Functional differential equations. 5: Time travel and life

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Abstract

Physics must be non-mechanistic to account for everyday experience. Existing physics becomes non-mechanistic if advanced interactions exist. Advanced interactions are usually eliminated on metaphysical grounds of "causality", but we explain why that is not valid. Admitting advanced interactions involves no hypothesis, but only an acceptance of the most general formulation of physics, using mixed-type FDEs. If advanced interactions are rare, the resulting physics remains approximately mechanistic. The mixed-type FDE model readily resolve various paradoxes of time travel. Specifically, time *machines* are impossible, since realistic time travel implies spontaneity (different from chance). The novel features of this model can be expected to be especially prominent at the microphysical level of biological macromolecules and single particles.

1 Introduction

The twentieth century was marked by two great revolutions in physics: relativity and quantum mechanics. It is common to glorify these revolutions, but our objective is to *understand* them. To that end, we need to ask: what *defects* in the old physics led to these revolutions?

1.1 Relativity and time measurement

The relativity revolution concerned time, as we saw in the previous article in this series.[1] There was a conceptual error about time measurement in Newtonian physics. It did not define equal intervals of time, and hence had no "correct" way to measure time. Consequently, even Newton's first law, by itself, is not meaningful. Relativity corrected that error and provided a definition of equal intervals of time.

The advantage of trying to understand defects in the old physics is clear: it led to a new theory of gravitation—retarded gravitation theory—which uses FDEs, even in gravitation. This new theory suggested a new way to resolve the problem of galactic rotation curves without the need for either dark matter or *ad hoc* modifications to Newtonian physics. Newtonian gravity remains a first approximation limited to the solar system. But even within the solar system, tiny departures from it would be observable as in the NASA flyby anomaly attributable to the novel gravitational effects of the rotation of the earth.

1.2 FDEs and time asymmetry

However, there is a second fundamental difficulty with time in the old physics: the difficulty with time asymmetry or the "arrow" of time. Actually, however, the difficulty with time asymmetry is part of an even more fundamental difficulty.

Even a child can distinguish between living organism and non-living things, but the equations of the old physics make no such distinction. Hence, those equations ought to apply equally to both: living and non-living.[1] That is, physics *must* be compatible with biology, *and* mundane human experience. But is it?

[1] Indeed, since the old physics provides no way to separate living from non-living, it gives us no way even to articulate any claim that "physics does not apply to living organisms".

Irreversible aging is our most basic experience from birth to death. This observed irreversibility is *contrary* to the old physics, which was time reversible. If the equations of physics are written down using only ODEs and PDEs, the transformation $t \to -t$ does not change those equations. But, on mundane experience, it is impossible to reverse aging, and turn an old man into a baby! Science must be compatible with observation: if physics disagrees with widespread experience, we should correct physics, not dismiss the experience as an illusion.

Retarded FDEs partly correct this error in the old physics, for they model an irreversible physics. Recall that [2, 3] retarded FDEs arise in classical electrodynamics simply by doing the math correctly. That is, we (a) take into account the neglected *coupling* of ODEs and PDEs, required for the many body problem, and (b) use retarded propagators for the solution of PDEs (as in retarded Lienard-Wiechert potentials). Similarly, retarded FDEs are used in the new theory of gravitation explained in the previous article. But why use only retarded propagators?

1.3 Mundane time

Thus, an asymmetry between past and future only partly describes our mundane experience of time. For, on our mundane experience, repeated thousands of time each day, our actions often successfully *create* or "bring about" (a tiny part of) the future cosmos. All the plans we make for the future (including applications for research grants) are premised on this belief that our actions *now* contribute in deciding the future outcome.

This human creativity (in general, the creativity of all living organisms) is possible only if future is not fully determined from past by physics. That is, apart from the two problems of time measurement and time asymmetry, there is a third problem about time in the old physics: physics is mechanistic and that needs to be corrected.

However, any sort of indeterminism is not acceptable: just as there are many deterministic models, there could be many varieties of indeterminism. This is clarified by the chocolate-ice-cream machine.[4, chp. 8] The machine indeterministically selects a chocolate or ice cream, and slams its choice down our throats. What we will eat is not determined, but that is not the same as choosing between chocolates and ice cream in mundane life.

