A TRAVELING FORMS INTERPRETATION OF QUANTUM MECHANICS

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Abstract. The Traveling Minds interpretation of Quantum Mechanics is a no-collapse interpretation on which the wavefunction evolves deterministically like in the Everett branching multiple-worlds interpretation. As in the Many Minds interpretation, minds navigate the Everett branching structure following the probabilities given by the Born rule. However, in the Traveling Minds interpretation (a variant by Squires and Barrett of the single-mind interpretation), the minds are guaranteed to all travel together–they are always found in the same branch.

The Traveling Forms interpretation extends the Traveling Minds interpretation in an Aristotelian way by having forms of non-minded macroscopic entities that have forms, such as plants, lower animals, bacteria and planets, travel along the branching structure together with the minds. As a result, while there is deterministic wavefunction-based physics in the branches without minds, non-reducible higher-level structures like life are found only in the branch with minds.

1. From many-worlds to many-minds

According to the Everett many-worlds interpretation (MWI) of quantum mechanics, the wavefunction evolves deterministically over time and encodes the whole truth about physics. After an electron in a superposition of spin-up and spin-down states passes through a magnetic field in the Stern-Gerlach experiment, the wavefunction encodes it as being in a superposition of two different positions, say an upper position corresponding to the spin-up state and a lower position corresponding to the spin-down state. When an observer then checks whether the electron is in the upper or lower position, the wavefunction encodes the observer as being in a superposition of a state of observing the upper position and a state of observing a lower position.

But in fact we never perceive ourselves to be in a superposition of two different observational states. To explain that, the Everett interpretation notes that the final state can be described as split into two superimposed branches: one where the electron has spin-up, is in the upper position and is observed as being in the upper position, and the other where it has spin-down, is in the lower position, and is observed to be in the lower position. These branches can be thought of as worlds inside a multiverse, and so there is an observer in one branch who unambiguously observes the upper position and an observer in the other branch who unambiguously observes the lower position.

A standard objection to MWI is that it does not do justice to prospective probabilities. Suppose that the initial electron state is so prepared that the spin-up state has significantly higher weight than the spin-down state, which nonetheless has non-zero weight, and that I am the observer. Thus the state is

$$a|\uparrow\rangle + b|\downarrow\rangle$$

where $|a| \gg |b| > 0$ and $|a|^2 + |b|^2 = 1$. Then according to the Born rule, which is empirically central to quantum mechanics, I should assign probability $|a|^2 > 1/2$ that I will observe the electron as being in the upper position and that I will not observe the electron as being in the lower one. But it seems that there are two final branches: one with an observer observing the upper position and one observing the lower position. The two observers are ontologically on par, and they each derive from me.

It seems that given the metaphysics of the situation, I should make one of four predictive judgments:

(1) Each observer is a future me, so I should assign probability one to *both* observations.

(2) Neither observer is a future me, so I should assign probability zero to *both* observations.

(3) By indifference, as the observers are metaphysically on par, I should assign probability 1/2 to each observation.

(4) This is a situation where probability assignments make no sense, so I should take each observation to be a probabilistically nonmeasurable[1] event.

But none of these are what the Born rule requires of us, which is an asymmetrical assignment of a high probability to the upper position observation and a low probability to the lower one. Granted, the wavefunction assigns a higher weight to the branch with the upper position observation. But this weight does not describe either an objective chance or an uncertainty of any proposition (whether *de dicto*, *de re* or *de se*). Imagine that you were going to branch into two future persons, one of whom had *literally* a higher weight—i.e., was fatter—than the other. You wouldn't epistemically privilege the events that will happen to the fatter one. Why should you

[1]In fact, saturated nonmeasurable, i.e., with neither a lower nor an upper probability.

epistemically privilege the events that will befall the one with the higher wavefunction weight?[2]

Defenders of MWI have two main answers to this. The first is to say that in reality the branches are not neatly delineated, and we cannot say that there are only two relevant branches. That challenges option (3), but strengthens option (4), and leaves (1) and (2) unaffected. And (3) was already the weakest of the options, because of its reliance on the dubious principle of indifference.

