

Neural Unpredictability, The Interpretation Of Quantum Theory,
And The Mind-Body Problem. *

Matthew J. Donald

The Cavendish Laboratory, JJ Thomson Avenue,
Cambridge CB3 0HE, Great Britain.

e-mail: mjd1014@cam.ac.uk

web site: <http://people.bss.phy.cam.ac.uk/~mjd1014>

abstract It has been suggested, on the one hand, that quantum states are just states of knowledge; and, on the other, that quantum theory is merely a theory of correlations. These suggestions are confronted with problems about the nature of psycho-physical parallelism and about how we could define probabilities for our individual future observations given our individual present and previous observations. The complexity of the problems is underlined by arguments that unpredictability in ordinary everyday neural functioning, ultimately stemming from small-scale uncertainties in molecular motions, may overwhelm, by many orders of magnitude, many conventionally recognized sources of observed “quantum” uncertainty. Some possible ways of avoiding the problems are considered but found wanting. It is proposed that a complete understanding of the relationship between subjective experience and its physical correlates requires the introduction of mathematical definitions and indeed of new physical laws.

Plausible Ideas Confronted.

Recently, some plausible ideas about quantum theory have led to claims about the interpretation of the theory which, in my opinion, are simplistic. On the one hand, it has, from time to time, been suggested that quantum states are merely states of knowledge (or of belief) (Wolfe 1936, Wigner 1961, Peierls 1991, Fuchs 2002). This idea has led to the claim that quantum theory “needs no interpretation” (Fuchs and Peres 2000). On the other hand, various authors have argued, in various ways, that quantum theory is fundamentally just a theory of relations or of correlations (Wheeler 1957, Saunders 1995, 1998, Rovelli 1996, Mermin 1998). This idea has led to the claim that it is not necessary in a many-worlds interpretation to specify the concept of a “world” (Wallace 2001a, 2001b; an introductory account is given by Butterfield 2001). In this paper, I shall confront these ideas with some empirical facts about the complexity and unpredictability of human neural processing which indicate how wrong it would be to think of human observers as deterministic robots. I shall argue that these facts should prevent us from being satisfied with an imprecise approach to the problems of understanding the composition and possible changes, either of our knowledge or of our correlations.

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The Wider Picture.

The wider purpose of this paper is to draw attention to problems which could be significant in any attempt to understand the physical underpinning of individual human awarenesses. In a long series of previous papers ([Donald 1990, 1992, 1995, 1997, 1999](#)), I have proposed a solution to these problems in the context of a many-minds interpretation of quantum theory. Whatever else they might amount to, I believe that these papers do provide a serious attempt to grapple with the kind of detailed technical issues which are involved in a complete and consistent version of this sort of interpretation. In this paper therefore, I shall use my earlier work to illustrate some of the ways in which difficulties can arise and some of the ways in which those difficulties might be resolved. In particular, much of this paper relates to the problem of giving a description of the physical structure of an individual human observer which is sufficiently complete to express everything about that structure which is directly relevant to the observer's mental life, and so I shall review my previous attempts to find the most simple such description. I shall also frequently refer to ideas from consistent histories theory which I see as a useful step towards a more complete analysis. Nevertheless, many of the broader arguments here do not depend on the assumption of a universal (Everettian) quantum theory; albeit that some of the problems may be least easy to ignore given the radical indeterminism of that kind of theory.

The fundamental premise is that it is not an illusion to suppose that an individual consciousness has a past and a future, or a range of possible futures. Given that premise, we can ask what can be said about someone's possible future experiences and their probabilities. It will be taken for granted here that we have full knowledge of the observer-independent behaviour of all the physical matter involved, and it will also, of course, be assumed that mind has no direct physical effect on matter. However, in a many-minds interpretation, the observer-independent behaviour, given by some form of Schrödinger equation acting without "collapse" at the level of the entire universe, is very different from the apparent behaviour as observed by any individual. Even in the context of a classical deterministic physics, we cannot hope for a complete analysis of the experiences of an observer unless we know what aspects of the matter constitute the observer. With the observed nature of human neural processing and the observed unpredictability of physical events at a molecular scale, characterizing the physical constitution of humans as observers raises difficult problems, however we might wish to interpret quantum theory. One of the underlying aims of the paper, therefore, is to justify the proposal that a complete understanding of the relationship between subjective experience and its physical correlates, and of the dynamics of that experience, does require the introduction of mathematical definitions and indeed of new physical laws. In part, this will be on the grounds that the facts about human observers leave so many openings, that nothing less specific can be satisfactory.

Such mathematical definitions and new physical laws are central in a complete many-minds interpretation (cf. [Barrett 1999](#), p.197). It seems to me that, aesthetically at least, this is a great advantage of interpretations of this type. At the end of

the paper, we shall briefly consider the situation in some other interpretations; supposing that the technical problems of those interpretations can be solved. In those interpretations, how the private experiences of an observer are constituted, while still problematic, can be separated from the physical dynamics. This allows the mind-body problem to continue to seem as strange and unnatural as it sometimes appears in the writings of philosophers ignorant of quantum physics. In a many-minds interpretation, however, the constitution of the private experiences of the observer is essential to the dynamics of those experiences, so that there is a compatibility between the problems of the philosophy of mind and those of the philosophy of physics.

Multiply-Localized Indeterminacy and Natural Assumptions.

According to many interpretations of quantum theory, the observed unpredictability of human neural processing is a consequence of the small scale indeterminacy of molecular motions in a warm wet fluid. This indeterminacy appears to be “multiply-localized”, in the sense that it seems to involve many distinct individual event choices at many different places. In trying to understand psycho-physical parallelism, or the mind-body problem, in a multiply-localized indeterministic physics, it seems to be very difficult to avoid intuitively natural assumptions which, unfortunately, are question begging. In particular, indeterministic observations are naturally interpreted in terms of a set of well-defined futures, each with associated probabilities. The problem, even ignoring quantum complications, is that, in a multiply-localized indeterministic physics, such an interpretation necessarily involves a particular choice of boundary of observation. It may also involve a choice of a scale of observation. Without such choices, futures and probabilities for individual observers are undefined. In everyday life, however, these choices are implicit in our nature as observers. We automatically take the existence of an observer for granted; we always see from some “point of view”.

It may be tempting to suppose that all that is being referred to here is a question of level of coarse-graining and so it may seem that any problem can be resolved just by reference to a natural consistency between different levels. Undoubtedly there can be a natural consistency between different levels of coarse-graining in simple classical models, but this is of little relevance. The systems we are considering are very very far from simple. They are also not perfectly classical and, without careful and specific definition, different levels cannot be assumed to be better than approximately consistent. Most importantly, however, they are self-observing. A change in level of observation of a system external to an observer merely requires taking or discarding additional data; a change in internal level makes an entirely new observer. Moreover, even the task of finding a natural choice of levels of coarse-graining for internal observation within the human brain seems essentially equivalent to the task of characterizing the physical structure of humans as observers. It is all very well for a relational approach to probability (Saunders 1998) to suggest that probability should be thought of as a relation between a present and a possible future. But such a relation depends on a present and a future being specified. The self-observation of the brain is a lively

dynamical process, continually subject to possibilities of growth and decay which are not easily classified.

Brains are Physical Systems.

Some authors have argued that problems relating to the nature of consciousness are not problems for physics and that they should be “set aside” (Mermin 1998); other authors are entirely explicit about the choices to be left to the (external) observer (Griffiths 1998). Although these attitudes seems to me to be far superior to simple denial that any problems exist, I shall also argue here that they are ultimately untenable. The fundamental problem in the interpretation of quantum theory is to understand the states occupied (or apparently occupied) at any moment by any physical system. Brains are physical systems and so quantum theory calls their states and histories into question, but brains also appear to be the systems through which all observations are ultimately made. Understanding the act of observation therefore requires an understanding of the physical nature of neural processing.

