'An infinite universe is the only reasonable universe' – A False Assumption

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Abstract

The idea, that underlies most modern cosmological models, that the universe must be infinite, is examined and found to be uneeded. Attention is given to finite cosmological models which are found to be preferable since they provide a solution to Loschmidt's paradox.

Introduction

Two paradoxes will be central to this essay. One is of philosophy; the other is of science – both are important to cosmology. The first paradox is one which was noticed by German philosopher Immanuel Kant and it is, roughly: If the universe is finite, what caused it? On the other hand, if the universe is infinite, how can any event be 'reached?' [1] (This latter half of the paradox bears resembelence to the infamous, ancient "Achilles and the Tortoise" paradox concieved by the Greek philosopher Zeno of Elea) I should point out that this paradox has not been *explicitly* solved in modern physics, in fact it is the first part of this paradox that makes an infinite universe – such as the so-called 'multiverse' or the cyclic model – seem so desirable.

The second paradox, this one directly from physics, is also one which remains to be *explicitly* solved by modern physics. This is Loschmidt's paradox, which is that: It should not be possible to deduce time-asymmetrical effects from time-symmetrical laws. This specifically refers to the "second law of thermodynamics" which is sometimes called the 'arrow of time.' [2]

We will be seeing how infinite and finite cosmologies of the universe deal with these paradoxes.

Finite vs the infinite

When the Big Bang cosmolgy first began to be developed, based on Edwin Hubble's observations, it was not favoured by Fred Hoyle and other physicists because it seemed to suggest that the universe actually had a finite beginning in time, unlike the 'steady-state' model which would have contained an infinite number of events. Perhaps to ammend the situation, Albert Einstein proposed a cyclic model in which the universe would end in a 'big crunch' which would be the 'big bang' of the following cycle. However, in 1934 Richard C. Tolman showed that this would not work because, since entropy must continually increase (overall) each subsequent cycle would be larger and larger and last longer and longer. This would mean that, going backwards in time, you would not be able to avoid an initial big bang. [3] (It was found in 1995 by Maruisz Dąbrowski and John D. Barrow that, in Einstein's cyclic model, the cycles must eventually end and the universe simply continue expanding [4]) In addition to this, Einstein's cyclic model would have required the universe to go through a phase of contraction which would apparently violate the second law of thermodynamics, forcing entropy to decrease as time goes on. [5]

Despite this, many modern physicists feel that a 'complete' cosmology is one in which the universe, as a whole, is infinite (at the very least in terms of the number of events which would take place) and so there have been several attempts, in recent times, at formulating a cosmology which is either – the so-called – 'multiverse' or is a cyclic model. For examples see: (Linde 2003), (Steinhardt, Turok 2004), (Smolin 1999), (Penrose 2011).

There are two motivations for looking for an infinite cosmology: One is a desire to explain the 'specialness' (Penrose 1989) of the initial singularity at the Big Bang i.e. its very low-entropy state and so the 'unlikely' universe we see today. However would not such a reason merely stem from, what Douglas Adams would call [11], "puddle thinking?" Quoting Richard Dawkins:

> *"... imagine a puddle waking up one morning and thinking, 'This is an interesting world I find myself in, an interesting hole I find myself in, fits me rather neatly, doesn't it? In fact, it fits me staggeringly well, must have been made to have me in it!' This is such a powerful idea that as the Sun rises in the sky and the air heats up and as, gradually, the puddle gets smaller and smaller, it's still frantically hanging on to the notion that everything's going to be all right, because this World was meant to have him in it, was built to have him in it; so the moment he disappears catches him rather by surprise. I think this may be something we need to be on the watch out for."*

The point here, of course, being that we human beings have a tendency to think of the universe as if it were

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centred around us, and so one can argue that we obviously would ascribe special status to the state of the universe at the big bang and therefore feel that it should be 'unlikely' and in need of explaination.
The second reason for seeking an infinite cosmology is most likely a desire from the first part of the paradox highlighted by Kant; that is that if the universe is finite, what caused it? Yet infinite cosmologies do not 'escape' for they are placed firmly in the second part of the paradox: How are an infinite number of events reached? If one does not see this last part of the paradox as a problem then why should we find the first part troubling either? Indeed some cosmologies *do not* think of it as a problem, an example being the *Hartle-Hawking no-boundary proposal* [12] which is the suggestion that only the spatial dimensions existed at the big bang, without time. In this model there is apparently no need to provide a 'cause' or an explaination for the big bang since time is non-existent 'beforehand.'
All of this discussion could be accused of being merely philosophy; having no bearing on serious scientific matters but as we will be seeing truly finite (i.e. non-cyclic) cosmologies have the oppurtunity to provide a **solution** to Loschmidt's paradox which infinite cosmologies *do not*. An example of an *explicitly* finite cosmology is one suggested by Barrow in 1986 where the universe actually exists in a closed time loop. [13] Another, similar cosmology to Barrow's, was formulated by Richard Gott and Li-Xin Li; in theirs the universe once again exists within a closed time loop, however 'baby' cosmos are able to 'branch off.' [14]