The second response is to offer axioms of decision theory and prove, given the axioms, that probabilities should be attached in accordance with the Born rule (the pioneer is Deutsch 1999). This response suffers from two serious difficulties. The first difficulty is that it assumes that if we were to find ourselves in the metaphysical scenario described by MWI, there would be a rational decision theory available to us giving rational ways to assign values to uncertain future outcomes. But the plausibility of (4) undercuts that assumption.

The second difficulty is a reliance on axioms that are dubious in fission situations. For instance, consider the principle that adding an additional payoff v_2 to each outcome of a game E_1 with value v_1 results in a game with value $v_1 + v_2$.[3] But now suppose that playing E_1 results in a metaphysically symmetric fission of the player into n branches, where $n > 1$. Then by

[2] Here's a potential answer: perhaps personal identity goes along the higher weight path. But on that view, you are *certain* to make the upper position observation and *certain* not to make the lower one, which does not match the Born rule when the spin-down state has non-zero weight.

[3] In Deutsch's (1999, p. 3133) setting, this principle is a direct consequence of his understanding of additivity, so an argument against this principle is an argument against additivity as he understands it.

symmetry the player either survives in all branches or in none. If the player survives in all branches, then the value with the extra payoff will be $v_1 + nv_2$ as the player will get the extra payoff twice. If the player survives in no branch, then the value with the extra payoff will be just v_1, which will be the value of certain death. Only in the special case where $v_2 = 0$ does the composite game have value $v_1 + v_2$. And if we add that there is no fact of the matter as to what the number n of branches is, then things only get worse: there is no fact of the matter about the total value received.

In order to solve the probability problem, Albert and Loewer (1988) introduced the many minds interpretation (MMI) of MWI. The idea is that there are infinitely many minds associated with each branch and (conscious) brain pair in the branching multiverse. When branching occurs, infinitely many of the minds go into each outgoing branch. However, each individual mind has objective chances of going into a particular outgoing branch defined by the Born rule. Thus, in the above spin case, each of my infinitely many minds independently has chance $|a|^2$ of going into a branch where it observes the upward position, and chance $|b|^2$ of going into a branch where it observes the downward position. If I am identified with one of these minds, my credence in the two observations should be $|a|^2$ and $|b|^2$, respectively, as the Born rule requires. Nonetheless, equal infinite numbers of these minds populate the outgoing branches.[4]

[4]It turns out that there is a technical problem here. In order to allow for uncountably many branchings, Albert and Loewer suppose that the infinity of minds associated with a branch-brain pair is the uncountable infinity of the continuum. However, there is no guarantee that if continuum many minds each independently has a non-zero chance $|a|^2$ of going into an up-branch and a non-zero chance $|b|^2$ of going into a down-branch, then continuum many will go into each branch. Not only is there no guarantee of this, but on the standard product probability measure model one cannot even say that the probability

However, even though MMI solves the problem with *prospective* probabilities, it suffers from a different problem. The uncollapsed wavefunction of the universe includes many strange branches. The brains in some of these branches inhabit sceptical scenarios. For instance, there will be brains in vats and Boltzmann brains—brains that appear suddenly out of thermodynamic chaos, live for a short time, and go back to chaos. Some of these brains will have phenomenal states exactly like ours. And because of the infinities involved in MMI, infinitely many of the minds with phenomenal states exactly like yours right now inhabit a sceptical scenario and infinitely many of them do not. Moreover, the infinities are supposed to all be of the same cardinality, that of the continuum. So it seems that you cannot say that it's more likely than not that your mind is in the non-sceptical scenario set.