Psycho-Physical Parallelism.

In conventional terms, the evidence for mind-brain parallelism is so overwhelming that many have argued that it amounts to an identity. Everything we experience is directly reflected in the functioning and structure of our nervous system. You cannot see the back of your head without a mirror. You cannot see at all, but perhaps you can still move your toes, if your eyes are gouged out or your optic nerve is cut or the back of your head is shot off. You cannot move your toes, but perhaps you can still see, if your foot is amputated or your spinal cord is cut or you get a bullet in the top of your head. Indeed, it seems that the parallels between our physical structure and our experience can be made as precise and detailed as we like. Modern philosophy of mind is concerned either with denying (in the context of classical physics) that there is anything beyond the physical structure (Dennett 1991) or with trying to understand the parallelism (Chalmers 1996). Quantum physics calls all our ideas of “physical structure” into question and seems to give a special role to the “observer”. In this context, therefore it seems sensible, at least at the outset, not to condemn as mere naivety the separation between the ideas of mind and of brain.

Self-Reference.

Psycho-physical parallelism implies that the knowledge of any individual must be reflected in his or her physical neural structure or functioning. Individual knowledge is the foundation of all knowledge, and so the physical structure of individual human brains underlies all knowledge. As physical systems, brains are merely complex collections of ions, atoms, and molecules. Ions, atoms, and molecules are quantum mechanical systems, and so the brain is a quantum mechanical system. If quantum states are states of knowledge then the physical structure of a brain, considered as a quantum system, is fundamental to that knowledge. This might appear to lead to problems of self-reference. Indeed, in a published reply to published correspondence, Fuchs and Peres (2000) write, “The main point of disagreement we have with Brun

and Griffiths is about the existence of a wavefunction of the universe that would include all its degrees of freedom, even those in our brains. We assert that this would lead to absurd self-referential paradoxes.” Of course, if there really are “absurd self-referential paradoxes” here, then they amount to a *reductio ad absurdum* for the thesis that quantum states are states of knowledge, but I am not at all sure that that thesis is entirely wrong; certainly, it has led to some valuable insights (Fuchs 2001a, Caves, Fuchs, and Schack 2001). My opinion is that the issue is problematic as much as paradoxical. It is not, for example, that an observer must know everything that could be known about himself and also have the additional knowledge that he knows it. Rather, an observer must, in some very broad sense, *be something* through which his knowledge is experienced. As far as explicit or usable knowledge is concerned, that something is merely some kind of extreme upper bound. In my many-minds theory, the possible futures of an observer, and therefore the external quantum states he can expect to observe, are ultimately determined by what he is, rather than by his explicit knowledge (see the discussion around definition 6.4 in Donald 1999). Nevertheless, in many relevant cases, the determining information can be expressed in terms of explicit knowledge in such a way as to provide a foundation for the idea of quantum states as states of knowledge. For example, when Alice has observed an up spin for one spin from a singlet state, that observation, which is sufficient to determine that she will observe the other spin to be down, is both part of what she has become and part of what she explicitly knows.

Internal and External Observers.

If knowledge is fundamental, then we ought ultimately to be able to identify the aspects of the structure or state of a brain on which that knowledge depends. The empirical facts which we ought to be able explain do not consist simply of the existence of all sorts of correlations between all sorts of different physical systems. The most significant fact of all is that we do each individually experience a world, or what we call a world. How can that fact be expressed in the mathematical framework of quantum theory? If we cannot identify the aspects of a brain on which that fact is based, then our foundations are built on sand. Wallace (2001b) has argued that this is not important. According to him, worlds in a many-worlds theory or minds in a many-minds theory are like tigers and a tiger is “any pattern which behaves as a tiger”. The problem with this is that although “behaviour” or “tigers” or “correlations” or “knowledge” can easily be spotted by an observer external to the system being considered, physical observers are constituted by their own physical systems. The observers of many-worlds quantum theory, for example, are internal to the universal quantum state and must, in some sense, find themselves within it. An implicit appeal to an external observer is analogous to Bishop Berkeley’s solution to the problems of idealism by appeal to a divine mind.

The Entry-Price Problem.

Another reason why, if knowledge is fundamental, we need to be able to identify aspects of neural structures as a basis for our actual observations is that otherwise we

cannot define probabilities for our future observations from our present and previous observations. In an indeterministic theory, probabilities are what get us from moment to moment. An entirely classical model is sufficient to demonstrate the problem: Suppose you are offered the opportunity to play a game in which five ordered, fair, and independent coins marked 0 on one side and 1 on the other will be tossed and in which your winning will be the sum displayed as a binary number. Thus, with equal probability, you could win any sum between $00000 = 0$ and $11111 = 31$. A fair entry price for the game would be 15.5. If the first two coins are to be ignored, then a fair entry price would be 3.5. But a game with an undetermined number of coins has no fair entry price; neither does a game during which some coins may arbitrarily be removed or others may be added. In this sort of undefined game, even if we could make a list of possible outcomes, we would still not have a good theory of temporal change.

With equiprobable events, the individual events in a five coin game have probability $\frac{1}{32}$, while in a three coin game the individual events have probability $\frac{1}{8}$. With an external observer, this is all perfectly simple: $\frac{1}{32}$ is the probability of seeing 10101, while $\frac{1}{8}$ is the probability of the last three coins reading 101. But what if the physical structure of the observer is a set of coins? Such an observer might say that his current state was 01101 and that, at the next “snapshot”, he could be one of thirty-two equiprobable five coin possibilities; or he might say that his current state was 01101 and that, at the next “snapshot”, he could be one of eight equiprobable three coin possibilities; but surely, there would be something missing if he said that, at the next “snapshot”, there were a total of 40 possibilities, either five coin or three coin, but there was no answer to the question of how likely each would be? It is, of course, true that three coins is a subset of five coins, so that classical probability theory (as long as it is appropriate) provides a perfectly adequate external description which allows for choices in the scale of observation. Nevertheless, once again, we are not seeking a description subject to the choices of some implicit external observer, but rather a basis for our actual observations.

The main goal of this paper is to argue that problems analogous to the entry-price problem do arise in the analysis of psycho-physical parallelism and that there are no easy ways of dealing with, or avoiding, those problems. In particular, the complexities of the physical expression of neural information are such that there is no easy way of specifying either an exact number of “coins” in play at any moment or the possible changes with time in such a number. Nevertheless, analogs of such specifications are required if the “internal” probabilities of observations are to be determined, and, because the details of neural processing are so unpredictable, those probabilities do depend significantly on how that requirement is met.

Quantum Problems.

The entry-price problem for an undetermined coin game is simple by comparison with the problems of a fully quantum mechanical theory. As an example, one can consider the set selection problem in consistent histories theory which effectively adds the problem of defining the coins themselves as quantum entities. There are continuously

many sets of consistent histories and they are, of course, not all mutually consistent. The entry-price problem merely requires us to choose, at each moment, a classical coarse graining (the number of coins in play). For the brain, there are an entity-type problems, problems of continuous variation for given entity-types, and time-dependent coarse-graining problems. It is also possible with quantum theory that there can be further problems specific to the nature of the subject. For example, were the brain to function as a quantum computer, it might be that we would face problems directly involving interference effects or requirements on the purity of particular subsystem states. However, I do not in fact believe that this sort of problem does arise. This is because I do not believe that the brain has somehow evolved any special capacities which would make it in any way like a quantum computer. The arguments developed here therefore recognize the importance of decoherence theory for the description of warm wet systems like the human brain, but aim to demonstrate that, even although that theory may, by and large, move the mathematics from quantum to approximately quasi-classical probabilities, it still does not solve the fundamental problem of how awareness is represented by changing subsystems of a quantum universe.