One way to formalise the difference between mundane time and the time of the old physics is to speak of the topology (or structure) of time, in the sense of temporal logic.[4, chp. 8] The time of daily experience is linear towards the past (we believe we cannot change the past), but branches towards the future (we believe the future is NOT already determined by the past but is influenced by our choices and efforts).

This past-linear future-branching mundane time is *not* the same as the time of physics which is usually assumed to be superlinear (i.e., to have the topology of the real line). That belief arose for a peculiar reason: because of a wrong way of doing calculus, as currently taught in universities. That requires time to be like the real line just to be able to make sense of the differential equations of physics.

Can we make physics compatible with the observed mundane creativity of living organisms? Minimal compatibility with everyday observations requires that we reformulate physics in a non-mechanistic way so that the entire past does *not* fully determine future. FDEs provide an easy way to do that provided we admit also advanced propagators instead of discarding them as "unphysical". This amounts to a minimal change in existing physics. If advanced interactions are rare, and retarded interactions predominate, the model remains time irreversible.

1.4 Causality

Why were advanced propagators excluded as "unphysical"? Physics texts typically justify this on the *metaphysical* grounds of "the principle of causality". That is problematic for various reasons. First, it is confusing, as metaphysics often is.

Thus, the word "causality" is commonly used in diametrically opposite senses. One sense is that of *mechanistic* causality: that the future is determined by the past, just as initial data determines the solution of an ODE, or past data determines the solution of a retarded FDE. The second sense is that of *mundane* causality that human actions are partly responsible for the future: we believe a thief is the cause of a theft. In both cases, future events have an antecedent cause. However, in the case of the thief we believe his actions were *not* fully determined by *his* past, hence we punish the thief (not his past!).

That is, the single word "causality" has two opposite meanings: (1) that the future is fully determined by the past (hence we exclude advanced propagators) and (2) that human actions, *not* fully determined by the past, are partly responsible for the future (hence we punish thieves). It is an elementary principle of classical logic that from contradictory premises any desired conclusion may be drawn. Hence, the word "causality" with its diametrically opposite meanings is a rich source of confusion, for it can be used to conclude anything we want!

What complicates matters further is that *both* the above contradictory senses of causality are related to deep-rooted religious dogmas. Thus, Aquinas maintained that God rules the world with eternal laws of nature (determinism). On the other hand, the church has long maintained, since Augustine, that God punishes evil-doers in hell. Why should a person be punished (or rewarded) if the future is already determined and hence entirely beyond his control?

Such questions bring out the manifest incoherence in these dogmas about "causality". To "manage" the contradictions, and incoherence, and "save" those dogmas from rejection, there is a vast and confusing discourse on the theology of "free will", which invariably creeps into discussions about time in physics.[5]

However, the very use of the term "free will" should warn us that the discussion has strayed from physics to theology. The issue at hand is whether physics agrees with everyday experience, as it must. Why should theology be essential to mediate a conflict between physics and everyday experience?

To reiterate, if scientific theory does not agree with mundane experience, we should construct a better scientific theory more in accord with experience.

1.5 The tilt in the arrow of time

As already noted, a simple way to do that is to admit *both* retarded and advanced propagators, though in different proportions. That is, we use a convex combination of the two propagators, with weights α and $1-\alpha$, where α, the coefficient of the advanced component, is a small number (say, $\alpha \approx 10^{-10}$). This situation has been described as a "tilt in the arrow of time": *most* physical interactions travel from past to future, but in some rare cases interactions travel from future to past. A "tilt" also raises the interesting possibility of "time travel", in some sense.

Note that a "tilt" does *not* involve any new physical hypothesis. On the contrary, we just *dropped* the hypothesis of (mechanistic) "causality" used to reject advanced propagators. A convex combination of advanced and retarded propagators just gives us the *most general form* of classical electrodynamics and post-relativity physics (including gravitation). We should first study this general form and *then* compare the results of such a study with observations. If the comparison with observations so requires it we can put $\alpha = 0$, to recover (mechanistic) "causality". This approach is obviously better than proceeding on metaphysical guesswork influenced by religious dogmas.

The immediate mathematical consequence of a "tilt" is this: the resulting equations of motion (of a charged or neutral particle) are mixed-type FDEs. The time asymmetry provided by mixed-type FDEs differs from the time asymmetry provided by retarded FDEs.

