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Time really exists! The evolving block universe

George Ellis

Department of Mathematics, University of Cape Town, Rondebosch 7701, Cape Town, South Africa.
george.ellis@uct.ac.za

Abstract

My starting point is the question, did it make sense for the Planck team to announce the present age of the universe? This talk will propose that it did, because spacetime is an evolving block universe, with the present being the future boundary of a spacetime which steadily extends into the future as time progresses. The present separates the past (which already exists) from the future (which does not yet exist, and is indeterminate because of foundational quantum uncertainty). There are some technical aspects to this namely (1) simultaneity has no physical import, it is a purely psychological construct, (2) one can define unique surfaces of constant time in a non-local geometric way (and show how this relates to the standard ADM formalism), (3) this proposal solves the chronology protection problem (it prevents existence of closed timelike lines). In this context, (4) the arrow of time is distinguished from the direction of time, which is non-locally defined in the evolving block universe context.

1. Prolog

There are fossils in the Karoo National Park, South Africa, from amazing extinct wildlife that once thrived in the ancient Karoo during the Late Permian Period. The curator explained as we walked round, "That the skeleton is 255 million and 23 years old!" Amazed, we asked how he knew this. He said "When I came here 23 years ago, it was 255 million years old".

The same idea applies to the universe today. In March 2013, analysis of Cosmic Microwave background radiation brightness data obtained by the Planck Satellite, see Figure 2, determined that the universe was 13.82 Billion years old. Is it now (December 2013) 13.82 Billion Years and six months old? In my view, the answer is yes. Time flows on and the universe is now older than it was then. But this view contradicts what many scientists claim.

Figure 1: *Fossilized Skeleton.*

2. Time as an illusion

The nature of spacetime in both special and general relativity has led some to a view that the passage of time is an illusion. Given data at an arbitrary time, it is claimed that everything occurring at any later or earlier time can be uniquely determined from that data. Time reversible Hamiltonian dynamics provides the basis for physics in general, and gravitation in particular. One can predict equally to the past and the future from present day data.

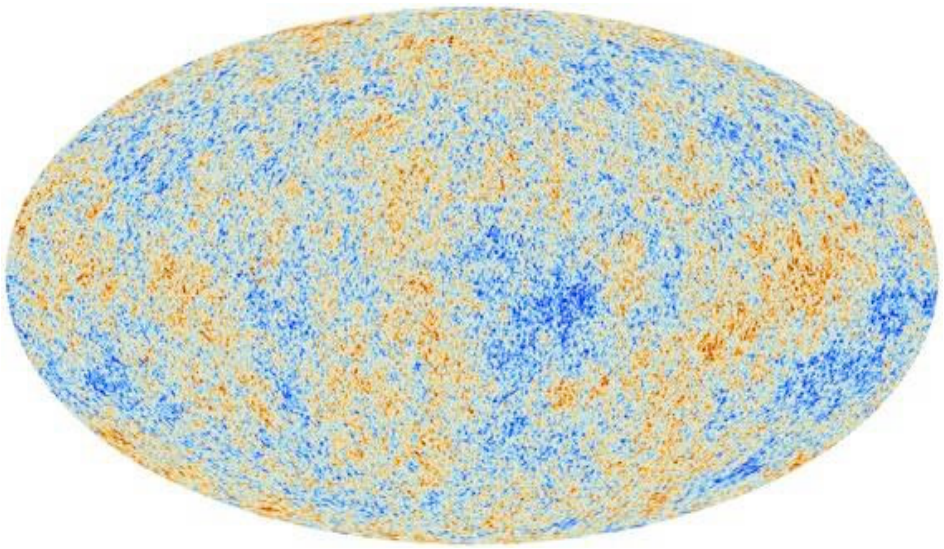

Figure 2: *CMB Sky Map from Planck. [Image credit: ESAPlanck Collaboration]*

Consequently, nothing can be special about any particular moment; there is no special "now" which can be called the present. Past, present and future are equal to each other, for there is no surface which can uniquely be called the present.

An example is this statement by Julian Barbour in his book "The End of Time" [1],

> *... the apparent passage of time is an illusion. If we could stand outside the universe and see it as it is, it would appear to be static.*

Various articles in the Scientific American Special issue of January 25, 2012, entitled "A Matter of Time", put the case that time is an illusion, and/or that time does not flow.

