The Mentaculus Vision: From steam engines to the framework of a probability map of the universe.

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Aim of this talk

- I will explain a framework for a scientific theory that David Albert and I have taken to call “The Mentaculus”*. It purports to be a framework for a “complete” scientific theory in that it provides a probability distribution that grounds thermodynamics and other special science laws, chances, counterfactuals and causal relations.
- The Mentaculus has applications to many issues in philosophy. It provides accounts of time’s arrows (records, influence, the feeling that time is passing) and has connections to issues in metaphysics and epistemology including the natures of laws, counterfactuals, objective probabilities, causation, the reducibility of special sciences, naturalistic epistemology and skepticism and the reconciliation of free will and determinism. The Mentaculus probabilities are to credences what truth is to belief. I will tell part of this story in this talk.

- *“Mentaculus” comes from the Coen Brothers’ film “A Serious Man” where it is used by the nebishy brother of the film’s main character as a name of what he calls “a probability map of the world.”

The Mentaculus

- 1. The dynamical laws that describe the evolution of the fundamental microstate of the universe (and its isolated sub- systems). Of course the final laws are not known but we assume they will be similar to earlier proposals e.g. Hamilton's equations, Schrödinger's equation, GR field equations, the laws of a yet to be discovered quantum gravity theory etc.

- 2. a law (or law-like proposition) specifying the macro state of the early universe (soon after the time of the Big Bang) M(0). The important feature for our purposes is that in agreement with contemporary cosmology M(0) is a state whose entropy is very small and in agreement with conemproary cosmology. aka "the Past Hypothesis" (PH).

- 3. A uniform objective probability distribution over the possible microstates (histories) that realize M(0).

- It is important that the probabilities are "objective"

- The idea that the Mentaculus provides the framework for a complete scientific theory of the world has been advocated by David Albert (*Time and Chance, After Physics),* and Barry Loewer (“Counterfactuals and the Second Law", “Two Accounts of Time and Laws”). Similar proposals have been made by Ludwig Boltzmann, Richard Feynman *(Character of Physical Law) ,* Roger Penrose and Sean Carroll (*From Eternity to Here)* and others.

Some Assumptions

- We assume that there is a fundamental ontology, a notion of the state of a system at a time (or on a surface) and that there are fundamental dynamical laws that describe the temporal evolution of state and that all macroscopic phenomena supervene on the fundamental states and laws. For example, in classical mechanics the fundamental ontology consists of a system of material particles occupying 4 dimensional space/time. The state of a system at t is specified by the positions and momenta of the particles at t. The dynamical laws specify the evolution of the system's state.

- Classical mechanical dynamical laws are temporally symmetric and deterministic. This means that if a sequence of particle positions is compatible with the laws then a temporally reversed sequence is also compatible with the laws. Other proposals for fundamental theories are also time-symmetric. We assume that the true dynamical laws will also exhibit temporal symmetry in that if a sequence of the positions of a macroscopic system is compatible with the laws then the temporal reverse sequence is also compatible with the laws. This means that the ordinary distinction between past and future is not built into the dynamical laws.

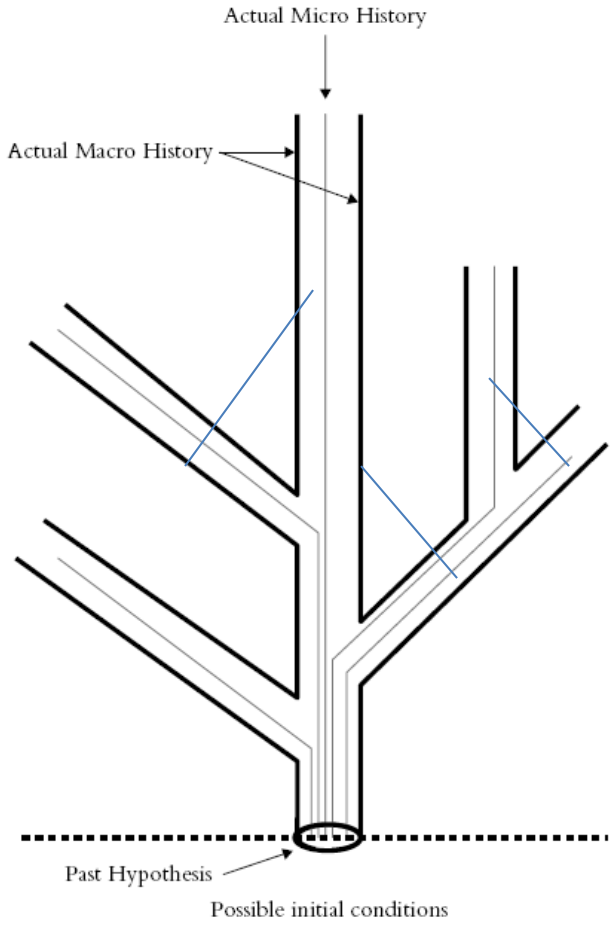
Micro and Macro

- The micro state of a classical mechanical system consists in the positions and momenta of the particles that compose it. Macro states/histories are sets of micro states/ histories. They are characterizable in ordinary and scientific macro language terms The relevant macro properties/quantities are those that participate in simple law-like generalizations and which are connected to our ordinary macro concepts (for example, the language of thermodynamics- temperature, pressure, density, entropy, average frequency of radiation.) The actual world instantiates a unique micro history and unique (modulo vagueness) macro history (relative to the macro languages). It follows from the temporal symmetry of the dynamical laws that if a macro history H supervenes on the positions of particles and is compatible with the laws then the temporally reversed macro history H* is also compatible with the laws as in a film played in reverse. However, in classical mechanics (and certain versions of QM) the micro-history evolves deterministically but the macro-history appears to evolve indeterministically.

