The Past-Future Asymmetry[1]

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Abstract

As the past-future asymmetry – that fact that we have records of the past but not the future – is still a puzzle the aim of this paper is twofold: a) to explain the asymmetry and its status in philosophy and physics and to critically review the proposed solutions to this puzzle; b) to advance a dynamic solution to the puzzle (which is lacking in alternative proposals) in terms of the 'universality' of the entropy relation in statistical mechanics.

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I. Introduction.

(...) energy is Nature's currency (...). W. Alvarez, *T.rex and the Crater of Doom* (1997, 8)

It is a commonplace that we can influence the future but not the past; that we have knowledge of the past but not of the future; and that on most accounts time travel into the past engenders paradoxes, which do not arise from time travel into the future. There exists therefore a *past-future asymmetry,* with these aspects. Although it is a commonplace, the asymmetry is, on reflection, also puzzling, since no such problems exist on the spatial analogue. We can return to a place we have visited in the past an indefinite number of times; we can alter a past place and an architect's plan incorporates knowledge of future places. Yet, in the temporal analogue, we are powerless with respect to the past, if not with respect to the future. There is no here-there space-asymmetry in the same way as there is a past-future time asymmetry. But why can we not visit past times in the same way that we can visit past places? A simple answer, inspired by presentism, is: the past no longer exists and the future has not yet arrived; only the present is real. But this simply postpones the puzzle: why does the past no longer exist? And when does the present exist? Saint Augustine may have a point when he says that the present moment is infinitely small for any event that is Now – say, the utterance of a word - can be subdivided into past and future moments. Note that the simple answer does not hold for the spatial analogue. For it could reasonably be said that the past exists in fossil records and old monuments. I can lay my hands on the Sphinx in a way that I cannot lay my hands on Bismarck. It should also be noted that the simple answer presupposes a dynamic view of time. It contradicts, as we shall see, the Special Theory of Relativity, which has destroyed the notion of a universal Now and seems to imply the so-called block universe, in which past, present and future are equally real. The block universe implies a static view of time. So does the widespread view that the fundamental laws of physics make no distinction between past and future, that they are time-reversal invariant.

Philosophers have provided a number of answers to the puzzle of the past-future asymmetry. The purpose of the paper is to review some of these standard answers and to revisit the question by appeal to the 'universality' of the entropy relation in thermodynamics and statistical mechanics. The discussion will necessarily be limited to the familiar macro-world because it is in this world that humans experience the past-future asymmetry. If this experience is to be explained by appeal to the notion of entropy, it is this notion as it appears in standard textbooks of statistical mechanics, which must carry the explanatory weight. (Connections of entropy with quantum mechanics and cosmology will be further discussed in the footnotes.)

II. The Block Universe.

There is a prominent view amongst physicists and philosophers – the block universe – on which the past-future asymmetry does not arise. This view harks back to antiquity (Parmenides) but has gained much support from the Special Theory of Relativity. As the Special Theory of Relativity is not a cosmological theory, it does not consider the expansion of the universe and the possibility of a cosmological arrow.[2] The block universe is *inferred* from the results of the Special Theory. According to this view, the physical world simply exists and the passage of time is a human illusion or at least a product of human perception. (Cf. Norton 2010) Imagine that the physical world is totally determined in the sense that today's state of the world determines tomorrow's state, just as yesterday's state of the world determined today's state, *ad infinitum*. Human beings are too limited to survey the physical state of the universe at its various stages, so that they are forced to view the world stages sequentially, which gives the impression of the flow of time. But this passage of time is merely a result of our perceptual limitations. Laplace's famous demon is able to see the vista of world history in one fell swoop. For the demon of superhuman intelligence all the stages of world history are already recorded like frames on a film. It is only the weakness of human perception and intellect, which requires humans to see the frames sequentially. For if the laws of physics determine the states of the universe, from A to Z, then these states already exist, in the past and in the future, irrespective of whether they have occurred (or not) or have been observed. By way of an analogy, consider that a mighty demon has singled you out to win next Saturday's jackpot in the national lottery. Then you already are the winner in the eyes of the demon, although for you the event has not yet occurred. On this scenario then the demon possesses equal knowledge of past and future affairs; and human beings come closest

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[2] It should be kept in mind that according to the latest cosmological discoveries, the universe not only expands but expands at an accelerated pace. See Schmidt (2005) Already in 1929 Edwin Hubble discovered a linear relationship between redshift and distance of galaxies, which is known as Hubble's law: $v=Hr$, where v is the radial velocity, r the distance and H is Hubble's constant.

to such knowledge in the laws of physics. Still this demon would not be able to change the past but time travel into the past and the future seem to constitute no problem.

Immanuel Kant arrived at a similar view. On the Kantian view time is a pure form of intuition – a condition of the mind, which apparently imposes a temporal order on the appearances. The result of this conception is that in the absence of humans, there is no time, no temporal order of things in themselves.

> It [time] is no longer objective, if we abstract from the sensibility of our intuition, that is, from that mode of representation, which is peculiar to us, and speak of *things in general*. (*Critique*1787, B51/A35)

Kant is worth mentioning in this connection because many physicists thought that the Special Theory of Relativity endorsed a Kantian view of time. Under this scenario of the block universe let us consider time travel into the future and time travel into the past for it will throw an illuminating light on the past-future distinction. Time travel is only possible if the block universe exists and its consideration will equip us with tools, which will enhance our understanding of the past-future asymmetry.

II. 1. Special Theory of Relativity: Time travel into the future.

Time travel into the future is a popular fiction, the best example of which is H. G. Wells' *The Time Machine*, in which a time traveller leaves his own time (1895) to travel into the distant future and then to return to his own present. Time travel into the future does not involve the kind of paradoxes, which beset time travel into the past. But it involves certain oddities, because time travellers into the future can learn of future discoveries, which they can take back to their own time. This possibility is illustrated by the tale of a time travelling mathematician. (Davies 2001, 114) The mathematician has struggled for years to prove an important mathematical theorem without success. One day he decides to build a time machine to explore if future generations have found a proof. He strikes lucky and finds an elegant proof in a mathematical journal published in the future. He returns to his own time and publishes the proof. The assumption, admitted on the block universe, is that the future already exists. Its discoveries and inventions can be harvested by a time traveller into the future. Time travelling into a pre-existing future is also a central feature of H. G. Wells's famous book, *The Time Machine* (1895). H. G. Wells operated with a notion of space-time, which is reminiscent of Minkowski space-time and central to the Special Theory of

Relativity. The latter involves the so-called twin paradox, which is sometimes presented as a form of time travelling into the future.

But there are important differences between the Wellsian and the relativistic notion of space-time.

