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The emergence of time's arrows and special science laws from physics

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In this paper, I will argue that there is an important connection between two questions concerning how certain features of the macro world emerge from the laws and processes of fundamental microphysics and suggest an approach to answering these questions. The approach involves a kind of emergence but quite different from 'top-down' emergence discussed at the conference, for which an earlier version of this paper was written. The two questions are (i) How do 'the arrows of time' emerge from microphysics? (ii) How do macroscopic special science laws and causation emerge from microphysics? Answering these questions is especially urgent for those, who like myself, think that a certain version of physicalism, which I call 'microphysical completeness' (MC), is true. According to MC, there are fundamental dynamical laws that completely govern (deterministically or probabilistically), the evolution of all microphysical events and there are no additional ontologically *independent* dynamical or causal special science laws. In other words, there is no ontologically independent 'top-down' causation. Of course, MC does not imply that physicists now or ever will know or propose the complete laws of physics. Or even if the complete laws were known we would know how special science properties and laws reduce to laws and properties of fundamental physics. Rather, MC is a contingent metaphysical claim about the laws of our world. After a discussion of the two questions, I will argue the key to showing how it is possible for the arrows of time and the special science laws to emerge from microphysics and a certain account of how thermodynamics is related to fundamental dynamical laws.

Keywords: time's arrows; special science laws; physics

1. INTRODUCTION

Time's arrows are the temporally asymmetric phenomena and processes that pervade the world. There are a subjective arrow and objective arrows. The subjective arrow is associated with our experience of time passing. The objective arrows include the pervasive increase in entropy described by the second law of thermodynamics and the temporal asymmetries of knowledge (that we can know about past events in ways that are different from knowledge of the future), of influence (that we have some influence over the future but never over the past), of counterfactuals (that small counterfactual differences at time t may lead to big differences at subsequent, but not prior, times to t.), of causation (that causes precede their effects) and of many special science laws and processes. How the subjective and objective arrows are related, as they certainly are, is a difficult issue. It is plausible that an account of the objective arrows of time will play a role in accounting for our experience of time passing, but an adequate account of the subjective arrow would involve a discussion of the nature of consciousness and its relation to physical phenomena beyond the scope of this paper.

Understanding how the objective arrows emerge from microphysics is a huge obstacle. The candidates for dynamical laws that are taken seriously in physics (with a couple of qualifications) have no temporal direction built into them.[1] They are temporally symmetric (or 'time reversal invariant'). As a consequence, if a sequence of fundamental states is compatible with the dynamical laws, then there is a sequence of states compatible with the dynamical laws that result in the same macro behaviour but is temporally reversed.[2] So, for example, since the melting of an ice cube in a pail of warm water is (as it obviously is) compatible with the fundamental dynamical laws, so is the temporally reversed process of an ice cube spontaneously forming out of water while the surrounding water grows warmer. Temporal symmetry holds not only for the laws of classical mechanics, but also for electromagnetic theory, deterministic versions of quantum mechanics (Bohm and Everett) and relativity theories. The situation is a bit more complicated for certain indeterministic versions of

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One contribution of 15 to a Theme Issue 'Top-down causation'.

[1]This claim requires some qualification. There are certain microphysical processes involving kaon decay (resulting in conservation of parity violation) that seem to involve a temporally directed process and there are certain indeterministic versions of quantum theory that specify probabilistic evolution in one but not in the reverse temporal direction. But taking these qualifications into account does not affect the thrust of my argument.

[2]In classical mechanics, the state of a system is specified by the relative positions and momenta of the particles that compose the system. If a sequence of states is compatible with the classical mechanical laws, then the sequence whose momenta are reversed is also compatible with the laws.

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quantum theory but the implications for grounding the arrows of time are the same.[3] The dynamical laws by themselves do not do it.

One way of responding to the difficulties of grounding temporal direction in physics is to appeal to claims about the metaphysics of time. For example, some philosophers hold that time 'flows' and the direction of flow determines the direction of time's arrows. Others hold that while there is no literal flow, time has a built-in direction that somehow accounts for time's arrows.[4] My view is that despite their initial metaphorical attractiveness, these accounts do not work. They fail to provide a scientific explanation of how the metaphysics engages with what we know of physics and psychology. I would not argue that here but instead describe a proposal from physics for grounding time's arrows.