A Probability Map of the World

- The Mentaculus provides a probability map of the universe in that it determines a probability density over the physically possible trajectories of microstates emanating from M(0) and thereby probabilities over macro histories and a conditional probability over pairs of maco states. It purports to be a complete scientific account of the world in that it contains an answer to every question of the form “What is the objective probability of B given A?” for all physically specifiable propositions A and B.

The Universe According to the Mentaculus: microphysical determinism and macro indeterminism with branching toward the future



Evolution from the BB

- M(0) is the state of the universe 13.72 billion years from the present. It is widely held by cosmologists that M(0) describes a very small, very hot, very simple and almost homogeneous, very low entropy state that has evolved as matter gravitated to form stars and galaxies to an immensely more complex and higher entropy macroscopic state. In the very distant future as the universe continues to expand it will evolve to a very high entropy and again a simple state. If the universe has an equilibrium state then eventually macroscopic branches will begin to converge until the universe reaches equilibrium where it remains for eons except for occasional fluctuations to lower entropy states.

Branching from the PH

- Since M(0) greatly constrains the micro state at one temporal boundary but there is no similar constraint at what we think of as the far future as the universe evolves during the time when its entropy is relatively low (as it is currently) branching away from the PH dominates.

Questions

- 1. What is the account of laws and probability that best fits the Mentaculus? Given that the dynamical laws are deterministic what does “probability” in the Mentaculus mean?

- 2. What, is the status of the PH? And what if anything explains why it is true?

- 3. Why take the Mentaculus seriously as the framework for a theory of the universe?

- 4. How does the Mentaculus propose to account for temporal asymmetries, special sciences, causation etc.?

Humean fundamental ontology according to Lewis.

- The totality of the actual world consists in the distribution of instantiations of fundamental perfectly natural properties (e.g. field values, mass, charge) throughout a geometrically structured space-time; the “Humean Mosaic” (HM). All truths supervene on the HM.

Lewis' BSA of Laws and Chances

- Take all deductive systems whose theorems are true. Some are simpler better systematized than others. Some are stronger, more informative than others. These virtues compete: An uninformative system can be very simple; an unsystematized compendium of miscellaneous information can be very informative. The best system is the one that strikes as good a balance as truth will allow between simplicity and strength. How good a balance that is will depend on how kind nature is. A regularity is a law iff it is a theorem of the best system. (Lewis 1994a p.478)

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- Consider deductive systems that pertain not only to what happens in history, but also to what the chances are of various outcomes in various situations - for instance the decay probabilities for atoms of various isotopes. Require these systems to be true in what they say about history....Require also that these systems aren't in the business of guessing the outcomes of what, by their own lights, are chance events; they never say that A without also saying that A never had any chance of not coming about. (1995 p.480)

Chance Laws

1) A law L specifying chances earns a place in the optimal system by providing information about the Humean Mosaic. Lewis proposes that information be measured by the degree of fit which is specified by the probability of the actual world conditional on the theory but there are better proposals for measuring the information provided by a probabilistic theory.

2) Lewis says that determinism and non-trivial chances are incompatible but this is wrong. A law specifying an objective probability distribution over initial conditions (or trajectories) may greatly enhance the informativeness of a system at little cost in simplicity.

Alternatives to Humean Accounts

- 1. Governing accounts: Laws are features of reality over and above the HM that “governs” or “constrains” its evolution. Chances are degrees of propensities specified by laws that “guide” evolution of state.

- 2. Laws are truths determined by powers that reside in the fundamental quantities.

The Package Deal Account of laws and probabilities

- Consider all language L, theory T and manifolds M where L is a candidate fundamental language and T a candidate TOE formulated in L and M the arena in which the predicates of L are instantiated. For each L and M select from <L,T, M> the T* that best systematizes the distribution of property instantiations throughout M and best combines scientific virtues- simplicity, informativeness, comprehensiveness, fit, and *descryability* of macro descriptions, special science laws, counterfactuals and so on. By *descryability* is meant locating and account for macro facts in terms of fundamental facts. The theory of the world that specifies fundamental ontology, laws and chances is the one that effects the best balance among these desiderata.

Esfeld's and Deckert's Proposal

- The ontology is consists of permanent matter points with distance relations between them.
- The history of the world is the history of configurations of matter points.
- The best system systematizes this history along the lines of quantum field theory where the wave function is employed as a device of systematization in the manner of the way chance is understood by Lewis.

The Mentaculus as the Lewisian Best System of the World

- The Mentaculus is a proposal for the Lewisian Best system of the world. It is the system that optimally balances simplicity and informativeness including information about macro facts especially the distribution of thermodynamic quantities (and other law determining criteria). So understood two issues in the foundations of statistical mechanics are clarified. First, the nature of statistical mechanical probabilities are understood so that non-trivial probabilities are compatible with deterministic dynamics and apply to the initial conditions of the universe. Second, the PH is understood as a non-dynamical law.

Why Take the Mentaculus Seriously s a candidate for the Best System?

- 1. Thermodynamics
- 2. Other physical probabilities and chances (macro dynamics, coin tosses, mutations etc.)
- 3. Time's Arrows (asymmetries of influence and knowledge, the feeling that the present is special and time is passing)
- 4. Counterfactuals and causation
- 5. Provides a framework for "reduction" of the special sciences.
- 6. Fits with a Humean or best system account of laws and probabilities.

Thermodynamics

- Thermodynamics consists of laws relating certain macroscopic properties of systems- temperature, pressure, energy, density, work, frequency of radiation etc. static laws e.g. for a gas in equilibrium PV=kT and dynamical laws e.g. temperatures of bodies in contact equilibrate.

- Chief among the dynamical laws is “The Second law” which in its original formulation says that in processes of energy exchange the entropy of a system never decreases and typically increases until the system reaches equilibrium (its maximum entropy state).

- Entropy is a function of thermodynamic properties that measures the quantity of energy in a system that is not available for work. e.g. the entropy of an engine prior to combustion is lower than after combustion when the energy in the fuel has been partly converted to heat.

