The Time Flow Manifesto

Chapter 3. Reversibility in Physics.

Andrew Holster

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We now turn to the claims *5* to 8**. These are the main explanatory consequences supported by claims: *1** - *4**. The claims and concepts of *5** - *8** are modelled on the classical theory of thermodynamics – i.e. thermodynamics based on a fully deterministic micro-theory, developed in the time of Boltzmann, Loschmidt and Gibbs in the late C19th. The classical theory has well-known 'reversibility paradoxes' when applied to the universe as a whole. But the introduction of *intrinsic probabilities* in quantum mechanics, and its consequent *time asymmetry,* fundamentally changes the picture. However we begin with the situation in a deterministic 'classical' thermodynamics.

The Reversibility Problem in Deterministic Classical Physics

We suppose first of all that the laws of physics are fully deterministic and time symmetric. Physical systems (and our universe as a whole) evidently evolve from low-entropy states (highly ordered) to higher entropy states (randomised). For a simple model, to engage our intuitions, imagine that we start with a set of particles that start in a state where they are forced together in a tight ball, and then released. They will expand outwards, filling space more homogenously.

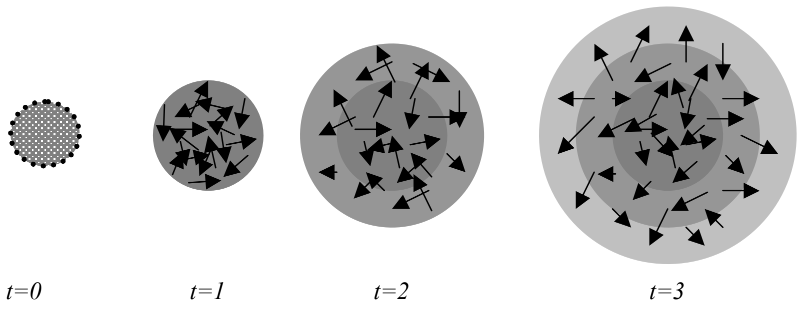


Figure 3. A ball of particles is released at *t=0*, and expands outwards due to 'random' particle motion and collisions. The entropy steadily increases with time, until the space is uniformly filled.

Of course this process looks ‘irreversible’ – in real life, we can’t actually produce the reversed process, involving a large cluster of particles spontaneously ‘shrinking’ into a ball through multiple collisions. But in a *time symmetric deterministic theory,* the reversed process is just as possible as the normal process – at least for a completely isolated system, or for the universe as a whole considered as a closed system. (It is not possible if there is even a very weak coupling of the system with random influences from the outside world.)

The reason is because of the *time symmetry of the classical laws,* or *classical reversibility*. The original process goes through a sequence of complete micro-states like: $s_0 \rightarrow s_1 \rightarrow s_2 \rightarrow s_3$. *Each micro-state at time t fully determines the following state* at $t+1$ (on the assumption that the system is completely isolated – or that it comprises the entire universe). *Reversibility* is then said to mean that there is an equally deterministic process: $Ts_3 \rightarrow Ts_2 \rightarrow Ts_1 \rightarrow Ts_0$, *starting with the reversed final state,* and returning to the reversed initial state. Time-reversed states have the same appearance of order (or thermodynamic entropy) as their originals, since particles have the same spatial distribution, and precisely reversed velocity distributions. Hence the reversed process winds entropy back down.

(We should stress that this is a little inaccurate to start with, because as we have just seen, time symmetry means that for the time-reversed sequence, each later state fully determines each earlier state, like: $Ts_3 \leftarrow Ts_2 \leftarrow Ts_1 \leftarrow Ts_0$. *Time direction is still* from left to right, but law-like determinism is from right to left, i.e. backwards in time. However given a theory is *fully deterministic*, all causal chains are unique, and there must be a law-like causal chain forward in time as well, which must be like: $Ts_3 \rightarrow Ts_2 \rightarrow Ts_1 \rightarrow Ts_0$. *Then the classical argument can proceed).*

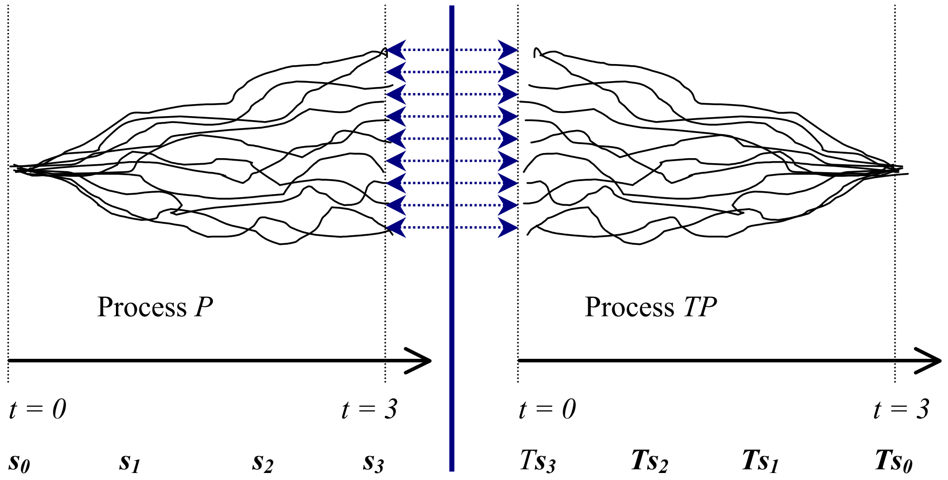
This classical analysis is the standard visualisation found in the literature. The lesson drawn is that *in a reversible theory, the time reversal of any ordinary thermodynamic universe is just as physically possible as the original universe, hence reversible laws cannot determine that the second law of thermodynamics is law-like. The second law, that entropy increases, cannot be dictated by reversible micro-physical laws alone.*

It is then inferred that *the only explanation for thermodynamic directionality in the context of a reversible micro-theory is a contingent one. I.e. it must appeal to a contingent fact (or boundary condition), stating that the universe started in a low-entropy state.* Thus the paradigm for explanation of physical time asymmetry: it must appeal to *time symmetric laws plus time asymmetric facts.*

The Solution in Probabilistic Quantum Mechanics.