The Insufficiency of Decoherence.

In this context, it may also be noted that, especially for complex systems, decoherence theory does not by itself solve the preferred basis problem, but merely provides a framework within which a quasi-classical solution to the preferred basis problem is not ruled out. Consider, for example, the state of a living human brain considered as an unobserved or non-collapsing quantum system for a period of a few minutes or longer. The blood delivers oxygen to the brain and carries away carbon dioxide, at a rate, calculated from data on page 290 of [Bell, Emslie-Smith, and Paterson \(1980\)](#), of the order of 10^{19} molecules per second. In the process, heat is also exchanged to maintain the vital constancy of temperature. This means that, at least on small scales, the quantum states of many significant degrees of freedom of the unobserved brain will tend to approximate to thermal equilibrium states. The local density matrices for those degrees of freedom will therefore be close to density matrices with multiple degeneracies. Such density matrices do have approximate decoherent decompositions into quasi-classical states, but they also have many other approximate decompositions which are not quasi-classical (some relevant examples are given in [Donald 1998](#)).

Knowledge.

Many of the most difficult questions for interpretations of quantum theory might seem to be answerable in terms of an observer's knowledge. The observer knows in what context an observation takes place, and what is being measured, and perhaps even what basis he or she prefers. If a coarse-graining is required, then perhaps it can be chosen in terms of what the observer can know. When we do try to assign a quantum state to an external physical system, we do often make reference to our knowledge and we often face choices which seem knowledge-related. For example, with a sample of gas, we might assign a state close to a Gibbs' equilibrium state

given the “known” temperature and pressure. On the other hand, we may think of the “real” state as being some “unknown” wavefunction (i.e. pure state) in a Hilbert space for the atomic particles of the gas. Similarly, there are different ways in which quantum states might be assigned to a functioning human brain and these ways may also be knowledge-related. The knowledge of central interest here is the knowledge of the brain’s possessor. The mind-brain parallelism discussed above suggests that this knowledge be specified in functional or biological terms.

The Basis of Neural Functioning.

Neural firing appears to be the basis of neural functioning. There are around 10^{11} neurons in a human brain. At least as a first approximation, biologically important information in the brain seems to be coded into the all-or-nothing dichotomies for individual neurons of either firing or not-firing. If we want to assign quantum states to our own brains compatible with our own knowledge, then it might seem that a reasonable starting point would be to assume that the current pattern of neural firing is “known”.

What Do We Know?

To say that we “know” about the state of our own brain is not of course to say that we have direct scientific knowledge of our own neurophysiology. Rather, we know the state through the representations we construct of external reality. Our current experiences are what they are entirely because of our present and previous brain states. These states are apparently caused by the external world and that is *how* we experience them, but *what* we experience is the brain states. Yet it is difficult to see what level of detail our knowledge provides. When, for example, we watch fireworks, we know increased levels of excitation in different parts of our head as bright lights and loud noises. However it seems implausible that our awareness of an external world would be sufficient to determine well-localized positions for each individual molecule inside the brain. On the other hand, while it might seem desirable to try to define a correct level of coarse-graining in terms of a level of phenomenological knowledge much coarser than that of detailed neural firing patterns, it is hard to find any straightforward way in which this can be done. Furthermore, any problems of specification and of unpredictability which arise with neural firing patterns will also contaminate these higher levels.

It is at this point that problems of the philosophy of mind can merge with those of the philosophy of physics. If there are no facts except observed facts, then what determines our observations is identical to what our observations determine. In this situation, we have to combine ideas from two initially distinct fields of study. One consequence is that concepts of “naturalness” and of “simplicity” have to be re-developed. For example, it may be that what our awareness determines and is determined by is not be something “natural” in terms of elementary physics (perhaps involving particle positions or the states of an orthonormal basis), but rather something “natural” and “simple” in terms of observation or awareness or information while, at the same time, being “natural” and “simple” at some more sophisticated level of quantum mechanical analysis.

Patterns, Indicators, Manifestations.

Natural correspondence between the level of neural information and the quantum level requires some sophistication in analysis on both levels. For example, the idea of “a pattern of neural firing” is certainly not sufficiently well-defined to correspond to a unique pattern of quantum states. A neuron is a macroscopic object which firing takes a significant time to cross, and not all firings on a single neuron are identical anyway. Nevertheless, it is possible to find spatially localized, quantum mechanically simple, subsystems of neurons which can act as indicators of neural firing (Donald 1990, 1995, 1999), and it is possible to define “patterns of neural firings” in terms of the spacetime arrangements of the neural functioning of those indicators (Donald 1995). And yet there does not seem any natural way to make a unique identification of the indicators. Not only can they each vary in type but also they can each vary continuously in, for example, position. With my proposed definition of a pattern, there are only finitely many patterns for a completely specified set of indicators, and so it is possible to postulate a unique correspondence between “observer” and pattern and to calculate probabilities for observers in terms of that postulate. Although each pattern will still have continuously many “manifestations” as quantum histories, corresponding to the possible variations in the physical indicators, probabilities, patterns, and observers can be defined over these continuous sets.

The Coin Model.

For a preliminary investigation, it is sufficient to continue with a naive idea of a pattern of neural firings. Suppose then that, as a first step, we model such a pattern as a pattern of coin tosses in something like the sort of game mentioned above. Then the important information in this model would be which coin (or neuron) was which and when it turns (or fires). This information can be defined in geometric terms, by the position of the coins relative to others and by when each coin turns relative to other tosses. It is possible to abstract a finite pattern from this information by considering only the spacetime arrangements between the coin tosses, although, for any set of arrangements, there are continuously many compatible positions which actual coins could occupy.

Biological Advantage.

A physicist without much knowledge of neurophysiology might think that most of the unpredictability in such a model would be caused by uncertainty in external inputs to the brain. An important purpose of this paper is to point out that this idea is completely false. In fact, the precise order of neural firings is utterly unpredictable and most of this unpredictability is due to the internal mechanisms of neural functioning. Unpredictability at a detailed level is entirely comprehensible in biological terms. Neural nets evolved in order to co-ordinate rapid responses such as fight or flight. It is vital that a threatened animal flees from a predator, but it would give a great advantage to the predator if the flight follows an exactly predictable path. The timing of turns and darts and lunges should always be unpredictable.

Sources of Unpredictability.

There are many sources of fine-grained unpredictability in the brain. Indeed, the brain is a vast patchwork of metastable fluid systems with the timing of each neural firing linked to that of many others. As a result, small uncertainties in the timing of one firing can rapidly magnify to affect the entire macroscopic firing pattern. Even in recent work (Berry et al. 1997, de Ruyter van Steveninck et al. 1997) in which the firings of certain sensory neurons in response to given stimuli are demonstrated to be quite highly reproducible in biological terms, such small initial uncertainties are present. A major source of uncertainty in the timing of firing comes from the uncertainty of information passage between connected neurons. Although there is a background of spontaneous firing, in general the firing of one neuron is controlled (either enhanced or inhibited) by the firing of the thousands of neurons which connect to it. Connections between neurons are made at synapses where electrical signals are converted into chemical signals. However, this conversion is a stochastic process with a high failure rate. Regehr and Stevens (2001) review experimental evidence showing that, at least in certain systems, the probability of an individual synapse making a given conversion can average 0.3 with a mode of 0.15. Once again, randomness in individual synaptic connections is biologically plausible. It has long been believed that learning involves changes in synaptic transmission. As neural firing is to a large extent an all-or-nothing effect, it is naturally controllable by alterations in the probability of transmission.