The second law

- The melting of ice, the diffusion of smoke, the formation of stars, the aging of our bodies, the transfer of energy from the sun to the earth to space are some of the myriad manifestations of the second law.

- The second law is temporally asymmetric! It specifies a temporal direction that is aligned with what we take to be the distinction between past and future.

- How can the temporally asymmetric second law be reconciled with the temporally symmetric fundamental dynamical laws?

Answered by Ludwig Boltzmann

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Boltzmann entropy

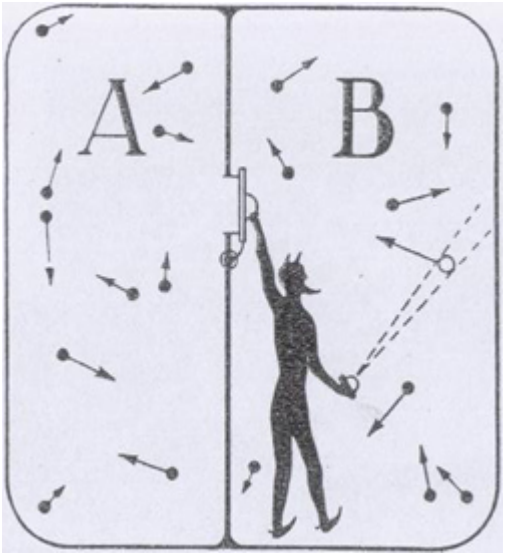
- Boltzmann identified the entropy of a macro state M (and the entropy of micro states that realize M) with the logarithm of the volume on the standard Lebesgue measure of the set of microstates that realizes M.

- $S = k \log W$

- Entropy measures how much information about the micro state about a system's micro state is "hidden" in its macro state and the inverse of the entropy of a system's macro state specifies how much information its macro state contains about the micro state that realizes it. So the second law says that an isolated system's macro states evolve from specifying more to specifying less information about its microstate.

The second law is probabilistic

Assuming particles moving more or less randomly it is overwhelmingly likely that entropy will increase



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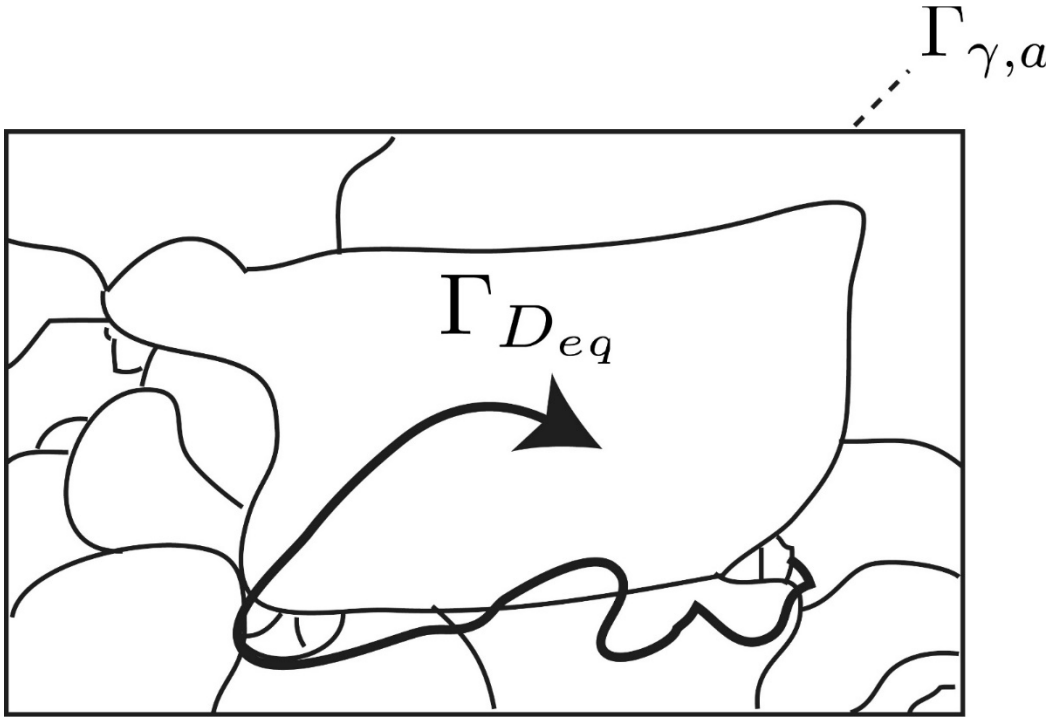
The path of a typical trajectory toward equilibrium



Recovering Thermodynamics

- Boltzmann interpreted the measure as specifying a probability measure over the space of all microstates and hoped to show that a probabilistic version of the second law followed. The argument, in a nutshell, is that since overwhelmingly most (on the measure) of the micro states that realize the macro state M of a system not at equilibrium are sitting on trajectories that evolve according to the dynamical laws to realize macro states of greater entropy it follows that it is overwhelmingly likely that entropy will increase as the system evolves. Thus Boltzmann modified the second law to say that the entropy of an isolated system doesn't invariably increase but is very likely to increase.
- More generally, work in thermodynamics has shown that it is plausible that if it is a thermodynamic law that system S at time t in macro state M will evolve to be in macro state M* at t* with probability p then Boltzmann's probability distribution will recover this regularity.

- Boltzmann's probability hypothesis is vindicated by its spectacular success in accounting for the second law and other thermodynamic laws!

Thermodynamics of subsystems

- Suppose that S is a subsystem of the universe that at time t “branches off” from the rest of the universe to become more or less energetically isolated and that the macro state of S is m (t). We can think of the degrees of freedom associated with the micro state of S as being selected “at random” conditional on m (t) from the degrees of freedom of the macro state of the universe M(t). Since “almost all” (i.e. measure almost 1) micro states realizing M(t) are entropy increasing and those which are not are randomly scattered in the phase space “almost all” of those states realizing m(t) will also be entropy increasing; i.e. P(entropy S increases/m(t)&M(0)) is approximately 1. More generally systems that possess the same thermodynamic properties will likely undergo similar evolutions. As the universe evolved this leads to energetically isolated systems coming into existence whose microstates are typically on entropy increasing trajectories. But of course this doesn’t preclude systems that contain parts that are entropy decreasing while the entropy of the system as a whole is increasing. For example the entropy of your kitchen is increasing while the entropy of the water in your kitchen’s freezer is decreasing.

