Time and Causation in Gödel's Universe.

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In 1949 the great logician Kurt Gödel constructed the first mathematical models of the universe in which *travel into the past* is, in theory at least, possible. Within the framework of Einstein's general theory of relativity Gödel produced cosmological solutions to Einstein's field equations which contain *closed time-like curves,* that is, curves in spacetime which, despite being closed, still represent possible paths of bodies. An object moving along such a path would travel back into its own past, to the very moment at which it "began" the journey. More generally, Gödel showed that, in his "universe", for any two points P and Q on a body's track through spacetime (its *world line*), such that P temporally precedes Q, there is a timelike curve linking P and Q on which Q temporally precedes P. This means that, in principle at least, one could board a "time machine" and travel to any point of the past.

Gödel inferred, in consonance (as he observes) with the views of Parmenides, Kant and the modern idealists, that under these circumstances there could be no such thing as an objective lapse of time, that time or, more generally, change, is an illusion arising from our special mode of perception. For consider an observer initially at point P (with time coordinate t seconds as indicated by his own clock). At point Q (with time coordinate t') he boards a time machine and travels back to point P, taking time t'' to do so. In that case, according to his own clock, $t' - t + t'' > 0$ seconds have elapsed, and yet an identical clock left at P would show that 0 seconds have elapsed. In short, there has been no "objective" lapse of time at all.

Gödel remarks that in his universe this situation is typical: for every possible definition of an "objective" time one could travel into regions which are past according to that definition. He continues:

> *This again shows that to assume an objective lapse of time would lose every justification in these worlds. For, in whatever way one may assume time to be lapsing, there will always exist possible observers to whose experienced lapse of time no objective lapse corresponds… But if the experience of the lapse of time can exist without an objective lapse of time, no reason can be given why an objective lapse of time should be assumed at all.*

Gödel also raises the issue of whether the fact that objective lapses of time fail to exist in his universe has any consequences for the universe

in which *we* live—for us, at least, the real one. He points out that, while our universe differs observationally in certain respects from his model, there might be models containing closed timelike curves which are observationally indistinguishable from ours (a possibility later confirmed). In that case, it is already *possible* that our universe is one in which objective time is an illusion. And in any event, he goes on to say,

> *The mere compatibility with the laws of nature of worlds in which there is no distinguished absolute time and in which, therefore, no objective lapse of time can exist, throws some light on the meaning of time also in those worlds in which an absolute can be defined. For, if someone asserts that this absolute time is lapsing, he accepts as a consequence that whether or not an objective lapse of time exists (i.e., whether or not a time in the ordinary sense of the word exists) depends on the particular way in which matter and its motion are arranged in the world*[1]*. This is not a straightforward contradiction; nevertheless, a philosophical view leading to such consequences can hardly be considered as satisfactory.*

Such a philosophical view is called *materialism.* But it would be a bizarre materialism indeed which made the very existence of objective time depend on the distribution of matter!

There are even more disturbing features to Gödel's universe than the illusory nature of time. To begin with, there is the possible presence of *closed causal loops*, that is, circumstances in which the relation of causation is *symmetric:* two events *A* and *B* for which *A* causes *B* and *B* causes *A*. Such a causal loop, one that could conceivably arise in Gödel's universe, was presented in an ingenious science-fiction story by William Tenn. A professor of art history from the future travels by time machine some centuries into the past in search of an artist whose works are celebrated in the professor's time. On meeting the artist in the flesh, the professor is surprised to find the artist's current paintings talentlessly amateurish. The professor happens to have brought with him from the future a catalogue containing reproductions of the paintings later attributed to the artist, which the professor has come to see are far too accomplished to be the artist's work. When he shows this to the artist, the latter quickly grasps the situation, and, by means of a ruse, succeeds in using the time machine to travel into the future (taking the catalogue with him), where he realizes he will be welcomed as a celebrity, so stranding the professor in the "present". To avoid entanglements with

[1] This is because in general relativity the geometry of the universe is determined by the distribution of matter in it.

authority the critic assumes the artist's identity and later achieves fame for producing what he believes are just copies of the paintings he recalls from the catalogue. This means that *he*, and not the artist, created the paintings in the catalogue. But he could not have done so without having seen the catalogue in the first place, and so we are faced with a causal loop.