Moreover, one can find a pair of sets of continuum-many minds phenomenally indistinguishable from yours, such that (a) your mind is in one of these sets, (b) no two minds ever occupied the numerically same brain but instead the sets pick out minds from completely separate branches, and (c) all the minds in one set are associated with sceptical scenarios and none the minds in the other set are. Because of (b), one cannot use the branching chances that MMI uses to solve the prospective probability problem to say that it is more likely that your mind is in the non-sceptical set than the sceptical set. It thus appears that MMI leads to scepticism.[5]

that each branch will get continuum many minds is non-zero—the event of each branch getting continuum many minds is non-measurable in the product measure. Perhaps the probability measure can be extended to solve this problem. For more discussion, see Pruss (2016).

[5]A possible solution is to say that there is no fact of the matter as to which brain—one of the sceptical or non-sceptical brains—your mind is attached to. But in that case, we

There are also ethical problems with MMI. Suppose Alice, Bob and Carl are suffering from an equal pain, and only one full dose of a painkiller is available. However, Alice and Bob will gain complete relief from a half dose, while a full dose is needed to give Carl relief. If all three are innocent strangers and I am choosing between giving a half dose to each of Alice and Bob or a full dose to Carl, I should choose to relieve two people's suffering rather the suffering of one. But on MMI, whether I give (a) a half dose to Alice and Bob each, or (b) a full dose to Carl, the same infinite number of minds have relief from pain, since $\mathfrak{c} + \mathfrak{c} = \mathfrak{c}$, where $\mathfrak{c}$ is the cardinality of the continuum. So, it seems, I have no moral reason to give the half dose to Alice and Bob over the full dose to Carl, which is absurd.

2. From many minds to traveling minds

What if instead we suppose that there is at most one mind per brain, so that when branching happens, that mind goes to one of the outgoing branches, with chances given by the Born rule? This is called the single-mind view, and it is rejected by Albert (1992, p. 130) because it leads to the "mindless hulk" problem. When branching occurs, all but one of the branched brains will be mindless hulks. As the minds spread out through the branches, eventually only one brain in the vicinity of a given mind's brain will be minded, and all the other brains around will be mindless hulks. Thus, on this view, we are probably surrounded by zombies, which is absurd, and makes much of ethics useless.

There are at least two ways of fixing this problem. One way is to suppose that when branching happens and a mind goes along a branch, new minds

have another problem: there is no fact of the matter whether you are or are not in a sceptical scenario. And that destroys realism.

come into existence to populate the brains in the other branches. Prospective probabilities will still be given by the Born rule, but there are no more mindless hulks around us.

But this leads to two problems. First, it means that probably we (or at least our minds) are much younger than we think we are. Given the exponential explosion in minds on this picture, most minds come into existence at some point well advanced in life. Second, it means that although the brains around me aren't the brains of zombies, their minds are probably not the same ones that I met with yesterday. And this may well create ethical problems by undercutting promises.

The second solution to mindless hulk problem is to say that while there are many mindless hulks, there are none around here. The idea is that the minds are fellow-travelers. When one goes down a branch, the others all come along. So our friends and family (and strangers and enemies) all go with us. The brains around us have minds, and indeed the same minds that we encountered in the past. This traveling minds (TM) view was first offered by Squires (1990) and then by Barrett (). It avoids the mindless-hulk problem, without creating the diachronic identity problems that the constant creation of minds view faces. It solves the probabilistic problem facing the MWI. It is not subject to MM's scepticism problem, as there no longer guaranteed to be infinitely many minds, some in sceptical scenarios and some not, with the same phenomenal state as me. Nor is this subject to the ethical problems of MM, as Alice, Bob and Carl each have exactly one mind.

There are two apparent costs of TM as a version of MWI. The first is that the law of nature requiring the minds to travel together may seem *ad* *hoc*. In Section 5 we will see that this is a merely apparent difficulty: there is a very natural way to develop TM out of modal views.

The second is that TM is a dualist theory, and hence more ontologically complex than plain MWI. Moreover, it is *more seriously* dualist than MM. For on MM, facts about the states of minds supervene on the wavefunction: each brain in each branch is occupied by the same cardinality of minds. But on TM, some branch-brain pairs correspond to one mind and some to none. However, as is well-known, MM is still a pretty seriously dualist theory. For although global facts such as that a cardinality κ of the minds transitioned from state A to state B supervene on the wavefunction, there are primitive facts about the identities of minds such as that mind m_{20} will transition from state A to state B, which do not supervene on the wavefunction.