2.1 The Block Universe

Such a view can be formalized in the idea of a Block Universe: space and time are represented as merged into an unchanging 4-dimensional spacetime entity, with time the vertical axis and spatial directions sideways. The histories of all particles and events can be represented in the diagram of Figure 3 (see Ref. [2] for a detailed description). In this diagram, no particular space section is identified as the present time, and no evolution of spacetime is taking place. The universe just is a fixed 4D spacetime block, representing all events that have happened and that ever will happen.

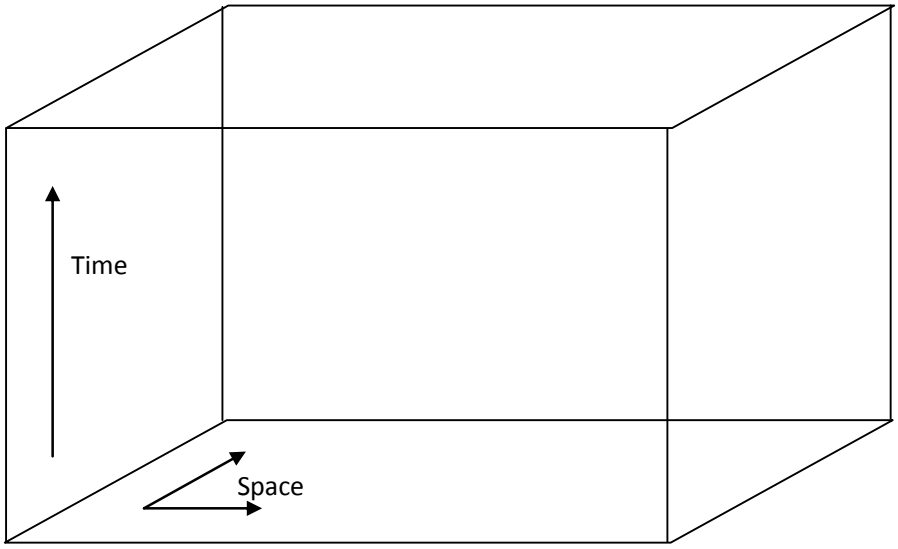

Figure 3: *The block universe.*

This representation implicitly embodies the idea that time is an illusion: time does not "roll on" in this picture. Both the past and the future already exist, and are uniquely determined. Nothing unexpected can happen. The present has no significance.

3. Taking time seriously: Things actually happen in time!

The problem with this view is that it is in profound contradiction with our experiences in everyday life, with physical chemistry, with engineering, with biology, and with psychology, where time is indubitably experienced as remorselessly flowing on. This model does not represent key features of the way the world works for which we have a great deal of evidence. The mathematical model is inadequate! We must be able to do better.

3.1 The macromicro tension

There are time-reversible laws at the micro level, obeying Hamiltonian dynamics, which lead to the block universe picture. But these laws involve detailed micro variables for billions of particles, such as their individual velocities and positions. When you average to get a coarse grained macroscopic description, given by variables such as the pressure, density, temperature, and entropy, one finds time irreversible physics at the macro level, as explained clearly by Roger Penrose in his book "Cycles of Times" [3].

The entropy of an isolated system is a macro variable representing the microscopic randomness of its component particles. The loss of information when one views a microscopic system at a macro level, combined with coarse grained dynamics, leads to the Second Law of Thermodynamics: as time passes, the entropy of an isolated system always increases.

This is a fundamental feature of the macroscopic world of physics, chemistry, engineering, and biology. It is expressed beautifully by Arthur Stanley Eddington as follows in his Gifford Lectures entitled "The Nature of the Physical Universe" [4].[1]

> *If someone points out to you that your pet theory of the universe is in disagreement with Maxwell's equations —then so much the worse for Maxwell's equations. If it is found to be contradicted by observation— well, these experimentalists do bungle things sometimes. But if your theory is found to be against the second law of thermodynamics I can give you no hope; there is nothing for it but to collapse in deepest humiliation.*

If your spacetime description does not describe this feature, you need to try harder. Your model fails to capture a key feature of reality.

3.2 Quantum physics

Irreversibility also occurs at the micro level, where quantum physics holds sway. Quantum mechanics applies to the real universe, as numerous experiments prove, and does not only involve time reversible unitary transformations, as one might believe from many articles and textbooks. Measurements happen; collapse of the wave function takes place; classical outcomes occur. Ignoring this is ignoring a fundamental feature of physics. This is where the uncertainty of the future changes to the definiteness of the past.