2 Advanced FDEs

To understand the difference, let us first consider the fully advanced case $\alpha = 1$. The simplest advanced FDE is of the form

$$\dot{y}(t) = y(t+\tau) \tag{1}$$

where $\tau > 0$ is constant. An advanced FDE such as (1) models a situation where the present state of a system $y(t)$ depends upon its *future* state $y(t+\tau)$.

This equation cannot be solved just by prescribing "initial" data $y(0)$: we can see this by repeating the reasoning used in the retarded case.

However, an advanced FDE cannot be solved even by providing past data. An advanced FDE is the exact time reverse of a retarded FDE: from the theory of retarded FDEs we can obtain the theory of advanced FDEs just by interchanging past and future. That is, to solve (1), we need to prescribe *future* data $y(t), t \geq 0$. We can use this future data to obtain a unique *past* solution, $y(t), t \leq 0$.

We saw that a retarded FDE can be solved forward in time but cannot, in general, be solved backward in time. Symmetrically, an advanced FDE can be solved backward in time but cannot, in general, be solved forward in time. We can see this by slightly modifying the earlier example used for retarded FDEs.

2.1 An example

Consider the FDE

$$y'(t) = a(t)y(t+1), \tag{2}$$

where a is a continuous function which vanishes outside [0, 1], and satisfies

$$\int_{-\infty}^{\infty} a(t)\ dt = \int_0^1 a(t)\ dt = 1. \tag{3}$$

For example,

$$a(t) = \begin{cases} 0 & t \leq 0, \\ 1 - \cos 2\pi t & 0 \leq t \leq 1, \\ 0 & t \geq 1. \end{cases} \tag{4}$$

For $t \geq 1$, the FDE (2) reduces to the ODE $y'(t) = 0$, so that, for $t \geq 1$, $y(t) = k$ for some constant k $(= y(1))$.

Now, for $t \in [0,\ 1]$,

$$\begin{aligned} y(t) &= y(1) - \int_t^1 y'(s)ds \\ &= y(1) - \int_t^1 a(s)y(s-1)ds \\ &= y(1) - y(1)\int_t^1 a(s)ds, \end{aligned} \tag{5}$$

since $y(s-1) \equiv k = y(1)$ for $s \in [0,1]$. Hence, using (3), $y(0) = 0$, no matter what k was. However, since $a(t) = 0$ for $t \leq 0$, the FDE (2) again reduces to the ODE $y'(t) = 0$, for

$t \leq 0$, so that $y(0) = 0$ implies $y(t) = 0$ for all $t \leq 0$.

Hence, the future of a system modeled by (2) cannot be predicted from a knowledge of the entire past; for if the past data (i.e., values for *all* past times $t \leq 0$) are prescribed using a function ϕ that is different from 0 on $[-\infty,\ 0]$, then (2) admits no forward solutions for $t \geq 1$. If, on the other hand, $\phi \equiv 0$ on $[1,\ \infty]$, then there are an infinity of distinct forward solutions. Fig. 1 shows three such solutions. In either case, knowledge of the entire past furnishes no information about the future.

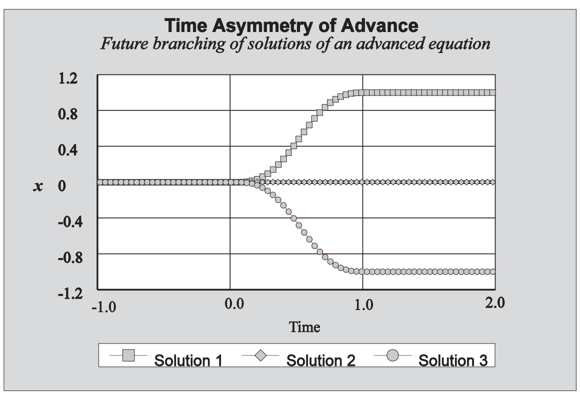

Figure 1: **Asymmetry of advanced FDEs:** Three different solutions of an advanced FDE with the same past have different futures, so that advanced FDEs cannot be solved forward in time. That is, future cannot be inferred from knowledge of past.

With advanced FDEs, multiple futures may collapse to a single past, a situation which may be better described by saying that solutions of advanced FDEs *branch* towards the future.