Special science laws are laws expressed in the vocabularies of special sciences: chemistry, biology, psychology and economics. They typically apply *ceteris paribus* and are often probabilistic. They typically connect properties that typically multiply realized relative to more fundamental properties. An example cited by Jerry Fodor is Gresham's law 'bad money drives out good money'.[5] It seems to hold for a wide variety of political and economic systems. In a very influential paper, Fodor argued that, on the one hand, special science laws have a kind of autonomy from laws of fundamental physics but, on the other hand, they are implemented by fundamental laws [1].[6] How can these two ideas be squared with each other? That is, how do the special science laws emerge from fundamental physical laws and phenomena? Here is a passage from a paper in which Fodor expresses puzzlement concerning this question.

> The very existence of the special sciences testifies to reliable macro-level regularities that are realized by mechanisms whose physical substance is quite typically heterogeneous.... Damn near everything we know about the world suggests that unimaginably complicated to-ings and fro-ings of bits and pieces at the extreme micro-level manage somehow to converge on stable macro-level properties ... the somehow, really is entirely mysterious ... (*it is hard to see*) ... why there should be (how there could be) macro-level regularities *at all* in a world where, by common consent, macro-level stabilities have to supervene on a buzzing, blooming confusion of micro-level interactions ... So then, why is there anything except physics? .... Well, I admit that I don't know why. I don't even know how to think about why. I expect to figure out why there is anything except physics the day before I figure out why there is anything at all, another (and presumably related) metaphysical conundrum that I find perplexing. ([2] p. 161).

Fodor has no doubt that there are special science laws. But he is puzzled as to how this can be so given that the fundamental micro-physical dynamical laws completely govern the motions of the particles and fields. How does all the to-ing and fro-ing of particles conspire to satisfy an economic regularity like Gresham's law?

The differences between fundamental dynamical laws and special science laws make Fodor's question especially difficult to answer.[7] As we have already discussed, fundamental dynamical laws of physics are temporally symmetric. In contrast, typical special science laws are temporally directed. There is no time-reversible special science law corresponding to Gresham's law.

An other difference is that typical special science laws are causal. For example, Gresham's law says that the introduction of bad money *causes* the hoarding of good money. But not only is causation temporally directed, it also does not appear anywhere in the fundamental laws of physics.[8] Relatedly, fundamental dynamical laws are *global* in the sense that they specify how the global state of an isolated system (or the universe as a whole) evolves. Typical special science laws and causation are local in that they connect relatively local features of systems or a collection of interacting systems. In fact, the fundamental dynamical laws say surprisingly little about how an isolated special science system evolves. For example, given a macro characterization that specifies an isolated system consisting of an ice cube bobbing in a pail of warm water at *t*, the fundamental laws say almost nothing about the state of that pail at *t*', an hour after (or before) *t*. The ice cube may melt or it may grow larger while the water grows warmer or the whole pail may disperse and form a cloud in the likeness of the Queen. Similarly, given a macro description of the Earth and the Moon at *t*, there are micro states compatible with that description that the fundamental dynamical laws evolve the system into bizarre macro states (e.g. the particles composing the Moon dispersing into empty space). Of course, in practice, astronomers (rightly) ignore such micro states. Nevertheless, given pretty much any macro state, there are micro states that realize those macro states that evolve in conformity with the dynamical laws in bizarre ways. The upshot is that the fundamental laws by themselves entail very few interesting macroscopic regularities. In summary, fundamental laws are temporally symmetric, do not mention causation and are global. Special science laws are typically temporally asymmetric, causal and local. My conclusion is that it is impossible for the fundamental dynamical laws to explain special science laws on their own.

Puzzlement over the question of how special science laws and causal relations can arise from fundamental dynamical laws of physics can lead one to propose that there are ontologically emergent dynamical/causal laws, a view I will call 'causal emergentism'.[9]

[3]Certain indeterministic versions or reformulations of quantum mechanics—e.g. GRW theory—plausibly supply the probabilities of statistical mechanics and so, if the thesis of this paper is correct, play a role in grounding time's arrows and special science laws. [3].
[4]Maudlin [4] holds that time possesses an intrinsic direction.
[5]*Gresham's law* is an economic principle 'which states that when government compulsorily overvalues one money and undervalues another, the undervalued money will leave the country or disappear from circulation into hoards, while the overvalued money will flood into circulation'.
[6]Fodor [1].

