

On the place of qualia in a relational universe

Lee Smolin*

Perimeter Institute for Theoretical Physics,
31 Caroline Street North, Waterloo, Ontario N2J 2Y5, Canada

January 2, 2020

Abstract

We propose an approach to the question of how qualia fit into the physical world, in the context of a relational and realist completion of quantum theory, called the causal theory of views[27]. This is a combination of an approach to a dynamics of discrete causal structures, called energetic causal sets[52]-[57], developed with M. Cortes, with a realist approach to quantum foundations, called the real ensemble formulation[49, 50].

In this theory, the beables are the information available at each event from its causal past, such as its causal predecessors and the energy and momentum they transfer to the event. We call this the view of an event. That is, we describe a causal universe that is composed of a set of partial views of itself.

We propose that conscious perceptions are aspects of some views. This addresses the problem of why consciousness always involves awareness of a bundled grouping of qualia that define a momentary self.

This gives a restricted form of panpsychism defined by a physically based selection principle which selects which views have experiential aspects.

We further propose that only those views which are novel, in the sense that they are not duplicates of the view of any event in the event's own causal past, are the physical correlates of conscious experience.

*lsmolin@perimeterinstitute.ca

Contents

1	Introduction	3
1.1	Brief summary of the proposals made here	4
1.2	Some comments on the mind-body problem	5
2	The context: relational physics	9
2.1	Basic principles of relational physics	9
2.2	How to describe a cosmological theory? The general picture and vocabulary	11
3	Hypotheses about physical correlates of consciousness (PCC)	13
3.1	The causal theory of views[27]	13
3.1.1	The basics of energetic causal sets [52]-[57].	13
3.1.2	Connecting to the real ensemble formulation	14
3.1.3	From views to correlates of consciousness	17
3.2	Common and unique views	18
3.3	The hierarchy problem	19
4	Principle of precedence	19
4.1	Routine and novel events	20
4.2	Principle of precedence: details [28]	20
4.3	The principle of precedence applied to an energetic causal set theory	22
4.4	Energy and qualia	23
5	Conclusions	23

1 Introduction

This paper addresses the mind-body problem. More specifically, what Chalmers has called “The Hard Problem” of consciousness[1]. The problem is why conscious perceptions, such as the experiences of the colours red or blue, are associated with particular physical processes—namely excitations of neurons in the cerebral cortex—whose complete description in terms of the laws of physics does not and indeed cannot reference these subjective aspects of experience. The languages the neurosciences give us so far, such as synaptic potentials, electric currents, neurotransmitters, etc. explain a lot about how neurons work, but do not seem to have the capability of either describing or explaining, why or how these relate to the subjective mental experiences we all perceive.

The point has been put several different ways, from Leibniz’s mill[2], to Jackson’s knowledge argument[3], featuring Mary the colour-blind neuroscientist to Chalmers’s zombie argument[1]

Leibniz, in his *Monadology*, put the point as well as any,

It must be confessed, moreover, that perception, and that which depends on it, are inexplicable by mechanical causes, that is, by figures and motions, And, supposing that there were a mechanism so constructed as to think, feel and have perception, we might enter it as into a mill. And this granted, we should only find on visiting it, pieces which push one against another, but never anything by which to explain a perception. This must be sought, therefore, in the simple substance, and not in the composite or in the machine.

But I should hasten to add that while I address the “hard problem,” I do not solve it. What I aim to do is to solve the “next hardest problem”, which is 1) to identify those *physical processes, events or states* that are “associated with” or “correspond to” instances of conscious perception (we will call these PCC for physical correlates of consciousness), and 2) explain some of the characteristic features of conscious perception, to be described below, in terms of the features or structure of these correlates of consciousness. While I do not solve this either, I have some specific proposals and hypotheses to make concerning the physical correlates of consciousness.

These proposals situate the search for an approach to the mind-body problem within the search for what I call a *completion of quantum mechanics*. This is what is sometimes called a *non-local hidden variables theory*: it is a realist description of precisely what goes on in each individual event or process, which reduces to quantum mechanics in a certain limit and averaging procedure. For reasons I described elsewhere[30, 22, 21], I confine the search to completions of quantum mechanics which are relational, so that they address also issues in quantum gravity.