Reversibility Problem

- 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 is also approximately 1. e.g. that very likely an ice cube in an isolated Martini glass was smaller an hour ago and even earlier was entirely melted (assuming that the martini glass has been isolated during that time). The reason is that for every state S that realizes the system there is another S* state that realizes the system whose velocities are reversed and which evolves to the past exactly as S evolves toward the future.

- More generally, it implies that if M is the macro state of an isolated system (or the universe) at time t then on the uniform probability conditional on M it is likely that M is an entropy minimum from which it is likely that entropy increases in both temporal directions. Of course this consequence is absurd. 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 pretty sure that the ice cube was larger in the past. So, while on the one hand, Boltzmann's probability posit apparently accounts for entropy increasing toward the future, on the other hand, it entails the absurdity that entropy was greater in the past. This is the "reversibility paradox."

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Solution

- The Mentaculus solves the reversibility problem by conditionalizing on the low entropy initial condition M(0); i.e. the PH. This results in a probability distribution that gives the same *predictions* (inferences from M(t) to times further away from M(0)) as Boltzmann's prescription when applied to the universe as a whole and to its energetically isolated subsystems while avoiding the disastrous retrodictions we found without the PH. The reason for conditionalizing on M(0) is that nothing short of placing the low entropy condition at the first instants of the universe insures that given the Boltzmann probability distribution the second law holds throughout the universe's entire history.

Entropy and gravity

- The claim that the entropy of the early universe was very low may seem surprising since an ordinary gas spread out in a container at uniform temperature is a system whose entropy is high and the state of the universe at the BB was very homogenous wrt temperature and density. But while the effects of gravity are miniscule for the gas in the container in the very dense early universe the contribution of gravity to entropy is significant. Most cosmologists (e.g. Penrose, Guth, Carroll) claim that if we take gravity into account the state of the early universe has a very tiny entropy. The reason for this is that in the presence of gravity a very dense uniform distribution of matter/ energy is very special (i.e. low entropy) and will likely evolve in accordance with the second law to higher entropy states as matter/energy clump to form stars that undergo thermonuclear fusion (which is entropy increasing) and some of which collapse to form black holes. (most of the entropy of the universe currently is in black holes). However, how to think about the nature of micro states of black holes (and other systems where gravitation is important) is controversial and depends on the development of an adequate quantum theory of gravity.

The Mentaculus outside of thermodynamics

- Further support for the Mentaculus comes from manifestations of objective probabilities outside of thermodynamics. Albert observes that applications of fundamental dynamical laws (e.g. those of classical mechanics) to macroscopic bodies implicitly assume a probability distribution over the microstates that realize the body's macro state. The reason is that there are "aberrant" microstates compatible with the body's macro state on which the dynamical laws fail to correctly predict the body's trajectory. For example, applications of classical mechanics to predicting the orbit of a comet from the location of its center of mass assume that the comet's microstate is not one in which the comet ejects a few particles at great speed in one direction and then accelerates in the opposite direction. In calculating the motions of the comet physicists are right to ignore such aberrant states because they are enormously unlikely. The Mentaculus underwrites this by supplying the probabilities on which aberrant behavior is enormously unlikely.

Objective probabilities and chances

- It is plausible that objective probabilities outside of thermodynamics can be identified with Mentaculus probabilities.

- Chances (e.g. the chance of a die when thrown in the ordinary way landing Six face up) are statistical mechanical probabilities associated with a certain type of system (die throwing) that are stable when conditionalized on a wide variety of propositions about the macro state. (Note: on this account non-trivial chances are compatible with determinism)
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The Mentaculus and Cartwright's objection to laws.

- Consider a macro system S consisting of dollar bills dropped from a tower on a windless day. As a dollar bill falls to earth it will be buffeted by particles of air striking from various directions. On the statistical mechanical distribution the dollar bill it is as likely to be struck from one direction as from another so it is plausible that the Mentaculus yields the statistics describing the course of a random walk and a distribution of bills once they hit the ground. The example is taken From Nancy Cartwright's *Dappled World.* She uses it to argue for the incompleteness or falsity of the dynamical laws. To the contrary, by adding the statistical postulate it is plausible that the dynamical laws account for the observed distribution

Time's arrows

- The second law provides a temporal arrow from M(0) to the universe reaches equilibrium.
- Other temporally asymmetric phenomena are
- 1. epistemic: we can know much more about the past than we can know about the future
- 2. influence and control: we can control to an extent the future but not the past.
- 3. feeling of time passing
- 4. causation and counterfactuals: causes temporally precede their effects. Counterfactuals are temporally asymmetric.

Metaphysical accounts of time's arrows

- Some attempt to explain the direction of time metaphysically by positing fundamental tensed facts: changing presents (Zimmerman), growing blocks (Broad, Tooley), moving spotlights (Williamson?) or a fundamental arrow distinguishing past/future (Maudlin).
- In contrast the Mentaculus attempts to explain the temporal asymmetries scientifically in terms of the PH and laws.

The Mentaculus doesn't presuppose past/future distinction but grounds it.

- . It may appear at first that the Mentaculus explanation of the second law presupposes the past/future distinction rather than explains it since it posits the PH; a low entropy condition 13.7 billion years or so in the past. But the Mentaculus only says that there is a very low entropy macro condition M(0) at one temporal boundary (the time of the big bang) and posits no similar very low entropy condition at any other time between this boundary and the time the universe reaches equilibrium. This orients the entropy gradient from low entropy at the time of the big bang to the time equilibrium is attained. The Past Hypothesis will earn its name if it can be shown that the other arrows of time are aligned with the entropic arrow entailed by the Mentaculus. That is, if it can be shown that the Mentaculus not only explains the second law but also explains the asymmetries of knowledge, control, and causation then time's arrows will be explained by the Mentaculus in a way that justifies claim in that the time between the present and the low entropy boundary condition is the past. Here I will only sketch how it grounds the epistemic asymmetry.