[7]See Loewer [5] for a more extensive discussion of the differences between fundamental laws of physics and special science laws.
[8]Most famously this point was made by Bertrand Russell 'The law of causation,... is a relic of a bygone age, surviving, like the monarchy, only because it is erroneously supposed to do no harm'. ([6], p. 193).
[9]Tim O'Conner in his paper in this volume is sympathetic to what he calls 'productive causal emergence'. His characterization is systemic

According to causal emergentism, some special science dynamical laws are as metaphysically fundamental as laws of microphysics. Based one variety of causal emergentism, there are special science laws or causal relations that *override* the fundamental laws of microphysics. Another variety of emergentism claims that there are gaps left by the fundamental laws of microphysics that are to be filled by fundamental special science laws.[10] Both these views are incompatible with MC, since they posit ontologically fundamental 'top-down' nomological/causal connections. Based these accounts, the explanation of how 'the to-ing and fro-ing' of particles manages to converge on macro regularities is that there are top-down laws over and above the micro-physical laws that enforce these regularities and produce causal connections.[11] In my view, this kind of top-down causal emergentism is not plausible. Physics has accumulated a great deal of evidence in favour of MC and there is little reason to think that the fundamental micro-physical laws can be overridden or are gappy in the way that these versions of emergentism require.[12] It is important to note that the denial of causal emergentism is perfectly compatible with the existence of non-fundamental special science laws and with weaker forms of emergentism including the version I will discuss later.[13]

The problems of accounting for time's arrows and special science laws (and accounting for them given MC) are obviously connected with one another. A deeper connection between special science laws and time's arrows is brought out by looking more closely at a particular 'special' science—thermodynamics—whose central law characterizes one of time's arrows.

The science of thermodynamics was developed during the nineteenth century to account for the observable connections among heat, work, pressure, temperature and certain other macroscopic quantities and behaviours including entropy and equilibrium. Entropy was first introduced as a measure of the portion of energy in the system that is not available for work. So, for example, the entropy of a system consisting of a cylinder in which a movable wall separates a hot gas from a cold gas is lower than the entropy of the cylinder once the hot gas has pushed the wall (thereby doing work) and allowed the temperature to become uniform. An equilibrium state of a system is a state at which the system's entropy is maximum. The main dynamical law of thermodynamics, the second law, says that the entropy of an energetically isolated system never decreases and typically increases until the system reaches an equilibrium state. The second law entails that an ice cube in a bucket of warm water will melt, that heat flows from warmer to colder regions, that the burning of coal produces heat, that broken eggs do not come back together again and so on. Obviously, the second law, unlike the fundamental laws governing the motions of particles, is not temporally symmetric.

Towards the latter half of the nineteenth century, the issue of the relationship between the second law and fundamental physics became especially pressing as physicists grew increasingly confident that matter consists of atoms whose motions conformed to the classical mechanical laws. The temporal symmetry of the laws means that if a sequence of states of a system of particles is compatible with the laws, then so is there a temporally reversed sequence obtained by reversing the direction of the particles' momenta that is also compatible with the laws. For example, if the melting of an ice cube in warm water is compatible with the laws (as it is), then so is the spontaneous formation of an ice cube out of warm water. The later process obviously violates the second law.

More generally, if an evolution of states conforming to the dynamical laws is entropy increasing, then the temporally reversed evolution is entropy decreasing and also conforms to the dynamical laws. Thus, it seems that there is no possibility of grounding the second law or, for that matter, any of the arrows of time in the classical dynamical laws alone. This gives rise to the problem of explaining how the second law emerges from the fundamental dynamical laws.

The first big steps towards answers addressing this problem were taken by Ludwig Boltzmann. The upshot of his years of investigation as follows: Boltzmann characterized the thermodynamic properties of a macro system—pressure, temperature, energy, entropy, equilibrium, etc—in terms of classical mechanical quantities (position, momentum, total energy, etc.) and a measure (the standard Lebesgue measure) over the set of micro states.[14] He then observed that even though there are infinitely many entropy-decreasing (towards the future)

properties that exert a non-redundant, productive causal influence on the behaviour of the system's more fundamental parts. [It] implies that fundamental physics is not 'causally closed' in the sense of there being, for any fundamental physical state, a *complete* set of determinants that entirely comprises of same-level fundamental physical states.