The finite and time-asymmetry

As mentioned earlier, Loschmidt's paradox (sometimes called the reversibility paradox) is that it should not be possible to deduce irreversible processes from time-symmetrical laws and yet the so-called 'arrow of time' seems to exist within nature.
It is important that one understands what the 'arrow of time' is and why it seems to arise:

The second law of thermodynamics tells us that the entropy of any dynamic system is extremely likely to evolve into states of higher entropy. The entropy of a dynamic system is defined by the equation:

$$S = k \log V$$

S is the value of entropy of the system. k is Boltzmann's constant (which has the value 1.38×10^{-23} JK^{-1}) and V represents the volume of a 'box'[2] of phase space that the state of the system $\boldsymbol{X}$ currently occupies. Since states of higher entropy make up for a greater volume of the (finite) phase space, it becomes increasing more likely that the system will evolve into those states. Therefore the paradox is, when we are retrodicting the evolution of a system – say a gas in a container – and we want to know what state it was in at some time before 'now', thermodynamics tells us that, apparently, it is just as likely that the entropy of the system should increase in the past direction. Yet we know this can not possibly be true, for we have observed the past evolution of the system. What is going on?

To understand we have to think of the universe *holistically*, as one system[3]. With this in mind we appreciate the fact that, since the universe began in a very low-entropy state, as time goes on it is overwhelming more likely that the universe will evolve into states of greater and greater entropy. So far we still have the paradox, for now.
A second concept to understand is that if we were somehow able to start the system in a state of thermodynamic equilibrium, this state occupies the greates volume of the phase space, (in the context of the universe this would have to be absolute maximum entropy) then it would be more likely that, eventually, the system would evolve into states of **lower** entropy. This is *only* if the system was to begin in a state of *maximum entropy.* (See (Penrose 2010) for a more detailed description) And the universe began in a state of *low-entropy...*didn't it?
A third concept that will need to be introduced here is that of a poincaré recurrence. The poincaré recurrence theorem states that a *finite* dynamical system, after a sufficiently long time, *must* return to a state very close to, or at, its initial conditions. [16] This occurs because once a system reaches *maximum* entropy, all of the regions corresponding to lower volumes have all already been 'crossed.' (This means that when the system evolves from its starting state the volume of phase space available for the system to 'traverse' is constantly decreasing) Following this, for the system to continue evolving, the system *must* reconnect to its starting point.

Let us consider these principles in terms of cosmology and our paradox:

We know that the system we are describing, the universe, began in a state of very low-entropy. We have good

2 The 'box' represents a *coarse grained* region
3 It is after all the only truly *closed* system

theoretical reasons to believe that, since the universe is expanding, it is likely that in the far, far future of the system *heat death* will occur; that is, the universe will reach a point of *maximum entropy.* (It is very important to note that the action of 'dark energy' – or whatever is causing the universe's accelerating expansion – **does not** 'add on' additional degrees of freedom to the system; the universe can still attain maximum entropy even if the universe was to continue expanding beyond that point.) [17] Let us now consider something unconventional: Let's suppose that the heat death is actually the starting point of the system. If this was the case, how would we expect to see the system evolve over time? Since the system would begin in a state of maximum entropy, the second law of thermodynamics would tells us that the system was overwhelming more likely to evolve into states of *lower* entropy as time went on. The system should evolve into a *low-entropy singularity.*
Such an evolution matches our **retrodiction** of the evolution of the system we experience; the universe. That is, this aligns with the evolution we see in the 'past' direction. But wait! Then the evolution of the system in the opposing time direction would be at odds with what we observe. After all, we must choose one beginning state for the universe, Big Bang or Heat Death; we surely can't have **both**...can we?