2.2 Popper's pond paradox

Even this basic knowledge about advanced FDEs easily resolves the pond paradox which so confused Karl Popper. Thus, the retarded solutions of the wave equation correspond to the ripples that spread out when a stone is dropped into a pond. The advanced solutions are the time reverse: they correspond to ripples that spontaneously converge from the edge of the pond. We normally observe the former but not the latter solution.

But suppose someone were to observe this rare occurrence and video record it. A physicist might suspect that the record has been faked; that someone actually video recorded the ripples spreading outward, and then recaptured the video playing it backward. He then falsely claimed that he has actually observed one of those rare events corresponding to advanced waves. How to discriminate between the two possibilities?

In a series of articles in the journal *Nature* long ago [6, 7, 8, 9] Popper suggested that the physicist should ask: by what *process* can one make this (converging ripples) happen? He used Huygens' principle to argue that ripples which arise spontaneously at the edge of the pond could build up into a converging wave *only* if they were coherent. This coherence basically requires a single source; it could happen if we have a perfectly circular pond and the ripples originate from the centre and are reflected back at the edge. Popper opined that coherence could not arise in any other way, except by chance. Further, Popper argued, the probability of coherence happening by chance, across multiple sources, is negligible.

2.3 Resolution of the pond paradox

If we think about it a little, Popper's conclusion is strange because he used metaphysical reasoning to limit physical phenomena. Whether or not advanced interactions exist is a matter of physics, for it should be determined by empirical observations. How did Popper manage to exclude them without reference to physics?

The above understanding of advanced FDEs brings out the error in Popper's reasoning. Phenomena modeled by advanced FDEs *cannot* be explained causally (from the past) just as phenomena modeled by retarded FDEs cannot be explained teleologically (from the future). No "cause" (past data) can explain the spontaneous convergence of advanced waves any more than a "purpose" (future data) can explain a divergent ripple.

Popper's error was the metaphysical stipulation that all phenomena *must* admit a causal explanation, so that there must be a way to make the future happen mechanistically. This is just a disguised and more confusing version of the same old argument for rejecting advanced interactions by invoking causality. (Recall that mechanistic causality was Aquinas' theological dogma, but is now masquerading as an argument about physics in a high-impact journal.)

Popper admitted that my arguments were "strong"[10]; he said he would respond in more detail later, but died before he could do so. In fact, there is no answer to the argument: the existence of advanced interactions must be decided empirically, not by appeal to confusing metaphysics.

Incidentally, we derive the following valuable conclusion from the simple example above. If advanced interactions exist, empirical proof of that would be the existence of some "spontaneous" phenomena which do *not* admit mechanistic explanations from the past.[11]

To better understand the empirical consequences, it is important to study mixed-type FDEs, for, not only Popper, but leading physicists, such as Richard Feynman, have got confused by reasoning intuitively about the issues involved.

2.4 Earlier theories

Thus, advanced electromagnetic radiation was admitted in the Wheeler-Feynman absorber theory of radiation.[12, 13] That theory sought to explain time asymmetric radiation damping starting from time-symmetric propagators (i.e., $\alpha = \frac{1}{2}$). The observed predominance of retarded radiation was explained by putting a condition on the cosmos: namely that it should be totally absorbing.

However, the arguments of Wheeler and Feynman are circular, as I pointed out long ago.[14] Wheeler and Feynman, themselves, did sense the possibility of such circularity and tried to resolve it. Like Popper, they stated that the past motions of particles are uncorrelated. However, in the presence of even a tiny amount of advanced radiation ($\alpha \neq 0$), correlations *will* travel into the past, just as they travel into the future with retarded radiation. So, with time-symmetric propagators the time asymmetric assumptions made by Wheeler and Feynman (or Popper) of random and uncorrelated past motions were wrong. Unfortunately, some people (e.g. [**?**]) are still using the Wheeler-Feynman absorber theory without addressing that error. My own version of the absorber theory predicted that small amounts of advanced radiation actually exist.[14] Issues concerning the absorber theory were summarised in an earlier article in this journal, also posted on the arxiv.[15]

2.5 The new theory

However, the existence of advanced interactions is now being considered from a fresh point of view,[4] unconnected with any absorber theory. To reiterate, the new point of view is this: it is incorrect to exclude advanced interactions on metaphysical grounds such as causality or Popper's argument. We should instead (1) set up a theory which includes advanced interactions, (2) determine its empirical consequences, and (3) compare those consequences with empirical observations to *then* decide whether or not advanced interactions exist.