[10]A third view that qualifies as ontological emergentism holds that although the fundamental dynamical laws are complete, there are also fundamental macro laws. The two kinds of laws over determine the evolution of macro processes. This is a peculiar view, but it is a plausible reading of Fodor's view about the autonomy of the special sciences. [7].

[11]Theories of the collapse of the wave function in quantum mechanics that claim that collapse occurs only when measurements or observation occurs provide examples of ontological emergentism.

[12]The most serious worries about whether our universe contains a complete set of fundamental laws comes from the problem of reconciling general relativity with quantum mechanics and whether quantum theory itself can be understood as specifying objective laws. While many physicists are content to understand quantum mechanics instrumentalistically, there are a number of interpretations that construe it as specifying objective laws (see [3]). While the reconciliation problem remains, it concerns regimes (black holes, the Big Bang) far from the concerns of the special sciences. Some philosophers, e.g. Nancy Cartwright [8], claim that that evidence for fundamental physical laws is obtained only in very special circumstances for very simple systems and does not provide support for the nomological completeness of physics. I cannot get into this issue in this paper except to remark that a Nobel Prize is waiting for the scientist who demonstrates that the fundamental laws of physics that hold for microscopic systems fail for macroscopic systems. For a good discussion of Cartwright, see [9].

[13]It is compatible with O'Conner's 'predictive' and 'explanatory' emergentism (Glossary for the conference) and also with a novel kind of emergentism that involves nomological constraints on initial conditions that I discuss later in this paper.

[14]The entropy of a macro condition M is given by $S_B(M(X)) = k \log |\Gamma_M|$ where $|\Gamma_M|$ is the volume (on the measure) in Γ associated with the macro state M, and k is Boltzmann's constant. S_B provides a relative measure of the amount of Γ corresponding to each M. Given a partition into macro states, the entropy of a micro state

micro states that realize a system not in equilibrium (e.g. an ice cube in warm water), for typical systems such states are, in a certain sense, *sparse* relative to the measure. The sense is that the measure of the set of micro states realizing the thermodynamic condition of an isolated non-equilibrium system (e.g. the ice cube in the bucket) that are entropy decreasing is very small. Furthermore, for typical systems, the measure of the set of entropy-decreasing states in small neighbourhoods of typical micro states is also very small. His next step was to construe the measure as a probability measure that specifies the probability that a system is in micro state m given that it is in macro state M. It follows that the conditional probability of a system in a non-equilibrium macro condition M being in a micro state that lies on an entropy-increasing trajectory is approximately 1. So, the second law should not have been stated in the first place as an absolute prohibition on entropy decreasing but rather as decreasing being enormously unlikely.

Initially, this seems to solve the problem of accounting for the second law. But a problem was soon observed (by Loschmidt, Zermelo and others) with Boltzmann's proposal. As a consequence of the temporal symmetry of the fundamental dynamical laws, the uniform probability distribution applied to a system at time t in macro condition M entails that the probability that the entropy of the system was greater at times *prior* to t also is approximately 1. Boltzmann's probability assumption entails that very likely the ice cube in an isolated Martini glass was smaller an hour ago and that even earlier it was entirely melted (assuming that the martini glass has been isolated during that interval) so that the ice cube spontaneously arose in the warm water. More generally, Boltzmann's probability posit applied to the macro state of the universe at time t entails that it is likely that its entropy was greater at both later and earlier times. This is absurd.[15] If we come upon an ice cube in a martini glass that we know has been sitting isolated in a warm room for an hour, we can be practically certain *that* the ice cube did not spontaneously arise out of warm water but was previously larger and has melted. So, while, on the one hand, Boltzmann's probability hypothesis accounts for entropy increasing towards the future, on the other hand, it entails the absurdity that entropy was greater in the past. This is the 'reversibility paradox'.

The history of statistical mechanics is littered with responses to the reversibility paradox. One response is to construe Boltzmann's probability merely as an instrument providing advice for making predictions but to refrain from using it for retrodictions. This avoids the paradox, but in common with other instrumentalist proposals, it leaves unanswered the question of why the prescription works.[16] Further, an account of why the increase in entropy is lawful and how it can be explanatory looks like it requires more than an epistemological understanding of statistical mechanical probabilities. This is not the place for a survey of various non-instrumentalistic attempts to ground the second law while avoiding the paradox, so I will simply describe a proposal that can be seen as originating in Boltzmann and has recently been developed by David Albert.[17] It turns out that this proposal has profound consequences not only for the second law but also for times' other arrows and for special science laws.