Estimates vary, but there are probably at least 10^{14} synapses in an average human brain. Neurons fire at an average rate of order a few times per second. If every synaptic transmission is an uncertain event with probability significantly distinct from 0 or 1, then there will be at least 10^{14} such events per second in the brain. Thus uncertainty in ordinary everyday neural functioning may overwhelm, by many orders of magnitude, many conventionally recognized sources of observed “quantum” uncertainty and may, in fact, be the major source of unpredictability in human affairs. If we interpret quantum states as states of knowledge, then any uncertainty about what we do not know becomes a quantum uncertainty. In classical terms, whether a message is passed on by an individual synapse is determined by the precise state of that synapse when the message arrives; in particular, by the positions and states of the synaptic vesicles which could discharge their contents into the synaptic cleft. In quantum terms, the state of a synapse observed only by the effects of its transmissions is a result of many individual unobserved molecular collisions. It is a decoherent state with probabilities for many different classical possibilities. When a new transmission becomes possible, the state of the synapse will be a mixture of that transmission occurring and failing to occur.

Individual synaptic transmissions depend as much on small-scale thermally driven molecular motions as on biologically significant information. And yet they can rapidly give rise to biologically significant information, because they affect the timing of subsequent neural firings, leading to greater differences at subsequent synapses, and altering the complex pattern of combinations of firings and feedbacks which are involved in every neural processing. The brain is warm and wet, unpredictable, unstable, and

inhomogeneous. There is, in my opinion, no evidence that it functions in any way like a coherent quantum computer, and nor can I see any plausible way in which such functioning could have evolved. However, the brain also does not function like a deterministic classical computer which uses a fixed mechanism to take given inputs into predictable outputs. Instead, the physical nature of the brain makes its outputs and its detailed behaviour unpredictable. At each moment, the short term future of a brain has a very large number of different possible macroscopic configurations, each with significant probability.

How Large is the Space of Possibilities?

$2^{(10^{14})}$ different patterns may seem high, but it is negligible by comparison with the minimum dimension (around $10^{(10^{26})}$) of the space of thermally active wavefunctions available to any quantum system with the physical entropy of the brain. These numbers are both measures of the number of possibilities at the microscopic level. Although the larger should always be kept in mind in discussions which treat human observations using concepts from simple quantum mechanical models, even the smaller may seem far too large to be an appropriate indicator of the lack of predictability at a mental level. Indeed, although our thoughts wander and we can surprise ourselves, they wander on comparatively long timescales, while much of our mental content seems to consist simply of received external data. Nevertheless, as with a random walk, it is not the rate of wandering but the dimension of the space of possibilities which is ultimately most important in the long term unpredictability.

In the short term, small variations in the space of patterns will correspond to small variations in the precise pattern of excitation, and particularly in the precise ordering, of the 10^{11} neural firings which occur during a given second. Although these variations may not in themselves constitute functional distinctions – for example, [Abeles \(1991, chapter seven\)](#) suggests ways in which the same messages might result from varieties of different initial local firing patterns – they do have the potential to seed functional distinctions. At the very least, this indicates that, in any theory based on functional distinctions, all possible functional distinctions will be genuine physical possibilities. In other words, human possibilities – whether, for example, someone might be about to say “Um, well, it seems to me”, or “Well, it seems to me, um” are like the possibilities that a radioactive decay will cause a Geiger counter to make its next click when its clock reads 2:03:17.434 or 2:03:17.412.

This seems to me to be a significant conclusion however one interprets the idea of “physical possibilities”. Although our thoughts naturally tend to be most concerned with features of our lives that we can predict – like what we should buy to eat for dinner tonight, or when we should set off on a journey if we are to expect to get to a given destination by a given time – the unpredictable features constantly push us around in the space of possibilities. That space has so many dimensions and the dynamics is so unconstraining that after any deviation we should surely never expect to get back to where we would have been. The length of queue at the supermarket and the mood in which we leave the shop depend on exactly how long we take to make our choices and whether we happen to arrive just as the till is being emptied.

The close miss around the corner as the idiot boy-racer coming towards us overtakes, depends to the second on when we left our house and when he left his. Major historical outcomes also turn on apparently minor choices and on precise timings (Cowley 1999, Durschmied 1999) and so no doubt does the genotype of our children.

The different possible orderings of neural firings demonstrate a significant failure in the sometimes plausible analogy between neural imaging and imaging on a computer screen. Pixels on a screen are refreshed in a determined order and once one frame is complete, the next frame starts. There is, by contrast, no rule which tells us where the next neural event will be found. The difference is important in terms of the amount of information which might be “known” about the underlying physical states. We cannot avoid this problem simply by claiming that, regardless of the order of its formation, ultimately, the same picture will always result, because this is false – small initial differences may lead to large final differences, and anyway, there is no unambiguous way of choosing moments when “frames” might be said to be filled. Thus, when it is suggested below that instantaneous neural states might indeed be interpreted as pictures, any individual change in a single pixel will determine a new “instant”. This seems almost inevitably to lead to the idea that the timings of neural events need to be defined to sufficient precision that changes in the time-orderings of each pair of spatially distinct events can be distinguished. But since this involves an ordering of, say, 10^{11} events in a second, or at least an ordering of the timelike separations among those events, this implies a temporal precision which in biological terms is simply ridiculous. Nevertheless, although an appropriate minimum biological timescale for individual local events might be 10^{-4} s, a description, simple in physical terms, of information changes across the brain does seem to require a much shorter timescale. The fact is that, like the minimum biological neural lengthscale of 10^{-6} m, a timescale of 10^{-4} s is “macroscopic” in physical terms in this context. To work on such macroscopic scales directly would require the definition of some method of averaging over the smaller scales and this would introduce at least as much ambiguity as it would resolve.

Counting Futures.

If probabilities for our possible futures are to be defined, it has to be possible to define those futures. In Donald (1997), I argue in favour of discrete probabilities. Although continuous probabilities can certainly be useful as models for circumstances in which external observers can vary the scale of their observations over a wide range, observers observe their own reality by direct experience so that the scale of the observation is part of the experience and is not variable. Nevertheless, it is not easy to see how we should count the number of possible ways in which, in a short period, we might have knowledge of our own neural states. Defining equivalence classes of functional distinctions would require that we could say what it would mean for two neural states to be functionally equivalent in such a way that if neural state A was equivalent to neural state B and neural state B to neural state C then neural state A would be equivalent to neural state C . However, in general, if we work at a high level, we are likely to see functional similarities between neural states rather than

functional equivalences. Relations like “similarity” or “closeness” are not transitive and do not define equivalence classes. In my opinion, the simplest way to cope with this problem is to invoke the fact that individual neural firings are effectively discrete and to attempt to work with discrete indicators of those individual firings.

Finding the Observer.