But this classical logic (assuming it is correct) cannot be transferred to quantum physics, because *quantum mechanics is not time symmetric.* The picture of thermodynamic asymmetry has to be rethought. What happens if we try to generate the time reversal of a thermodynamic process in this case? The reason the deterministic process can (theoretically) be reversed is because we imagine taking the *precise reversal of a final state,* and this is so precisely defined that it can unfold in perfect reverse order – something that seems miraculous from our ordinary point of view, because the states (positions and velocities) of all the particles must be coordinated with each other to an incredible degree of accuracy to ensure the highly improbable anti-thermodynamic process unfolds. But this is indeed possible in a fully deterministic universe.

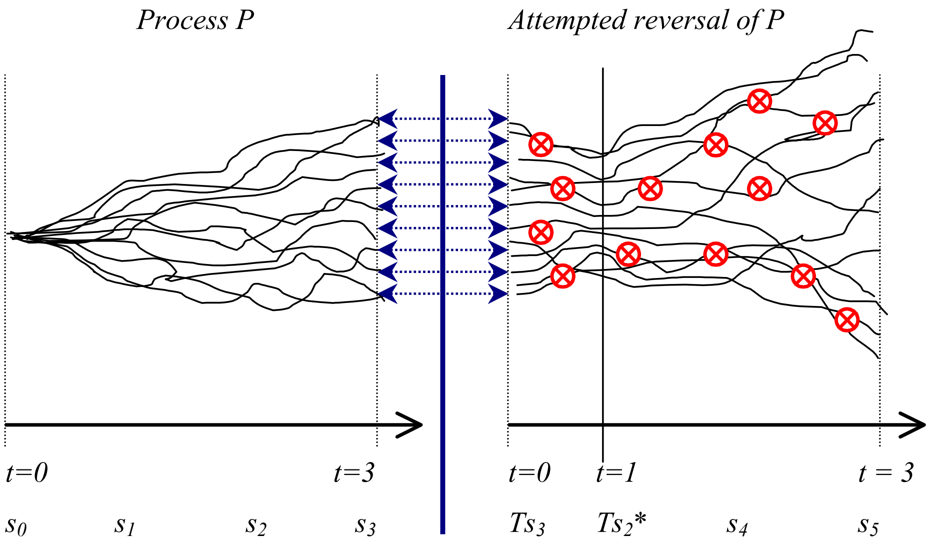
However it is absolutely impossible in a process with intrinsically probabilistic events that can spread their influence – because probabilistic events will inevitably disrupt any degree of 'implicate order' encoded in the reversed state. This is quite simple to demonstrate in general principle. The conclusion will be that *quantum processes are not reversible. The time reversal of an ordinary quantum thermodynamic process is not really physically possible. The time reversal of the real universe, leading back to the 'big bang', is not physically possible. Quantum thermodynamics ensures that the time asymmetry of processes is law-like, not contingent, or 'fact-like'.* I will first sketch the general idea behind the proof of this, and then illustrate it using phase space or configuration space diagrams.



time-reflection of all final particle states, s_3
to create initial particle states, Ts_3*.*

Figure 4. Classical time reversal of the process in Figure 3. If a deterministic state is precisely reversed, and the micro-laws are reversible, the system will retrace exactly the same path followed by the original. The time reversed state, $\boldsymbol{Ts_0}$, has an 'implicate order' where all the individual particle states are precisely coordinated with each other to reverse the process.

But what happens if there are *intrinsically probabilistic or random or wilful events* involved in the reversed process? It takes only a tiny disruption of the 'implicate order' in the reversed states to completely wreck the reversed process.



Time-reflection of all final particle states, s_3 to create initial particle states, Ts_3.

Figure 5. Time reversal in a probabilistic system.

A system is started in the time reversed state, Ts_3, hoping to cause it to retrace the original process back to Ts_0. But there are random probabilistic events (red crosses) that upset the ‘implicate order’. The process ‘reverses entropy’ for a short period, but by t=1, the reversed process has reached Ts_2*, diverging significantly from Ts_2. From then on, the particles become completely unsynchronised from the reversed states, and ordinary thermodynamic behaviour takes over again. The probability of retracing the original path is infinitesimally small. The system will quickly revert to ordinary thermodynamic behaviour again.

A Statistical Model Demonstration.

How can we prove this? I start by clarifying the statistical picture with a simple example, and then making it more precise. Suppose that the initial state, s_0, in the example above, has a low entropy. Then it belongs to a small local volume in phase space, call this $\boldsymbol{S_0}$. A local volume in phase space is a set of similar micro-states. For simplicity, imagine that $\boldsymbol{S_0}$ contains just the one state, s_0. The later higher-entropy state, say s_3, belongs to a much larger local volume in phase space, $\boldsymbol{S_3}$, lets say 1,000,000 times larger than $\boldsymbol{S_0}$, or with 1,000,000 states. Corresponding to these are their time reversed images: $\boldsymbol{TS_0}$ has one state Ts_0, and $\boldsymbol{TS_3}$ has 1,000,000 time-reversed states from $\boldsymbol{S_3}$, including Ts_3. Note that $\boldsymbol{TS_0}$ and $\boldsymbol{TS_3}$ have the same entropies as $\boldsymbol{S_0}$ and $\boldsymbol{S_3}$ respectively.