It is generally believed on the basis of cosmological observation and theory that the state of the universe at or right after the Big Bang is one whose entropy is very tiny and has a simple macroscopic characterization.[18] Call the very low entropy macro state at this time $M(0)$ and the claim that the $M(0)$ is a boundary condition of the universe the 'past hypothesis' (PH). Albert proposes that it is a law that there is a uniform probability distribution over the possible micro states that can realize $M(0)$. Albert's proposal is that the fundamental theory of the world includes three ingredients:[19]

— The fundamental dynamical laws.
— The PH.
— A law specifying a uniform probability over the micro states that realize $M(0)$.[20]

These three hypotheses provide a kind of probability map of the universe since they entail a probability distribution over the micro-histories of the universe. With apologies to the Coen brothers and their film 'A Serious Man' I will call the package (i), (ii), (iii) 'the Mentaculus'.[21]

The Mentaculus replaces Boltzmann's original proposal. It says that the correct probability distribution given the macro state $M(t)$ is not the uniform

relative to this partition is the entropy of the macro state to which it belongs.

[15]If Boltzmann's probability posit is applied to the macro condition of the universe at t since it implies that it is likely that this macro condition arose out of higher entropy states and in particular this means that the 'records' in books, etc. likely arose out of chaos and not as accurate recording of previous events. This undermines the claim that there is evidence reported in those books that support the truth of the dynamical laws and so results in an unstable epistemological situation.

[16]Also, the prescription will prescribe incompatible probabilities at different times since the uniform distribution over the macro state at t will differ from the uniform distribution over the macro state at other times.

[17]Albert [10]. Versions of the same idea can be found in Carroll [11], Feynman [12], Penrose [13] and much earlier in Boltzmann [14].

[18]Although there are issues concerning how to think of entropy in the very early universe, it is generally held that right after the Big Bang the entropy of the universe was very tiny. This may strike one as counterintuitive since during the Big Bang, the universe was enormously tiny and dense with matter/energy uniformly distributed in space. But because gravitation acts to clump matter, this is a very low entropy condition. For a discussion, see [11,13,15].

[19]While the account is developed on the assumption of a classical mechanics ontology of particles and deterministic dynamical laws pretty much the same considerations carry over to deterministic versions of quantum mechanics (e.g. Bohmian mechanics, and Everettian QM). If the dynamical laws are probabilistic (as on GRW theory), then while the initial probability distribution no longer needs to be part of the account although the PH still plays the role it plays in the account that I sketch. See Albert [10] for a discussion.

[20]Maudlin suggested in discussion that if the uniform probability distribution accomplishes all Albert claims for it, then infinitely many other distributions will do as well. This may be so. If so and if probabilities are understood objectively in the way I discuss later, then there may be empirical discernable differences among these distributions or it may be a case of massive under determination. It is reasonable to posit the uniform distribution since it is the simplest.

[21]The name 'Mentaculus' was suggested by David Albert. It comes from the Coen brothers movie 'Serious Man' in which a character is working on 'the probability map of the universe', which he calls 'the Mentaculus'.

distribution given $M(t)$ but the uniform distribution given $M(0)\&M(t)$.[22] Conditionalizing on the PH blocks, the inference that led to the reversibility paradox. Furthermore, given the fantastically low entropy of $M(0)$, it entails that it is overwhelmingly likely that for any time prior to the universe reaching equilibrium it is overwhelmingly likely that its entropy will increase in accordance with the second law.[23]

The second law (probabilistic version) says not only that the entropy of the whole universe likely increases (or rather is likely to never decrease) as long as the universe is not yet at equilibrium but also that the entropy of typical isolated sub-systems is likely to never decrease and typically will increase. Here is a rough 'seat of the pants' argument that the Mentaculus has this consequence. Suppose that $M(t)$ is the macro state of the universe at t and m(t) is the macro state of a subsystem S of the universe that is 'cleaved off' from the universe to become practically isolated (e.g. an ice cube in a warm glass of water). We can think of the micros state of the particles comprising S as being selected 'at random' conditional on $m(t)$ from the macro state of the universe $M(t)$. Since 'almost all' (i.e. measure almost 1) micro states realizing $M(t)$ are entropy increasing 'almost all' of those realizing $m(t)$ will also be entropy increasing; i.e. P(entropy S increases/ $m(t)\&M(0)$) is approximately 1. Of course, this does not mean that it is likely that the entropy of *every* subsystem of the universe is likely to increase. Some sub-systems are interacting with other parts of the universe so as to make the entropy decrease of the subsystem likely (e.g. a glass of water in a freezer) although the entropy of the system of which it is a part (the freezer and its environment) increases. And a system may be specially prepared so that even when it becomes isolated, its entropy will very likely decrease.[24] The job is to get the second law from the Mentaculus *in so far as* the second law is correct and, arguably, the Mentaculus does that.