Asymmetry of records

- The epistemic asymmetry is grounded in the asymmetry of records; the universe is full of records of the past (direction to M(0)) but not records of the future. A recording system S possesses state r1,r2…. That are correlated with states q1,q2….of the system measured. The state r(k) at t is a record of q(j) at t' in circumstances C at t iff P(q(j)/r(k)&C) is near 1.
- e.g. snow on the ground is a record that it snowed the night before in usual circumstances C since P(snowed last night/snow on ground &C) is near 1.

Asymmetry of memory

- Asymmetry of memory is a special case of asymmetry of records. Assuming my mental state supervenes on the fundamental physical state of my brain then given only the fundamental dynamical laws the state of my brain is almost completely independent of the macro state outside of my brain or the macro state even in the recent past. i.e. there are no correlations.

PH is required for the existence of records

- But adding the Boltzmann probability distribution and the PH allows for the existence of records and for correlations between my current mental state and the state outside of my brain. Without the PH statistical mechanical probabilities fail to support the existence of records since it entails that entropy increases in both temporal directions. But with the PH it is plausible that the Mentaculus probabilities ground the existence of records of past states/events and my knowledge of what is outside my brain based on my memories.

Knowledge and the Mentaculus

- If the Mentaculus is correct then whatever we know or can know about the probabilities of future and past events can be obtained by conditioning on what we know (or can know) about the present. The claim is not that anyone explicitly employs or can employ the Mentaculus to make inferences from the present to other times. Rather, it is that the Mentaculus provides a scientific account of account of the correlations that ground the existence of such knowledge and how it can be justified by the world's objective probabilities.

Credence and the Mentaculus

- Al Hajek asks
- “Belief is to truth as credence is to ???.
- His answer is “Chance”
- i.e. credences ought to match objective probabilities in the same sense as belief ought to match truth. e.g. Your credence that that it will rain tomorrow is an estimate of the objective probability of rain tomorrow conditional on certain relevant information. The Mentaculus supplies the worlds objective probabilities that credences aim at.

The Asymmetry of Control

- The temporal arrow of control consists in the fact that while we can exert some control over future events (e.g. our decisions) we have absolutely no control over past events. Philosophers who attempt to explain this temporal asymmetry often invoke metaphysical accounts of time. For example, that time flows from past to present or that the future is open and the past is closed. In contrast the Mentaculus explains the asymmetry scientifically as grounded in the asymmetry of records. To evaluate what a person A can control we assume that she has *unmediated* control at time t only of her decisions at t and then evaluate what that entails about what she indirectly controls. This procedure involves what we call "decision counterfactuals" like "If A at time t were to decide to bring about B at t* then the probability of B would be p." In order for A to have control over B in circumstances C there must be counterfactual dependence in C between A's decisions and the probabilities of B occurring or not occurring. This counterfactual dependence must be robust so that it persists in a wide variety of circumstances C* that are similar to C and she must know or have reason to believe that these dependencies obtain since if she didn't have reason to believe this she would have no reason to make her decision.

Decision Counterfactuals

- To evaluate “decision counterfactuals” we find those states of her brain which realize her decision to select the antecedent (i.e. to do A) and which are as similar to the actual circumstances C at t as possible and then determine the probability that B occurs given that one of these states occur in C. Note that this way of evaluating decision counterfactuals doesn’t presuppose a past/future distinction. What we want to show now is that the Mentaculus entails that there are counterfactual correlations between decisions and future events but not between decisions and past events or that if there are such correlations they cannot be used to control past events because they are not robust and not knowable.

Why we have no control over the past

- Suppose that A decides to bring about B but B pertains to a time prior to A's decision (i.e. a time between the PH and t). If the actual world contains a record R(-B) outside of A's brain that B did not occur then since the decision to bring about B corresponds to a small localized condition in A's brain sufficiently similar states to the actual state in which A decides to bring about B will continue to contain R(-B) and so be probabilistically independent of B. That is, the record R(-B) *screens off* A's decision from B. The situation is quite different if B pertains to a time after t (i.e. a time not between the PH and t). In that case there typically will be no records of whether or not B will occur at t and so it may be that A's alternative decisions at t are correlated with whether B obtains. In this way the temporal asymmetry of records underlies the temporal asymmetry of control.

What if there are no records of -B

- There are two possibilities to consider. One is that there are no records even in A's brain of whether or not B occurred at time t. The other is that A's decision is itself the only record of B's having occurred. In the first the probability of B's occurring is counterfactually independent of A's decision. So A's decision has no influence over B's occurrence. If there are no records external to A's brain but A's decision is itself a record of B's occurring then although there is counterfactual dependence between A's decision and the probability of B's occurring A will typically not know or have reason to think that this is the case. In fact, usually she will have reason to suppose that there are external records of whether B occurred. In this case although the probability of B's occurring is counterfactually dependent on her decision she has no control over B's occurring.

Experience of the passage of time

- Our awareness of the temporal asymmetries of records and control, gives us the sense that the past is closed and that the future is open. Over time as memories and perceptions accumulate our view about what is closed (what events we can no longer control) and what is open (what events we can control) changes and our memories, intentions and plans respond. Our awareness of this process goes some way towards accounting for the feeling as it is often put that “time passes”. Philosophers have often attempted to account for this feeling and more generally the other temporal asymmetries by positing a fundamental flow or directionality to time itself. But it is far from clear that metaphors of time’s flowing or having an intrinsic direction make sense or even if they do what role they could play in accounting for our experience of time’s passing and the temporal asymmetries. How can we detect the fundamental directionality of time? How can it account for the second law, the prevalence of records, and so on? Even if there were a metaphysical directionality (e.g. Maudlin) of time the entropy gradient would be determined by the PH and Boltzmann’s probability distribution i.e. by the Mentaculus. But without an account of why the Mentaculus should be aligned with the supposed metaphysical arrow it would play no role and if it is aligned then it looks to be redundant.