1.1 Brief summary of the proposals made here

In this paper I look to find the correlates of consciousness within the framework of a recently proposed completion of quantum theory, called *the causal theory of views*[27]. This incorporates elements of two other frameworks, the real ensemble formulation of QM[49, 50, 27], and the energetic causal set framework, which we developed with Marina Cortes[52]-[57]. I also look to another proposed completion of quantum mechanics, called the principle of precedents[28], and find there another suggestion for the PCC.

To anticipate in the simplest possible terms, the key ideas are first, that the universe is constructed from nothing but a collection of *views* of events, where the view of an event is what can be known about that event's place in the universe from what can be seen from that event[27]. In other words, the beables of this theory are views from events, comprised of the energy, momentum and other conserved charges that combine to create the event, from its causal predecessors. Within such an ontology of views, it seems natural to propose that instances or moments of conscious experience are aspects of some views. That is, an elementary unit of consciousness is not a single qualia, but the entire of a partial view of the universe, as seen from one event.

The second proposal restricts the views that are associated with consciousness to within a very small set. Most events and their views are common, in that they have many near copies in the universe. Most events could also be called routine, in that nearly identical views appear numerous times within their causal pasts. I then propose that these common and routine views have no conscious perceptions. Then, there are a few, very rare views which are unprecedented, which are having their first instance, or are unique, in that they have no copies in the universe. I propose it is those few views of events, which are unprecedented, and/or unique, and are hence *novel*, which are the physical correlates of conscious perceptions.

Elsewhere[30][60]-[65] I have argued in detail for the view that quantum mechanics is incomplete, in that it does not give a full description of, nor explanation for, all individual physical processes, independent of our knowledge, or interventions. This implies the need for a "realist" completion of quantum mechanics. I will not repeat these arguments here. Of course, a completion is also required for unifying gravity, spacetime and cosmology into the rest of physics. The causal theory of views is intended to be a completion in both senses.

The causal theory of views is the present stage of a research program I have been carrying out since the 1980's to construct such a realist double completion of quantum mechanics and general relativity[60]-[65]. The common theme, motivating all these attempts, has been that of a *relational hidden variables theory* [60]-[65]. This situates it within the relational tradition developed by Leibniz, Mach, Einstein, and others, according to which physical degrees of freedom describe dynamically evolving relationships amongst particles, fields or other dynamical actors, rather than being defined against a fixed, non-dynamical background structure such as absolute space. My aim has been that this would be the case also for the additional "hidden variables" needed to complete the quantum

dynamics[60].

I simultaneously developed the idea that the relational variables which completed quantum mechanics would also underlie a discrete formulation of spacetime, so that the full theory would be a completion of both quantum mechanics and general relativity, ie it would also be the quantum theory of gravity. So, I like to think that it is no coincidence that the basic tools for describing a system of relations, namely, networks, and matrices, occur in all background independent formulations of quantum gravity [20]-[26] as well as in the various relational hidden variable theories I and others introduced[60]-[65],[67, 68].

All of these developments, beginning with several formulations of relational hidden variables theories[60]-[65], and developing into the real ensemble formulation[49, 50, 27], the principle of precedence[28] and the causal theory of views[27] are each described in detail in previous publications[30]. The causal theory of views, is also a development of a class of models of causal spacetime, called Energetic Causal Sets, developed in a series of papers with Marina Cortes[52]-[57].

To summarize briefly this already brief summary, taking the relational philosophy seriously-in a way that lets us read the Principle of the Identity of the Indiscernible as a dynamical principle (see below)- makes possible two concepts on which to base a theory: First is the proposal of taking the beables of a relational theory to be the views of events. Second is the possibility of making a physical distinction between common and routine states, on the one hand, and novel and unique states, on the other. The whole point of this paper is that a relational theory that incorporates both ideas offers a possible setting for bringing qualia and consciousness into physics. The physical correlates of consciousness are the novel or unique views of events.