So, as a preliminary model of personal “knowledge”, we can take the changing faces of a set of N coins, with N at least 10^{11} (in Donald (1995), I suggest thousands of indicators per neuron, making N at least 10^{14}). As a first result, we have that, at any moment, the Shannon entropy of the distribution of values for these faces is quite large. Suppose that we want to use such a model as a foundation for the idea that quantum states are states of knowledge. As long as we assume that we can identify an observer and his neurons and a set of neural status indicators and their current status, this seems fairly straightforward. For any given quantum system, the quantum state to be assigned to that system should be the most likely state given all that information, where by “most likely”, we presumably mean “maximal entropy” in some sense. It seems to me, however, that the assumption here is much too strong to initiate a consistent foundation for quantum mechanics. The difficulty of finding a natural set of neural status indicators has already been referred to, but, there is also the much harder problem of “finding” the observer. A version of this problem will arise in any indeterministic theory in which as soon as we take our eyes off an observer he disappears into a soup of possibilities, but it can most easily be expressed in the formalism of many-worlds quantum theory. In such a theory, if any implicit appeal to an external observer is to be avoided, then the individual observer should pull himself and his world out of the undifferentiated background state which is the quantum state of the universe. A state which is almost entirely uncontaminated by observation is what we think of as the “initial state of the universe”; in other words, the state at the big bang. (To make it entirely uncontaminated, we may need also to allow variable big bang dates, and maybe even variable “physical constants” (Donald 1999).) As all states can be viewed as Heisenberg states, this state can also be considered as a state for the present moment, at which time it will be a superposition of all possible current states for the universe given a big bang origin. This is not a state in which definite sets of neurons exist, waiting for information to be painted into them. Instead, sets of neurons only exist as possibilities. We must find the neurons in the process of finding the information.

Quantum Theory Needs An Interpretation.

Interpreting coins as pixels, we can think of the instantaneous state of the brain as a picture; with each picture corresponding to a unique choice from, for example, $2^{10^{11}}$ possibilities. It is then not entirely implausible that, if we could give a precise definition of an instantaneous three-dimensional structure as a “neural snapshot”, we could use those pictures to label our fundamental correlations, our preferred basis, and our states of knowledge. This might be possible. Is this the sort of idea which those who want to claim that quantum states are states of knowledge are assuming? Or are

they actually assuming that knowledge is somehow outside the realm of physical law? In either case, the claim that “quantum theory needs no interpretation” seems to me to be obviously incorrect; in the first case because the identification of fundamental structures is an interpretative problem, and in the second because the identification of the unphysical (“classical?”) realm is.

The Problem of Temporal Progression.

My own approach to this problem is somewhat different. I attempt to identify *four-dimensional* structures by looking for developing histories of neural snapshots. This introduces technical problems in the quantum mechanical analysis, because, in a conventional language, it becomes necessary to allow for a history of apparent state “collapses” (i.e. changes of Heisenberg states), rather than dealing merely with a single apparent “collapse” out of the initial state of the universe. On the other hand, this does have the advantage of building temporal progression into the structure. The two major problems in the interpretation of quantum theory can be seen as the “preferred basis problem” – or the problem of what quasi-classical entities can exist at a moment; and the problem of temporal progression – or of how we go from one quasi-classical moment to the next. Relativity theory makes defining the notion of a “moment” a significant part of these problems. The idea that quantum states are merely clusters of correlations fails to solve the problem of temporal progression over more than a single step. Of course we can use a single quantum state to learn, for example, that if I have spin up then you will have spin down; and even that, if we have spin up now then there is probability $\frac{2}{3}$ that we will have spin down in five seconds. However, these are things which we learn only if we assume that we know what “we” are and that we are outside the frame of the state, and even then, we need to know how we should take account of our new knowledge if we are to learn what might happen next.

Localization and Number.

Return to the “neural snapshot” picture. What are the possible futures of a given snapshot? Are they the possible snapshots in the same place? “Same place” in which frame? How can we accommodate changes in the substructure of the localization due to relative motions of biological components? Do all possible future snapshots use the same number of “pixels”, or “coins”, or “neurons”, or “neural indicators”? How can we accommodate changes in number due to growth or decay or turnover of biological components? What number, or level of detail, should we start with? Issues of localization and number, similar or related to these, seem to me to be at the heart of the temporal progression problem. Issues involving the localization of a quasi-classical entity are tricky, because localization is always tricky in quantum theory, but the most difficult issues seem to be those related to number. Moreover, the unpredictability of the details of neural processing means that alterations in number correspond to significant changes in probabilities. If most of the functioning of a brain were predictable, then it would not make much difference to short term future probabilities if there was a change of the level of coarse-graining under which neural structure was defined. As it is, however, it seems plausible that, in the language of

a many-worlds interpretation of quantum theory, most of the “worlds” we experience differ by differences due to events within our heads rather than due to external events, so that if we want to count our worlds – which should be the first step in defining probability – then we have to be able to identify neural “events”.

The Trimming Problem.

My analysis of this situation has eventually led me to define a finite Markov process on a space of patterns of histories of neural events. In terms of such a process, the problems which need to be solved in order to explain the experience of an indeterministic physics are to identify a state space and to define transition probabilities on that space. The prevalence of neural unpredictability means that transition probabilities for such a process can be strongly dependent on the precise definitions used. In particular, a specific number problem arises which, in [Donald \(1995\)](#), I refer to as the “trimming problem”. In the coin model, with a space of 10^{11} coins, the problem would be that if a few of the coins were omitted from the state space, then probabilities would increase but hardly any significant information would be lost. This is troubling, because even in a classical picture of a brain, alterations in neural substructures happen all the time while, as has already been discussed, in a fully quantum mechanical picture, the neurons themselves only exist as possibilities. In [Donald \(1999\)](#), by detailed analysis of the temporal structure of an observer, I propose a solution to this problem which allows “coins” or “neural indicators” or “switches” to be added retrospectively. This allows the structure of an observer to develop towards a natural balance between increase of number and decrease of probability.

An Abstract Approach.

The difficulties of finding neurons in the initial state of the universe leads me to an entirely abstract approach to the definition of a “pattern”. I do not directly define a “pattern of neural firing”, but rather a pattern of a certain type of information coded as spacetime arrangements of “yes-no” events (“switchings”). The yes-no events correspond to the heads and tails of the coins or to the firings and not-firings of the neurons. The spacetime arrangements define whether pairs of different events are spacelike separated or time ordered. The total amount of information in a pattern is finite, but because the spacetime relations are defined for every pair of events, a considerable amount of biologically irrelevant information is given, and the space of patterns available to a single observer is correspondingly very large. The resulting plurality might be thought of as the price of a simple abstract structure, although it turns out that it does have advantages ([Donald 1999, section 8](#)). The primary purpose of this paper, however, is not to repeat my earlier work; the significant points here are simply an indication of the type of problems which may arise when one tries to express human knowledge as a pattern of physical events, and the comment that an attempt to solve the preferred basis problem locally may well lead to a “solution” in which distinct possibilities are not actually defined by orthogonal wavefunctions. Thus, with my definition, pairs of different patterns will often correspond to overlapping rather than orthogonal states. This does complicate the analysis of probabilities, in

particular in that it introduces a normalization requirement, but while orthogonality may seem a reasonable criterion in the context of simple models in low dimensional Hilbert spaces, it is of little relevance for thermal states of localized macroscopic objects, for which wavefunction descriptions are in general inappropriate. The very name “preferred basis problem” begs the question of whether a basis is the right way to classify distinct possibilities at the level of the human observer. In my opinion, it is not.

Public and Private Physics.

It is tempting to think that all this is just very esoteric and to claim that events external to an observer are not affected by internal events and that therefore physics can be restricted to the calculation of probabilities for those external events. The preliminary model here would be that we have two systems of coins some of which constitute an observer and some of which are external. Our modelled restriction of physics would then be permissible as long as we could show that the external coins are independent of the internal coins. This is certainly plausible and, under this sort of assumption, we can construct a common, public, intersubjective physics. But the question we ultimately have to face as individual observers is why, as separate individuals, this public physics is also the physics that we observe privately. The complexities of neural functioning outlined in this paper make this not an entirely simple question to answer.