And TM is a surprisingly attractive theory, filling a niche in logical space that has largely been assumed to be unavailable. It can be elaborated to be a dualist theory where the physical world is causally closed, but yet there is robust and non-overdetermined mental causation, thereby solving the interaction problem. It can likewise be elaborated to yield robust libertarian free will together with a causally deterministic physical universe.

Here is how these tricks are done. The physical basis of the story is MWI: a causally deterministic physical multiverse. If one so wishes, one can further specify that this physical universe is causally closed: no physical state is even partly caused by any non-physical state. But in addition to the physics of the physical multiverse, there is a mental dynamics. The minds are connected to particular portions of the multiverse, and travel through it following the Born rule. We can then specify that what portion of the multiverse a given mind is connected to at a given time is at least partly determined by its mental state (and maybe some additional primitive relation). The current mental state of your mind together with the wavefunction of the multiverse then causally affects where in the multiverse your mind will be attached in the future, with a dynamics obeying the Born rule.

But because our minds are constrained to travel together, when your mind takes a branch, mine comes along. Thus, your mental states affect which portion of the multiverse *my* mind is connected to, and *vice versa*. Which portion of the multiverse my mind is connected to affects my experience. But it also affects my bodily state. It does this by affecting which three-dimensional body slice in the multiverse counts as *my* current body slice. Hence, your mental states can robustly causally affect what my mental and physical states are. This causation does not contradict the causal closure of the physical, and does not overdetermine any physical states. Rather, it affects which physical states are whose if anybody's.

Furthermore, the mental dynamics are indeterministic. We can suppose them to be under the agent's control but nonetheless in accord with Born's rule. This control could either proceed through agent causation (with chances of action corresponding to the probabilities in Born's rule) or using a variant of Kane's (1996) non-causal libertarianism. Thus, we have robust libertarian free will together with a causally deterministic physical universe.

Of course, one does not have to accept causal closure of the physical along with TM. One might suppose, for instance, that there is a non-physical first cause of the universe, making an initial-state exception to causal closure. Or one might allow the minds to affect the wavefunction of the universe, but of course then one no longer has a solution to the interaction problem and the simplicity benefits of not having wavefunction collapse largely disappear.

3. From traveling minds to traveling forms

In Aristotelian hylomorphism, human minds are forms of bodies. But all material substances have forms, not just human bodies. So if we are to build an Aristotelian version of MWI, we will need to decide what happens to the forms of other substances. Bare MWI doesn't have forms in it, so it is not satisfactory from an Aristotelian point of view.

Each of the dualist views building on MWI has an obvious analogue where the claims about minds are extended to all forms. Doing this does not, however, resolve any of the difficulties we saw facing MM, single-mind or one-mind-per-brain. If anything, the difficulties multiply.

For instance, the Aristotelian analogue to MM will say that there are infinitely many forms associated with each appropriately shaped chunk of matter. But in addition to the epistemological and ethical problems, which are in no way helped by extending the theory beyond minds, we now may have the problem of multiple forms informing the same matter, something that Aristotelians tend to deny. Or, once the single-mind view is extended to include forms, we have the problem that not only most of the human-shaped chunks of matter around us are mindless hunks, but the chunks of matter that would seem to fit other forms are mere formless heaps. Quite likely, the earth has no elephants or oak trees, but only heaps shaped like them but literally formless. But then the Aristotelian apparatus is not very useful for studying the world around me—perhaps the only biological substance I ever met is myself.

We resolved the problems facing MWI and other dualist extensions of MWI by going with traveling minds (TM). We can now craft an Aristotelian analogue to TM: the traveling forms (TF) interpretation. In addition to there being minds—i.e., forms of thinking animals like us—that travel together through the branching multiverse, there will be other forms, and all of these will travel together, sticking to the same branch.