The Wellsian time traveller travels along the temporal axis, which exists as a fourth dimension, in a spatial sense. Wells treated time as a fourth dimension in addition to the three spatial dimensions:

> There are really four dimensions, three of which we call the three planes of Space, and a fourth, Time. There is, however, a tendency to draw an unreal distinction between the former three dimensions and the latter, because it happens that our consciousness moves intermittently in one direction along the latter from the beginning to the end of our lives. (Wells 2005, 4)

The Wellsian time traveller uses his knowledge of future history to return to his own present and to warn people of the detrimental evolution, which has split the human race into the gentle Eloi and the ferocious Morlocks. The Wellsian time traveller uses time in a spatial sense, which means that it is a temporal road on which the time traveller can freely travel up and down, spanning centuries. The time traveller already hints at the existence of a Parmenidean block universe and a Kantian notion of time before it became associated with the Special Theory of Relativity. According to Wells, then, the only difference 'between Time and any of the three dimensions of Space' is that 'our consciousness moves along it.' (Wells 2005, 4, 94) Of the various snapshots of a person's life he says that they are 'Three-Dimensional representations of his Four-Dimensioned being, which is a fixed and unalterable thing.' (Wells 2005, 5)

On a first approach the Wellsian time traveller seems to be engaged in a form of future time travel, which is similar to a well-known scenario, which goes by the name of the twin paradox in the Theory of Relativity. Two twins, Homer and Ulysses, decide to confirm the time dilation prediction of the Special Theory of Relativity. Homer will stay at home, whilst Ulysses will go on a space journey to a nearby star, which lies 8 light years away. Ulysses will travel at a velocity of v = 0.8c, apart from short bursts of acceleration and deceleration. According to Homer's clock it will take twenty years for Ulysses to complete his journey – ten years for each leg -, so that Homer will be twenty years older. But for Ulysses the journey will only take 12 years, according to his clock, which measures time t', since his clocks slow down, as seen from Homer's clocks. If longer journey times were chosen for Ulysses to more distant planets and higher velocities, the temporal discrepancies between the earth inhabitants and the space traveller could amount to thousands of years. (Lockwood 2005, 48; Novikov1998, 77) Ulysses would then return to earth where history had advanced for millenia. He would, as some conclude, have travelled into the future, whilst aging only a moderate amount of time. (Davies 2001, 15-7) But Ulysses, on his return to earth, is as much a prisoner of time as the earth inhabitants he will find. He will not be able to return to the present, from which he started, as does the Wellsian time traveller; he will not be able to affect the course of history on earth after his voyage into space. 'There are no contradictions involved in Ulysses' travel. Both Ulysses and Homer move forward in time but the motion is slower for Ulysses than it is for Homer.' (Novikov1998, 232) In other words it is not real time travel into the future in the Wellsian sense.

Wellsian space-time is quite different from the representation of time in the theory of relativity, where space and time become welded into a union of space-time, and hence we speak of Minkowski space-time. In Minkowski space-time spatial and temporal lengths become subject to relativistic effects, known as time dilation and length contraction. For the Wellsian time traveller time is just another dimension in the geometry of space, which enables him to return to the year 1895, from which he departed far into the distant future. The time traveller experiences no relativistic effects. He enters his time machine in his own time and then observes as his particular location changes through the centuries, as his time machine accelerates along the temporal highway. But the theory of relativity has led to the same inference, which Wells draws. The 'four-dimensional being', which is 'fixed and unalterable', is the block universe. But different observers 'slice' this block differently, which leads to disagreements about their respective clock times and the simultaneity of events. According to the Special theory there exists no universal Now. Thus an inference is drawn from the results of the Special Theory of Relativity to the atemporality of the physical world. The latter is associated with the block universe.

> Due to the absence of an observer-independent simultaneity relation, the Special Theory of Relativity does not support the view that 'the world evolves in time'. Time, in the sense of an all-pervading 'now' does not exist. The four-dimensional world simply is, it does not evolve. (Ehlers 1997, 198)

The four-dimensional world does not evolve, which means that its states stretch both into the future and into the past, as seen from the present frame. Some limited form of time travel into the future seems possible, given the time dilation effect, as illustrated in the twin paradox. But a Wellsian time traveller would encounter a number of oddities, like the exploitation of future knowledge, for his own gain in the present. The question then arises, given the block universe, whether the Special theory permits time travel into the past and how it would deal with the paradoxes which arise.

II. 2. Special Theory of Relativity: Time travel into the past.

Can Ulysses travel into the past? Whilst time travel into the future does not seem to involve paradoxes, time travel into the past certainly abounds with them. To see the difference between mere oddities and paradoxes, consider Michael Dummett's story of a time traveller *from* the future who returns to the 20th century to visit a painter who, in the time traveller's own era, is regarded as a great artist. (Dummett 1986, 155) When the time traveller sees the artist's work he is disappointed and concludes that the artist is still to paint the paintings for which he will become famous in a future era. The time traveller shows the painter a book of reproductions of these famous paintings but then has to leave in a hurry, leaving the catalogue behind. The painter begins to copy these reproductions onto canvas. There are no obvious contradictions involved, yet the story strikes us as odd because it seems to involve no artistic creativity. The painter copies reproductions and produces paintings from reproductions. Whilst the time travelling mathematician finds a proof published in a future journal – it could have been produced by a future mathematician - there is no creativity involved in Dummett's tale. These are oddities, which seem to leave open the conceptual possibility of time travel *from* the future. Note, however, that in both scenarios – time travel *into* and *from* the future - it is assumed that the future already exists, which is a permissible assumption in the block universe view.

Time travel into the past also comes in two flavours. One is cosmological time travel, which involves such fanciful scenarios as the splitting of universes, closed time-like curves, baby universes and wormholes. (Cf. Gott 2001; Carroll 2010) There are considerable technical problems associated with these scenarios but, at any rate, they do not amount to the free time travel, which presumably is possible in conventional time machines. Conventional time travel, however, depends on the idea of time machines, which take Wells' time traveller into the past rather than the future. This kind of time travelling can lead to paradoxes. One, for instance, is the grandfather paradox. If time travelling into the past were possible, a time traveller could return to his own past, kill his relatives just before his birth, and thus prevent his own existence in the future. How then was he able to travel into the past? David Lewis maintains that time travel into the past is possible and that the paradoxes of time travel – like the grandfather paradox – are mere oddities. On the block universe view he can return to the past but he cannot change the past. 'Time travel constitutes a possible pattern of events in a four-dimensional space-time, with no extra dimensions.' (Lewis 1976, 149; cf. Davies 2001, Ch. 4; Novikov 1998, 233-4) Time travel into the past is logically possible because it involves no genuine paradoxes. It is true, Lewis admits, that a time traveller cannot return to, say, the year 1921, kill his grandfather and change the past. But the word 'can' is equivocal. What the time traveller can do (in the past) is compossible with certain past facts but not with others. Thus Lewis imagines that the time traveller can buy a gun, lie in wait for his grandfather, 'one winter day in 1921', but he cannot kill his grandfather who died in fact in 1957. The time traveller cannot kill grandfather because such an act is not compossible with the ensuing history of events. But, according to Lewis, a time traveller can visit the past, in the sense of a passive observer, who nevertheless performs certain compossible actions in the past, like observing grandfather. Yet Lewis overlooks that many more facts about the time traveller fail to be compossible with the past than he contends. What his time traveller is permitted to do – buying a rifle in 1921, renting a room, kicking a stone, observing grandfather – is already changing the past, since these actions are not compossible with certain physical facts about 1921.

