time? I can see no justification at all for this position. As argued above, our experiences are local in character and independent of global simultaneity—they do therefore not lend support to the hypothesis that global temporal distinctions exist in reality. A theory about the nature of reality according to which there is global becoming transcends direct experience much more than any interpretation that stays on the local level. There is consequently no reason to think that the temporal differences we experience can only refer to something global. Consequently, if it turns out to be possible to develop a view of reality in which there is becoming and a difference between space and time in a local way, the resulting conception will have every chance of being better supported than rivals postulating global becoming.

To start with, let us have a closer look at what the doctrine of global becoming precisely consists in. The global aspect is that the supposed temporal ordering extends over the whole universe. But becoming itself is not implied by the existence of an ordering, whether it is global or not—a stack of papers is linearly ordered but surely the papers do not come into successive existence by virtue of this. So independent of the question of temporal ordering, an analysis of becoming *tout court* has to be supplied. As I have argued, any such analysis will apply *a fortiori*, with better support, to a doctrine of local becoming. Sense must be made of the notion of the becoming of events in any case, both in order to get the global and the local doctrines off the ground.

Now, the four-dimensional spacetime diagram *records* events with their qualities and relations. But in order to be recordable at all, the events in question must *occur*. They must *happen*. It is exactly here that there is room for 'coming into being' in the block universe. Events come into being by occurring, by happening; what else could there coming into being be? Since non-occurring events are evidently not represented in the four-dimensional picture, events can only be part of the block universe if they in fact come into being at their own spacetime location. Their coming into being is a *precondition* for their being part of the block universe. In the block picture it is recorded for each actual event *that*, and where/when it occurs. The specification of the coordinates of an event document first of all *that* it happens; all represented events actually happen. Thus, our proposal is that 'coming into being' means the same thing as 'happening'. Since everything that happens is recorded in the block universe diagram, 'coming into being' is also fully represented. There is no need to augment the block universe in any way.

This proposal boils down to a deflationary analysis of becoming: becoming is nothing but the happening of events, in their temporal order. This obviously requires some ordering structure in the space of events. However, there is no need that this is a total linear ordering. In fact, relativity theory tells us that there is a different temporal ordering in reality, namely the partial ordering induced by the lightcones. Each event is later than the events in its past lightcone, earlier than the events in its future lightcone, and not temporally ordered with respect to events outside these two lightcones. This ordering structure (a partial ordering) can without difficulty be applied to define becoming. The total pattern of relativistic temporal ordering relations in the block universe accordingly represents how events come into being with respect to each other. Given any event, some other events come into being later or earlier, and still other events—those at spacelike separation—come into being without being earlier or later than the given event. In particular, the successive happening of events along a worldline implements the notion of 'becoming' with respect to an object or causal process.

One may object that the mere ordering with respect to each other of localized events is not sufficient to justify a notion of becoming, though. Events can be spatially ordered as well, and this does not lead to spatial becoming (from left to right, for example). So we still have to assume that there is a difference between space and time that makes it possible to reserve the label 'becoming' to temporal succession. We do not need to come up with something new here, however: spacetime physics indeed makes such a distinction. There is an objective difference between spacelike and timelike vectors; this relates to the fact that space and time are treated differently in the expression for he metric (in local Lorentz coordinates the metric tensor has one -1, for the temporal dimension, and three times $+1$ for the spatial ones). Given the objective distinction between spatial and temporal ordering, that events *happen* or *occur* and are not just spatially juxtaposed can be seen as a *sui generis* attribute of events. The block picture is complete in its representation of this becoming: it contains all information about exactly which events occur, where and when this happens, and in which temporal order.