The proposals I describe here are made within the language and frameworks of the specific theories, just mentioned. This does not rule out the possibility of implementing them in the context of another approach to quantum foundations. But at present I only know how to express them within these, closely related frameworks.

1.2 Some comments on the mind-body problem

Before getting to my specific proposals, I make some general comments on the mind body problem.

First of all, I take the existence of our conscious perceptions such as colours and tones-which are often called qualia, to be a fact about the natural world[6], to be naturally incorporated into, and even explained by, any fully complete theory of the natural world[6, 4, 5]. Further, I take various features and characteristics of our experience (to be discussed below) as phenomena to be explained by the theory.

I should hasten to add that the suggestions I make here are all within the paradigm of naturalism, so that I assume that qualia and other aspects of our conscious experiences are aspects of the natural world, alongside energy and charge. Here I follow a number of

philosophers¹, including William James[10], Russell[11], Eddington[12], Strawson[6] and Goff[4, 5].

I would also consider these suggestions to be within the constraints of physicalism, if by that we mean the assumption that all our understanding of the natural world is eventually to be grounded in (which is to say, possibly emergent from) the final, correct complete theory² of physics[4].

My thinking on these questions was to a large extent inspired by the panpsychists, or Russellian neutral monists, whose proposal that qualia are universal aspects of the intrinsic or fundamental nature of matter, seemed to me, for a long time, to be the most plausible view[13]. The neat trick of making qualia causally null, by making them “inner aspects” of all physical processes, and so not conflict with the causal completeness of the standard laws of physics, in spite of being real, seemed to me too perfect a solution to the body-mind problem not to take seriously³.

But when you take it seriously, it raises a number of puzzles which seem hard to address, given the assumptions made. Among them, if all physical processes have intrinsic aspects which are qualia, what distinguishes those bundles of qualia we experience from the qualia associated to the myriads of processes that unconsciously fill our heads? Following this are a number of questions about the particular ways our conscious experience appears to be structured which seem hard to address, given the claimed universality of the merging of physical and experienced aspects of nature.

The monist step of seeing qualia as aspects of physical processes seems promising. It is the assumption that the correspondence is universal that seems to land us in trouble.

The question I want to raise in this paper is then whether we might find a more explanatory theory if we keep the monist-dual aspect ontology, but restrict the association of qualia and consciousness to a restricted subset of physical processes, events or states, where the restriction was based on purely physical properties? The proposals I make here are intended as first steps in this direction.

The view I propose here might be called a kind of *restricted panpsychism*. It departs from the usual formulation of panpsychism on several points.

It does not propose that qualia are associated with all material states or processes. Instead, I propose that there are specific, generally rare, aspects or features of certain physical processes, which allows them to be correlates of consciousness.

We are thus challenged to discover a *selection principle* which is a physically based criteria which distinguishes the small minority of events, or states, or processes, to which correspond conscious perceptions. These will be **physical correlates of consciousness**. (*PCC*).

This strategy is not new; a prior example is *integrated information theory*, which pro-

¹A very clear introduction to the philosophy of “neutral monism” espoused by these philosophers is in the book of Rodolfo Gambini[9]

²Note that I say theory here, rather than laws, because I believe that the laws must be restricted to subsystems and evolve on cosmological scales[31]-[33].Indeed will suggest below that the physical correlates of consciousness may be related to the evolvability of the laws.

³For a good discussion, see [14].

poses a certain physical quantity, *the integrated information*, as a measure of, or selection principle for, consciousness[43, 44]⁴.

Note here something important: Neuroscientists look for **neural correlates of consciousness**[34]-[37]. (NCC) and our program will gain a lot by their success. But, we should expect that neural correlates of consciousness should be such because they are composed partly of physical processes which are physical correlates of consciousness!