The probability that s_0 makes the transition to exactly the state s_3 is very small - only about 1/1,000,000 (slightly smaller when we allow for thermodynamic randomness). But there are 1,000,000 states similar to s_3 in phase space $\boldsymbol{S_3}$, with the same probability that s_0 makes the transition to each of these. So the probability that s_0 transitions to $\boldsymbol{S_3}$ is roughly: 1,000,000 x 1/1,000,000, or very close to 1. We have:

$Prob(s_3|\, s_0) \approx 1/1{,}000{,}000$
$Prob(s_3|\, \boldsymbol{S_0}) \approx 1/1{,}000{,}000$
$Prob(\boldsymbol{S_3}|\, s_0) \approx 1$ *entropy almost always increases from* s_0 *to* $\boldsymbol{S_3}$
$Prob(\boldsymbol{S_3}|\, \boldsymbol{S_0}) \approx 1$ *entropy almost always increases from* $\boldsymbol{S_0}$ *to* $\boldsymbol{S_3}$

(With all probabilities going forwards in time from $t=0$ *to* $t=3$.) Now the 'reversibility' of quantum mechanics (i.e. *cause-effect exchange symmetry)* means that:

$Prob(Ts_0|Ts_3) \approx 1/1{,}000{,}000$
$Prob(\boldsymbol{TS_0}|Ts_3) \approx 1/1{,}000{,}000$

And this holds equally for each state in $\boldsymbol{TS_3}$, so:

$Prob(Ts_0|\boldsymbol{TS_3}) \approx 1/1{,}000{,}000$
$Prob(\boldsymbol{TS_0}|\boldsymbol{TS_3}) \approx 1/1{,}000{,}000$

(With all probabilities going forwards in time from *t=0 to t=3*.) This means that:

- *The system will almost never make the transition from* Ts_3 *(or any other state in* $T\boldsymbol{S}_3$ *) back to* Ts_0 *(or any other state in* $T\boldsymbol{S}_0$*).*
- *Entropy will almost never decrease from the high entropy of* Ts_3 *(or any other state in* $T\boldsymbol{S}_3$ *) back to the low entropy of* $T\boldsymbol{S}_0$

The behaviour is completely different to the classical behaviour. Quantum thermodynamics has a law-like time asymmetry: entropy increases with overwhelming probability and there is no way to stop it in normal physics. It doesn't matter if we take the perfect time-reversal of a probabilistic system, its entropy is still overwhelmingly likely to increase after a short period. The quantum system will not retrace a process like a classical system.

Phase Space Visualisation of Quantum Irreversibility.

The best way to visualise what is happening is with a phase state diagram. Each point in phase space represents the complete state of a system (or the universe). Dynamic processes are paths through phase space.

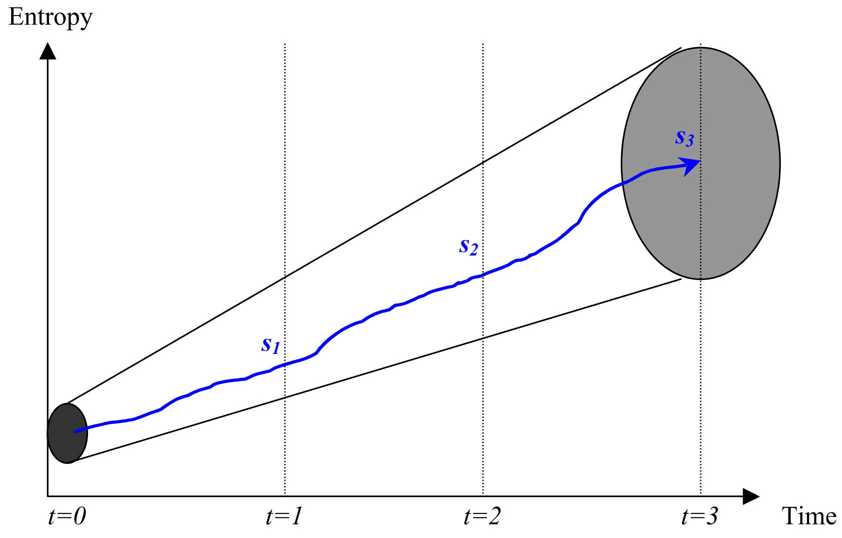


Figure 6. Development of the classical process in phase space. The initial state, s_0, belongs to a dense ball of similar low-entropy states, $\boldsymbol{S}_0$. The future paths from $\boldsymbol{S}_0$ go to a distended ball of states, $\boldsymbol{S}_3$, at t_3. Almost all the future paths lead to higher-entropy states like s_3.

The critical thing however is that *the total volume of states in* $\boldsymbol{S}_0$ *is exactly the same as the volume of their future states in* $\boldsymbol{S}_3$ - but $\boldsymbol{S}_3$ is distended across a much greater volume of phase space. The reason is that the states in $\boldsymbol{S}_3$ that come from s_0 are highly ‘filamented’.

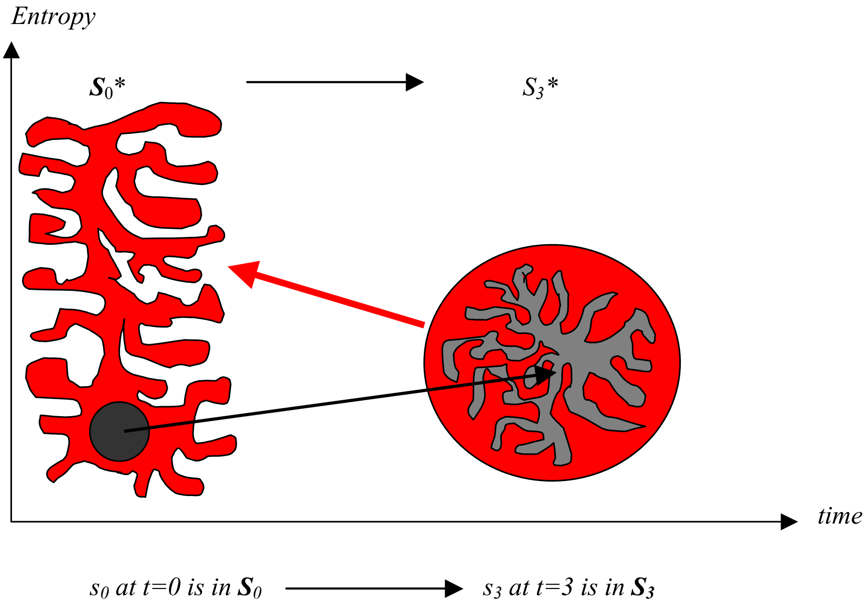


Figure 7. The filamented structure of $\boldsymbol{S}_3$ in classical physics. $\boldsymbol{S}_0$ is the grey ball at $t=0$ containing the state s_0, and $\boldsymbol{S}_3$ is the grey filamented volume at $t=3$ containing the state s_3. $\boldsymbol{S}_3$* is the red ball at $t=3$ (enclosing and including $\boldsymbol{S}_3$) and $\boldsymbol{S}_0$* is the red filamented volume at $t=0$ (enclosing and including $\boldsymbol{S}_0$).