Our first question was 'How do the arrows of time emerge from microphysics'? My proposal is that they emerge from microphysics together with the Mentaculus. This suggestion immediately faces the objection that it simply posits a past initial condition and so assumes the past–future distinction. But this objection is mistaken. The PH does involve a temporal asymmetry but, despite its name, it does not *assume* an arrow that points from the past to the future. The PH will earn its name as the 'PH' if it can be shown that the other arrows of time are aligned with the entropic arrow and that it plays a central role in explaining these other arrows. That the two are aligned is obvious. The direction of the increase in entropy goes together with the direction of influence, etc. Showing that the Mentaculus is part of the explanation of the epistemological, influence and causation arrows is a big project.[25] Here, I will just give a hint about how it can account for the epistemological asymmetry.

Exactly what is the epistemological arrow of time? It consists not only in the fact that we typically know and can know much more about the past than the future but also in the fact that inferences from the present to the past are grounded in a way that inferences about the future are not. We can *predict* the future on the basis of current conditions. But we can make inferences from *records* of past events. For example, given what we know about current weather conditions—clear sky, air pressure, temperature, wind, etc.—we can make predictions about the near term future weather, for example, that the chance of snow tonight is less than 20 per cent. Tomorrow we will have records (newspaper accounts, memories, testimony, etc.) of what the weather was like tonight and so can do better. The fact that we have records of past events but we do not have records of the future is the fundamental epistemological temporal asymmetry. It is not merely a linguistic stipulation about the meaning of the term 'records' but is a fact about the lawful structure of our world that we can have records of the past but not of the future.

My claim is that this lawful structure is contained in the Mentaculus. Initially, this may seem incredible. What can statistical mechanics and the fact that the entropy of the universe 13.7 billion years ago was very small have to do with the formation of records? To see the connection, we need to look more closely at records. Some records are produced by explicit measurement. So let us start with them. In a measurement interaction, the final state at time t of the measuring device, say a pointer position, is correlated with the value at a prior time t^* of the property being measured. Thus, the final pointer position *records* the value of the property. For this to work, the measuring device must at an even earlier time t^{**} be in what Albert calls its 'ready to measure state.' Here is an example: a camera is set up to record the order of finishing in a race. (The 'pointer positions' are the possible images on the film at the completion of the race.) In order for the final state of a measuring device (the photographic images) to be taken to be a record at time t of the prior condition the order of finishing at time t^* we need to assume that the camera was in its 'ready to measure' state (film is blank, camera pointed at the finishing line, etc.) at an even earlier time t^{**}. This is completely general and holds for all records whether or not they were produced by measuring devices. The snow on the ground providing a record of an earlier snowfall depends on the ground being snow- and water-free at a still earlier time. Given that the ground was water-free at the earlier time, there is a correlation between whether or not it snowed and whether or not there is later snow on the ground.

The key point is that inferences based on records involve an inference from two states at two times to

[22]An important question is what probability means when talking of an objective probability distribution over initial conditions and when the dynamical laws are deterministic. In a number of papers [16,17] I have developed, David Lewis' Best system account of laws and chances so as to provide what seems to me to be the best account of these probabilities.

[23]It is thought that the length of time it would take for entropy to increase to equilibrium is far greater than the approximately 14 billion years that have passed since the Big Bang.

[24]See Albert [10] for a discussion of how a system can be prepared so that its entropy is likely to decrease.

[25]What follows is my version and development of the accounts proposed in [10]. Further discussion can be found in [7,10,11,18,19].

the situation at an intermediate time. Inferences to events that occur between the present time and the time of the PH (13.7 billion years ago) are like this. Since the PH characterizes a state of tiny entropy, such inferences are highly constrained. In contrast, inferences from the present in the direction away from the time of the past hypothesis are not constrained in this way, hence the asymmetry between what we can justifiably infer from the present to the past (i.e. the time of the past hypothesis) and what we can justifiably infer from the present to the future. Note, again, a distinction between past and future is not being assumed, but rather the epistemological asymmetry is shown to be aligned with the entropic asymmetry.