Among the things we would like to explain are structural questions about consciousness, some of which are the following:

1. **The “scene” or “bundling” problem:** Why are qualia never perceived singly, but only bundled together with others into a frame or scene?
2. **The “viewpoint” or “self” problem:** Why is our conscious experience shaped in ways that appear to depend on our prior beliefs and intensions? i.e. why does our consciousness seem to reflect a point of view of the world around us, more an active probe than passive recipient of “raw sensations.”
3. **The “presentism” problem:** Why does that scene bundled together represent, approximately to be sure, a thickened (ie of some small duration) moment of time.
4. **The “unique self” problem:** Why does there seem to be only a single unique framed or bundled scene for every human brain, at each time? Why not many? This is especially puzzling given that the brain is simultaneously running a great many parallel processes, most of which we are unaware.
5. **The structural mismatch problem**[18]: Goff makes the point clearly[4] p 203:

“On the face of it, the structure of the brain seems radically unlike the structure of the conscious mind, as revealed through introspection. But if the mind and the brain are identical, or at least grounded in the same micro level base, one might expect them to have the same structure”

Or, as Edelman and Tononi emphasize, the majority of neural processing in the brain is never experienced or perceived[34]. It is the job of a physical theory to explain why some are and most aren't, not just by describing the NCC, but by explaining on the basis of a physical selection principle why the NCC are, such, because they incorporate the PCC.

6. **The modality problem:**⁵ Why are different modalities, such as sight, sound, pain, smell, etc. experienced as qualitatively quite different, in spite of their corresponding NCC being quite similar?

⁴It is intriguing that both the integrated information and the notion of *variety*, introduced with Julian Barbour in[51], which plays a crucial role in what follows, are measures of complexity.

⁵Also called the “Palette problem[4] pps 193-202”

7. **The “linear scale” problem:** Why do several of the modalities, while qualitatively distinct, distinguish within themselves by a linear scale? Why is this true of some modalities (vision and hearing), while not true of others (olfaction, touch)?

Panpsychists are exploring ways to address these questions, this has led to a large literature, mostly in philosophy of mind, that I am not sufficiently a scholar of to summarize⁶. But it does seem to me that the obstacles are challenging. Because they must assume that all physical processes are PCC, they have a hard time explaining why all neuronal processes are not experienced, or why the tiny fraction that are experienced, are those that are structured as they are.

That is—and this seems to me an important fact—there is nothing easier than imaging instances of conscious experience which are never experienced by us, to start with experiences of pure colour or sound, or experiences of higher level organizations like species or families. Pan-psychism starts with a disadvantage, because they are committed to believing all forms and organizations of matter have or manifest internal aspects which are instances of consciousness. There is, if they are right, a universe of experience that they must explain how and why is disconnected from ours.

Any proposal for such a selection principle is bound at this point to be highly speculative and the ones that follows are no exception⁷. However, even if, as is likely at the present state of knowledge, any particular proposal for the selection principle or PCC turns out to be wrong, I would suggest that the search for them is likely eventually to lead to success.

It seems to me unlikely that qualia can be grounded in the classical, ie non-quantum side of physics. For one thing, I don’t see that they have anything to offer for a selection principle for addressing the structural questions just mentioned. Consider the structural mismatch problem, applied to proposals for a PCC. If our conscious experience is not structured anything like the brain, it is even less structured like a classical physical system. We know how to reduce the description of a metal to the physics of its atoms, but as we have remarked (the self problem) conscious experience has no atoms of experience it can be reduced to.

But as pointed out by several authors, most recently by Chalmers and McQueen [47] and Gambini and Pullin[48], the ontology of quantum states does seem to be structured in some aspects like a conscious experience. Due to the entanglement, or non-separability of quantum states, such states have properties attributable only to the entire of a composite system, which are not reducible to properties of the parts. The way in which single colours, motions and sounds are woven together into a single framed conscious moment, seems to have an at least partly similar character. It has also been pointed out that both

⁶A good introduction is the recent book [4].

⁷One that comes to mind as a partial, if not yet successful, precedent for what I am about to propose is the Penrose-Hammeroff proposal[39], that consciousness has something to do with dynamical collapses of the wavefunction in a theory where that has become a physical process, where those events are taking place within microtubules of neurons in the brain. But see also [40] for criticism of specifics of this proposal.

conscious states and quantum states seem vulnerable to an instability of observation, in that measuring or observing them necessarily changes them.