States that start off very close together in $\boldsymbol{S}_0$ become far apart in $\boldsymbol{S}_3$ – hence its filamentation. This is the ‘butterfly effect’: small differences in initial conditions lead to large fluctuations in final states.

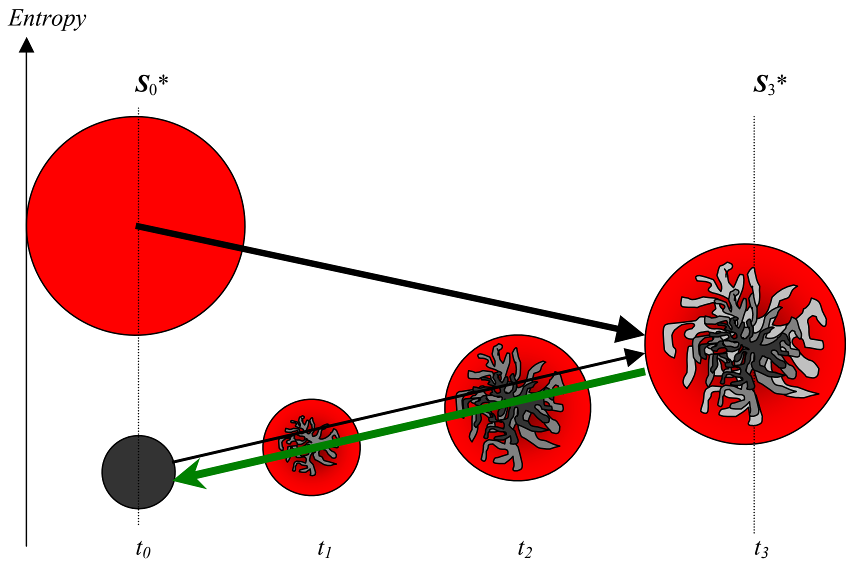
Because of this filamentation, many states very close to s_3 in phase space *are not in* $\boldsymbol{S}_3$ *– they have not developed from the low-entropy* $\boldsymbol{S}_0$. Instead they have developed from $\boldsymbol{S}_0^*$, a larger volume of phase space at t=0 that encloses $\boldsymbol{S}_0$. $\boldsymbol{S}_0^*$ is filamented just like $\boldsymbol{S}_3$ is – the ‘butterfly effect’ backwards in time means that small differences in final conditions lead back to large fluctuations in initial states. Most of $\boldsymbol{S}_0^*$ will be from higher-entropy states than $\boldsymbol{S}_3$.

This structure illustrates the fact that, when we consider reversing the states $\boldsymbol{S}_3$ *and* $\boldsymbol{S}_3^*$*, very small changes from the final reversed state* Ts_3 *will usually result in states in* $T\boldsymbol{S}_3^*$, and these lead to *large fluctuations away from* Ts_0*,* and almost always to *increased entropy.* This is why it is so critical to set the reversed state, Ts_3*,* with extreme precision if we want the time reversed process to occur.

But for a process of any complexity in quantum mechanics, with intrinsically probabilistic events, no matter how precisely we set the reversed state, Ts_3*,* somewhere along the reversed process the state is almost certain to jump out of the desired path, e.g. at $T\boldsymbol{S}_2$*,* and move into $T\boldsymbol{S}_2^*$ instead, and subsequently develop into a higher entropy state. The probabilistic nature of quantum mechanics make this an intrinsic, physically necessary, law-like feature of quantum processes.

The Reversibility Paradox.

It is worth mentioning the ‘reversibility paradox’ here as well, although it is not intended to deal with this in detail. This paradox comes about primarily because *our normal inferences from future to past (retrodiction; interpretation of physical systems as carrying information about the past)* conflict with our picture of *causality from past to future* in the context of a time symmetric micro-theory.



Normal retrodiction, from t_3 to t_0, infers a chain back to a low-entropy origin.

Figure 8. In real life, we normally infer that a system in S_3* *(medium entropy)* has actually evolved from S_0 *(low entropy),* not from S_0* *(higher entropy).* Yet most possible micro-states in S_3* evolve from S_0*, so it is puzzling how we can justify this inference.

In reality we make a 'fact-like' assumption that systems in our universe originated in a common low-entropy ancestor state of 'branch systems' (Reichenbach). But can we reconcile this with the laws of physics?

If we start with an observation that a system is in a state in S_3*, without being able to distinguish whether it belongs to the special filamented structure S_3, and consider its causal origin, we should conclude that it almost certainly started in from a higher entropy state in S_0*, and not from a special lower entropy state in S_0. This is because there are far more high-entropy states in S_0* than low entropy states in S_0. If we do not have some additional reason to believe that S_0 is preferred over S_0* as the origin of the thermodynamic state in S_3*, then we can hardly avoid this inference. Since the states in $\boldsymbol{S_3}$* are very close together in phase-space, i.e. have very similar micro-states, it seems that we cannot tell directly whether the micro-state, s_3, really lies within $\boldsymbol{S_3}$, or in $\boldsymbol{S_3}$*.

In real life, however, we constantly infer that systems originate from *lower entropy states,* i.e. we infer from $\boldsymbol{S_3}$* back to $\boldsymbol{S}_0$, and not to $\boldsymbol{S}_0$*. Without this, we would simply not be able to make sense of physical structures as *carrying information about the past*. Physics would become a *reductio ad absurdum,* because the present state (that we observe directly) would no longer allow any normal inference to its past.

There are three main points to make about this paradox.

1. **Paradox is unavoidable in a time symmetric theory.** In the context of a truly time symmetric theory (such as either reversible classical physics, or quantum mechanics with the additional constraint of time symmetry), the paradox seems almost impossible to avoid! This is because, as we have seen earlier, time symmetry along with cause-effect exchange symmetry *implies thermodynamic equilibrium* as the expected micro-state for the universe. If this is taken as a fundamental law of nature, then the most probable cause of any low-entropy state of the universe (such as we actually observe) has to be as a chance fluctuation away from a long-term equilibrium – exactly as Boltzmann realised.