The unitary time-reversible part of the evolution, described by the Schrodinger or Dirac equation, does not describe all the microscopic level dynamics [5, 6]. Quantum measurement is a time-irreversible process whereby information is lost as the uncertain future becomes the definite past (a superposition of states becomes an eigenstate). Through the Born rule, one is able to predict probabilities of the outcomes in the future before they occur, even though one

[1] An online version of Eddington's Lectures is available at `http://www.giffordlectures.org/Browse.asp?PubID=TPNOPW&Cover=TRUE`

cannot predict what the specific outcome will be. But this is not true in the reverse direction of time: one cannot even give probabilities of what the initial superposition of states was from data available after an experimental outcome has been attained. Information is irreversibly lost as time progresses and classical outcomes are realised.

One's spacetime model should clearly model this process of uncertainty changing to certainty at an irreversible transit of the quantum state from indefinite to definite. Note that this takes place all the time everywhere as quantum indefiniteness changes to classical states, for example when photons hit a leaf and cause release of specific electrons in chlorophyll molecules, or when nucleosynthesis took place in the early universe and led to specific nuclei of helium coming into existence. One can set up experimental situations where one controls where and when this happens, but the process of collapse of the wave function to a specific unique state does not require laboratory experiments in order that it occur. It is the foundation of all classical existence, whether or not an observer is present.

4. An evolving block spacetime

By contrast to the Block Spacetime view, one can suggest that the true nature of spacetime is best represented as an *Evolving Block Universe* ("EBU"), a spacetime which grows and incorporates ever more events, "concretizing" as time evolves along each world line, with quantum uncertainty continually changing to classical definiteness [7].

To motivate this spacetime model, consider a massive object in space such as an asteroid, with two computer controlled rocket engines attached, one at each end, that move it either right or left. Let the computer determine when the engines fire on the basis of measurements of radioactive decay products of excited atoms. Then the outcome is unpredictable in principle, because radioactive decay is a quantum event: the times of emission of decay particles is unpredictable because of foundational quantum indeterminacy. There are a whole lot of possible paths in the future at a time t_0; at a later time t_1 one of those paths will have been chosen and the rest —the paths not taken— will have been rejected. This repeats to the future of t1, and so on: the possibilities of the future become the determined choices of the past as time progresses (see Figure 4).

As the asteroid has mass, it curves spacetime according to the way it moves, so the outcomes of these irreducibly random quantum events determines the spacetime curvature as time progresses in the future. Thus the future spacetime structure is not determinable or predictable from current data (as was foreshadowed in the Bohr-Einstein debate): one can only find out what it becomes by observing what happens as it happens.

At any time t_0, the past has been determined and is fixed; the future is uncertain and still has to be fixed. The future does not exist in the same sense as the past or the present, because it

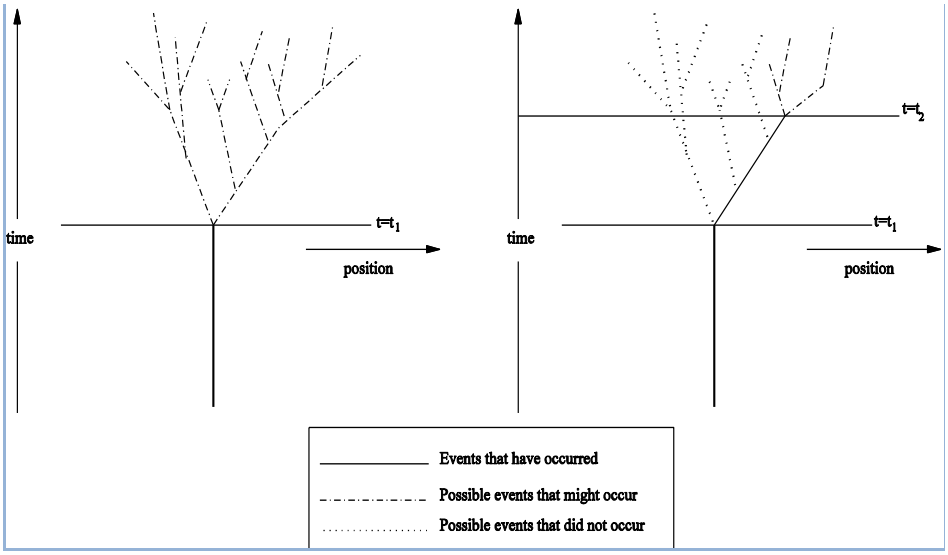

Figure 4: *The change from uncertainty to certainty: the present is where the indefinite future changes to the determined past.*

is not yet determined what it will be. The past is fixed and partly determines what happens at the present, so it must exist, else we will have uncaused events at the present. The present is where the change takes place. It is crucially different from both the past and future, and indeed separates them.