Counterfactuals and the Mentaculus

- David Lewis thought that his well known similarity account of counterfactuals entailed that small counterfactual variations in antecedent conditions can result in large variations in subsequent consequents but not in past consequents and thus grounds time's arrows. e.g. "If Nixon had pushed the button there would have been nuclear war". So his account of world similarity grounded a temporal asymmetry. However the account is defective since there are worlds that begin in a high entropy state and evolve so that by a small violation of law come to match the actual world (no nuclear war) from that time forward (Elga). The quick fix is to add the condition that violations of the PH count against similarity in the same way that violation of dynamical laws does. This answers Lewis' question of how the temporal asymmetry of counterfactuals is related to the second law (Loewer).

More on Counterfactuals

- Our prescription for evaluating decision counterfactuals has the feature that small alterations in the state of one's brain (decisions) at time t may be counterfactually correlated with large differences in the probabilities of future events but typically not with large differences in the past in virtue of the prevalence of records in our world. To the extent that other kinds of counterfactuals can be modelled on decision counterfactuals this will also apply to these counterfactuals. So, for example, in evaluating "if the storm center had struck the coast 100 mile further north the city would very likely have been flooded" we look at a late time earlier than the time at which the storm center struck the coast where an unremarkable very small departure in its macroscopic trajectory (on the order of the size of a decision) would have brought it 100 mile further north and ask how likely it is to have flooded the city. Note that this way of evaluating counterfactuals doesn't involve violations of the dynamical laws since given the actual fundamental dynamical laws there will be world trajectories that are macroscopically indiscernible from the actual history but then diverge from it at a time prior to the time of the antecedent to

Causation

Simple probabilistic accounts of causation characterize causation in terms of certain probabilistic correlations. e.g for distinct events; C is a cause of E iff P(C/E)>P(C). For example, a particular tossing of a lighted cigarette into the forest caused a fire iff associated with the toss increasing the probability of the fire. Three problems that confront accounts of causation in terms of probabilistic correlations are 1) what is the nature of the probabilities that are claimed to ground causation and where do they come from? , 2) Correlation is temporally symmetric but causes typically temporally precede their effects and 3) more generally, not all correlations are associated with causal relations. For example, effects of a common cause are correlated though neither is the cause of the other. The Mentaculus looks like it will help with these problems since it supplies the objective probabilities that are needed to ground causal relations. The problem is to characterize those probabilistic correlations that count as causal. Intuitively, these are correlations that can be exploited make it likely that decisions make the states they aim at more likely.

Special Science laws

- The special sciences contain lawful generalizations that describe how macro systems are likely to evolve under certain conditions:
- e.g. Gresham's law(Fodor's favorite example)
- The introduction of bad money into an economy drives out good money from the economy.

Fodor's Question

- "So then, why is there anything except physics? That, I think, is what is really bugging Kim. 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" (Fodor 1998 p.161)

The Mentaculus answer

- If F's obtaining at t is followed by Gs obtaining at t' is a law then the Mentaculus implies that the given that the conditional probability of G obtaining at t' given that F obtains at t and that the *cp* conditions hold is close to 1. So it is physics (the Mentaculus) that explains "why there is anything except physics."

The Mentaculus Answer (continued)

- If the Mentaculus is the Best System of the universe then in so far as special science properties and processes are physically specifiable as sets of micro trajectories and in so far as special science laws specify probabilistic relations among such properties special science laws are in principle reducible to the Mentaculus. e.g. the Mentaculus specifies the probability that given certain features of the current macro state that "bad money" introduced into an economy will lead to the hoarding of "good money" (Gresham's law). So there are economic laws because they are entailed by the Mentaculus. However it may be that what makes a conditional probability in the special sciences count as a law involves further conditions e.g. it is a component of a simple system specified in the language of the special science. And the grounding conditional probabilities will typically be buried deep within the Mentaculus and so are not accessible. The claim is not that economists should take up physics but it does mean that laws of economics, such as they are, are grounded in physics. i.e. There are special science laws because there is physics!

Conclusion

- The Mentaculus is a probability map of the world that grounds thermodynamic laws while avoiding the reversibility paradox. In the course of doing so it assigns probabilities to all physically possible trajectories of fundamental states and thereby conditional probabilities to all pairs of macroscopic propositions that supervene on fundamental physics. It provides a realist and unifying account of thermodynamics. I attempted to make it plausible that it also accounts for the temporal asymmetries of records, control and is a needed ingredient of accounts of counterfactuals, causation, and special science laws. Further, it supplies objective probabilities as targets for credences. We conjecture that it provides the framework for a scientifically complete theory of the world (in Lewis' sense of a Best System.)

- A lot of work needs to done to fill in details but in view of all this there is ample reason to take seriously the Mentaculus as a proposal for the probability map of the world and do the work.

Three Philosophical Issues

- 1) the nature of Mentaculus probabilities, and laws. How to understand objective probability so it is compatible with determinism and it makes sense for there to be a probability distribution over the entirety of initial conditions.

- 2) The epistemic and metaphysical status of the PH.

- 3) the Boltzmann brains problem.

What are stat. mech. probabilities?