2. **QM solves the paradox**. Real-world quantum mechanics is probabilistic and time *asymmetric,* and we are not forced to the paradoxical conclusion. Instead we are free to propose our normal causal explanations, that thermodynamic systems have been evolving for a long period of time from a low-entropy state of the early universe.

3. **Why is this a better explanation?** Why is this a better explanation than the conventional philosophy that the laws of nature are really time symmetric? What we observe in the universe are not simply ‘thermodynamic states’, like $\boldsymbol{S_3}$*, (e.g. hot water, cold water), we observe highly complex structures, repeated over and over again in similar forms. In terms of a theoretical solution, we need to show that we can observe or infer that micro-states like s_3 in our example *really do belong to the filamented structures like* $\boldsymbol{S_3}$*, and not just to* $\boldsymbol{S_3}$*. To stress this in Figure 8, I have shown the filamented structure as building up a *depth of*

complexity (like a fractal pattern), with layers of repeated structures, rather than just a 'flat' filamented structured.

The approach associated with Prigogine 1985 [22] which is closely related to chaos theory shows that far-from-equilibrium thermodynamic systems naturally evolve complex structures (Onsanger). We need such theories for the detailed scientific explanation of complex structures. Chaotic *deterministic* dynamics is often inferred to be sufficient to determine law-like irreversibility. I will not consider this here, but chaos theory and far-from-equilibrium thermodynamics is a leading attempt to explain the development of complex ordered structure from chaotic beginnings, and is mutually supportive of the view here.

Cosmological Time.

We have been considering micro-physics so far, but it is also important to see how this combines with modern cosmology. There are four general types of models considered (conventional models, without going into many-world theories, fractal universes, holographic universes, etc). But we will see these are all naturally *time asymmetric.* Cosmology does not support time symmetry either.

***C1. Steady State Universe**.*	*Continuous future generation of matter or order.*
C2. Open Universe.	*Origin from a singularity then eternal expansion*
C3. Closed Universe.	*Origin from a singularity, collapse back to singularity.*
C4. Cyclic Universe.	*Eternal cosmological cycle of expansion and collapse.*

- The main point here is that *all these models are time asymmetric.*

C1. Steady state models typically propose continuous regeneration of matter and order. Normal thermodynamics degrades entropy: special mechanisms peculiar to the steady state theory restores entropy. Such models are explicitly directed in time. But since there are no popular models for this any more I will not discuss it further here.

C2. The open universe is proposed to originate a finite time ago with an initial ‘singularity’ (or point of infinite energy density), to explode through the Big Bang, and continue expanding forever after. This requires asymmetric cosmological time. The universe ‘appears from nothing’ but continues expanding forever in the future. Micro-physical (thermodynamic) directionality also continues in the future, leading to ‘heat death’.

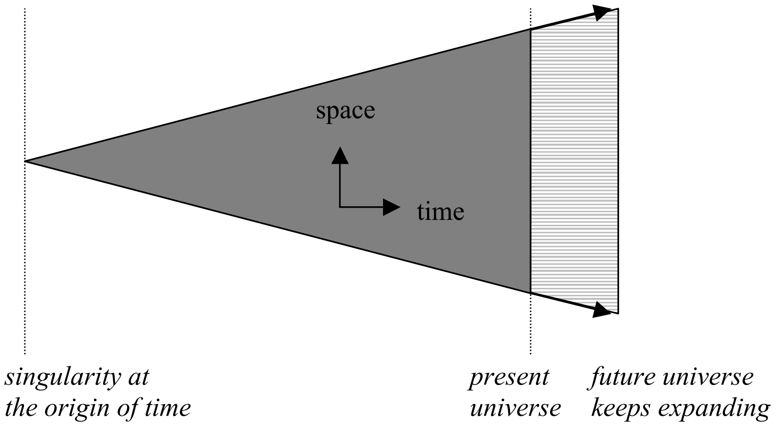
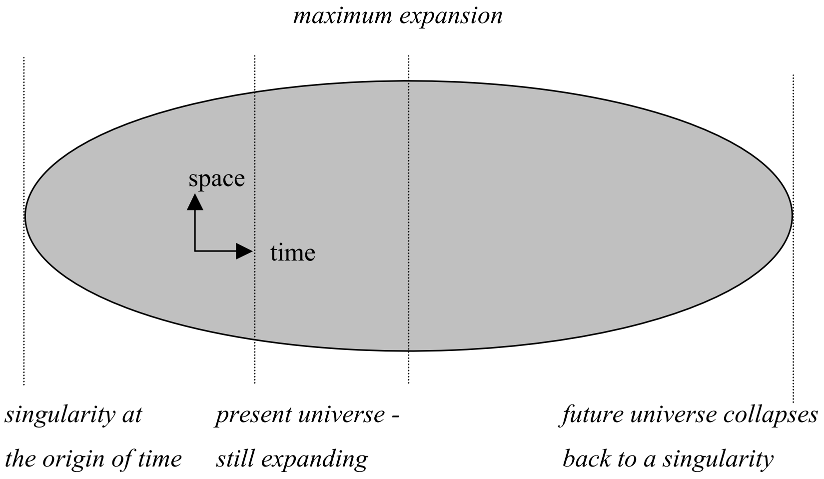


Figure 9. Open universe started at a point (singularity) and continues to expand forever in the future. Expansion could be slowing or accelerating – it is not likely to be constant as shown here – this diagram is purely schematic.



C3. The closed universe originates like the open universe from a singularity, but eventually collapses back into a singularity, and vanishes from existence. This has a finite start and finite end in time, so cosmological time is symmetric in that sense. The spatial expansion may even be symmetric around the mid-point. The point that will be made here however is that micro-processes in the universe must be *time asymmetric,* being driven by thermodynamics, with development of complex structures and information towards the future.

Figure 10. Closed universe starts at a point (singularity), expands, and collapses back to a point.