Observer-effects might arise in many ways in a system as complex as a human brain, and we would, perhaps, like to be able to argue, for example, that no such effects arise due merely to increased neural activity. However, [Donald \(1999\)](#) provides an example of just how difficult it can be in a fully-defined theory to argue for the general absence of observer-effects. In that paper, I split the problem of relating public physics to private physics into two theses. The first thesis states that a typical modern human observer should be aware of a world in which quantum theory is accepted and in which its detailed theoretical predictions are confirmed. The argument for this thesis considers the observation of summaries of many experimental results. Classical and quantum versions of the laws of large numbers can be invoked to tell us that the theoretical probability that such summaries are consistent with quantum theory should be close to one. That events of theoretical probability close to one should typically be observed is a comparatively simple test for a model of observation. The second thesis, however, is the claim that, under appropriate circumstances, there should be a fairly direct agreement between public and private probabilities for observing single individual quantum events; for example, individual clicks of a Geiger counter.

Intuitively, there would appear to be no problem in calculating these probabilities: Consider the possible events in a given time interval. Divide those events into a class in which a click is heard and a class in which a click is not heard. Weigh the counting of each event by its individual quantum probability. Use the weighted sum over the two classes to give the probabilities of hearing and of not hearing a click in the given interval.

This intuitive picture, however, is, once again, a picture from the point of view of an implicit external observer. The nature of classes of events and of fixed time intervals are already decided when we choose to imagine a world which is like the world we see but indeterministic. But what we should be trying to imagine is a world in which the observers are self-defining. The division into classes of events should be made internally rather than externally. Everything which makes a click-hearing observer a click-hearing observer should be in the structure of the relevant quantum states and their temporal development. Now we really do face problems in saying what an event is which are analogous to the preferred basis problem or the consistent-histories set selection problem. And we do have to solve the trimming problem. The events which ultimately lead to an observation are neural events rather than external events. Neural observations are made by the parallel processing of many small pieces of ambiguous information over time intervals which allow many successive firings at some individual neurons and therefore a combinatorial explosion of possible patterns of synaptic events over the entire brain. This suggests that observer effects might even arise due simply to the time taken for a particular outcome to be realized.

These are problems which should not be ignored. If they are addressed, then they can be used to constrain interpretative hypotheses. For example, there was a significant change between the proposals of Donald (1995) and of Donald (1999). This was required precisely in order to avoid an implausible observer-effect in the situation of listening to a Geiger counter. The difficulty stems from the fact that a click naturally excites more neural activity than silence. The proposal of Donald (1995) failed because it ignored “non-events”; where a coin face changing would model an event, while a coin face which stayed unchanged would model a non-event. The normalization of the probabilities of overlapping states could then lead to considerable under-weighting of neural inactivity. The solution I put forward in Donald (1999) effectively allows non-activity to be observed in circumstances in which activity can be observed. The details here may only be important in the specific context of my proposals, but there should be no doubt that, in any kind of detailed analysis, problems will arise from the underlying facts that neural states are thermal and that they have much more complexity over short time scales than simple models might suggest. A cat being looked at by a person is not something being seen simply as “dead” or “alive”; rather it is one enormously complex quantum system interacting through several different channels with another even more enormously complex quantum system.

Avoiding the Problems.

Technical problems arise as soon as one accepts the goal of describing personal observations by a well-defined stochastic process. In order to avoid those problems, one might argue that such a description is unnecessary. For example, one might claim that it is not necessary for probabilities of single events to be precisely defined; or that an observer’s self-knowledge is never perfect; or that memory is part of the instantaneous present structure of an observer so that there need be no well-defined connection between the past of an observer and the present; or that observers simply can exist in innumerable many ways and that our experience just happens to be of

one of those ways; or finally, one might claim that some alternative physical theory makes any problems about the nature of observers irrelevant.

Are Probabilities Precise?

The claim that it is not necessary for probabilities of single events to be precisely defined is surely correct for several of the ways in which probabilities have been understood (Gillies 2000). For example, prominent among these ways is the suggestion that probabilities are relative frequencies; applying not to single events, but to infinite sequences of events. Alternatively, if probabilities for individual events are characterized by betting quotients or by degrees of belief, it would also seem unnecessary that they should be exact; at least, as long as the idea of a belief is itself not taken to be foundational for physics. Nevertheless, the fact that there are situations in which these kinds of imprecise probabilities are appropriate and useful, does not rule out a propensity theory for an indeterministic physics in which there are some fundamental probabilities which are physical facts defined as part of the physical laws. A propensity theory is also not ruled out by the fact that, because probabilities can only be measured by looking at long sequences of events, their measurement can never be exact. Indeed, it seems to me that the probabilities in any physical theory with fundamental indeterministic events have to be lawfully-defined propensities. One might, for example, interpret such propensities by supposing that a random string of digits is part of the initial conditions of the universe, and that it is part of the laws of physics that digits from the string should be brought into play at appropriate moments. If the probability of a future event is a fundamental physical fact of this kind, then the precision which is required to make such a theory complete is precision in the lawful way in which randomness is brought into play. The interpretation I propose does have this precision.

Epistemology or Ontology?

It is, of course, correct to say that an observer's self-knowledge can never be perfect. My counter-claim is that "observers" are fundamental parts of our reality and exist as definite entities. As I have no idea what vague existence can mean, unless it is existence through the eyes of an external observer, I believe that this amounts to no more than taking the position on the mind-body problem that "minds" exist. Indeed, to the extent that it makes observers fundamental, my developed theory is close to a form of idealism, with physical laws and initial conditions merely providing probabilities for mental histories. Well-defined probabilities for observations and definite existence of observers are the mutually sustaining demands by which I have found myself led, much to my surprise, towards this idealism.

Escapism.

The claims that there need be no direct connection between past and present and that we might exist just in one of innumerable many ways seem to me both to be absurd. They are absurd in the same sense that the conceit that one might be a brain in a vat is absurd. Philosophical scepticism is important. We should always be aware of how little of our knowledge is certain and be prepared to doubt everything. But

beyond a certain point, the idea that anything is possible becomes escapism. Above, I describe the problem of temporal progression as one of the two major problems of the interpretation of quantum theory. I think that it is escapism to claim that this problem can be “solved” by ignoring it and supposing that we have memories but not pasts. Carried to its logical extreme, this produces the timeless theory of [Barbour \(1999\)](#). In such a theory, predictive probabilities are illusory; our probability calculations are merely present memory traces of probability calculations; our hopes and fears are empty. Any plausibility this idea might have as a theory of mind, would seem to depend on some sort of materialist functionalism in which a mind is taken to inhere in the way that an instantaneously associated brain would function were there time in which it could. In [Donald \(1997\)](#), I have criticized the attempt to base functionalism on the idea of disposition to function rather than actual historical functioning. Where there is never any actual historical functioning, however, the very idea of a disposition to function seems to me to be ludicrous.

As to the suggestion that our experience just happens to be one of innumerably many possibilities, this seems to me even more dubious than the suggestion that we only exist in the present. Instead of Barbour’s explicit statement that we have no past and no future, we would be encouraged to believe in past and future, but rather than being required to construct them, we would be supposed to allow in some unexplained way for all possible frameworks. Thus we would be supposed to contemplate ourselves with futures and pasts defined some arbitrary path through the states, sometimes of 6, and sometimes of 6,000, and sometimes of 4,721,637, of our neurons. Once again, I suspect that this idea ultimately depends on materialist functionalism, as how else are we supposed to make sense of any particular collection of neurons except by trying to work out how that collection either might behave or has behaved? Once again, however, any form of functionalism seems questionable without a clear choice of dynamical framework.