Thus the determinate spacetime region grows with time: spacetime itself is growing as its future boundary extends (the past boundary is fixed and unchanging). In this way, the evolving block universe grows with time: it is exactly the same as the block universe, except it does not extend to infinity. It has a future boundary: namely the ever-changing present. It exists up to that time, but not for later times, which have not yet come into being

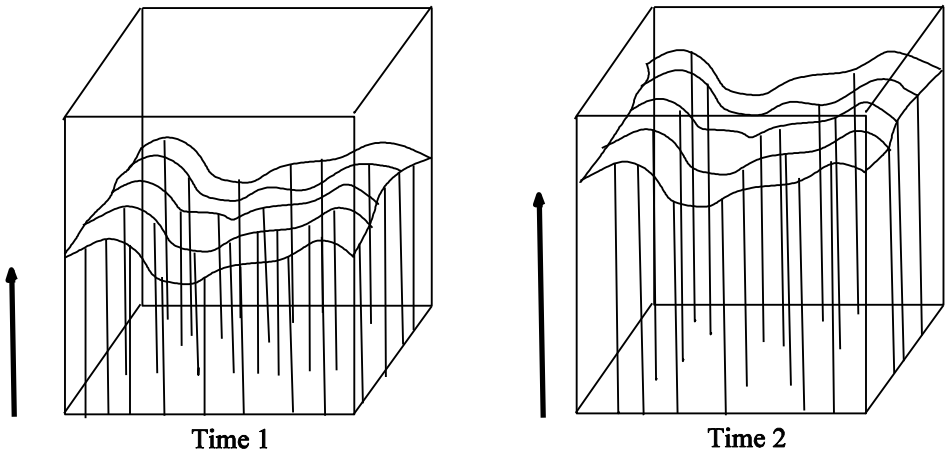

Figure 5: *The evolving block universe grows with time.*

4.1 Surfaces of change

The primary problem with this is the claimed unique status of "the present" in the EBU — the surface where the indeterminate future is changed to the definite past at any instant. It

is a fundamental feature of Special Relativity that simultaneity is not uniquely defined, it depends on the state of motion of the observer. Hence the block universe model is natural: it is the only way a spacetime model can incorporate this lack of well-defined surfaces of instantaneity. Hence time is an illusion.

However simultaneity as usually defined, determined by radar, is irrelevant to physical causation! Consider the Mars Rover, where the communication time delay between the control centre on Earth and the rover on Mars is about 20 minutes on average. What matters physically is the emission event E1 on the earth where a signal is sent, the interaction event E2 on Mars where the signal is received and a response transmitted, and the final reception E3 on Earth where the return signal is received. These affect physical outcomes. Which event S at the Earth is considered to be simultaneous with the interaction event E2 on Mars has no physical significance at all: it only has psychological value. We like to think "Now the signal is being received on Mars". But as regards physical causation, it does not matter when we think this.

Resolution: Physically, things happen along timelike worldlines the histories of particles and macroscopic objects – rather than on spacelike surfaces. What we need is a definition of "the Present" that is based on timelike world lines, for they can be the histories of clocks.

What really matters is the proper time measured along preferred timelines $x^i(v)$ by perfect clocks, which are the foundations of all local physical laws, as well as of measurements in General Relativity theory (as described nicely by J. L. Synge [8]. Proper time along a timelike world line is determined from the metric tensor $g_{ij}(x^k)$ by the basic formula

$$\tau = \int (ds^2)^{1/2} = \int \left(-g_{ij}(dx^i/dv)(dx^j/dv)\right)^{1/2} dv \tag{2.1}$$

This value is independent of the parameter v used to describe the curve; however obviously τ is a preferred curve parameter. It is the time parameter that occurs *ib al* local physical laws such as Newton's equations of motion, Maxwell's equations, the diffusion equation, the Schrodinger equation, the Dirac equation, and so on.