C4. The cyclic universe is the most interesting from the point of view of time directionality, and it illustrates a naturally occurring *time asymmetric cosmology.*

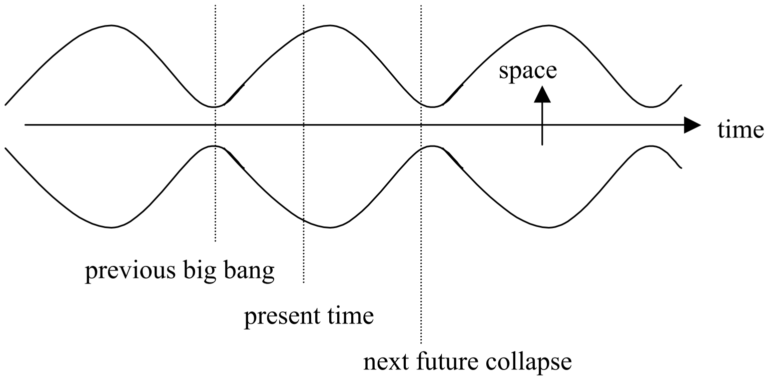


Figure 11. A cyclic universe expands and collapses through an infinite cycle.

This is discussed more in detail next, but a brief digression to consider which cosmology we actually live in.

The Incompleteness of Cosmology.

Most physicists would claim at present that the '*open universe'* is the most likely option, citing two theories: (i) the General Theory of Relativity applied to the earliest universe predicts an initial 'space-time singularity' (Hawking and Penrose), and (ii) the theory of dark energy indicates that the universe's expansion is accelerating and it will never collapse back into another singularity. But we should not take opinions on which kind of universe we are too seriously yet. Cosmology is too incomplete, and these are temporary guesses and hunches in the process of trying to work out a theory. Current models and current evidence are not decisive about such matters. Some reasons are worth emphasising.

On the first point, the theory of 'space-time singularities' used by Penrose and Hawking is a mathematical extrapolation from a theory of gravity (GTR) with no independent *evidence* I am aware of. It is obtained by taking GTR and extrapolating it to an extreme limit, where physical quantities are *literally taken to infinite values*. But there is no evidence that GTR is valid at such limits. In fact, although physicists talk of them all the time, there is no empirical evidence that I know of that singularities, naked or otherwise, really exist in nature! The only basis for belief in *physical singularities* is the theorist's metaphysical faith that GTR is a universal truth. But many theorists think GTR is incomplete at the fine scale where it meets QM, and a more complete theory will correct GTR in the extreme limits where it generates singularities. String theory is proposed partly as a way to fix singularities.

The existence of infinite quantities in nature (like infinite energy densities) contradicts our realist intuitions. The methodology of extrapolating theories like GTR to reach extreme consequences, inferring the physical possibility of circular time loops, reversed causation, worm-holes through space-time, etc, is speculative metaphysics if we cannot eventually confirm these things *independently*.

Note that infinite quantities appear in classical theories too if we take extreme limits – e.g. classical laws of gravitational and electric forces both involve the factor $1/r^2$, and as we limit $r \rightarrow 0$ *(go infinitely close to the center of a point mass or electric charge),* the forces theoretically become infini reflecting real physics. Instead we as classical theories break down at these

"Event Horizon Telescope".

MIT Haystack Observatory. 2012.
"Project Summary: A long standing goal in astrophysics is to directly observe the immediate environment of a putative black hole with angular resolution comparable to the event horizon. Realizing this goal would open a new window on the study of General Relativity in the strong field regime, accretion and outflow processes at the edge of a black hole, the existence of an event

factor: $1/(1-2MG/c^2r)$ in the Schwarzschild solution. This goes to +/- infinity when $r \to 2MG/c^2$ *(the black hole event horizon), and to zero when* $r \to 0$ *(the naked* singularity), giving two singularities. But there is no reason to think these mathematical singularities are physically real in the final account.

"*But don't black holes exists? As predicted by GTR? Doesn't that prove the event horizon exists?*" Not quite. There is evidence for 'black holes' in a generic sense – there are large conglomerations of matter in the centres of galaxies, and their gravity probably traps their light – but similar objects appear on many theories of gravity. The problem is that no one has observed the detailed features of a *GTR event horizon* yet, precisely enough to confirm it explicitly as a *GTR black hole.* This would be a new experimental confirmation of GTR if it was achieved. [See inset].

Similarly, dark matter and dark energy are recent hypotheses introduced to rescue theoretical consistency with GTR in the face of observational anomalies. But these now threaten to enter the realm of speculative metaphysics, because neither substance has been independently observed or detected, despite much trying, and no one seems to have any idea of what it could realistically be composed of. The observational evidence claimed for the *accelerating* expansion of the universe is very theory-dependant. This whole explanatory scenario is liable to collapse when a new unifying theory comes along. Dark matter and energy may be comparable to C17th theories of phlogiston.

We should not to take the *unconfirmed theoretical* hunches and extrapolatums of physicists too seriously as a source of metaphysical wisdom.

http://en.wikipedia.org/wiki/String_theory

Wikipedia, "String Theory"

"Many theoretical physicists (including Stephen Hawking, Edward Witten, and Juan Maldacena) believe that string theory is a step towards the correct fundamental description of nature. This is because string theory allows for the consistent combination of quantum field theory and general relativity, agrees with general insights in quantum gravity such as the holographic principle and black hole thermodynamics, and has passed many non-trivial checks of its internal consistency. According to Hawking, *"M-theory is the only candidate for a complete theory of the universe."* Other physicists, such as Richard Feynman, Roger Penrose, and Sheldon Lee Glashow, have criticized string theory for not providing novel experimental predictions at accessible energy scales and say that it is a failure as a theory of everything."

The Cyclic Universe Model is Naturally Asymmetric.

But we do not have to decide on any specific cosmological model to make the key point here, because all are time *asymmetric* in the same essential way as the *cyclic universe,* which illustrates time asymmetry most vividly. The cyclic universe expands and contracts in an endless cycle, swinging between states of high density ('Big Bangs') and low density (maximal expansion). Rather than contracting to a mathematical point and appearing/disappearing by magic, we assume that it 'bounces' after reaching a certain density. This cosmology operates through two sets of laws:

(i) the deterministic expansion-contraction cycle of space – we may assume this is time symmetric
(ii) the micro-physical laws of ordinary processes – assume this is like QM

The conventional assumption is that such a cyclic process *should have time symmetric laws.* However when we consider the thermodynamic cycle in such a model, we find it is naturally directed in time.