Still, one may feel the need for a deeper explanation of what 'temporality' and 'coming into being' exactly consist in. Indeed, the four-dimensional picture only tells us *that* events occur and that they have certain spatiotemporal relations between them. It only gives us a structural description of the web of events; does this exhaust the essence of becoming? To counter this request for explanation, it should be noted that the same thing may be asked with respect to spatiality. 'Being something spatial' is a quality whose content is not fixed by saying that it belongs to elements possessing the interrelations of the points of the Euclidean plane. A picture of a plane only represents structural properties, in the same way as the four-dimensional block universe picture; and it can be applied to very different entities that happen to exemplify the same structure. To fix the reference to spatial things something additional must be invoked. A natural move to make is to embed ourselves in the network of relations, and to identify some of the experiential relations between ourselves and the world around us as spatial. The same manoeuver can be carried out in the spatiotemporal context: then the relevant experiences will partly refer to 'becoming'. If we do not want to invoke experience in this way, both 'spatial position' and 'occurrence' must be regarded as *sui generis* attributes—of objects and events, respectively.

So according to this proposal, 'coming into being at (x, t)' is what *it means to be an event at* (x, t). The four-dimensional picture represents the relations between events, but does not explain further what events are. In order that a spacetime diagram is acceptable to us as a representation of the universe, we *already* have to know what events are, by acquaintance with them via other means than the contemplation of such representations. That events happen is something we should already know. We should not become confused, of course, by the fact that a concrete representation before our eyes is itself very different from what is represents, namely the events in the history of the universe. If a spacetime diagram is on a sheet of paper, it is itself part of the events in the life of the paper, and happening in that sense. But this is different from the happening of the events represented *in* the diagram. The fact that the block diagram itself at any instant is perceived as purely spatial and does not 'flow' is irrelevant for the status of what is being depicted.

So 'coming into being', 'happening', 'taking place', 'occurring', are what it is for an event to be an event—it is a primitive concept that cannot be defined by means of more basic notions. This suggestion seems to be close to the analysis of 'becoming' put forward by Savitt [21] and Dorato [6].

5 Conclusion: local becoming

Becoming thus consists in the successive coming into being of events. This does not require a global notion of time as in Gödel's "infinity of layers of 'now' which come into existence successively". Our direct time experience does not impose such a total ordering on becoming, and the special theory of relativity has made us already accustomed to the idea that events possess only a partial temporal ordering. Since our experience does not tell us anything about temporal ordering that goes beyond this special relativistic ordering (induced by the light cone structure), it is natural to be led by the characteristics of this partial ordering structure in our theorizing about the characteristics of objective becoming. So the natural view is that the history of our universe is realized by events that come into being; and that they come into being after and before each other as dictated by the partial ordering relation induced by the spacetime structure [4]. According to this proposal the life of the universe is not one linear series of events, but a partially ordered set of events. The process of becoming is *local* in two respects: first of all and most importantly, the focus of becoming are the local events that come into being; and, second, the ordering relations that govern the temporal relations in this network of happenings are not global in character. The resulting picture is in accordance with what relativity theory tells us about the structure of spacetime and the role of time in it: it captures the 'many-fingered' aspect of time. It accords with our direct time experience as well. It thus provides us with a scientifically informed notion of becoming.

What has just been said presupposed that an unambiguous temporal ordering indeed exists. But this condition is not fulfilled in all solutions of the Einstein equations: in Gödel-like universes ambiguities arise about the temporal order of events. This may be countered by declaring such models unphysical—we have encountered this move before and argued that it may possess a certain plausibility. But another and I think better possible response is to say that 'happening' or 'occurring' of events is the essential thing, and that whether or not a consistent large-scale ordering is possible between these local happenings is a secondary question. If we take this line,

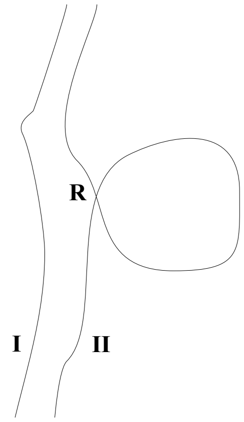

Figure 2: Becoming along an almost closed worldline.

local becoming can be accommodated in all models of general relativity, even in universes with a complicated Gödel-like temporal ordering structure.