The genuine time traveller is not part of the normal past. In the language of modern physics, macro-objects and their location 'decohere' through the interaction with the photons in the environment. (Schlosshauer 2008; Gell-Mann and Hartle, 1990, §5) All the macro-objects in 1921 decohered through the interaction with the environment. Hence a time traveller enters an environment, which has already decohered all the objects of the past. A time traveller would therefore necessarily have to change the past because photons and background particles would start bouncing off her/him. He would therefore change the past through energy exchanges but the past is fixed in *all* respects.[3] To appreciate the problem, consider the world of 1921 on the analogy of financial transactions but instead of a monetary balance there is an energy balance. On the credit side there is a certain amount of energy, which is available to do useful work; on the debit side there is a certain amount of lost energy (entropy), which can no longer be employed to do useful work. Although the total amount of energy in the universe of 1921 remains the same, every time energy is 'moved' from the credit to the debit side the overall entropy balance of the universe changes. If Lewis's time traveller were to perform these acts in 1921, s/he would change the entropy balance of the world of 1921, of which the time traveller was not originally a part. Changing the entropy balance of the past means changing the past, but what is done cannot be undone. Thus the suggestion that 'no paradox would ensue,' as long as the time traveller is 'inactive and invisible' (Lucas 1973, 50) will not do because even an inactive time traveller, through their mere act of visiting, changes the entropy balance in the past. Even if the time traveller merely observed events in 1921, s/he would change the past. For observation involves a photon interaction between a perceptual apparatus and an object. In the normal past, no time traveller's eyes spied on grandfather going about his daily routines. Photons bounced off objects in 1921 to be observed by grandfather's contemporaries. The past is fixed because there is no more decoherence left to do for the time traveller.

The time traveller could only change the past if he were part of it. A possible defence of time travel into the past is to say that the time traveller is already part of the past. (Nahin 1993, 208) Lewis suggests that a 'time traveller (...) is a streak through the manifold of space-time, a whole composed of stages located at various times and places.'[4] (Lewis 1976, 146) Such a suggestion is compatible with the view that objects in four-dimensional space-time exists as four-dimensional world tubes. Then the time traveller can indeed interact with people of the past (he is part of it) but he still cannot kill his grandfather. The suggestion involves the

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[3] Atkins (2003, 118 fn6) calculates that at room temperature (20°C) humans generate entropy at the rate of about 0.3 joules per Kelvin per second. One of the reviewers provided a helpful clarification: 'One can calculate that a person who eats 2000kcal/day converts energy at the rate of 2000kcal/day x 4187J/kcal x 1 day (24 hrs x 3600 seconds) = 97 Watts. That is, a person converts energy at a rate comparable to a 100W light bulb. If this all is transferred ultimately to the environment's internal energy via heat processes, one gets the entropy generation rate 100J/300K = 0.33J/K/sec. to one significant digit, this confirms (and also clarifies) Atkins' estimate.'

[4] Lewis's assumption of existence in stages implies that the time traveller's world line, which should start after 1921 with his birth, has earlier pieces in 1921, which must be cut off from his continuous world line stretching from his birth to his death.

weird notion that a time traveller consists of 'scattered stages.' (Lewis 1976, 149) Yet it is not really time travelling in the sense of leaving one's own period to visit another period of time. Lewis claims that, from the point of view of the early stage of the time traveller's existence, in which he is part of grandfather's present, the time traveller has the *ability* to carry out his murderous intentions, since the future looks open to him and his act would be compossible with facts relevant to 1921; yet some accident prevents him from doing so. Still from the point of view of the later stage of the time traveller this act of killing is impossible because grandfather died in 1957. So the later stage must 'cause' the earlier stage to fail. And yet, in the notion of the block universe, past, present and future are equally real and determined, so there is no need for backward causation. Either then the time traveller has already scattered stages of existence in the past, in which case he is not a genuine time traveller, or the time traveller does cross the boundaries of his own period of existence, in which case he needs to interact with the past, and thus change it.

In the latter case, Lewis's time traveller in a four-dimensional block universe neglects important thermodynamic features about the physical universe, which are essential for a consideration of the past-future asymmetry.

Given these features, it would be preferable to consider the past-future asymmetry without reliance on the block universe because this view – like the common-sense view – comes with a package of philosophical commitments, which skew the answer to the past-future asymmetry. The block universe is committed to the view that time is a human construct, which it derives from the well-known consequences of the Special Theory of Relativity: time dilation effects, the twin paradox and the relativity of simultaneity. The physical world itself is timeless on this view. But many commentators regard the Special Theory of Relativity as being concerned only with kinematic features, at the expense of dynamic features, which are part and parcel of the physical universe.[5]Hence there is a need to understand the asymmetry between the frozen past and the open future without reference to the block universe.

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[5] The claim that the Special theory is only a kinematic theory, which ignores dynamic features (Geroch1978, 20; Janssen 2009; Born 1962, Ch. VI.7) must be made with some provisos in mind. It is customary, in textbooks on relativity, to treat the Special theory as a kinematic theory only. But it is always possible to include dynamic aspects, if 'why' questions are asked about the behaviour of clocks and rods in relativistically moving systems. Why do clocks appear to slow down, and why do rods appear to contract in systems, which are moving inertially, at relativistic speeds, with respect to a system considered at rest? In order to answer such questions, dynamic considerations must be taken into account, which refer to the behaviour of the atomic systems, which ultimately make up the macroscopic systems. The idea is that time dilation and length

III. Some attempts to explain the past-future asymmetry.

Are there any independent reasons to ground the past-future asymmetry? Consider some attempts to explain the past-future asymmetry, which rely on more fundamental considerations and do not assume the 'truth' of the block universe.

1. Michael Lockwood (2006, Ch. 12) makes use of J. S. Mill's conditional model of causation, according to which the cause, *C*, of an event, *E*, can be broken down into a set of necessary and sufficient conditions. Jointly, the antecedent necessary and sufficient conditions can explain the occurrence of *E*. Lockwood introduces the term 'nasic conditions', which is an acronym for Millian necessary and sufficient conditions in the circumstances. A causal set of antecedent factors, *C*, is a nasic condition for the occurrence of event *E*, where appropriate background conditions are taken into account. A cause introduces a change in the normal running of things. Lockwood furthermore embraces Reichenbach's observation that 'one can infer the total cause from a partial effect but one cannot infer the total effect from a partial cause. (Figure I) (Lockwood 2006, 253)

Figure I: *Partial effects and total causes*

Partial effect → total cause → past (records)
Partial cause ↛ total effect ↛future
(Total cause = common cause of multiple effects, Reichenbach 1956, 180)

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contraction may not simply be perspectival phenomena but may find an explanation on the quantum-mechanical level. Such a view was proposed by Wolfgang Pauli and lately defended by H. Brown (2005; see also the discussion in Janssen 2009). It must be stressed, however, that such an atomistic theory of length contraction and time dilation is not yet available. It is also common practice in physics to use idealizations and approximations, which means that a kinematic description is preferred at the expense of a dynamic description, which may either be unavailable or unhelpful for the discussion at hand. It is therefore a pragmatic question to which extent a relativistic system is to be described kinematically only or also dynamically. On the standard interpretation, space-time is regarded as a fixed background and questions about length contraction and time dilation are merely perspectival features. (Whitrow 1980, §5.5) But such a convenient separation of kinematics and dynamics no longer applies in the General theory of relativity because space-time itself becomes a dynamic entity. (The author would like to thank D. Giulini for discussion on these points.) The Special theory can be dissociated from the static block universe in favour of a 'growing block' view, which has implications for the past-future asymmetry, but doing so would require reference to, say, thermodynamic features, as the author has spelt out elsewhere, see Weinert 2010a; 2010b.