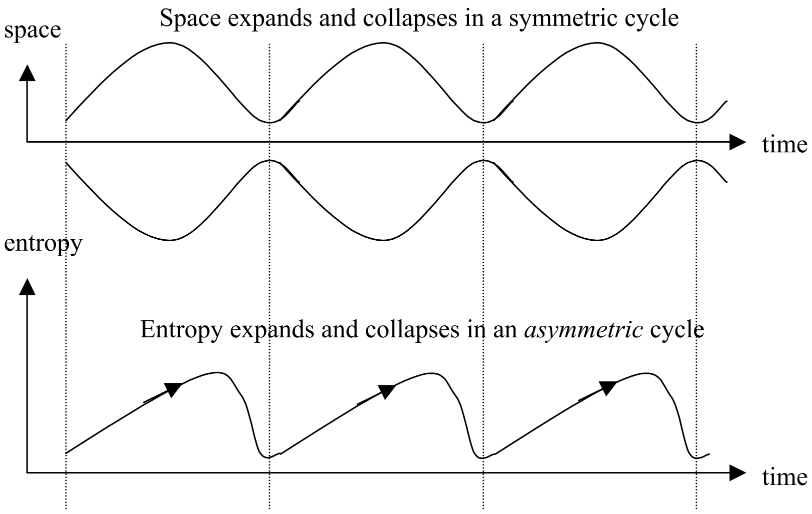


Figure 12. The entropy cycle for the cyclic universe is *asymmetric* – it points in the same direction as quantum mechanical probabilities. The entropy cycle has a 'saw-tooth' shape: it begins very low at the beginning of each cycle, increases steadily for most of the cycle, then rapidly falls back to a low value.

I will now try to show why this time asymmetry is inevitable, in the symmetrically expanding and collapsing cyclic universe. The first point is that given the universe has a cyclic state, *the entropy must fall back to the same low level by the beginning of every cycle. Yet ordinary thermodynamics tells us that it must also increase through much of the expansion cycle. So how does entropy fall? Isn't it supposed to always increase, according to thermodynamics?*

How Entropy Falls in the Cyclic Universe.

A popular speculation in the 1960's (due to Gold) was that entropy is related to the cosmological expansion – and it will start falling if the universe stops expanding and starts contracting, in a time symmetric fashion. But it was quickly pointed out that this does not make sense in terms of real physics. There is no known reason why ordinary processes (e.g. burning of suns; flowing of rivers; breaking of eggs…) should reverse if cosmological space begins to contract. There is no known reason we would even become aware that the expansion era has ended. Nonetheless the intuition remains with many writers that *the thermodynamic cycle for a cyclic universe may be time symmetric, because all the underlying laws of nature are time symmetric.* But this is simply a mistake – because the underlying micro-physical laws *are not time symmetric.* Once this mistake is dismissed (claims 1* - 4*), we can look at the mechanics with fresh eyes.

It is essential to realise that the reason entropy decreases in the collapse period is because *the configuration space itself is being compacted.* There are two components to a thermodynamic system: *the configuration space, which determines the freedom micro-states have to move in; and the micro-state itself.* When space expands in the cosmological model, *it expands the configuration space.* The micro-state responds by evolving into new states, and randomising itself in the new state-space – just as when we released the ball of particles in the earlier example, the particles had a larger space of possible states to inhabit. Conversely, when space contracts in the cosmological model, it forces the configuration space to contract – and eventually forces the entropy down. The entropy cycle lags behind the configuration space cycle, and it is not until the later stages of contraction that the entropy is forced down.

This is evident in the standard physics of the ‘big bang’. In the early stages, when the universe was extremely compacted, it was impossible for ordinary particles to form – all the energy was forced into dense ball, with a small set of possible states. After the explosion, it became possible for the energy to crystallise into ordinary particles and atoms – allowing the highly complex states of the present universe.

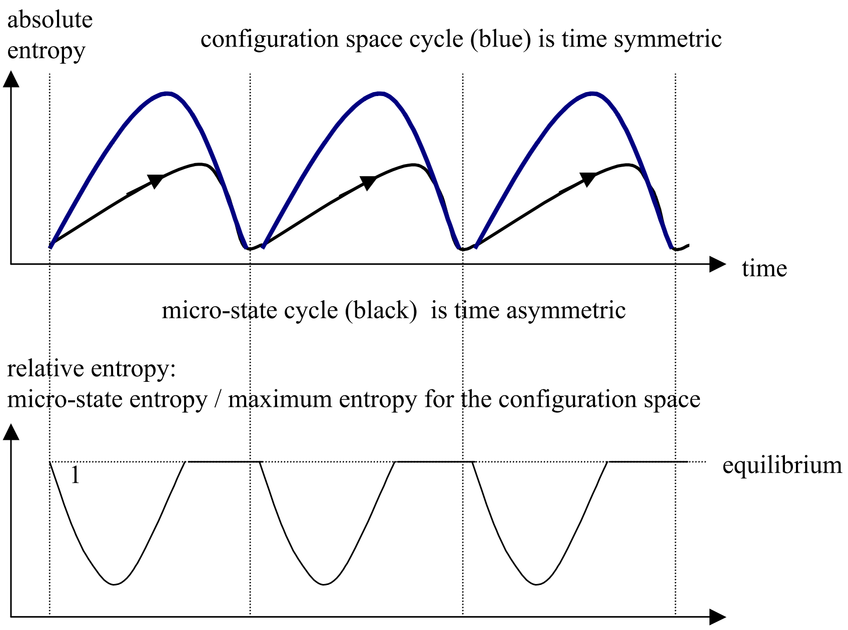


Figure 13. The top panel shows the configuration space cycle (maximum entropy allowed in the universe) in blue, and the micro-state entropy (actual entropy of the particle universe) following this in black. The latter is time asymmetric – a saw-

tooth shape. The bottom panel shows the 'relative entropy' (or departure from *equilibrium*). Equilibrium occurs when the particle micro-state entropy is maximised relative to the entropy permitted by the configuration space, i.e. when: micro-state entropy/configuration space entropy = 1.