From this general perspective advanced interactions and mixed-type FDEs are not limited to electrodynamics. The retarded gravitation theory, outlined earlier,[1] can be easily modified to include advanced interactions. That is, mixed-type FDEs are relevant to the interaction of all particles, not just charged particles.

3 Mixed-type FDEs

Mathematically speaking, a tilt results in mixed-type FDE of the following kind:

$$\dot{y}(t) = \alpha y(t+\tau) + (1-\alpha)y(t-\tau). \qquad (6)$$

(This is a simplified equation, and not the most general one possible.) This describes a situation where the rate of change of y depends upon both the future and past in different proportions. What happens in this situation?

Some general features are obvious. First of all, if the coefficient of the advanced term, α, is small, we can regard it as a perturbation on the retarded FDE model. That is, the retarded FDE model ($\alpha = 0$) would continue to describe the world to a first approximation: the world is approximately mechanistic, and future is approximately decided by the past. Time asymmetry persists, for the reverse situation is not true: future cannot be used to determine the past even as a first approximation.

Since, however, $\alpha \neq 0$, there is an advanced component, hence future cannot be *fully* determined or controlled from the past. Thus, full control is impossible from either past or future.

The curious conclusion, however, is this: even if we prescribe most of *both* past *and* future, that may no longer determine the present!

For example, consider the following mixed type FDE,

$$\dot{y}(t) = a(t)y(t+1) + b(t)y(t-1), \qquad (7)$$

where a has the same properties as above. For b we use the same function used in the retarded FDE case, namely that it has $\int_0^1 b(t)dt = -1$, but now stipulate that it has support on the interval $[2,\ 3]$.

On the interval $(\infty,\ 1]$ we have $b \equiv 0$ so (7) is a pure advanced FDE, and we get future branching solutions from past data as earlier. On $[1,\ \infty)$ we have $a \equiv 0$ so (7) is a pure retarded equation, and we get past branching from future data as before. Combining the reasoning used in the separate cases of retarded and advanced equations, we obtain the solutions below.

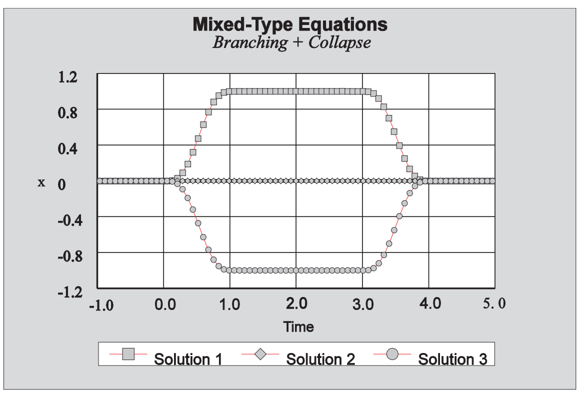

Figure 2: With a realistic mixture of history-dependence and a small amount of anticipation, the past still fails to decide the future. With this model, all phenomena do not admit mechanistic causal explanations, so that spontaneity really is possible. The existence of a small tilt is exactly the condition for time-travel of the second kind.

3.1 Consequences

That is, with a model which uses mixed-type FDEs, with a small advanced component, we have the following immediate consequences.

1. Retarded FDEs, would remain a good first approximation, so past data could still be used to *approximately* determine the future.

2. Time asymmetry persists, since future data cannot similarly be used to determine past, even as a first approximation.

3. Past data fails to decide future exactly. Even if we could prescribe the entire past accurately, that would still not determine the future.

4. There must exist "spontaneous" phenomena which do not admit an explanation from the past ("causal" explanation), in principle.

As is clear, this describes a situation closer to experience.

4 Time travel

The puzzling and counter-intuitive features of such a model are best brought out by the vast confusion in both physics and popular literature (and films) about time travel. Therefore, let us now turn to the question of time travel with a tilt in the arrow of time.[16]

In the popular imagination, time travel is associated with time machines. While physics has not defined life, it is easy enough to define a machine. The defining feature of a *machine*, any machine, is that it can be fully *controlled* (by pressing a button for example). But can a time machine be controlled?