Reichenbach himself points out that the '*inference from the partial effect to the total cause* is typical of all forms of recording processes.'[6] (Reichenbach 1956, 180; italics in original) Partial effects are typically sets of conditions, which obtain locally in conjunction with other partial effects and general background conditions. Consider Karl Popper's pond analogy: when a stone is thrown into the centre of a pond it will create divergent waves, which will break on the shore of the lake. (Popper 1956, 538) From the arrival of divergent waves and the breaking of the waves on the shoreline it can be inferred that a disturbance at the centre caused the divergent waves. The analysis of the divergent waves may tell us something about the physical properties of the object. But knowing only partial causal conditions prevents us from inferring what the total effect of these conditions will be. Thus knowing that a stone has been launched at an angle α, and that some additional parameters are satisfied, we can calculate various characteristics of its trajectory; but if we do not have more information we cannot predict that it will hit the middle of the pond, that it will cause divergent waves, that it will startle a duck which flies off into the sight of a hunter's rifle. Using these notions, Lockwood attempts to explain the past-future asymmetry. He holds that 'events frequently have highly localized nasic conditions in the past' but they do not tend to have 'highly localized nasic conditions in the future'. (Lockwood 2006, 253) Lockwood's view on the difference between past and future can be summarized as follows:

a) Past outcomes are genuinely overdetermined by their currently prevailing partial effects. The totality of various partial effects overdetermines the total cause. Hence, in line with Reichenbach's inference, we can infer the total cause from their various partial effects. Note that we have to learn a lot about the partial effects to be able to exclude alternative causes, and ensure that the total cause identified has a much higher probability of explaining the effect than alternatives causes. (Such painstaking detective work went into the identification of the cause of the extinction of the dinosaurs 65 million years ago. According to the Alvarez

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[6] This conclusion does not necessarily hold under conditions of uncertainty about partial effects and when the cause-effect relationship is a many-to-one relation, as it may occur in irreversible thermodynamic processes. For instance, the present temperature of a gas near equilibrium may have multiple microscopic configurations as a cause. For a discussion see Schlegel (1968), 176-80.

hypothesis it was due to an impact from outer space rather than volcanic activity; but it has not yet been established whether the impact was due to an asteroid *or* a comet; see Alvarez 1997)

b) By contrast, events do not have highly localized nasic conditions in their future. (Lockwood 2006, 253) Whilst effects radiate out from some highly localized causal event, it is not the case that some future events are so highly localized that they could serve as nasic conditions for present events. This fact has been labelled the 'law of conditional independence': incoming influences emanating from different directions in space are uncorrelated. (Penrose and Percival 1962; cf. Price 1996, 118) Consider again Popper's pond analogy to illustrate this difference. When a stone is thrown into the middle of the pond, its waves will diverge towards the shore. From the divergent waves we can infer at least that some local disturbance caused the ripples on the surface of the lake, although further investigation may be required to determine the nature of the disturbance. By contrast there are no highly localized nasic conditions on the shore of the lake which would cause convergent waves towards the centre. That is, we do not expect a disturbance in the middle of the lake to be caused by correlated conditions on the shore of the lake. It is highly unlikely that conditions on the lake shore will conspire to produce converging waves towards the centre where they will lift a stone from the bottom of the lake. Thus Lockwood's explanation of the past-future asymmetry boils down to the statement that present events are conditionally dependent on past events, whilst present events are conditionally independent of future events.

But seen in this light Lockwood's analysis is more like a redescription than an explanation of the asymmetry between past and future events. We can always ask for a physical mechanism why 'nasic conditions' are typically highly concentrated in the past and why future actions cannot be regarded as nasic conditions for current events.

2. David Albert introduces a distinction between the prediction of future states and the retrodiction of past states and distinguishes retrodictions from records of past events. (Albert 2000, Ch. 6) Both predictions and retrodictions are inferences from the present state of affairs to either a future state of affairs (say, the occurrence of a solar eclipse) or to a past state of affairs (say, the identification of an unidentified celestial object in Galilei's notebook as the planet Neptune). The ability to make predictions and retrodictions depends on the use of appropriate equations of motion, and the availability of boundary conditions. But according to Albert most of what we know about the past cannot be derived from retrodictions; we know it by means of indelible records. Such past records are irreversible data of past events. According to Albert we have epistemological access to the past other than by means of retrodiction, because records are related to a certain feature of the Second Law of thermodynamics. This feature involves the so-called Past Hypothesis, which states that 'the world first came into being in whatever particular low-entropy highly condensed big-bang sort of macro-condition.' (Albert 2000, 96; see also Novikov 1998, 204ff) Albert's thesis is that we have records of the past because our experience is 'confirmatory of the past hypothesis but not of any future one'.[7] (Albert 2000, 118)

But it seems decidedly odd to say, as Albert does, that 'the reason there can be records of the past and not of the future is nothing other than that it seems to us that our experience is confirmatory of a past hypothesis but not of a future one.' (Albert 2000, 118) It seems implausible to relate the existence of past records to the beginning of the universe and its particular energy state. Rather, as Murray Gell-Mann and James Hartle observe, 'a record is a present alternative, that is, with high probability, correlated with an alternative in the past.' (Gell-Mann and Hartle 1990, §10) The current state of the world is branch-dependent on the past state, where the past state may have happened quite recently: it is 'contingent on events that have happened.' (Gell-Mann and Hartle 1993, 3346) Lockwood seems to be closer to the mark with his suggestion that nasic conditions are highly concentrated in the past but not in the future. But Lockwood redescribes the asymmetry rather than explaining it. By contrast Albert hints at a connection between the past and the Second law of

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[7] It should be mentioned in this connection that both Lockwood's assumption that future events are uncorrelated with respect to the present and Albert's assumption that the entropy of the Big Bang is lower than the entropy of the Big Crunch have been questioned in the literature, see Price (1996); (2002); Schulman (1997).

thermodynamics but implausibly explains our experience of the past as confirmatory of a low-entropy Big Bang.[8]

3. Finally, Storrs McCall defends the view that the difference between past and future is that the future comprises many possibilities, while the past is actual and unique. (McCall 1994, Ch. 1, 2). It is not based on whether we can travel to the past, or whether we can change the past, or whether entropy increases, though it does imply that we cannot change the past. It is incompatible with the static block universe, since if the world is indeterministic (or probabilistic) this view requires that every physically possible future be situated on a different 4-dimensional branch, and that the probability of any future event is specified by the proportion of future branches on which that event occurs. The model is also incompatible with the view that time flow is a subjective phenomenon. The model is in the shape of a tree, the past being a single trunk, the future a multiplicity of branches, and the present the first branch point. (Figure II) Time flow is represented by the vanishing or “falling off” of branches, the one branch remaining being the “actual” one that becomes part of the trunk. The present moves stochastically up the tree. It would continue to do so even if all conscious beings in the universe died out. This view attributes the evolution of the universe, from past to future, from possibility to actuality, to the process of ‘branch attrition’.