Even though the absolute entropy is very low at the most compacted points of the cycle, the universe is still in equilibrium. It is forced close to equilibrium through the later part of collapse cycle, because the configuration space cycle forces the absolute entropy down to the micro-state entropy.

I briefly note one peculiarity of this model. As the configuration space contracts, it should force probabilistic state transition laws of quantum mechanics to alter. More exactly, it seems that it should force the *cause-effect exchange symmetry to fail.* (The so-called 'reversibility symmetry' of ordinary quantum mechanics should fail). If it were absolutely impossible for this symmetry to fail, this cyclic model would probably not be possible. However, this quantum symmetry does indeed seem to mysteriously break for a certain interaction, viz. K-meson decay, so we know such an effect is physically possible. And as noted earlier, it is not a real *symmetry transformation* anyway.

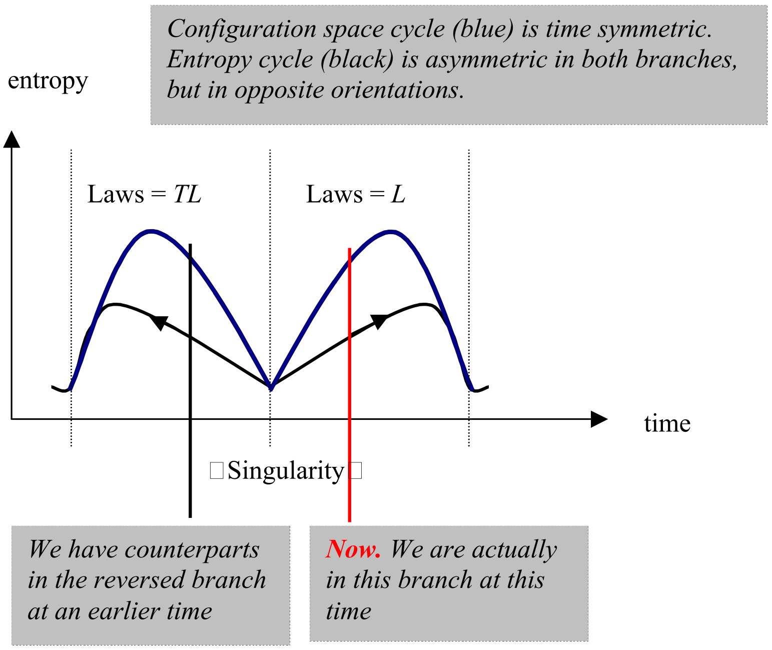
The point is that this class of models – time symmetric cyclic collapse models – naturally generate a *time asymmetric entropy cycle* in the context of any micro-theory with intrinsic probabilities. Such models *must have time asymmetric fundamental laws*. Such models *explain the thermodynamic directionality without postulating any special initial states or boundary conditions.* In fact the same mechanism for generating time asymmetric thermodynamics applies in the open and closed models too. They also *have to have time asymmetric particle physics,* just like quantum mechanics.

Their main difference with the cyclic model lies in their lack of any explanation for the initial creation of the universe at a specific moment. In the cyclic model, the universe is taken as a physical entity persisting for all time – it has always existed and always will exist – it simply changes its present state as time passes. The existence of this universe is mysterious in the sense that the existence of *anything* is mysterious.

But there are no ‘creation miracles’ *within* the natural history of the universe. Every physical state has an explanation in terms of preceding physical states. The open and closed universes seem to require ‘miracles’ to bring them into creation. They appear ‘created from nothing’, with no causal explanation for the original states of these universes. But the failure to explain ultimate causes does not undermine the explanation of irreversibility. Whatever the cosmology that produced our universe, the irreversibility of thermodynamic processes is a consequence of the parallel irreversibility of QM.

The Fallacy in the Conventional View.

The conventional defence will allow that our *asymmetric closed cyclic universe* may well be possible, but it will insist that if it is, then according to our best knowledge of the laws of nature, *the time reversed cycle must be equally possible.* E.g. they would insist that the kind of universe depicted below would be equally compatible with the laws of physics as the cyclic asymmetric universe I have depicted above. In this universe, there is a 'singularity' at the 'origin' of time, but with symmetric 'branches', going backwards and forwards in time respectively. The universe (thermodynamic behaviour) is symmetric around the singularity.



Configuration space cycle (blue) is time symmetric. Entropy cycle (black) is asymmetric in both branches, but in opposite orientations.

We have counterparts in the reversed branch at an earlier time

Now. *We are actually in this branch at this time*

Figure 14. A 'time symmetric' universe with two branches. Note that this is physically impossible, according to our current knowledge of physics, because *TL*

$\neq L$. This would contradict the notion that *the laws of physics are universal through time, or have time translation symmetry.*

The conventional philosophy insists that this universe must be just as physically possible as the cyclic universe depicted previously, because they believe that $TL = L$, i.e. that the laws of nature are time symmetric, and exactly the same time symmetric laws would hold in both branches. The only distinction between the two branches on their view must lie in the *boundary conditions,* at the 'singularity'. If this were true, their claims 5* - 8* would be supported. We would not be able to tell which branch we are 'really in'. We could have 'counterparts' in the reversed branch who think that 'time flow' occurs in the opposite direction to what we perceive.

However the whole discussion to this point proves that this is wrong, because $TL \neq L$! The 'time symmetric' universe would contradict the assumption that *the laws of physics are universal through time,* i.e. have time translation symmetry. In a cyclic universe where the laws of physics are the same in each cycle, *the thermodynamic cycle must be time asymmetric in every branch.* There is no possible way to generate a consistent model of the type of universe above by manipulating boundary conditions, as the positivists believe.

Conclusion. Fallacies 5* - 8*.

The fallacies in 5* - 8* have been demonstrated sufficiently to show that known physics does *not* support the positivist explanation of process directionality as a merely 'contingent fact'. Instead it supports the view that time is intrinsically directional, that this is reflected in the causal laws of nature, and process directionality or irreversibility in nature is a fundamental, law-like feature.

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Footnotes.