To see what this may result in, and how this contrasts with other analyses of 'becoming', consider the following example from Reichenbach's *Philosophy of Space and Time* [19, pp. 141-142]; see Figure 2. Worldlines I and II in the figure represent human beings; worldline II returns to the neighborhood of one of its earlier points, Gödel-style. Reichenbach describes the experiences of the individual associated with worldline II as follows: "Some day you meet a man who claims that you are his earlier self... Years later you meet a younger man whom you suddenly recognize as your earlier self... You also see your former companion again, exactly as old as he was when you last saw him...He denies any acquaintance with you and agrees with your younger self that you must be insane. After this encounter, however, you walk along with him. Your younger self disappears from sight and from then on you lead a normal life." Reichenbach goes on to conclude that the following must be true in universes with almost closed worldlines: "On the same world-line there would be periodic 'now-points' one after the other. In region R we would find two now-points of the same worldline in causal interaction; and under these circumstances we would lose the possibility of conceiving of the self as one identical individual in the course of time. There would be on this worldline a succession of new individuals who would travel the worldline at certain intervals. On worldline I we must also mark off such periods...".

Reichenbach is obviously thinking here in terms of a process of objective becoming that is progressing along the two worldlines. The way he represents this may at first sight seem plausible: he assumes that becoming consists in the motion of a 'now-point' along the worldlines. This same idea can be found in the work of many authors.[7] This conception is completely different from

[7]The famous words of Hermann Weyl, "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 certain section of this world come to life as a fleeting image in space which continuously changes in time" [26, p. 116], expresses the same intuition: the four-dimensional continuum needs the *addition* of a *moving* focus, this time that of consciousness, in order

the one put forward in this paper and it is important to be clear about the difference. The 'moving now' approach requires the *addition* of something to the four-dimensional continuum, namely a moving very narrow 'window' through which a small portion of the continuum is made visible (or 'real'). By contrast, what we have proposed here is a conception according to which nothing has to be added to the spacetime diagram: the four-dimensional picture *already contains* becoming. In Reichenbach's example the relevant processes of becoming are the successive happening of events along the two worldlines.

The 'moving now conception' leads to the well-known conundrum of how fast, and as a function of what, the 'now' changes its position. Motion, in the ordinary sense of the term, means different positions at different times and this kind of motion is already fully represented in the block picture as it is. The motion of the added 'now' is apparently a completely new concept, and we are at a loss to explain what it is. But as we will see, in the example at hand the implausibility of the whole approach becomes even clearer, *pace* Reichenbach. This observation will lend further support to the view that becoming does not reside in something to be added to the block universe—it is already there.

When the individual of worldline II talks to his younger (or older) self, the 'now' conception employed by Reichenbach says that both persons actually exist and must therefore be 'touched' by a now-point (because the 'now' identifies the points on the worldlines that are actual). So there must be *two* now-points in region R, which both are travelling up the worldline. But when the younger person now reaches R for the second time, the story repeats itself, so that a third now-point becomes necessary, and so on. Because actualized points on worldline I are in contact with actualized points on II, this multiplicity of now-points carries over to worldline I. So un unending sequence of now-points travel up the two worldlines, repeating the same history over and over again; the same events keep on happening and there no longer is a unique connection between a worldline and an object or individual. This appears a *reductio ad absurdum* of the doctrine of the shifting now. Indeed, the very idea of an event is that it occurs exactly once, namely at its own spacetime position; and the idea of the four-dimensional spacetime picture is that it fully contains the history of the whole universe, not an infinity of indistinguishable repeated histories. At the very least one should

to accommodate the notion of becoming.

say that an infinite multiplication of entities as necessitated by the moving now doctrine is a highly undesirable piece of metaphysics.

On our construal of becoming no such absurdities arise. Each event comes into being only once, at its spacetime position in the four-dimensional world. *Along the two worldlines* there is a linear temporal ordering, and therefore ordinary becoming. When the stroller converses with his younger self, he is in causal contact with an event that happened long ago in his own life, i.e., if measured along worldline II, but that is recent if measured along a different path. This is a direct consequence of the absence of a unique temporal ordering in the network of occurrences (as is to be expected in Gödel-type universes), but entails nothing about a periodicity in the process of becoming, let alone about a multiplicity of personalities. It seems clear that this sober account is to be preferred over an account according to which a mysterious 'now' travels through spacetime in an incomprehensible way while doing something unintelligible over and over again to events on its way.

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