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[8] It is now commonly assumed that our universe started in a low-entropy Big Bang and has expanded every since. This expansion, which actually accelerates, as well as the effects of gravity, establish a connection between the thermodynamic and cosmological arrows of time. Many cosmologists now believe that the universe will end in what the 19th century termed a ‘heat death’, that is, a total dissipation of energy, which will make life impossible. (See Carroll 2009; Penrose 2010) In this sense there is a connection between the expansion of space and the spatial spreading of energy states.

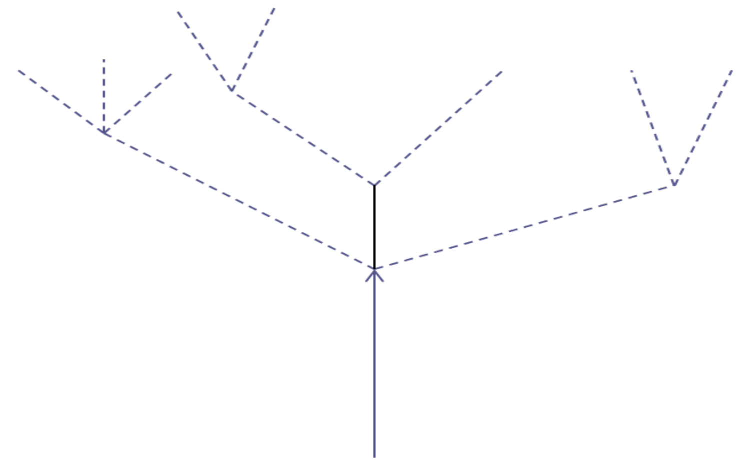

Figure II: *Branch attrition in the branching tree model, indicating the probabilities of the occurrence of future branches*

This tree model must be compatible with the principle of the Special Theory of Relativity.

> Since in the tree model the future is branched while the past is single, the way in which the universe tree branches will have to be relative not only to a time but also to a frame of reference. (McCall 1994, 10)

As McCall continues, the branched model makes each instantaneous state of the universe

> relative to a frame-time, i.e. relative both to a time and to a coordinate frame. (…) Becoming, then, is represented in the model by branch attrition within every frame-dependent or hyperplane-dependent branched structure. This does not make becoming observer-dependent, but it does make it frame-dependent. Time flow is not absolute, but is relative to a reference frame. (McCall 1994, 32-3)

In the tree model, branch attrition seems to describe the past-future asymmetry in an objective, observer-independent way. But branch attrition is not a known physical mechanism. The model only serves a descriptive purpose. It describes metaphorically why the frozen past is different from the potentialities of the future, but it does not *explain* the past-future asymmetry. Why, for instance, can we not descend down the tree trunk and return to the past? What is needed to make McCall's tree model plausible is a known physical mechanism, which can account for 'branch attrition'. Such a mechanism was also the missing element in Lockwood's redescription. In the recent physical literature the notion of decoherence has been proposed as a mechanism, which can explain the emergence of quasi-classical sets of histories, i.e. the individual histories of our classical world, which obey, with high probability, 'effective classical equations of motion interrupted continually by small fluctuations and occasionally by large ones.' (Gell-Mann and Hartle 1993, 3345, 3376) Decoherence signifies the emergence of classical macro-states from their underlying quantum states, as a result of measurements by their environments. Decoherence leads to different alternative histories for the universe, to branch-dependence of histories and the permanence of the past. (Gell-Mann and Hartle 1993, §10) Branch-dependence means that individual histories are 'contingent on which of many possible histories have happened.' (Gell-Mann and Hartle 1993, 2246-7) The permanence of the past expresses the feature

> of a quasi-classical domain that what has happened in the past is independent of any information expressed by a future projection. Neither the decoherence of past alternatives nor the selection of a particular past alternative is threatened by new information.(Gell-Mann and Hartle 1993, 3354)

Since decoherence can be understood as the carrying away of phase information into the environment, leading to noise (Gell-Mann and Hartle 1993, 3364, 3376), and as a form of continuous measurement of quantum systems by the environment, leading to entropy (Schlosshauer 2008, 41), decoherence leads to irreversible past records. But irreversibility is a feature of the Second law of thermodynamics and hence it is appropriate to associate the past-future asymmetry with the increase of entropy.[9]

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[9] Although the Second law of thermodynamics was discovered in the middle of the 19th century, it is a minor scandal in physics that no unanimous agreement exists on its precise meaning. For the purpose of the following discussion, which uses the notion of entropy to discuss a mechanism for the past-future asymmetry, it will be sufficient to use the established sense of the notion of entropy as it is discussed in statistical mechanics. As human awareness of the past-future asymmetry concerns macroscopic systems, a quantum-mechanical version of entropy, which refers to quantum states (see note 11), appears to be less useful than the statistical version of entropy. Furthermore, the notion of entropy can be used either to describe the asymmetries in the familiar environment – in which case we should speak of the *passage* of time – or in a cosmological context, in which case we should speak of the *arrow* of time. In the cosmological context, entropy is used to consider both the origin of time's arrow and the ultimate fate of the universe. The universe itself can be understood either as 'our' universe or as the ''multiverse', of which our universe would be only one universe in many parallel universes. (Cf. Carroll 2008; 2010; Krauss and Scherrer 2008) Although the arrow of time, and its origin, is a challenging task for cosmologists, the present discussion will be limited to the passage of time in our familiar environment, because it is this familiar environment, which provides us with the past-future asymmetry. It should be noted that our awareness of asymmetric phenomena is compatible with different topologies of time. For instance, the current understanding in cosmology is that the universe will expand forever, it is in fact accelerating, and hence its ultimate fate will be what the 19th century called the 'heat death' – the total dissipation of all energy gradients. This scenario suggests a linear topology, that our universe had its beginning in a big bang event but will expand forever. For the inhabitants of such a universe the asymmetry of events, the passage of time, would be the familiar experience. But if the universe, our universe, expanded from a big bang event to a maximum point of expansion and then began to re-contract to end in a big crunch (which may or may not be similar to the big bang event in terms of entropy) the inhabitants of such a universe would still experience the passage of time as asymmetric. The topology of such a universe would be a closed circle – a

IV. Entropy

Note that all of the approaches considered so far are engaged in obtaining a clearer conceptual understanding of the past-future asymmetry but they fail to provide a dynamic explanation. It is characteristic of philosophical discussions to consider the conceptual possibility of, say, visiting the past without due attention to physical possibilities. The latter are regarded as merely pragmatic limitations. But as we have seen in the case of Lewis's time traveller physical considerations can have serious conceptual consequences for the argument at hand. Albert alluded to a dynamic reason for the past-future asymmetry in terms of the Second law of thermodynamics, whilst decoherence encodes a physical mechanism to obtain the classical domain from the quantum realm.