On the other hand, if conscious states may seem in some aspects like non-separable or entangled states, we seem never to experience a conscious state which is a superposition of two or more conscious states. It seems true that in all the conscious states we experience, everything which is part of our view has a definite value. This has led to a long tradition according to which consciousness is proposed to be responsible for, or in some way associated with collapse of the wave-function, so that we always experience the results of our observations to be single, definite values[45, 46, 47, 48].

Indeed, Penrose and Hammeroff[39], Chalmers and McQueen[47], Gambini and Pullin[48], and others have already put forward proposals for how consciousness may play a role in the domain of possible completions of quantum phenomena. The proposals I make here are similar.

2 The context: relational physics

The relational tradition, which motivates the theories within which my proposals concerning PCC are made, is based on a few simple ideas. To put what follows in context, I state the main ideas in this short section.

2.1 Basic principles of relational physics

The following are all different ways to state the idea of relationalism[15, 16, 17, 20, 21, 22].

- *The principle of the identity of indiscernible (PII)* asserts that two individuals (events) with exactly the same view of the rest of the universe are to be identified[15, 16].

What is particular about the following is that I aim to achieve this dynamically, through a term in the action that seeks to maximize a measure of the diversity of views[50, 27], which we call the variety[51]. As a consequence, the occurrence of a pair of events with identical views is forbidden energetically.

Thus, one can say this theory is one that takes the PII seriously, and that this makes possible the proposals concerning consciousness I make here.

A consequence is the following:

- *Individuals are identified uniquely through their relations:* Individuals, whether events, particles, or subsystems, don't have intrinsic names or labels or coordinates. They are distinguished and named only by what they know about the rest of the system through their interactions or shared relationships, ie by what they see when they look around This is expressed as the *view of that individual*[15, 16].

So we never think of an individual particle as placed or moving in a background space. We think of an individual only in terms of its view of the rest.

- *Background independence*[20]: Most theories have non-dynamical fixed elements with respect to which the dynamical variables are defined. We call these the background, because it usually refers to a part of the universe that is not being modelled that is used as a fixed reference point against which to measure changes in the dynamical variables we are modeling. An example is Newton's absolute space, which Mach understood is a stand in for the "fixed stars," i.e the rest of the universe. A theory that has a chance to make a complete description of nature must hence be background independent; and depend on no fixed background structure.
- *No view of the whole universe as if from outside of it*[71, 59, 58]. We seek a theory that could be applied to the universe as a whole. Most theories we work with, including quantum mechanics, Newtonian mechanics, special relativistic field theory, cannot be extended to the entire universe because they rely on fixed background structure created by splitting the universe into two parts, one of which serves as the fixed, non-dynamical reference. By this slogan we remind ourselves that a theory of a whole universe—a cosmological theory—must be structurally very different from the theories we use.

One structure that is common to theories suited for subsystems of the universe is a fixed, timeless configuration or phase space, on which acts an Hamiltonian which generates ahead of time all the possible lawful histories. We call theories like this the Newtonian paradigm[59, 58]. The ability to determine all the possible configurations ahead of the evolution of the system corresponds to the existence of a clean separation between the effects of laws and of initial conditions. This requires that we are studying a class of subsystems of the universe, so we can operationalize the split in the functions of laws and initial conditions, by repeating an experiment many times, with different initial conditions.

Systems outside the Newtonian paradigm include those that, by their intrinsic complexity, make it impossible to work out the set of possible configurations ahead of letting the system evolve dynamically. Because there is only one universe, cosmological theories are cases where one cannot make a clean separation of the effects of laws and initial conditions; this is one of several reasons they fall outside the Newtonian paradigm.

So the slogan here is *one universe, described by many partial views*.

- *No causes from outside the universe*. Similarly all chains of causation must stay within the universe.
- *No global symmetries, hence no global conservation laws*.

A symmetry is a way to move the subsystem whose dynamics you are modelling relative to the fixed background without costing energy. Because of locality, the dynamical system can be assumed to be weakly coupled to the background-whose own dynamics can then be neglected.

Gauge invariances, such as diffeomorphism invariance in general relativity, are another story, they are a strategy to expunge non-dynamical backgrounds and transform a background dependent theory into a more relational, background independent theory.