Not unless we connect the two events, Big Bang and Heat Death, in terms of a *poincaré recurrence*. We could imagine that once the universe reaches maximum entropy – having 'used up' all of the available regions – its evolution continues if it returns to the *initial conditions*. Likewise if we start looking at the system from the state of maximum entropy, we could say this recurrence occurs once the lowest possible entropy state available to the system is reached – the singularity at the Big Bang.
This is all well and good but we would still need a *transfer operator* that would tell us how the two events connect. Since it is very hard to predict what is going to happen in the far future of the universe, this is very much an open question. We could foresee that, eventually, all matter is annihilated so that all that remains in the universe is photons and dark energy. (This would assume a number of things, including proton decay; that neutrinos can be annihilated; that every positron and electron does not become trapped inside of its own light cone and does encounter its respective antiparticle. To work around this problem, for his conformal-cyclic cosmology, Penrose has suggested that mass actually decays, although I feel this is too *ad hoc*.) If this situation did occur one recognises that photons, being massless, are *not* restricted by conformal geometry (Penrose 2011). In other words the action of 'dark energy' would be irrelevent and so space could return to a singularity. In conformal-cyclic cosmology the following 'aeon' is not recognised as being the same one (a closed time loop) but for the reason that information could apparently be passed along boundary that may result in temporal paradoxes. Yet I do not understand how this really *could* be a possibility when, if **mass decays**, how is one to expect *any* information of a useful kind to cross the boundary?
Other possibilities include: that the vacuum decays into an even lower energy state. What this means for the universe is speculative but it *could* result in, what we would recognise as, a 'black hole singularity.' Yet another is a 'Big Rip' in which the universe concludes with a singularity in which every distance diverges to infinite values. [18] There is one other suggestion of a 'Big Bounce' which requires the universe to contract *towards* a singularity but then the effects of quantum gravity cause a following expansion. [19] This cosmology suffers from being infinite and invalidates the solution to Loschmidt's paradox that a *finite* cosmology provides[4]. To help grasp why this really is the case, consider the following thought experiment:

> If we accept that the suggestions I am promoting here, where once heat death occurs a poincaré recurrence somehow takes place which puts the universe back to the big bang, then we would see that while the universe is *finite* in time there is no true beginning or end. The Bing Bang could be thought of as being in the far future; "after the end" or could be equally thought to be at the very beginning. It would just depend where your observations were taking place in the history – much to the joy of Einstein, the events are *relative*. What we have is not a cyclic model but a *self-caused* model. We have escaped Kant's paradox by taking a third-route: One in which the universe is finite while at the same time having the initial Big Bang singularity the *necessary* result of the natural, mathematical laws which govern the behaviour of our universe.
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> To quote a Zen proverb: "When you reach the top, keep climbing."
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> What the second law of thermodynamics **does** would depend on whether you were travelling towards the Big Bang singularity or away from it: If you were to travel *away* from the Big Bang you would see, as we do, that entropy increases overall until it reaches a maximum. On the other hand, if you were to travel *towards* the Big Bang you would see that, over time, systems would go from disorder to more and more ordered states; decreasing entropy until finally you found yourself at the "big crush" a.k.a the Big Bang.

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4 There is of course the finite 'big bounce' cosmology suggested by the infamous Peter Lynds although that one lacks a rigorous mathematical formulation.

Following this thought, it is obvious that we humans should see entropy increasing overall since we are biological systems existing within a series of temporally connected events that are tilted *away* from the Big Bang.
Now we could envision some other 'strange' entities, that we would think of being in “reverse”, existing in events that are tilted *towards* the Big Bang. Of course, as with the English and Australians, they too would think we were the 'wrong way around.' Their interpretation of black holes would be an interesting one, for they would percieve that Hawking radiation would become concentrated in areas of space eventually forming black hole singularities. These 'black holes' would then begin ejecting matter and energy – in other words the *heretics* – to coin a name for them - would understand our black holes to be white holes. For the *heretics* this matter and energy would seem to be being spontaneously generated from nowhere. The *heretics* would have a whole different kind of “information paradox” on their hands. They would not be asking “Where does the information go?” but “Where does the information come from?”

There is a problem with this thought experiment, of course, and that is that these *heretics* would not be able to exist. It seems reasonable to me to postulate that the actual process of conscious thought emerges *only* in events tilted *away* from the Big Bang. Conscious experience would therefore be said to only emerge in systems which progressively become more and more disordered. To borrow an analogue from Daniel C. Dennet and Douglas Hofstader [20] : Think of the conscious mind as being like the playing of a song; the song only sounds harmonious and meaningful if you play it forwards; once you play the song backwards it is nothing but an incoherent mess of sound without any meaning. This concept explains why we would see a universe with the “time-asymmetric” *arrow of time* and, perhaps, why we experience a *flow of time*.

Conclusion

To conclude, we have seen that in a finite cosmology, where we consider the 'beginning' to be the Big Bang and the 'end' to be the Heat Death, we find we can model the thermodynamic evolution of the system in a *holistic* way, and invoke a poincaré recurrence, to provide a solution to Loschmidt's paradox **and** to Kant's paradox since there is no true 'beginning' or 'end' to the system, there is only an *origin* point – which is the singularity. These concepts are also quite possibly importantly involved with explaining why we human beings experience a sequential 'flow' of time and it provides interesting implications for the 'black hole information paradox.'
Therefore, taking these considerations, one concludes that not only is an infinite cosmology not *necessarily* reasonable – such as a cyclic model (both philosophically and scientifically); one finds that a finite cosmology is actually *preferable*. Hence, cosmologists should look for a *transfer operator* that defines such a poincaré recurrence and determine if there is a way to make falisfiable predictions from this.

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