This section of the paper will consider a dynamic reason for the past-future asymmetry, which expands on the earlier criticism of Lewis's time travelling scenario and makes full use of the Second law of thermodynamics, and the notion of entropy increase. It leads to a general thesis: the entropy of past states is fixed and we cannot change them but we can influence the entropy of future states.[10] As mentioned above, the discussion will be confined here to classical notions of entropy, because humans experience the past-future asymmetry in the macro-world.

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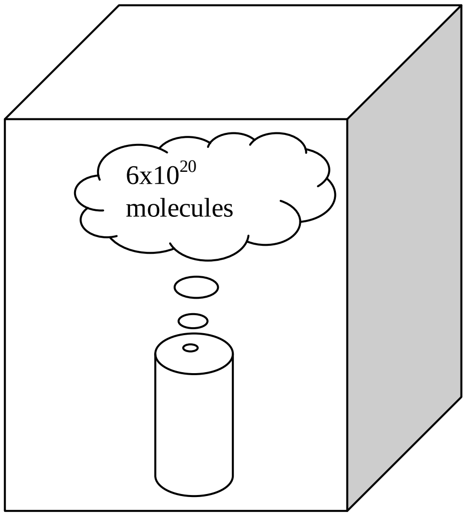
closed time-like curve – but every section of it would display the familiar asymmetry of our experience. For this reason the entropy notion of the following discussion in section IV is restricted to the passage of time. The difference drawn here between the local passage of time and the global arrow of time can be described as that between an asymmetry in local regions of space-time and the whole of space-time. (Davies 1974, §2.1)

[10] In the present article entropy is taken to be an important feature of physical systems, in line with classic statements in Davies (1974) and Penrose (2005; 2010). We also assume the validity of the notion of entropy as defined in Statistical mechanics and as an accepted part of standard textbooks. For instance Carroll (2010, 32) calls it Nature's most reliable law. It should be noted that entropy is difficult to measure experimentally and that it is actually inferred from macroscopic parameters, like temperature, pressure, work. (Čápek/Sheehan 2005, 26) However, it cannot be pretended that 'entropy' is an uncontested notion. There exists, for instance, a variety of different definitions of entropy in the literature; and the Second law can be stated without reference to entropy, since in its original Clausius statement it says that all work can be transformed into heat but not all heat into work. (Cf. Čápek/Sheehan 2005, Ch. 1; Uffink 2001; Leff 2007) Furthermore, the Second law lacks a thorough theoretical proof but 'its empirical support is vast and presently uncracked'. (Čápek/Sheehan 2005, 42; Sklar 1993, Ch. 7) Although its theoretical foundation is uncertain, it rests on firm empirical evidence, which justifies its use in the present argument. Despite the disagreement about the theoretical grounding of entropy, it will be assumed that a spreading descriptor (Leff 2007, 1744) is an appropriate tool to support the argument in favour of the past-future asymmetry.

It is customary in standard textbooks to describe the increase in entropy in terms of an increase in disorder or loss of information. For instance, the physicist Kip Thorne (Thorne 1994, 424) illustrates the notion by the case of a father who arranges the toys of his child's playroom in such a way that all the toys are stacked in one corner of the room. It is clear where the toys are. Then the child comes to play and scatters the toys all over the room. There is loss of information as to the whereabouts of the toys. When the child has grown tired and is put to bed, the father returns and restores the toys to their former ordered state. The information is restored. According to the Second law the overall entropy of the playroom situation, regarded here as a closed system, has increased because the father has to spend energy to restore order in the playroom and the child has spent energy to play (and spread the toys). However, this widespread illustration can also be very unhelpful because increase in entropy can be accompanied by an increase of order. For instance, the overall entropy of the universe since the Big Bang is commonly understood to have increased but the universe today exhibits a great amount of order as seen in the formation of solar systems, galaxies and clusters of galaxies. (Carroll 2008; Davies 1974, §4.6)

A better way to understand entropy is in terms of a *spreading* descriptor: the microstates of a system spread into the available phase space, thereby increasing the entropy of the system. To illustrate, consider a sealed container, in which a perfume bottle is placed. There are about 6×10^{20} molecules in this bottle. (Figure III) When the lid is removed from the bottle the molecules will begin to spread and mix with the air molecules. The amount of spreading is a function of time, since the perfume molecules will begin to occupy the

Figure III: *Expanding molecule cloud in phase space; spreading as a function of time*



space in the container. If we take a snapshot of the spreading at time t_1 ($t_1 > t_0$) we observe a certain amount of spreading; at a later time, t_2 ($t_2 > t_1$), the spreading will have increased. This spreading could serve as a primitive clock. Statistically speaking the amount of spreading will increase with high probability until the system reaches equilibrium. We can only stop the spreading if we decide to interfere in the system from outside, for instance by partitioning the box before the perfume molecules have filled all the available space. But then the spreading and increase in entropy are stopped by the injection of external energy.

This spreading metaphor may be made more precise in the following manner:

> An increase of entropy may be said to correspond to a “spreading” of the system over a large number, *W*, of occupied quantum states. Alternatively one might say that entropy is a measure of the extent to which the system in question is unrestrained; the less constrained it is, the greater the number of its accessible quantum states for given values of those constraints which exist.’ (Denbigh/Denbigh 1985, 44; cf. Čápek/Sheehan 2005, 17)[11]

Here W is the thermodynamic probability, which is related to entropy by the Boltzmann relation: $S = klnW$. In order to appreciate this relation, which is the definition of entropy in statistical mechanics, we must distinguish the macrostates of a system, like pressure and temperature, from its microstates, which is the constellation of the microscopic constituents of the system. The molecules from the perfume bottle are the microscopic elements, while the pressure of the molecules on the container wall is a macroscopic state. It generally holds that any macrostate corresponds to a large number of microstates but that any given microstate corresponds to one given macrostate. A useful analogy is to think of the number of ways, in which you can pay for an item that costs, say, £10. You may tender a ten pound note, ten one pound coins, twenty fifty pence coins, one thousand one pence coins etc.. The coins and notes correspond to the microstates, whilst the value of £10 corresponds to the macrostate. Thus any given macrostate in a physical system, like pressure or temperature, can be realized by a certain number of microstates. W is then the number of ways in which a macrostate can be realized. If W=1 the macrostate is

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[11] The quote explains spreading in terms of accessible quantum states. In quantum mechanics entropy is a state defined via the density matrix, ρ: $S_{\vartheta N}(\rho) = -kTr[\rho\, ln(\rho)]$, where the left-hand side of the equation is a measure of ‘the quantity of chaos in a quantum mechanical mixed state.’ (Čápek/Sheehan 2005, 17) Although the quantum mechanical definition is more basic, the past-future asymmetry is concerned with the macroscopic experience of human agents, which justifies the restriction of the discussion to a classical understanding of entropy.

in a state of least spreading but as W increases, the spreading of the microstates increases, and so does entropy. The spreading of the energy states of the system is at all times accompanied by a distribution of the energy states in a phase space. (More precisely, W is related to the number of arrangements in Γ-space, a six-dimensional space, which specifies the microscopic configuration (q_i, p_i) of an N-particle system. This description is needed to account for the motions of the individual molecules, in terms of momentum.) Although it is customary to describe the increase in entropy as an increase in disorder, it is more appropriate to think of the increase in entropy in terms of the increase of W.