> **Time of determination:** *Start at the beginning of time, at the start of the universe. Measure proper time τ along fundamental world lines from the start to the present, thereby determining the transition surface ("the present") $\{\tau = \tau_0\}$ at the time τ_0. As time evolves, τ_0 increases along preferred fundamental world lines and the total set of points $\{\tau = \tau_0\}$ along all fundamental world lines defines the present at that time. This is where the future is instantaneously changing to the past. It will happen on a later surface $\{\tau = \tau_1\}$ at a later time $\tau_1 > \tau_0$. So the process of change happens on preferred surfaces that are secondary to timelike world lines.*

Thus we can propose that

> **The present**: *The ever-changing surface $S(\tau_0)$ separating the future and past at the*

> *time τ_0 is the surface $\{\tau = \text{constant}\}$ given by the integral Eq. 2.1 along a family of fundamental world lines starting at the beginning of space time (a spacelike boundary). This is the 'present' at time τ_0. The spacetime exists at that instant for $\tau < \tau_0$ but not for $\tau > \tau_0$.*

At a later $\tau_1 > \tau_0$, it will have extended further to the future, incorporating all the events for $\tau_1 > \tau > \tau_0$ as well as those for $\tau_0 > \tau > 0$.

4.2 The preferred world lines

But is this well-defined, given that there are no preferred world-lines in the flat spacetime of special relativity? The second fundamental feature is that it is general relativity that describes the structure of space time, not special relativity. As shown by Einstein, gravity governs spacetime curvature; the metric tensor is determined by the matter present.

Because there is no perfect vacuum anywhere in the real universe (*inter alia* because cosmic blackbody background radiation permeates the Solar System and all of interstellar and intergalactic space), space time is nowhere flat or even of constant curvature. Therefore there are preferred timelike lines and surfaces everywhere in any realistic spacetime model. The special relativity argument does not apply.

A unique geometrically determined choice for fundamental worldlines is the set of timelike eigenlines $x_a(v)$ of the Ricci tensor on a suitable averaging scale (they will exist and be unique for all realistic matter, because of the energy conditions such matter obeys). Physically, this represents the average motion of all matter and radiation in the universe at each event, on the chosen averaging scale. Observationally, in practice it is the rest frame where there is no dipole in the observed CMB radiation intensity, for that determines the local rest frame of the universe.

The 4-velocity $u_a(v) = dx_a(v)/dv$ of these world lines satisfies the equation

$$R_{ab}u^b = \lambda_2 u^a \Longleftrightarrow T_{ab}u^b = \lambda_1 u^a \tag{2.2}$$

where the equivalence follows from the Einstein field equations. Thus we can further propose that

> **Fundamental world lines***: the proper time integral Eq. (2.1) used to define the present is taken along the world lines with 4-velocity $u_a(v)$ satisfying Eq. (2.2).*

This will give the usual surfaces of constant time in the standard Friedmann-Lematre-Robertson-Walker (FLRW) cosmologies. One should note here that these surfaces will in general not be simultaneous for the fundamental observers; indeed they need not even be spacelike if the universe is very inhomogeneous. This is because they are non-locally defined

via the properties of fundamental timelike world lines.

4.3 The overall proposal

Putting this together, we have the basic proposal:

> **The evolving block universe:** *The future boundary of spacetime at time $\tau = \tau_0$ is the present at that time, determined by the integral Eq. (2.1) along preferred timelike worldlines, which are defined by the average motion of matter in the universe, as given by Eq. (2.2). This is where the indeterminate future, which does not yet exist, changes at time τ_0 to the determined past, which does indeed exist because it has causal powers over the present. As time passes, τ_0 takes all values from $\tau_0 = 0$ at the start of the universe to $\tau = \tau_{\rm final}$ at the end of its history.*

The value $\tau_{\rm final}$ may be finite or infinite. In the latter case, it is never attained: it is always in the future, and no matter how long one waits, it is still as far away as ever.

5. The arrow of time

A long standing issue is, how can a difference emerge between the future and the past, on the basis of time symmetric micro-physics? How does time know which way to flow? Why does it flow the same way everywhere?

There is no basis for a determination of the direction of time from microphysics alone, because its basic equations are time symmetric. It is true that there is a very weak time asymmetry in the weak force, but this cannot provide a foundation for the arrow of time of the second law of thermodynamics in everyday life; indeed it is very difficult to detect this effect. It does not make a significant difference to chemistry and biology.

Setting this effect aside, microphysics is time reversible. How does macro physics know the direction of time? The Boltzmann H-theorem, which proves that entropy increases to the future, applies equally in both directions of time (take your proof and set $t \to -t$; exactly the same proof will still hold). This is Loschmidt's paradox, and it applies equally to the Quantum Field Theory derivation of the H-Theorem given by Weinberg. In the block universe, the past and future are equal. Not so according to the second law of thermodynamics!

Where does this macroscopic arrow of time come from, if it does not arise from the micro-physics?