- There are two very different notions of time within relational theories, giving rise to two different versions of relationalism, and hence, two versions of naturalism[21]. Some hold that time is not fundamental, but can be eliminated in favor of timeless law, this is called timeless naturalism. On this view there is no objective distinction between past, present and future; these are just differences of perspective. One version of timeless naturalism is the block universe of general relativity. Opposed to this is the temporal version of naturalism[21, 22, 59, 58], that embraces an objective distinction between past and the future, separated by an ever moving present moment. In these ontologies time is fundamental and irreversible, space is often emergent and laws evolve⁸.

Temporal naturalism is similar to presentism, but they are not the same thing.

It has been noted before that if one takes a realist attitude towards qualia and conscious experience one is pushed towards embracing time and the present moment as real. One way to say why is that there are two aspects of nature that are not capturable in a purported identification of the history of the universe with a timeless⁹ mathematical object. One is the present moment, the other is a conscious sensation. And indeed they seem related because every sensation is contained in a present moment.

2.2 How to describe a cosmological theory? The general picture and vocabulary

So how are we to go about constructing a cosmological theory within a relational framework?

The key thing we learned from the previous subsection is that if the completion we seek of quantum mechanics is to be at least the double completion including the requirement that it make sense as a theory of cosmology, it has several important features not shared by theories of subsystems. These will all be useful for identifying the PCC.

In a completely relational theory, a universe with no fixed background can be described as an inter-nested complex of dynamical subsystems, each one of which can be thought of as being described in terms of its interactions with the rest. We talk about this in terms of the *view* a subsystem has of its surroundings, by which we mean the information available to it of those other subsystems it interacts with most strongly. We call

⁸Very briefly, because timeless laws can be used to express variables at any time as functions of initial conditions, and hence eliminate time from the description of nature[59, 58].

⁹Timeless because temporal causation is modeled by logical inference.

them the subsystem's *neighbours*, by virtue of its interaction with them. The view of a subsystem, I , will be denoted V_I .

In different theories in this class, the views of the subsystems will have diverse mathematical descriptions. This may be given by labeled graphs, or by vectors in a vector space, or even the space of functions of a certain kind on a sphere. There is in each case, a set or space of possible views, \mathcal{S} .

In a background independent theory, the notions of space, position, relative distance in space are no longer fundamental, We posit that space is not present at the fundamental level of description, but is emergent, together with the relative positions of the various subsystems.

In this world a fundamental role is played, not by distances or coordinates in a background space, but by differences between pairs of views¹⁰. As a result, the principle of locality-that you interact most strongly and directly with that which is closest to you (in a background space) is replaced by a principle of similarity, according to which you interact with those whose views of the universe are most similar to yours. Note that this interaction will need to be repulsive to satisfy the PII as well as maximize diversity of views.

In many situations, locality will track similarity of views, because you and your neighbour will have similar views of the surroundings. This is especially likely for the views of massively composite systems, which we expect to be both complex and unique. This will be the basis for the recovery of standard physics. An example we find in the CTV is the emergence from an energetic causal set of a Minkowski spacetime, together with an embedding of the network of events and causes in it[27].

But not always: sometimes similarity of views will conflict with emergent notions of spatial distance. This is likely to be the case for views of microscopic or funamental events, as their views will have few degrees of freedom, and hence, in a large universe will have many accidental near copies. This, we show in the real ensemble theory and the CTV, is the origin of quantum phenomena, including nonlocal entanglement[49, 50, 27].

To study these ideas concretely we will need to formulate a space of views, \mathcal{S} , on which we will need to define a measure of difference of two views, I and J , ie a distance function on \mathcal{S} , which we will call $D(I, J)$ [52, 27].

In the absence of any notion of space, how do we define dynamics? We propose in [52, 50, 27] that the dynamics of a closed, relational system is to be expressed in terms of differences between views of its subsystems.