On this picture, in all but one branch of the multiverse, the macroscopic chunks are formless chunks or heaps or waves rather than substances. These formless quantum systems may correspond to the same aspects of the global wavefunction that a donkey or an oak tree does, maybe even having an exactly similar effective system wavefunction, but because of the lack of form all there is is the wavefunction. Only here, in our branch, does the wavefunction come together with an asinine or quercine form and produce a donkey or an oak, with its distinctive biological function, and, in the case of the donkey, its mental life. In the other branches, eliminativism about the biological and the mental holds sway.

One might also consider a more ontologically austere version of the view, where reference to forms is replaced by composition (cf. Koons, 2016). There are primitive facts about which pluralities particles compose a whole. And these facts are so arranged that non-trivial wholes travel together, while compositional nihilism holds in all the other branches of the universe. This is akin to Markosian's (1998) view that facts about composition are brute.

I am cautious, however, about the sense in which the constituents of the "macroscopic chunks" can correctly be identified. What there fundamentally is at the level of the physics is the wavefunction. One can *talk* as if there were particles in a branch (though the exact identification of branches is itself problematic), but it is far from clear that the particles are there in the ontology to be composed into wholes. One might do better to talk of partial constitution. Some facts about the wavefunction may be partially constitutive of the existence of substances. But only partially: what substances there are does not supervene on the wavefunction. There are fundamental contingent facts about which "aspects" of the wavefunction partially constitute a substance, with relevantly similar aspects in one branch (namely, our branch) giving rise to a substance but not so in another.

Nonetheless, plausibly there are metaphysically explanatory benefits of the full Aristotelian apparatus of forms, and so I shall develop the view in terms of traveling forms rather than, say, traveling constitution. But the interested reader can try to adapt the ideas to the more austere view.

4. What has form?

It is uncontroversial in Aristotelian metaphysics that all living organisms have form. But does anything else? Aristotle attributes form to artifacts in a derivative way. Instead of a house having an intrinsic form like a donkey does, a house's form is found in the mind of the architect. Since the TF picture has minds in it, it can take up this story about the forms of artifacts.

It is only our branch of the multiverse that has human (or alien) artifacts. In other branches there will be quantum systems whose effective wavefunctions that behave much[6] like the effective wavefunctions of people, and corresponding to that behavior there will be quantum systems whose effective wavefunctions behave much like those of houses. But there won't be any people in these other branches. Thus there won't be any designers in these branches with forms of houses in their minds. And hence there won't

[6]Or maybe even exactly. This depends on whether minds might not have some special ability to affect the wavefunction or whether an appropriate causal closure doctrine holds.

be any houses, unless they are made by *immaterial* substances like God or angels that are not localized to a branch.

What about particles? Do they have form? This way of asking the question is potentially misleading, as it suggests that there *are* such things as particles, and then queries whether *they* have form. But as we saw when considering the "traveling composition" view, it is far from clear whether bare MWI should be read as implying that particles are in the ontology.

If there are no particles in the bare MWI ontology, then insofar as TF builds on that ontology the question is whether TF will suppose particle forms, which combine with aspects of the wavefunction to constitute particles.

It is simplest to say that there are not, and hence develop a version of TF on which the ontology does not include particles.

If, on the other hand, we allow for particle forms in TF and suppose that bare MWI does not have particles, then it will be most elegant to suppose that just as the forms of larger things travel together, the forms of particles travel with them. On this version, the formless branches have no particles at all, just a wavefunction. There is something rather attractive about this picture, since it means that we do not have the strange spectacle of heaps of particles that behave just as donkeys and oaks but are mere "zombie" donkeys and oaks. On this view, instead, it is only in our branch that there are particles, and hence there are no "zombie" donkeys and oaks in any other branch—and presumably none in our branch either.