Where do the probabilities that characterize measurement correlations come from? The obvious answer from the perspective we have adopted here is that they are statistical mechanical probabilities. The Mentaculus is imperialistic since it specifies a probability distribution over *all* physically possible histories and hence a conditional probability over all pairs of (reasonable) macro propositions. These are understood as objective probabilities. It follows that any objective probabilities would either be derivable from them or conflict with them and thus threaten Mentaculus's explanation of thermodynamics.

Let us now turn to the consequences of the Mentaculus for the special sciences. Recall that the three features cited earlier that make it difficult to see how special science laws and causation can be reconciled with MC are (i) they are temporally asymmetric, (ii) they are local, (iii) they involve causation. Thermodynamics is not usually listed among the special sciences, but it shares important features with them that are important to our discussion.[26] Like special science properties, monetary exchange thermodynamic properties are multiply realized. Like special science laws, the thermodynamic laws (in particular, the second law) are temporally asymmetric and apply locally, and thermodynamic processes involve causation. . . . Putting an ice cube into warm water *causes* its melting.

Recall Fodor's puzzlement as to how it is that 'Damn near everything we know about the world suggests that unimaginably complicated to-ings and fro-ings of bits and pieces at the extreme micro-level manage somehow to converge on stable macro-level properties'. The Mentaculus relieves this puzzlement in the case of thermodynamics. While some patterns of to-ing and fro-ing lead to decreases in entropy given the primordial distribution, it is overwhelmingly likely on the primordial distribution that the to-ing and fro-ing that realize an ice cube in warm water lead to the melting of the ice cube. Similarly, while there are to-ings and fro-ings of the particles that make up the moon compatible with its macro states that lead to all kinds of bizarre behaviour, it is overwhelmingly likely that they lead to the moon continuing to orbit the Earth in (approximate) conformity with Kepler's laws. So, the Mentaculus promises to be able to account for both the temporal asymmetry and the locality of special science laws.

[26]Dunn [20] argues that thermodynamics should be considered to be a special science.

What about causation? As Russell observed 'causation' does not explicitly occur in the fundamental dynamical laws. But of course this does not mean, contra Russell's overstatement, that the notion of causation should be retired since that would be tantamount to rejecting the special sciences. In my view, the most promising accounts of causation characterize it in terms of probability. The basic idea, as a first stab, is that C causes E if C is temporally prior to E and $P(E/C\&B) > P(E/B)$. Complications are needed to deal with common causes and Simpson's paradox and various other issues.[27] Whether these problems can be dealt with remains to be seen, but for our purpose, the interesting point is that statistical mechanics supplies both an account of temporal priority and the objective probabilities that are needed by probabilistic accounts of causation.

So here is a conjecture. All special science regularities and all causal relations can be obtained by conditionalization from the Mentaculus. Once it is recognized that the best account of statistical mechanics introduces a probability distribution that is objective, accounts for the second law, is immune to the reversibility objection, plausibly grounds time's arrows and provides the probabilities for an account of causation this conjecture begins to look pretty plausible. Consider, for example, Gresham's law. For it to apply, a great many conditions that involve the existence of human societies, economic exchanges, money, political structures, legal systems and so on must be obtained. Given a characterization of these conditions (which would be included in a characterization of the macro state of the Earth at some time in the past) and whatever *ceteris paribus conditions* conditions are associated with the generalization the conditional probability on all these propositions and also that good and bad money are introduced into the economy the probability that good money is hoarded will be high. At least, that is the claim.

I have argued in this paper that in addition to the fundamental dynamical laws there is a law that specifies an objective probability distribution over initial conditions compatible with the very low entropy state of the universe at the time immediately after the Big Bang. This account, which I called 'the Mentaculus', provides a realist explanation of thermodynamics. I further argued that the account is a promising approach to a realist explanation of how time's arrows and special science laws emerge from the laws of physics. Fodor asked 'So then, why is there anything except physics'? ([2] p.161) If the account here is on the right track then the answer is 'because there is physics'?

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[27]There is a vast literature on probabilistic account of causation. Classic papers are Reichenbach [21], Suppes [22] and Cartwright [23]. Recent sophisticated accounts are Papineau [24] and Woodward [25].

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