4.1 Two types of time travel

To make matters clearer, time travel may be classified as being of two possible types: (1) with machines, and (2) without machines. Time travel of the first kind visualises time machines which physically transport entire human beings at the press of a button. In time travel of the second kind, only the occasional transfer of small bits of information from future to the past is contemplated, for example through an advanced signal coming from the future. With a "tilt" only time travel of the second kind is contemplated.

4.2 Time machines

However, time machines abound in the science fiction literature, the classic example being H. G. Wells' *Time Machine*. Travel across the galaxy, within the short lifespan of humans, is also visualised in the science fiction literature or films like Star Trek.

Time machines are also found in the scientific literature: for example, the Gödelian time machine based on the closed timelike curves which arise in the Gödel cosmos. (It is believed that given a timelike curve we can construct a rocket which will follow the curve. Such a rocket might require a large amount of energy, but the Gödel cosmos rotates and is not asymptotically flat; hence energy is not well-defined in it.)

Travelling large distances in a time span which is short (compared to light travel times, and the human life span) necessarily involves time travel. Hence, a more recent NASA funded study by Kip Thorne and others [17, 18, 19, 20] explored the possibility of time machines based on general relativity.

Thorne et al. focused on TWISTs: traversable wormholes in space time. A wormhole, such as one made in an apple by a worm, may connect two distant points of spacetime (analogous to the surface of the apple). If the apple is very big, like the cosmos, only a short time may be needed to travel through it compared to the time needed to travel around it (i.e., on the surface of the apple). Such a wormhole is called traversable if the tidal forces within it are not so strong as to kill the traveller. Thorne et al. concluded that such traversable wormholes could be built using negative energy. This possibility is visualised in Carl Sagan's novel and film *Contact*. Thorne even suggested ways of building negative energy, though he was earlier a strong advocate of the positive energy condition[2].

4.3 The tachyonic anti-telephone

This issue of control explicitly arose in the context of the tachyonic anti-telephone.[21]. Tachyons are hypothetical particles which move faster than light; if they exist, they can, in principle, be used to communicate with the past. The tachyonic anti-telephone is a hypothetical device which uses tachyons to allow one to converse with people in the past.

Suppose that, using this device, Shakespeare dictated the script of *Hamlet* to Bacon. Since Bacon came before Shakespeare he has

[2]and had earlier objected to my use of negative energy for gravitational screening

chronological priority, being the first person to actually write down the script of *Hamlet*. So, whom should we rightly regard as the author of *Hamlet*: Shakespeare or Bacon? To resolve this paradox, it was opined that though the cause is in the future, Shakespeare is the one who has *control* over the text of *Hamlet*, therefore he remains the author.

This naive belief that with time machines the future can be used to *control* the past involves a fallacy similar to Popper's pond. The fallacy is to put together two contradictory pictures of time: (1) the notion of time used in physics, according to which the evolution of the cosmos is determined by various equations ("laws of nature"), and (2) the time of our daily experience (mundane time), in which *we* make the future happen. These are contradictory not compatible as already explained. It is elementary that from contradictory hypotheses one may derive any desired conclusion. The solution is to remove the incompatibility, by making physics compatible with mundane time. If we do so by means of a tilt, we find that future cannot be used to control the past. That is, in the above scenario, Shakespeare has little or no control over the play Hamlet.

4.4 Other paradoxes

The resolution of the grandfather paradox and the Augustine-Hawking paradox is similar. In the grandfather paradox we use a time machine (constructed using relativity say) to send Tim back in time. Then we switch from the equations of physics to the (incompatible) mundane view of time, and suppose that acting on his own volition, Tim kills his own grandfather. So how could Tim have been born?

Similarly, the Augustine-Hawking paradox contemplates closed timelike curves in relativity. Then there is a switch to mundane time to say that given such a curve *we* can build a rocketship which will travel around the curve. Then Hawking concludes that the rocketship repeats its history, so we no longer have "free will"! This "free will", Hawking argues, is essential for the belief that we are free to perform any experiment we like. Once again, the contradiction arises from the unstated assumption that the equations of relativity on the one hand decide the future from the past, and on the other hand are compatible with mundane experience (that past does not entirely decide the future, leaving us free to do so). The paradoxical thing is that mundane time plus time travel is now being applied to try to create the past (which is implausible, even on mundane experience, or with a "tilt").