> A single system's phase point traverses the phase space in time as particles move and exchange energy. This traversal provides a graphic image of a system's particles spreading and exchanging energy through space, as time progresses. Energy, space, and time are all explicitly involved. In this sense, entropy can be thought of as a *spreading* function. (Leff 2007, 1750; italics in original)

To explain this spreading function further both the spatial spreading of processes and the temporal spreading of system states over accessible states must be considered. (Leff 2007) For instance, in the case of the child's playroom the spreading of the toys resembles a spatial disintegration of a neat pile but spatial spreading makes no explicit reference to energy balances. By contrast temporal spreading refers to the expansion of system states into the available phase space, as expressed in Boltzmann's statistical definition of entropy.[12] Boltzmann's statistical definition refers directly to the 'colonization' of the available phase space by the microstates, since the Boltzmann entropy is a measure of the number of microstates that are compatible with a given

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[12] In order to emphasize the importance of the spreading function, reference should be made to Liouville's theorem, which states that the temporal evolution of classical dynamic systems preserves volumes of phase space regions but not the shapes of these regions. A rather uniform region in the initial stage can become very fibrillated after the spreading of the system. Liouville's theorem in classical mechanics states that a volume element along a flowline conserves the classical distribution function $f(r, v)drdv$::

$$f(t + dt, r + dr, v + dv\,) = f(t, r, v)$$

(Kittel/Kroemer 1980, 408; Albert 2000, 73f). In other words, if we consider trajectories in phase space, which include both position and momentum of particles, then the equation of motion of such systems can be expressed in terms of its Hamiltonian, H. H expresses the conservation of total energy of the system. Liouville's theorem then states that the volume of the phase space, which an ensemble of trajectories occupies, remains constant over time. Liouville's theorem shows that the volume of the phase space regions is invariant over time even though the expansion of the trajectories within this volume can start from different initial states or end in different final states. But an immediate consequence of this theorem is that even though the *volume* is preserved the *shape* of this phase space region is not preserved and this implies a dynamic evolution of the trajectories within this region. For two shapes cannot differ from each other without an evolution of the trajectories. It also implies that a reversed evolution of the trajectories will preserve the volume but not the shape and hence that reversed trajectories need not be invariant with respect to the shape of the phase space region.

macrostate. Even though the equations of motion are time-reversible invariant, the spreading of, say, gas molecules into the available phase space occurs because there are many more ways of populating a larger than a smaller space. Another way of saying this is that, given the spread of the later state, the probability of the coherence of final conditions, which would be required for the temporal inverse of typical trajectories, is so vanishingly small that their physical realization is negligible. This argument appeals to the differences in the topology of the phase space of a system under consideration. (Hill/Grünbaum 1957)

The idea of spreading of energy states can be applied to the past-future asymmetry. Any past moment corresponds to an amount of spreading over the available phase space but the present moment, from which the past is observed, corresponds to a greater amount of spreading. As the present is an open system, we cannot manipulate the ensemble of microstates to return them to their past constellation.

As we have seen records are evidence of the branch-dependence of current states on past states. If past records are considered as decohered states – i.e. the result of an interaction with their environment, technically described as a loss of interference terms – then decoherence leads to an increase in entropy. Hence the time traveller, considered above, cannot decohere past records. Records reflect a differential in energy states between the present and the past. Records are evidence of past entropy states, but these are not necessarily ordered states – like a well-preserved fossil – but can also be disordered states – like a decomposed organism. One immediate problem with this suggestion is that, on purely statistical grounds, records of the past are as likely to have emerged from a higher entropy state, by a fluke fluctuation as from a lower energy state.[13] (Cf. Weizsäcker 1937; Earman 1974, §7; Horwich 1987, Ch. 4; Carroll 2010, Ch. 9) Earlier, we referred to the notion of decoherence, which is an umbrella term to describe various physical mechanisms, which leads to different alternative histories and branch-dependence. In

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[13] The temporal neutrality of statistical relations also throws up the notorious problem of Boltzmann brains: thermal fluctuations may give rise to human brains and their complexity in an otherwise high-entropy universe. The universe surrounding human observers is manifestly not in a state of high-entropy, and if it is the result of a fluctuation it was not a random fluctuation, if Carroll's scenario of baby universes is accepted. (See Carroll 2008; 2010, 221-4, 355-9) In a different context, Horwich (1987, 54) makes the relevant suggestion that the 'time reverse of every possible process is equally possible, though not equally probable.'

order to deal with the objection, just mentioned, it is important to recall the fundamental fact, that in the theory of decoherence it is normally not the case that every history of a system can be assigned a probability. (Cf. Craig/Singh 2011) In other words, some possible histories have a negligibly small probability of occurring, whilst others, like the familiar histories of classical systems, have a high probability. Thus, whilst all histories are equally possible they are not all equally probable. As shown below, most systems have a negligibly small probability of returning to their initial states. The probability of a history depends on the level of its entanglement with other systems, which act as a measuring environment. And decoherence needs to be paid for by an increase in entropy. (Schlosshauer 2008, §2.8)

Why concentrate on entropy? First, it is a universal relation, in the sense that no empirical violation of the Second law is known. (Čápek/Sheehan 2005, 13, 42; Carroll 2010, 284) Even though it is only statistical in nature, according to statistical mechanics, it affects many other arrows of time. Second, it provides a dynamic explanation of the past-future asymmetry, which was missing from the other accounts. The fact that the Second law is statistical in nature may invite certain reservations. It means that, in principle, a state in higher entropy may spontaneously return to a state of lower entropy, and such an unobserved reversed process is compatible with the Second law. For instance, a broken cup may spontaneously reassemble itself. In fact, according to Poincaré's theorem, a finite mechanical system, whose state S_o is characterized by the position (q_k) and momentum (p_k) variables of its micro-constituents, will return as closely as possible to the initial set of variables, in Poincaré recurrence time. Thus the Second law, in its statistical version, gives rise to *de facto* (not *de jure*) irreversibility.