> **The evolving block universe solution:** *The equations are time symmetric, but their spacetime context is not. In an EBU, the arrow of time arises because the past exists and is developing to the future, which does not yet exist, a global asymmetry of the physics context. It is this asymmetry that leads to the direction of time, which in turn leads to the various local arrows of time [9].*

Here I distinguish two fundamental concepts: the Direction of Time and Arrows of Time.

> *The* **Direction of Time** *is non-locally determined: it points from the start of the universe to the present time τ_0. It arises because the block universe has a beginning, which is fixed at the time $\tau = 0$ and bounds spacetime to the past, and a future edge at the ever changing present time τ_0. It is this process of change at the edge of spacetime, which is continually extending to include more events as time progresses, that determines which is the future direction of time, as opposed to its start.*

Thus if event Q on the boundary is fixed and unchanging as time evolves, it is at the start rather than at the evolving future edge; we assign it the time $\tau(Q) = 0$. If event P on the boundary at one time is inside at another time, it is at the evolving future edge; we assign it the time $\tau(P)$ given by Eq. (2.1). The direction of time points from Q to P. Then if the age $\tau(P)$ of the universe (the integral Eq. (2.1) from $\tau = 0$ to P) at event P is greater the age $\tau = \tau(R)$ of the universe at event R, then P is later than R and the direction of time is from R to P.

One can be influenced at the present time from many causes lying in our past, as they have already taken place and their influence can thereafter be felt. Past events affect today, for example the existence of the elements C,N,O, on Earth is because of nucleosynthesis in the distant past in the early universe. Similarly, cosmic rays emitted in the past influence events on the earth today. Hence the past must exist, else we have effects today with no cause.

This is the rationale for saying that the past exists but the future does not: if something can influence you, it necessarily exists. One cannot be physically influenced by causes coming from the future, for they have not yet come into being, and it is not yet definite what that future will be. Future possibilities exist, not specific outcomes.

Thus the direction of time points from the past that exists to the future that does not: a global definition that is not written into any local physical laws.

> *An* **Arrow of Time** *at the present is a locally determined arrow showing the direction of time according to local physical effects: the growth of entropy, electromagnetic waves are received after they are emitted, biological systems are born, grow and die, and so on.*

Special initial conditions (the *Past Condition*: that the universe starts in a low entropy initial state) then relates the local arrows of time to the non-local direction of time, leading to the local arrows of time agreeing with each other and with the direction of time. For example, the arrow of time in the second law of thermodynamics points in the direction of expansion of the Universe. Without the Past Condition, this need not be the case.

Hence it is the global context of the EBU that determines the direction of time, and thence the local arrows of time. This takes place by a cascading of the direction of time down from the cosmological scale to microphysical scales, and then back up to emergent entities (see [9]

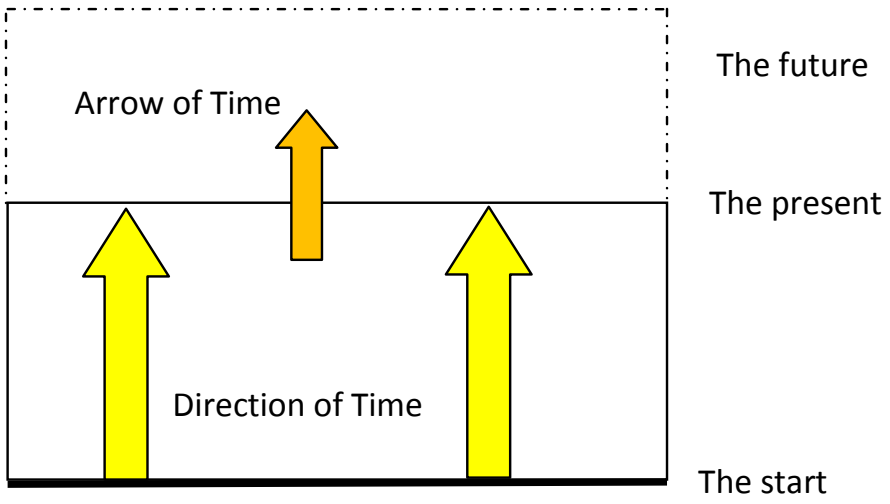

Figure 6: *The direction of time and an arrow of time.*

for a detailed description of how this happens).

6. Chronology protection

A longstanding problem is that, as demonstrated by Kurt Gdel, closed timelike lines can occur in exact solutions of the Einstein Field Equations with reasonable matter content. This opens up the possibility of many paradoxes, such as killing your own grandparents before you were born, and so creating causally untenable situations.