Hume and Parfit.

Following [Hume \(1739\)](#), [Parfit \(1984\)](#) describes persons as being like “nations”. A preliminary version of this paper was presented in Belfast; a reminder of the extent to which a nation is a purely human construct, with arbitrary boundaries drawn and redrawn by a succession of historical accidents ([Jackson 1997](#)). I do not disagree either with Parfit or with Hume about the ephemeral nature of experienced personal identity, but instead suggest that without a basis for that experience through the existence of a definable observer, a person would be as indefinite as, without an imposed legal framework, Belfast would be nationless. Hume suggests that personal identity amounts to nothing more than “a succession of parts, connected together by resemblance, contiguity, or causation”, while Parfit claims that “a person’s existence just consists in the existence of a brain and body, and the occurrence of a series of interrelated physical and mental events”. My problem with these views is that, in the context of a global quantum theory, and without assuming an external observer, I find it difficult to give meaning to the terms “succession”, “parts”, “connected together”, “resemblance”, “contiguity”, “causation”, “brain”, “body”, “series”, “interrelated”,

and “events”; let alone, “physical” and “mental”. Hume and Parfit could point to a “body” as the approximate or temporary possessor of an identity. Neurophysiological detail makes the external behaviour of a body an insufficient guide to its internal experience, while quantum mechanics calls any act of pointing into question. A definition for an observer might thus be seen as the least which is required for a precise reformulation of those problematic terms.

Many of Parfit’s arguments about personal identity are based on science-fiction thought experiments. It is possible to analyse each of these experiments in the light of the definition proposed in [Donald \(1999\)](#) and, at least when sufficient imaginary details are added, it is possible to draw definite conclusions. For example, I would always recommend travelling to Mars by spacecraft rather than by atomic disassociation on Earth and reconstruction on Mars. From my point of view, Parfit’s examples tend to turn on ways in which the abandonment of naive functionalism can open a gap between observed and experienced behaviour. Any specific definition of personal identity in terms of physical structure implies the possible existence of things which are actually not conscious but which appear to behave as if they were. It is almost inevitable, therefore, that problematical thought experiments can be described. According to my definition, consciousness depends on a physically continuous past history. If my body were to be reconstructed on Mars, I would argue that the actual consciousness of that body would be consciousness of a history beginning at the moment of reconstruction. Of course, being dependent in behaviour entirely on its physical composition, it would only be able to behave, as far as external observers are concerned, in ways in which my current, physically identical, body would behave. Thus it would say that it did not necessarily believe what it would tend to say if it tried to describe what it thought it was feeling! But the question we should be asking here is not, “what is that person saying about his experiences?”, but rather, “what would it be like to be nothing but an experiencing of that middle-aged body over just a few minutes, hours, or days?”. From the point of view of an external observer, this might seem to make ordinary consciousness look like a miraculous pre-established harmony between physical behaviour and awareness, because there is no necessary link between the behaviour seen by the external observer and awareness. However, the miracle lies rather in the existence of laws which can make long, rich, meaningful, coherent histories plausible. With suitable laws in place, the reason that there would tend to be harmony between physical behaviour and awareness, would be that awareness would be far more likely to arise in the context of appropriate behaviour than otherwise.

The Now.

Saunders, Wallace, and Butterfield all emphasize the analogy between splittings of a universal state into worlds and splittings of a spacetime into instants. [Butterfield \(2001\)](#), for example, writes “just as someone who accepts the tenseless conception of time can readily accept instants i.e. spacelike slices of spacetime, as (i) useful or even indispensable for describing phenomena, and yet (ii) not any substantive ontological commitment additional to the commitment to spacetime; so also an Everettian

can readily accept worlds as (i) useful or even indispensable, and yet (ii) not a substantive commitment additional to the commitment to actuality's being described by the universal state." While "instants", considered purely as an arbitrary mathematical slicing, may not imply a substantive additional ontological commitment, I would rather make the analogy between the Everett "world" that one is seeing and "now" – the time that one is seeing. In these terms, the analogy underlines the ontological commitment to a "one" or an observer. Ultimately, defining the present instant for an observer is equivalent to defining the present of the observer or to defining the observer's present world.

Observer Relative Terms.

The fundamental problem which the idea of psycho-physical parallelism raises for a physicist is whether anything needs to be added to the mathematical formalism of a physical theory in order to understand the apparent existence of observers. The standard justification of the proposal that nothing needs to be added seems to depend on the argument that there just are some natural physical structures which behave in particularly complex ways. As I see it, however, "natural", "structure", "behave", and even "complex", are all in fact observer-relative terms (cf. [Searle 1992, 9.V](#)), and so this leads to the problem of whether such structures can be, in some way, reflexive, self-relative, or self-defining and if so, whether they are sufficiently well-characterized by themselves to specify their individual pasts and their possible futures. This seems so implausible to me that I am prepared to propose as an alternative that there have to be fundamental physical laws defining the existence of observers ([Donald 1999](#)). The frequent invocation of assumptions about decoherence might be thought of as attempts to postulate such laws without having to make them explicit. In my opinion however, these postulates are insufficient. Decoherence merely helps to provide the circumstances out of which observers can emerge.

Alternative Physical Theories.

At least implicitly, the idea of the observer is central both to the idea that quantum states are states of knowledge and to the idea that quantum states are clusters of correlations. Given that there are difficulties in characterizing the physical structure of observers, it might seem appropriate to pursue some of the alternative approaches to the interpretation of quantum theory in which observers are not fundamental. At present, however, I am unaware of any such approach being fully compatible with experiment, with special relativity, and with quantum field theory. But even if we did have such an interpretation, the problems raised in this paper would still be important.

Ignorance Probabilities.

In a many-minds theory, the fundamental indeterministic events are individual observations. In most other theories, the probabilities of observations for an individual are thought of as "ignorance probabilities". The conventional use of such probabilities involves supposing that an observer's direct information can be combined with theoretical knowledge in order to provide rational odds for future observations. For

example, a Maxwell distribution may be predicted for molecular velocity observations as soon as the temperature of a gas at equilibrium has been observed. Probabilities of this type are not fundamental and need not be precisely defined for individual events. According to a classical theory, for example, the gas molecules simply have some definite velocities, which result from their past collisions and which cause thermometers to display the appropriate temperature. But although each individual measurement is simply an isolated fact, sufficiently long sequences of velocity measurements will be likely to fit a Maxwell distribution, or some version of the distribution corrected for a more sophisticated theory, to any required degree of accuracy. We can understand this theoretical distribution as being an appropriate description of any of the vast majority of ways in which a certain total energy can be shared by collisions between molecules, but we can hardly expect any actual gas sample to achieve perfection in randomization. It is none the worse for this type of ignorance probability that it is just an expression of the somewhat circular idea that we should expect to see a typical situation. Theoretical progress can still come from our ability to improve our description of “typical situations”. Conceptually, we can say that the situation which we happen to be seeing is just a reflection of the initial state of the universe, and the fact that that situation is typical merely tells us that no special explanation of this aspect of the initial state need be given.

Including the Observer.