- Statistical mechanical probabilities are most often construed epistemically as the degrees of confidence on ought to have in various micro states compatible with a system's macro state. The principle of indifference is then invoked to justify the uniform Boltzmann measure. The probabilities are construed as representing an observers ignorance of the exact micro state of a system given its macro state.
- But this is not an adequate account of the probabilities that are posited by the Mentaculus . One problem is the difficulty in stating and justifying an appropriate principle of indifference. Another (not unrelated) problem is that the principle of indifference is an *a priori* principle for assigning probabilities where the Mentaculus probabilities concern the actual frequencies of and patterns of events specified by thermodynamic laws. This is *a posteriori* since there are worlds compatible with the dynamical laws in which the frequencies diverge from those supported by the uniform measure. But the primary defect with an epistemic account from our perspective is if these probabilities are credences then it is difficult to see how they can play the role in causal explanation that the Mentaculus asks them to play. The Mentaculus probabilities are objective features of reality connected to laws that explain why smoke disperses, ice melts, and generally why entropy increases and not merely why anyone ought to think these processes occur. The epistemological account may be suitable for an instrumentalist account of statistical mechanics but not for the Mentaculus account.

Propensity and frequency accounts

- Propensity and standard frequency accounts fare no better. Propensity probabilities are incompatible with determinism. There is no frequency for the initial conditions and many frequencies are not probabilities. A satisfactory account of Mentaculus probabilities should be compatible with determinism, apply to the physically possible micro-histories of the universe, and construe probabilities as objective features of the physical world connected to laws. None of the usual accounts –propensity, frequency, epistemic- are suitable. But an account that does seem to fit the bill is David Lewis' "best systems" account (BSA) of laws and probabilities.

The BSA account of laws.

- According to Lewis' BSA laws are certain true propositions and equations that are entailed by the ideally best scientific systematization of the totality of fundamental truths of the world. This totality specifies the trajectory of microphysical states throughout all time (or space-time). Lewis says that the best scientific systematization of this totality is the true theory that best combines simplicity and informativeness and, perhaps, other theoretical virtues. Simplicity is an objective property of a system's simplest axiomatization e.g. a second order differential equation is simpler than a 4^{th} order equation (other things being equal). Lewis identifies the informativeness of a theory with the number of possibilities it excludes. Lewis says "Take all deductive systems whose theorems are true. Some are simpler better systematized than others. Some are stronger, more informative than others. These virtues compete: An uninformative system can be very simple; an unsystematized compendium of miscellaneous information can be very informative. The best system is the one that strikes as good a balance as truth will allow between simplicity and strength. How good a balance that is will depend on how kind nature is. A regularity is a law iff it is a theorem of the best system." (1994a p.478) Lewis imposes the requirement that the candidates for best systematization are formulated in the language of perfectly natural properties in response to a worry that without some such restriction the best system account collapses.

BSA account of probabilities.

- The BSA includes objective probabilistic laws by letting the language in which candidate theories are formulated include terms for probability functions. By specifying probabilities a candidate system may gain a great deal of informativeness while still being relatively simple. For example, consider a long sequence of the outcomes of measurements of x-spin of a y-spin electron. Typically, a simple description of the sequence in a language lacking probability functions will not be very informative and an informative description will be very complicated. But the proposition that the probability of a measurement of x-spin on a y-spin electron yields an "up" result is .5 and that the measurements are independent may be both simple and informative.
- Lewis proposes evaluating the informativeness of a probabilistic theory in terms of the "fit" of the world on the theory i.e. the likelihood of the world on the theory. This is problematic since it is plausible that the likelihood of the actual world on any plausible candidate theory is infinitesimal. For an alternative proposal see Loewer 2001)
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On the BSA account non-trivial probabilities are compatible with deterministic dynamical laws and a probability distribution over the entirety of initial conditions.

- According to the BSA P(A/B)=x is true iff the best system of the world entails "P(A/B)=x." The BSA may include laws that entail both dynamic and initial condition probabilities and so is compatible with deterministic as well as indeterministic dynamic laws. The BSA account of objective probability is similar to an actual frequency account in that it is the actual pattern of events that render a system best and so determines the truth values of probability claims. But unlike actual frequency accounts the BSA can assign probabilities to particular events and to the entire world histories as well as to repeated event types. Furthermore, the probability of a type of an event type can diverge from its frequency on the BSA and take on irrational values. The BSA differs from epistemic accounts of probability since its probabilities are objective features of the physical world and since it makes probability intimately connected to laws it provides an account of their role in explanation. Of course the BSA probabilities like other objective accounts of physical probabilities are connected to epistemic probabilities via a principle along the lines of the Principal Principle. In fact, unlike propensity accounts the BSA provides a rationale for principles like Lewis' Principal Principle that connect its objective probabilities with epistemic probabilities.

The Mentaculus and the BSA

- We propose that the best system in Lewis' sense for the actual world takes the shape of the Mentaculus and its probabilities be understood along the lines of the BSA. Start with a system S that specifies the dynamical laws. S is simple and informative in that it specifies the evolution of the complete micro state of an isolated system. But as we saw the dynamical laws by themselves are not very informative about the evolution of a system's macro state (because of aberrant micro realizations) or about special science laws and temporal asymmetries. But, as we have also seen we can achieve a great increase in informativeness at a small cost in simplicity by adding to S the PH and a uniform probability distribution over trajectories that satisfy the PH and dynamical laws. This application of the BSA calls for an understanding of informativeness that is somewhat different from Lewis'. Lewis proposes evaluating the informativeness of a system in terms of the size of the set of possible micro-histories it excludes or, for probabilistic systems, in terms of the likelihood of the actual micro-history given the system. I am supposing that the Mentaculus provides information by specifying the probabilities of macro propositions that concern thermodynamic properties and special science lawful generalizations. So we are expanding the language in which the candidates for a Best System are formulated to include predicates that denote thermodynamic properties. These earn their place by dint of the fact that there are simple and informative generalizations involving thermodynamic and special science predicates. This emendation to Lewis's account better fits with the idea that the criteria involved in evaluating law determining systems are garnered from scientific practice.