While causal loops engendered by trips into the past may be bizarre, paradoxical even, the above example shows that they are not necessarily inconsistent. However, certain uses of time travel into the past do seem to be barred on the grounds of outright inconsistency. Gödel remarks:

> *This state of affairs* [i.e., backward time travel] *seems to imply an absurdity. For it enables one, e.g., to travel into the near past of those places where he has himself lived. There he would find a person who would be himself at some earlier period of his life. Now he could do something to this person which, by his memory, he knows has not happened to him.*

Indeed, granted the very possibility of travel into the past, what agency would then actually prevent me, say, from travelling into the past and killing my infant self? Gödel makes the intriguing, and characteristic suggestion that self-contradictory trips into the past of this sort may be prevented by a kind of macrocosmic version of the uncertainty principle of quantum mechanics, elevating what would at first sight seem to be a mere practical limitation into a limitation *in principle.* He observes:

> *But the practical difficulties* [in travelling into the past] *would hardly seem to be trifling*[2] *Moreover, the boundary between difficulties in practice and difficulties in principle is not at all fixed. What was earlier a practical difficulty in atomic physics has today become an impossibility in principle, in consequence of the uncertainty principle: and the same could one day happen also for those difficulties that reside not in the domain of the "too small" but of the "too large."*

There is, however, an important difference between the limitative principles of physics and any principles (call them "temporal interdicts") invoked to block changes of the past. In the first case it is *logically possible* that, for example, a body's velocity could exceed that of light or that an electron's position and momentum could be simultaneously measured with pinpoint precision. But any violation of a temporal

[2] Gödel actually calculated how much energy would be required to make the trip into one's own past and complete it in one's lifetime; it turns out to be vast and apparently far beyond the realm of feasibility.

interdict would involve a *logical contradiction.* If I was as a matter of fact alive as an adult at a certain time, then I cannot (as a consequence of being murdered as a baby) be dead at that same time. If this were possible, then not only time, but what we call objective reality itself, would have to be counted an illusion.

While closed causal chains are, on the face of it, consistent, and accordingly not excluded as possible outcomes of trips into the past, it is difficult to see how any temporal interdict devised expressly to prevent time travel for the purpose of changing the past would not at the same time also frustrate time travel for the purpose of setting up closed causal chains. For example, suppose that, in William Tenn's story, the critic, insanely jealous of the artist's fame, resolves to travel a little further into the past with the intent of suffocating the artist as an infant in his cradle. This would have to be impossible if, as stipulated in the story, the artist *in fact* lived to adulthood. So the critic's evil design *must* be frustrated on pain of logical contradiction. But how? By the critic failing to complete his journey? If the critic's trip into the past could actually be completed in the original nonparadoxical case, it could surely also be completed in the second case: how could the time machine itself distinguish between its operator's intentions in the two cases? In that event, what remains to prevent the critic, once he has arrived at his temporal destination, from suffocating the infant, thereby creating a contradiction? Nothing, it would seem, apart from contrived coincidences such as his dropping dead on arrival, the infant's parents suddenly appearing, leading to the critic's arrest, and the like.

If the critic does succeed in suffocating the infant, then, assuming that reality is not an illusion, it would seem to follow that the "past" into which the critic has travelled is in fact a different "past" from the one in which the critic originated. That is, his actions have "caused" the universe to "split" into two distinct past branches: one in which the artist survived into adulthood, and another in which the artist died in infancy.

We conclude that, if time travel into the past is possible (and feasible), *and no restrictions are placed on the purposes to which such travel is put,* then the universe must branch. Accordingly we have three possibilities:

1. Time travel is impossible.
2. Time travel is possible, with no "changing of the past".
3. Time travel is possible, and the universe ramifies.

Ramifying universes have arisen in connection with quantum mechanics, in the so-called *many worlds* interpretation. In this account, when certain types of interaction occur, typically, measurements, the universe divides into different branches, one for each possible outcome of the interaction. Observers branch (or split) as well, and each observer on

each branch sees one of the possible outcomes. It is interest to note that recent work by Deutsch et al. has shown that time travel with no constraints, that is, situation 3, is compatible with the many worlds interpretation. But again observe that here time travel takes place from the present of one "branch" of the universe into the "past" of *another* branch. Gödel's puzzle arises with the possibility of time travel within a *single* universe, and for this the problem of devising convincing "temporal interdicts" remains.

References

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