As always, however, problems arise when we try to include the observer in the situation to be described. Now the fact that what we see depends on what we are enters into the equation. The focus of this paper has been on the probabilistic prediction of the future development of the information which defines consciousness given the past history of that information. The neural unpredictabilities and instabilities discussed above make even short-term probabilistic predictions of this kind highly dependent on precisely what form the information takes, regardless of whether the probabilities in the predictions are ignorance probabilities or propensities. Indeed, if the information includes precise positions for all the atoms in the brain, then short-term prediction of future firing patterns will clearly be much more reliable than if the information merely gives the past history of firing patterns. However, unlike in a many-minds theory or in a theory of quantum states as states of knowledge or of quantum theory as a theory of correlations, it can be argued in the context of a theory involving ignorance probabilities that being able to step from present information to future information is not fundamental. What we might see and how likely we are to see it, is not caused, but merely filtered, by what we are. Whatever will be will be. It is just a fact that we do not and cannot know what the future will bring and it is just another fact that we do not and cannot know exactly what we ourselves are. Nevertheless, this does not imply that there is not something which we exactly are.

External and Internal Observers.

From the point of view of an external observer looking at a functioning human brain, the physical nature of human mental processing makes it seem difficult to

identify anything as the essence of the existence of that brain for itself. However we are also, and indeed primarily, internal observers looking out. From that point of view, it seems necessary to accept that we are something. And if we are something, then, given the absurdity of vague existence, there is something which we exactly are. The contrast between internal and external points of views is reflected in a contrast between physical theories. On the one hand, there are theories, like many-minds theories, in which the concept of information is fundamental; and on the other hand, there are theories in which external physical reality is fundamental. In the first type of theory, the appearance of external physical reality is derived from the rules which determine the kind of information which exists; but in the second type of theory, the existence of information for itself seems rather unnatural.

Advantages and Disadvantages.

In an information-based theory, fundamental information can be taken to be local because an individual's information exists at that individual; a clear and simple recent analysis of this point is given by [Fuchs \(2002, section 3\)](#). This makes it possible to avoid the locality problems which plague other interpretations. Fundamental information can also be taken to be information possessed by individual observers. This puts mind at the heart of our physical theories and reflects our individual realities. Nevertheless, the advantage is not all in one direction. As we have seen, in an information-based theory in which local private information is fundamental, there is the possibility of "observer effects" which could make the likely private observations of individuals differ from textbook predictions of public observations. Except in cases with significant changes in the actual structure of the observer as a result of particular observed events, this problem does not arise with a theory involving ignorance probabilities, because, with such a theory, private observations are a consequence of public events. Thus, for example, with an ignorance theory, we hear a sequence of clicks which really happened, rather than, with a theory in which there are no facts except observed facts, becoming a hearing of a sequence of clicks. If, at the end of the sequence, we intend to publish a statistical summary of the clicks which we have heard, then that summary will have the same status for us as for anyone else, according to an ignorance theory. Under a many-minds theory, however, it will be a private event for us, but a public event for any other observer.

Classical Deterministic Theories.

Even in terms of nineteenth century physics, the idea that an observer is a physical subsystem which behaves as an observer would not be sufficient to delineate a unique class of human observers because the question of the scale at which a mind experiences a body would remain open. In such a theory, an attempt to understand psycho-physical parallelism would start with the idea that a given mind is an awareness of the workings of a given body. "Given" is a give-away for an implicit external observer, but even if it is allowed that, in a classical deterministic theory, "bodies" are natural physical structures, it is not at all clear that their "workings" are equally natural. It might be, for example, that an observer with awareness defined at the

molecular level would be different from an observer with awareness defined at the neural firing level. While one could say that it would be unreasonable to suppose that an observer would have awareness defined, in an arbitrary way, sometimes at the molecular level and sometimes at the neural firing level, this sort of remark is perhaps as far as one can go in a classical deterministic theory, towards constructing a reasonable and consistent picture of a human observer.

The Bohm Interpretation.

The Bohm interpretation provides a deterministic model of non-relativistic quantum mechanics. There are significant problems in understanding psycho-physical parallelism in this theory, in as far as it is not clear what role the hidden variables (the particle positions) should play (Albert 1992, Page 1995, Brown 1996). Particle trajectories are determined by the positions of other particles and by the guiding wave-function, and the physical constitution of an observer could depend on facts about both. Indeed, it could even be that the particle positions are entirely irrelevant to psycho-physical parallelism and that, despite the existence of those definite positions, we are aware of a stochastic process of patterned structures in the global guiding wave (which is Everett's universal wave-function). The spirit of the Bohm interpretation, however, would seem to suggest that we are aware, at any moment, either of the positions of some family of particles associated with our brain (Bell 1981), or that we have just enough information about some such family to be able to assign them an effective local wavefunction (Albert 1992). And yet it is unclear which family of particles is involved, nor how that family is updated as the brain changes. Moreover, the information is of a type which seems quite remote from biologically significant information. In my opinion, this makes the Bohm interpretation an example of a theory in which the existence of consciousness, although possible, is hardly "natural".

Stochastic Theories.

Stochastic or indeterministic theories – such as the spontaneous collapse theories reviewed by Stamatescu (1996) and by Pearle (1999) – can be interpreted in two distinct ways. In the first way, the idea is that the indeterminism is a matter of ignorance so that the situation is like that of classical statistical mechanics, or even Bohmian mechanics, with some ultimate deterministic theory underlying and causing the apparently indeterministic events. In this case, the theories present similar problems to the Bohm interpretation, only made worse in that the underlying deterministic theory is unknown. The alternative interpretation of stochastic theories is to suppose that the probabilities are objective. In this case, if there is something which we exactly are, then this something will also change indeterministically and it might indeed be conceptually accurate to see ourselves as something like some subset of a set of coins being tossed. There being something which we exactly are would now require rules as to which subset we are and as to how that subset might alter over time with differing possible outcomes. In both cases, as with the Bohm interpretation, it may seem unnatural that awareness should be defined in terms of structures at the level of the underlying physical theory, in as far as those structures seem so remote from the level of biologically significant information.

Quasi-classical Theories.

Collapse theories and the Bohm interpretation are both motivated by the goal of constructing a quasi-classical physics in which, in particular, macroscopic objects can be said to have quite well-defined positions at all times. As well as problems with locality, theories which aim at a quasi-classical physics also tend to have more general problems with quantum field theory, according to which the same physical systems can have both quasi-classical particle-like states and quasi-classical field-like states. This makes it difficult to see how one can make a universal choice of fundamental quasi-classical variable. Moreover, in order to explain our observations, we do not need to construct a quasi-classical physics; what we need to do is to explain our observations. That remains a problem even given a quasi-classical physics for the world external to an observer.

Conclusion.

The ultimate purpose of theoretical physics is to provide a consistent and plausible theoretical framework for our individual observations, including what we learn from others. However, the detailed nature of our individual observations depend on precisely what parts of the workings of our brains form the physical aspect of our consciousnesses. In approaches to the interpretation of quantum mechanics in which the ideas of information or correlation or mind are fundamental, there are no events except observed events, and those events and their possible futures are defined by the solution to this problem of psycho-physical parallelism. However the unpredictability of the normal functioning of the human brain means that different solutions at different scales will involve different sets of events with different future probabilities which cannot be assumed to be better than approximately consistent. Thus without some solution to the problem of psycho-physical parallelism such interpretative approaches are incomplete. Nevertheless, solving the problem is difficult. Some of the ways in which difficulties can arise have been sketched. Finally, it has been suggested that, like the classical physics they attempt to emulate, some alternative approaches to the interpretation of quantum mechanics provide frameworks in which human consciousness seems a peculiar and extraneous appendage to reality.

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