This picture has much in common with Bohmian interpretations of quantum mechanics. On Bohmian interpretations, there is an uncollapsed wavefunction, with many branches, but only one branch has particles, and the particles travel together through the multiverse. Most Bohmian interpretations are deterministic unlike TF, but Bell has offered an indeterministic Bohmian interpretation. Such a Bell-Bohm interpretation is very similar to a TF with particle forms, except that the Bell-Bohm interpretation privileges particles over other substances.

If, on the other hand, there are particles in the bare MWI ontology, then we can ask whether on TF (a) all (in all branches), (b) some but not all or (c) none of these particles have forms. Supposing that all particles, throughout all the branches, have forms makes for an inelegant system, given that this is not true of other substances on TF. Moreover, on this view we will have heaps of formed particles making up "zombie" donkeys and oaks in other branches, and perhaps it is a slightly lesser departure from common sense if the "zombie" donkeys and oaks are made from more "metaphysically shadowy" formless particles, ones wholly constituted by aspects of the wavefunction. Given TF, the view that some but not all of the particles have forms—presumably with the specification that the particle forms travel together with other forms—makes for greater elegance, and I will dismiss the "all" view. But if formless particles have physical behavior indistinguishable from that of formed particles, it may seem needlessly complex to saddle some particles with form, and so the "none" view appears simplest.

Whether or not there are formless particles in the bare MWI ontology, then, we have a choice to make between two views of formed particles: either there are none or they travel along with formed macroscopic things.

While it is in an important sense simpler to suppose that there are no formed particles, formed particles help solve a problem that faces TF as well as TM. On TM, minds came into existence in correlation with the brains in one particular branch out of many. What process selected that branch, and destined the others to be full of zombies?

An initially attractive hypothesis would be that the *first* branch to get a brain got a mind. But that doesn't seem right. For presumably there were some extremely low weight branches where very early on in the universe, particles (at least in a manner of speaking, if they aren't in the MWI ontology) quantum-tunneled into a Boltzmann brain. It seems implausible to suppose that that freak accident was what ensured that billions of years later non-Boltzmann brains, like human ones, would get minds in our branch. And it is not clear what would happen if there were no earliest brain in the multiverse (say because before each Boltzmann brain there was an earlier, or because there was a tie).

Now, TF can solve the branch selection problem for the initial minds that TM faces. Minded animals evolved from mindless animals. But mindless animals are still organisms, and hence have forms. The law of nature that ensures that forms stick together in a branch could be taken to ensure that it is in a branch that already has forms—say, of plants and mindless animals—that the forms that are minds of minded animals would arise. We might even say that the forms of plants and mindless animals causally contributed to the existence of the forms of minded animals.

Of course, this only pushes the problem back. Why did forms of plants and mindless animals arise in our branch but not in others? Now if we have formed particles in TF, then we can answer that question: For the same reason that minds only came into existence where there are forms of plants and mindless animals, the forms of of primitive organisms only came into existence where there were forms of particles.

If there were particles from the beginning of the universe, this pushes the problem to the beginning of the universe. Moreover, at the beginning of the universe it need not be a *selection* problem. For it may well be that at the beginning there is only one branch. Granted, there would still be a problem of explaining the origins of the universe and of a one-branch wavefunction at the beginning. But that's not an additional problem: the problem of *initial* or *boundary* condition faces every physical theory. But a mysterious branch selection *in media res* seems more problematic.

We don't know much about the very, very early universe. Maybe there were no particles there. But even if there were no particles, perhaps there were other primitive entities that had a form—maybe a field, say—and perhaps a similar solution can be invoked then. But if only the entities of higher level sciences like biology have form, then we are stuck with form appearing late in the history of the universe, and it is puzzling where it appears.

It is natural to think that forms could causally contribute to other forms' existence, and so pushing the existence of forms to the (admittedly mysterious) beginning of the universe will reduce the mystery over the rest of time.

The best version of TF so far, thus, holds that particles need forms to exist and that they exist along with other forms once the other forms come into existence during cosmic evolution.

There is, however, a further question about particles. Particles with forms are substances. But Aristotelian metaphysics holds that no substance has substantial parts. Are there, then, particles that are parts of macroscopic substances like donkeys and oaks?