The importance of *de facto* irreversible processes in the past-future asymmetry has been emphasized by H. Reichenbach and A. Grünbaum. *De facto* irreversible processes are to be understood as complex processes whose time-reverse is highly improbable in the history of the entire universe, although they remain theoretically possible. If they occurred, they would not violate the laws of the micro-processes in terms in which the macro-processes are understood. The fact that the reversibility of physical processes, if it occurs, is highly unlikely and does not violate the Second law, has been called weak T-invariance (Grünbaum‘s notion of *de facto* irreversibility).

This weak T-invariance must satisfy the

> requirement that its time inverse (although perhaps improbable) does not violate the laws of the most elementary processes in terms of which it is understood. (Landsberg 1982, 8)

This take on things implies that the T-invariance of physical laws is compatible with asymmetric solutions, if appropriate boundary conditions are taken into consideration. (Price 1996, 88-9, 96; Denbigh 1981, Ch. 6.2)

Thus it is not a violation of the Second law that a cold cup of coffee spontaneously reheats itself at some stage in the future history of the universe – through a fortunate self-rearrangement of the molecules – but such behaviour has never been observed. Nor is it expected to be observed in the remaining course of the history of the universe. But how improbable is the reversal of such processes? One aspect of an answer to this question is that the Poincaré recurrence time only exists for isolated systems in classical physics but modern quantum physics emphasizes the importance of open systems.

> Another version of the same argument is well known: why not reverse all the molecules’ velocities so the system will go back to its initial state? The answer is again probabilistic: among all possible velocity distributions, the ones returning to the initial state have a negligible weight. (Omnès 1999, 239)

This argument relates the probability of occurrences to the available number of realizable states, i.e. the inequality in the topology of the initial and final states. If *W* is much greater for the later state, it reduces the probability of the coherence of final conditions to return the system to its initial lower-*W* state.

To illustrate the negligibly small probability of the recurrence of a system to its initial state, note that the time scale for a Poincaré recurrence is of the order of $10^{10^{25}}$ years for a gram mole. (Denbigh/Denbigh 1985, 140; Ambegaokar/Clerk 1999) Or to give an example on the cosmic scale, cosmologists estimate the amount of time it would take for a volume of gas, containing 10^{18} molecules, to return to its initial state (position and momentum variables). It is assumed that each molecule (with an average molecular velocity of $5x10^{14}$ cm/s in both directions) would return to within 10^{-7} cm of each initial position variable and within 10^{2} cm/s of each velocity variable. The estimated time for a return to such a configuration would require $10^{10^{19}}$ years, which is well beyond the estimated age of the universe (~10^9 years). (See Schlegel 1968, 52-3) It has long been recognized that an increase in entropy should not be used to identify the arrow of time, precisely because of the theoretical possibility of recurrence. (Schlegel 1966) Although we have *de facto* irreversibility, we have *de jure* reversibility of physical systems, which obey the fundamental equations of motion both in classical and quantum physics. It remains nevertheless true that *de facto* irreversible processes are so overwhelmingly probable that they can serve as a dynamical explanation of the past-future asymmetry in our familiar world.

If the increase in entropy is a *de facto*, irreversible process, should arrows of time be linked to entropy increase? Would the arrow of time not reverse if a given system implausibly returned to its initial state? The answer adopted here is that it would be a mistake to identify arrows of time with entropy increases, because of the t-invariance (reversibility) of fundamental equations and the temporal neutrality of statistical relations. Several writers have warned against 'taking thermodynamics too seriously.' (Callender 2001; Uffink 2001; Horwich 1987; Earman 1974) But this recognition does not prevent us from regarding entropy – or more precisely, the thermodynamic probability *W* - as one of the *criteria* from which the anisotropy of physical time can be inferred. There are many parallel processes in the universe – a rise in the entropy gradient of many systems, the cosmological expansion of the universe, the emergence of classical systems through decoherence mechanisms – which all indicate a past-future distinction. In addition it must be recognized, as Popper's lake analogy illustrates, that the boundary conditions of the universe – in the present case the low-entropy initial conditions of our universe – must be taken into account when we seek to account for the arrows of time. A complaint of proponents of temporal symmetry against this approach has been that the boundary conditions are put in 'by hand.' But this objection has lost a lot of its force since present-day cosmology is precisely concerned with explaining events, like the Big Bang and its low entropy initial state. (Cf. Gott 2001; Carroll 2010; Penrose 2010) This research also strongly suggests that there is no evidence of a future low-entropy state of the universe. Even proponents of temporal symmetry concede that t-symmetric laws may have t-asymmetric solutions. (Earman 1967, 548; Price 1996, 88) When all these processes are taken into account we possess reliable criteria from which to infer the anisotropy of time.

V. Conclusion.

On this entropy account, then, we can explain several aspects of the past-future asymmetry:

1. We cannot travel into the past in ordinary time machines because even as non-participant observers we would interfere with the entropy balance of the past, which is fixed. In other words, time travellers cannot manipulate the conditions, which would allow them to roll back the amount of spreading that has taken place between, say, 1921 and 1957. At the time of grandfather's youth this distribution of the phase space had reached a certain configuration: going back to the past, even as an innocent bystander would necessarily change this configuration. But this cannot be done because what separates grandfather's configuration of the phase space from that of the time traveller's – his grandson – is a change in the distribution of states. One could say that the change in the distribution of states – for which grandfather was causally responsible – made grandson possible. The trajectory which led from grandfather to grandson is not a spatial trajectory, on which we could travel up and down a certain number of times. This is Wells's mistake. It is a spreading of energy states, which cannot be undone, because the energy spent on the trajectory has changed the entropy balance of the states and this state cannot be regained by the input of new energy. The spreading is also sequential. The time traveller cannot weave his way back through the multiple sequences of energy states because none of the energy spent between grandfather's time and grandson's time is recoverable, since only part of this energy will have been available to do useful work (as is clear from First law of thermodynamics). But even if it were possible, for a Maxwellian demon, to reverse the spreading and restore a former energy state the demon's actions would not constitute a return to the past but a return to a copy of the past. It would reemphasize the essentially linear nature of temporal processes in the natural world.

2. Whilst the state of spreading of the past cannot be changed, we can influence the future, as illustrated in the branching tree model. From the point of view of the present state of the universe, we can change the spreading of states into the future because we are free to use the available energy today to channel it in particular directions. If we decide to make a cup of coffee we use the available energy; if we do not, the energy remains available to do other useful work. We can choose not to open the perfume bottle or to stop its spreading by inserting a partition in the container.

3. We have records of the past but not of the future because records are manifestations of the entropic state of the world of the past. Records may be either of ordered systems – like footprints on a beach – or of disordered systems – like a dilapidated building. When Lockwood stresses the concentration of nasic conditions in the past, for which we have no equivalent in the future, he presumably has such records in mind. We do not have such records of future states, because a) present spreading is contingent on past but not on future records; and b) spreading is a progressive process, which is contingent on the past history of the system.

The past-future asymmetry has thus been grounded in a dynamic explanation, which refers to the Second law of thermodynamics. According to the entropy view, the past-future asymmetry exists objectively in the physical world because the energy balance of past stages of the world exists at a different level of ‘spreading’ than present and future energy balances.

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