The epistemic status of the PH and

- It has been argued (Feynman, Albert, Carroll) that given the Boltzmann probability distribution without the PH and conditional on the current state of my (your) brain it is more likely that my (your) brain fluctuated out of equilibrium than that it is the result of a what we normally take to be its past. This is called "the Boltzmann Brain Problem") It is just the reversibility paradox applied to the state of my brain. The theory T* (dynamics+probability distribution) without the PH is "cognitively unstable" in that it implies that what I take to be evidence for T* (reports of "past" experiments etc.) are likely to be unreliable. In contrast the Mentaculus (with the PH) is cognitively stable and (if my arguments are correct) provides an account of the reliability of memories, reports, and other evidence including evidence that supports it. Further it is self-supporting in that cosmological evidence (the CMB, red shift etc.) supports that the entropy of the universe was much smaller 13.82 years distant from the present. Epistemologically, the role of the PH in the Mentaculus is similar what Wittgenstein called a "hinge proposition". To doubt it (while holding the since to doubt it is to undermine connections between our present "evidence" and beliefs about the past.

The Scientific and Metaphysical status of the PH

- The Mentaculus construes the PH as a law. This fits well with Lewis BS account of laws since it is an element of an informative and simple system that summarizes the physical history of the universe. The PH has no further explanation in the Mentaculus. But a number of cosmologists (Penrose, Carroll, Albrecht) claim that it is not satisfactory to take the PH as a fundamental posit but that it "cries out" for explanation. Penrose' reason is that the very low entropy of the PH state is immensely improbable. He calculates 1 over 10 to the 10 to the 23^{rd} power. From the point of view of the Mentaculus this is a mistake since that probability is calculated from the uniform distribution but the appropriate distribution is given by the Mentaculus. On it the probability of the PH is 1. Nevertheless it would be interesting if there were an explanation of the PH.

Boltzmann's explanation of the PH

- Boltzmann proposed that the universe is eternal in both temporal directions. Most of the time its state is in equilibrium but from time to time it fluctuates out of equilibrium to lower entropy states. Very rarely it fluctuates to a very low PH state like the one the universe occupied at the Big Bang.

Poincare Recurrence

- Any bounded system in which energy is conserved and starts in a typical S will with probability 1 over an infinite amount of time return an infinite number of times to states arbitrarily close to S.

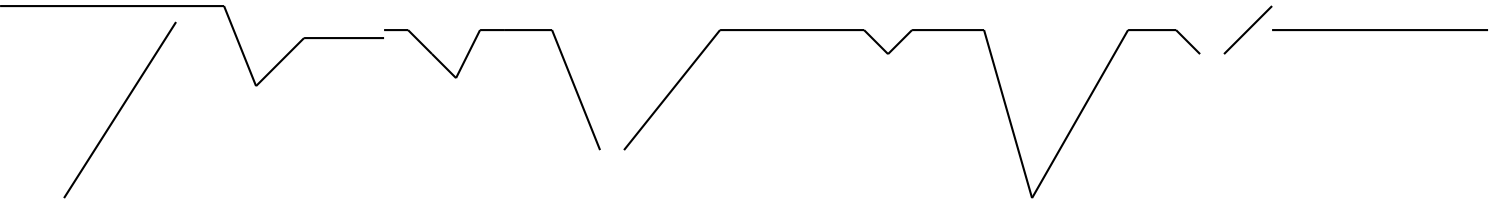
- This is incompatible with entropy always increasing (if the universe is bounded and eternal) since entropy will need to decrease to return to lower entropy states.

Boltzmann (1897)

- “One can assume that the entire universe finds itself at present in a very improbable state. However, one may assume that the eons during which this improbable state lasts, and the distance from here to Sirius, are minute compared to the age and size of the universe. There must then be in the universe, which is in thermal equilibrium as a whole and therefore dead, here and there relatively small regions of the size of our galaxy (which we call worlds), which during the relatively short time of eons deviate significantly from thermal equilibrium.”

- Boltzmann's idea is that the PH is explained as a fluctuation from a universe that is in equilibrium.

- Boltzmann’s infinite universe…entropy fluctuations



Boltzmann Brains

- But this apparently won't work since in such a universe fluctuations to situations whose entropy is greater than that of the PH are much more likely and in particular given the current state of my (your brain) it is much more likely that it arose as a fluctuation than that it is embedded in a 13.82 billion year old universe of the sort we think we inhabit. If so then all of what my (your) brain takes to be "evidence" for the past (including evidence that supports Boltzmann's theory) is misleading. In other words, Boltzmann's account is "cognitively unstable." If it is true our evidence for it is undermined.

Some proposals for “explaining” the PH

- 1. Inflation: But however plausible inflation might be the initial conditions that set of inflation must be of even lower entropy and more special than the entropy of the universe when inflation ends in the observable universe.

- 2. Eternal inflation and a multiverse (Carroll, Guth) with unbounded entropy. The universe evolves in both temporal directions from a “midpoint” with finite entropy producing baby universes that nucleate in typically low entropy states. Given our macro state we are likely to be located in the temporal vicinity of a low entropy boundary condition.

- 3. The PH is a fundamental law

Naturalistic epistemology and the Mentaculus

- A version of naturalistic epistemology holds that what a subject knows about her environment depends on lawful correlations between states of her brain (or body) and her environment. If physicalism obtains then the correlations must be grounded in the fundamental physical laws. On the basis of the fundamental dynamical laws alone there are almost no correlations between a person's brain states and her environment; i.e. she could be a brain in a vat etc. Add only the stat mech. probability distribution and the correlations will be the wrong ones with respect to the past (they will entail a higher entropy state for her brain) and not sufficient to ground her knowledge. But add the past hypothesis and it becomes plausible that there will be correlations grounded in the Mentaculus that underwrite her knowledge.

Humean Physicalism

David Lewis argued for a view we call “Humean Physicalism.” It says that the universe consists in the distribution of fundamental physical quantities throughout the entirety of space-time (which is a n- dimensional manifold with metrical/topological structure). The fundamental physical quantities might be particles, their masses, charges etc. field values, wave function values etc.