It has been hypothesized that a Chronology Protection Condition would prevent this happening. This is an ad hoc extra requirement on solutions of the Einstein field equations, which do not by themselves give the needed protection.

The EBU automatically provides chronology protection, because creating closed timelike lines requires the undetermined part of spacetime intruding on regions that have already been fixed. This would require the fundamental world lines to intersect; but if this were to occur, the density would diverge, and a spacetime singularity would occur where the fundamental world lines and indeed time would come to an end.

Thus the world lines cannot intersect each other and create closed timelike loops: whenever this threatens, singularities close off the future and prevent its occurrence. Hence unlike the usual case, the EBU as outlined above automatically provides chronology protection, so no "Grandfather Paradox" can occur. We can get only spacetimes with global time orientation in the Cauchy development of the initial data surface.

7. Emergence of complexity

The initial argument against the flow of time was that the future was uniquely implied by the past; thus the present, where the indefinite future changes to the definite past, has no meaning. This final section comments firstly on how this is not true in the real universe, because real complexity arises that is not implied by the initial data; and secondly how if it were true, it would raise much deeper paradoxes.

7.1 Complexity arises that is not implied by the initial data

Genuine emergence in time is needed because of the expansion history of the universe, represented in Figure 7.

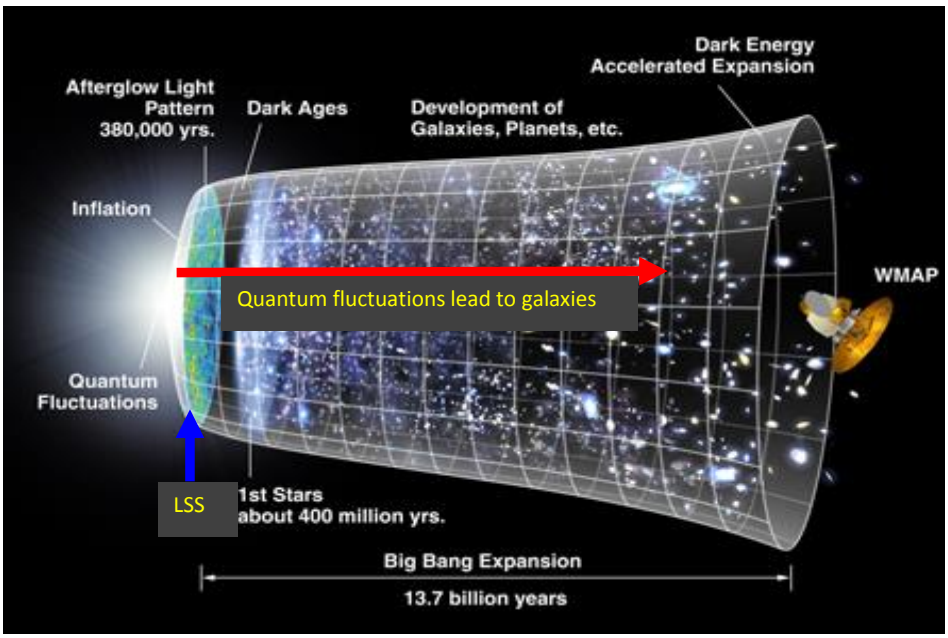

Figure 7: *Quantum fluctuations lead to the existence of galaxies.*

Time runs from left to right. An extraordinarily rapid initial accelerating period of expansion ('inflation') gives way to a hot big bang era, until matter and radiation decouple at the Last Scattering Surface (LSS), 300,000 years after the hot big bang. This is followed by dark ages until the first stars form and galaxies come into being through gravitational attraction. Some first generation stars then meet a fiery end as a supernova, spreading clouds of heavy elements in space that then allow second generation stars to form that are surrounded by planets which can provide a habitat for life.

Thus the expanding universe is the environment creating the conditions for life to exist today. The cosmic background radiation sky we observe today, see Figure 2 is an image of the density fluctuations on the LSS that are the precursors of all the galaxies that exist today.

Now the question is this: is all the future history of the universe uniquely encoded in the

fluctuations on the LSS? If we had future satellites far more powerful than Planck, that could detect every micro-fluctuation on the LSS, could one then in principle run that data forwards to predict the specific words on the page you are reading now? And going back even earlier, are these words implied by the state of the universe at the start of inflation? In short: is it true that in the real universe, the future is uniquely predicted by the past?