There are three interesting options. First, we could simply answer in the negative. On this view, defended by Scaltsas (1994) and Marmodoro (2013), particles cease to exist when accreted into a substance and the excretion of a particle by substance is an instance of the generation of a new particle. Second, we could answer in the affirmative, denying the maxim that substances are never composed of substances.

Third, and perhaps most interestingly, we could answer in the affirmative while maintaining the maxim. This may initially seem impossible, but there are at least three ways of telling this story. On all three stories, the particle's categorial status changes from being a substance to being something else, say an accident. On the first way, the particle's particle form perishes, but the metaphysical work done by its form is taken over by the form of the larger substance. On the second way, the particle loses its particle form, but the metaphysical work done by its form is taken over by a new accidental form within the larger substance. On both of these two ways, the post-intake particle is constituted by aspects of the wavefunction relevantly just as in the case of the pre-intake particle, together with a different form from the previous. We can further subdivide these two ways as to whether the particle can survive such a change of form. The third way is that when the particle becomes a part of the larger substance, its form remains, but changes from being a substantial form to being some other kind of form, say an accidental form.

We leave for further investigation which option to take.

5. Values of observables

Let me sketch a way of making the TF story more precise. Modal interpretations of quantum mechanics are no-collapse interpretations that single out a collection of privileged mutually commuting observables and posit that the privileged observables have definite values. Which observables are privileged can vary over time.[7] The evolution of the values of the observables over time is guided by the wavefunction.

Bohmian mechanics is a modal interpretation where particle positions are privileged, but where the evolution of the values of the privileged observables is deterministic. The determinism in Bohmian mechanics requires that the probabilistic nature of quantum predictions be grounded in our ignorance, and track back to the statistical features of the initial conditions of the universe. Such a deterministic ground for probability is philosophically problematic, and can be avoided by combining the privileging of positions with an indeterministic wavefunction-guided dynamics given by Bell (1987, pp. 173–180). Bacciagaluppi and Dickson (1999) then extended this indeterministic dynamics to other sets of observables, and adopting an indeterministic dynamics appears to be more typical among modal interpretations.

Now, the Aristotelian form of a substance defines the kind of thing the substance is, its metaphysical species. We can then think of a substance of a certain kind as having certain determinables in virtue of being the sort of thing it is. For instance, in virtue of being the sort of thing they are, conscious animals have the determinable *being phenomenally some way* (the determinate might be "null", when the human is unconscious), many organisms have the determinable *sex*, spiders have eight leg-state determinables (with a null determinate when the leg is detached), and so on. Call these *species-based determinables.*

[7] And on some versions, with context. But that is not an approach I will take.

We can then suppose that a given species-based determinable D of a substance x then corresponds to a physics observable $O(x, D)$, in such a way that x's having a particular well-defined maximally specific determinate C of D requires $O(x, D)$ to have a particular value $o(x, D, C)$. In the simplest case, $O(x, D)$'s having the value $o(x, D, C)$ is sufficient to nomically or causally ensure that D has the determinate C. But perhaps there are higher level properties that do not nomically or causally supervene on values of physics observables. In that case, O_D's having the value $O(o, D, C)$ will only be a necessary condition for the substance to have C and there will be no more specific physics observable that yields such a necessary condition.

Further, we shall suppose that there is a null value of the determinable D at times t at which the substance x doesn't exist. Hence, Alexander's war horse Bucephalus now has null sex, null leg-states, etc. This simplifies the story a little by not requiring the relevant observables to vary with time, though modal interpretations can handle such variation.

We finally suppose that the observables $O(x, D)$ will always commute, and choose a modal interpretation on which they always have well-defined values. And then we choose an indeterministic dynamics for the values of the observables, say that of Bacciagaluppi and Dickson (1999).

I now claim that this modal theory is actually a precisification of TF. It has the uncollapsed wavefunction in it, which constitutes the multiverse part of TF. It has forms in it. The only thing more it needs is for the forms to travel between branches.