These mistakes made by top physicists and philosophers such as Feynman, Hawking, and Popper show that talking about the future interacting with the past is a tricky matter, made murkier by the constant intrusion of church dogma about "free will" as in Hawking's arguments which directly mimic those of the theologian Augustine, as I have explained at length elsewhere.[5]

4.5 No time machines

In fact, the science fiction scenario of hopping into a time machine and pressing a button to go back into the past assumes the possibility of controlling the time machine from the future. The consequences of the mixed-type FDE model outlined above make this impossible. Hence, there can be no time machines.

We can understand this conclusion in another way.[16] Just as retarded interactions increase entropy, advanced interactions *decrease* entropy. (On the advanced FDE model one has less information about the past than the future.) So, the mixed-type FDE model may be thought of as a model involving a combination of two sorts of processes: those which increase entropy and those which decrease entropy. Processes which decrease entropy (of the entire cosmos) may exist without conflict with the entropy law (second law of thermodynamics), provided that entropy increasing processes predominate, as they do in the mixed-type FDE model.

However, if entropy decreasing processes could be *mechanically* controlled, at the press of a button, that would allow us to decrease entropy by an unlimited amount. In short, a time *machine* (which can be controlled) would be a perpetual motion machine, and is hence impossible. Time travel can only be of the second kind: without machines. That is, while time travel of the second kind is possible (e.g. with a tilt), time machines are not.

4.6 Empirical evidence for time travel

Finally, let us reiterate the empirical consequences of a tilt. Hawking[22] asserted that if time travel were possible, we would have been invaded by hordes of tourists from the future. That argument naively assumes that time travel means time machines which, as we just saw, is impossible. Hence, going round looking for tourists from the future as evidence for time travel is absolutely the wrong kind of thing to do.

Instead, we should expect to observe some rare events that are spontaneous, and cannot be explained from the entire past.

For example, in the grandfather paradox, the time traveller's chronologically earliest appearance in space time (which is earlier than his biological birth from his mother's womb) would be such a spontaneous event, for it has no possible explanation from the past. (If it can be explained from the past, there is no time travel involved.) However, that is just a figurative example, for, as already explained, time machines are impossible.

Is mundane human creativity (more generally, the creativity of all living organisms), or just the existence of life, an example of such spontaneity? I believe so. If so, that would be empirical proof supporting the mixed-type FDE model against other models.

4.7 Spontaneity vs chance

Note that spontaneity differs from chance. Mathematically, this is readily understood. Spontaneity is modeled by mixed-type FDEs. "Chance" can mean many things: in this context we take it to mean stochastically perturbed retarded FDEs. Though the two models are mathematically very distinct, the solutions have some similarity. One distinction is this: spontaneity leads to reduction of entropy or increase in negentropy. Chance, on the other hand, as in classical thermodynamics, is believed to usually lead to an increase of entropy. Of course, chance too could lead to a decrease in entropy; however, as a rule of the thumb, one expects that the time scale for that to happen would be much longer than the time scale for decrease of entropy with spontaneity.

4.8 Microphysical consequences

Whether or not scientists accept the empirically observed creativity of living organisms, which is our most common experience, we at least now have a model for it. Biology is becoming increasingly important, and mixed-type FDEs are the first model which can account for some basic biological observations.

Since the effects of advanced interactions would be tiny one may imagine that they are especially important at the molecular level, for biological macromolecules, say. Currently, molecular simulation is done using outdated Newtonian many-body theory, and the Coulomb force. It would be interesting to redo this using first retarded FDEs and then mixed-type FDEs.

At the level of single particles, the consequences of the mixed-type FDE model are likely to be even more prominent. We will take up the relation of a tilt to quantum mechanics in more detail in the next and last article in this series. Mundane experience shows that living organisms are somehow able to scale up spontaneity to the macrophysical level. Is this relevant to the current technological problem of scaling up quantum computers?

5 Conclusions

Physics must be compatible with biology and our mundane experience. A simple way to achieve compatibility is to permit a tilt in the arrow of time. This corresponds to using mixed-type FDEs (for both electrodynamics and gravitation). The resulting (non-local) physics is non-mechanistic. With mixed-type FDEs full control of future is not possible from past and much less so is control of the past possible from future. This understanding resolves all paradoxes of time travel. Hence, also, time travel can only be of the second kind: without machines (i.e, time travel is possible, but time machines are not). The correct refutable consequence of realistic time travel is the existence of spontaneous events, not hordes of tourists from the future.

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