This is not possible even in principle for two reasons. First, the inhomogeneities that occurred on the LSS were the outcome of quantum fluctuations during inflation. They were not determined uniquely by the state of the universe at the start of inflation, because until the relevant quantum fluctuations had become crystalized in classical fluctuations, the outcome was unpredictable, even in principle. Thus the state of the LSS is not uniquely determined by the state of the universe at the start of inflation; hence the existence of our specific Galaxy, and the Earth in it, is also not so determined.

Second, suppose we knew every detail of the state of the Earth and the life on it two billions years ago. That would not uniquely predict that humans would exist today, because cosmic rays have altered evolutionary history through causing genetic mutations; and the emission of a specific cosmic ray at a particular time and place is a quantum event, unpredictable even in principle. The outcome was only determined as it happened. A Laplacian demon who could calculate with infinite precision would not be able to predict our existence, much less what is written on this page, from that early data. It is not written into that initial state.

Hence this talk can't possibly be encoded in CBR data: quantum uncertainty prevents this from being the case.

7.2 Emergence of complexity

So how did complexity arise, leading to the words on this page, if they were not implied by the initial data? Through adaptive evolutionary and developmental processes that lead to the existence of genuine complexity, where higher levels of structure —such as brains and minds— come into being with genuine causal powers, not implied by the lower levels of structure on which they supervene.

Genuine emergence takes place and determines what happens. Higher level purposes structure events – for example by creating computers that then have the power to change the world. This outcome is not predictable from microphysics alone.

This emergence of higher level causal powers is possible because of the existence of both bottom-up and top-down causation in complex systems, leading to the possibility of inter-level feedback loops. Contextual effects occur when the higher levels of the hierarchy causally effect what happens at the lower levels in a coordinated way [10, 11]. This is the key to

biological emergence where, particularly through natural selection, top-down action from the environment codes information about appropriate responses to the environment into the detailed base sequence in each animal's DNA.

Adaptive Selection is the way meaningful information is created from a jumble of disordered objects, gained by discarding all the information received that is not meaningful. One can think of this as a selection gate creating order from disorder by deleting what is not wanted and keeping what is desirable in terms of meeting some higher level select criterion. The outcome is not uniquely determined by the initial state because it involves a randomisation process whereby an ensemble of states or structures is created that can then be selected from according to the operative selection criteria. Overall this process is non-unitary and unpredictable. It is the way new structures and information come into being that are not specifically implied by the initial date.

Irreversibility is introduced at the micro level by this process, whereby local entropy is decreasing as order increases. Erasing un-needed information is an irreversible dissipative process that creates order from chaos. It occurs all over: in biology, in physics, and in the way our minds operate, where it is the basis of learning and the development of technology.

The initial state of the universe allows this to happen, but does not dictate the outcome. It cannot do so because of the randomness created by quantum uncertainty, which unfolds over time and creates possibilities out of which complexity can arise.

7.3 Much deeper paradoxes

Finally, suppose this was not the case: forget quantum uncertainty and assume everything in the history of the earth is indeed written into the fluctuations on the LSS observed by Planck. We then have to explain how this talk, the theory of General Relativity, the Mona Lisa, the international banking system, etc. could all have been encoded there.

This is simply unbelievable. Who or what could have set the molecules then just so as to get these results? To determine every thought that Maxwell, Einstein, Karl Marx had? This is not even remotely credible. It is fantasy.

Such highly ordered logical systems cannot possibly be a unique outcome of random processes in the early universe. But if the initial data were ordered so as to produce these highly structured outcomes, what agent could have been responsible for this ordering? What kind of god or demiurge could have been responsible? Certainly not random quantum fluctuations, as envisaged in inflationary theory. By its very nature it only leads to random Gaussian processes.

In fact, emergence of brains with genuine causal powers leads to these thoughts and resultant theories, such as General Relativity Theory and the theory of Evolution. These are creations of the mind that are not written into the initial data in the universe. They are wonderful products of emergent human intellect with its extraordinary imagination and causal powers.

Their existence is not compatible with the block universe picture, where all that exists is uniquely written into the Cauchy data at any arbitrary time.

8. Conclusion

There is indeed a passage of time: The past is fixed and cannot be changed. The future is determined by a combination of chance, necessity, and purpose. It is determined as it happens: and is then irrevocably written into history.

> *The Moving Finger writes; and, having writ,*
> *Moves on: nor all your Piety nor Wit*
> *Shall lure it back to cancel half a Line,*
> *Nor all your Tears wash out a Word of it*
> *Omar Khayyam (Poem #545)*

The future is not determined till it happens. That is guaranteed to us by quantum mechanics. It is what is experienced in the macro world.

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