And they do. Consider the set $\mathcal{O}$ of all the observables $O(x, D)$ that correspond to the substances x and their determinables D. "Branches" of the multiverse now correspond to eigenvectors of all the observables in $\mathcal{O}$. At any given time t, the actual values of the observables in $\mathcal{O}$ define a vector $|\alpha_t\rangle$ in the Hilbert space corresponding to the wavefunction. This vector uniquely defined by these two properties: (a) it is an eigenvector of all the observables in $\mathcal{O}$ corresponding to the values that these observables actually have at t, and (b) its projection on the orthogonal complement $E_{\mathcal{O}}^{\perp}$ of that eigenspace $E_{\mathcal{O}}$ equals the projection of the actual full state vector on $E_{\mathcal{O}}^{\perp}$. Then $|\alpha_t\rangle$ corresponds to a particular branch of the multiverse.

Then what makes it be the case that a particular form inhabits a branch is that the actual maximally specific determinates of all the species-based determinables pick out a set of values of all the observables in $\mathcal{O}$, and a set of values of all the observables together with the actual value of the wavefunction picks out a joint eigenvector vector $|\alpha_t\rangle$ of the observables in $\mathcal{O}$ that corresponds to a "branch".

It now trivially follows that the forms travel together. No additional law of nature, besides the dynamics of the values, is needed to get the forms' togetherness. Rather, the togetherness is simply a consequence of the fact that the determinates of the species-based determinables of all the substances *jointly* pick out the branch (with the help of the wavefunction).

6. The ontology behind the wavefunction

There is one final gap in the story: What is the metaphysics behind the wavefunction itself? The wavefunction affects the dynamics. Thus whatever reality grounds the wavefunction appears to be causally efficacious. Moreover, even though the evolution of the wavefunction itself is deterministic, the wavefunction appears contingent: the initial conditions surely could be other than they were (e.g., the universe could have started in some pure state that always remained static).

In an Aristotelian picture, causal efficacy comes from substances and their accidents. We now have a choice. Either the ordinary formed substances—oak trees, people and maybe particles—ground the wavefunction or else the wavefunction is grounded in some other substance. One could certainly have a theory on which, in addition to the determinables that correspond to observables the substances had determinables which jointly determined the value of the wavefunction. But now our theory is becoming ungainly through too many degrees of freedom as to how the information about the value of the wavefunction is distributed. We could, for instance, suppose a Leibnizian story on which every single substance carries full global information, so that each substance has sufficient information to reconstruct the value of the wavefunction at any given time and, by two-way determinism, throughout time. On this view, the value of the wavefunction is overdetermined by the information carried by the individual substances. Or we could have the radical opposite on which at any given time there is one special substance that carries information about the global wavefunction, and then we have an arbitrary choice as to which substance that is. Or we could have something in between, whereby different particles carry different portions of information that allows the wavefunction to be reconstructed. There are many ways of setting this up, and it does not appear that any one of them is particularly natural.

It may be overall more elegant simply to suppose a special substance whose accidents determine the value of the wavefunction. This special substance causally affects the dynamics of all the ordinary substances. On the simplest version of the TF view, this interaction is unidirectional. (There are more complex versions on which some higher level substances can affect the wavefunction in ways that violate the Schrödinger equation, but then we lose the main benefit of not having collapse.)

7. Conclusions

The Traveling Forms account is a no-collapse interpretation of quantum mechanics that lets us take seriously non-microscopic levels of reality, as well as—we might add—higher-level laws, like biological ones, grounded in the forms of things. The account can be seen either as arising from many-minds interpretations via a generalization of the Many Minds interpretation which solves problems for the Everett interpretation, or as a natural modal interpretation of quantum mechanics that takes seriously the determinables that figure in higher-level laws.

The theory allows for an elegant story about how higher-level causes—including our will but not limited to our will—can be genuinely and robustly efficacious even if the microphysical level—the level of the wavefunction—is entirely closed. It is a story of robust higher-level causation that neither supervenes on lower-level causation nor requires downward-causation.

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