The other big idea is that the most important relationship involved in physical systems is causation: event E is the partial cause of event F [23, 71, 24, 52]. Indeed, nine of the ten functions that define the metric of spacetime go to describing the causal structure, that is which events were causally prior to which events. If we know the causal relations amongst events we have a very physical definition of a neighbourhood: a causal neighbourhood .of event E consists of those events causally prior to E .

¹⁰For a fully worked out model exhibiting these principles, please see [52]-[57].

Rafael Sorkin and collaborators have been studying models of discrete analogues of spacetimes where the only property an event may have is who is in its causal past[23]. These are called causal set models. Cortes and I made their structures slightly more complicated by giving the events and causal relations quantities of energy and momentum, as internal or intrinsic quantities; we call these energetic causal sets[52]-[57]. The causal theory of views[27] joins this with the real ensemble framework for quantum realism[49, 50].

3 Hypotheses about physical correlates of consciousness (PCC)

There is a great deal more to say to explain the motivation for the theories I will now discuss. However, as these are available in various books[58, 59, 30] and papers (cited above) I want to jump right in and describe in as simple language as possible the basic ideas as well as how these may work to generate hypotheses as to the physical correlates of consciousness.

3.1 The causal theory of views[27]

This approach is based on the application of the real ensemble formulation[49, 50] to a class of models of discrete or quantum spacetime we developed with Marina Cortes, called energetic causal sets (ECS)[52]-[57].

We begin with the latter

3.1.1 The basics of energetic causal sets [52]-[57].

We work within an ontology of events according to which the history of the universe is composed of events, connected by causal relations. We also hypothesize that energy and momentum are fundamental, and are transmitted from parent to child events, by the causal processes that create new events from present events, in such a way as to conserve them. Thus, while there is no space, and no spacetime fundamentally, there is a momentum space, whose geometry dictates how energy-momentum vectors are to be combined[69, 70].

Space is not part of the fundamental description, the events do not live in a space or a spacetime. At a later stage, a spacetime may emerge as a consequence of solving the equations of motion that guide the transmission of energy and momentum through the dynamically generated causal structure[52, 53].

The fundamental causal processes, ie *the activity of time*, is the continual creation of new events, by means of the selection of their parent events, from a reservoir of present events. At each step in the construction, parents events are chosen and an event is added, together with its causal connections to its parent events, following a rule which is part of the definition of the model. The details are in [52, 53], but the important thing to say

is that the rule aims to increase the diversity of the views of the present events. This event creation process creates a discrete partial order, or causal structure. Each event has a specified number of parents, N_p and can have at most N_c children.

After each step, the set of events can be divided into present and past events. A past event has had its limit, N_c , of children and can no longer directly influence the future, through the creation of new events. So the particular history of the system defines, at each step in the event creation process, a physically defined, thick present, which are those events which have after their creation, not yet been parents to N_c events. By thick we mean that two present events may nonetheless be causally related.

The future does not yet exist, and indeed may be undetermined, for example if the event creation rule has a stochastic element. This is important for what follows.

3.1.2 Connecting to the real ensemble formulation

In order to join this theory of events to the real ensemble formulation, which is a realist formulation of quantum physics, we need to specify what are the beables. What are the beables of an event?

The beable of an event is defined as its momentary *view* of the rest of the universe, ie it is the information available at that event of its near causal past (or past causal neighbourhood) through the causal processes that created it. Hence the view of an event is a snapshot of information about its ancestry, transmitted by its parent events. This includes the set of immediate past causal links and the energy and momentum they carry.

No elementary event has only one cause. Therefore there are no isolated elements of views, each view contains a number of elements unified by being part of the view of a particular event.

At an elementary level, the view consists of a framing, which is a two-sphere, marked with labeled points, each representing the incoming direction of each of its N_p parental causal processes (gotten from the direction of the incoming momentum), with the label taken to be a measure of the energy transmitted by that causal process¹¹. There is a space of possible views, \mathcal{V} of an event.

We can call this description of the view of an event its *sky*; it is literally what is seen looking outward (and hence back into its causal past) from the event. The views are sufficient to reconstruct the events and their causal relations as well as flows of energy-momentum. So, while we started thinking of events and causal processes, we end up with just the views, as the only beables.

Events may be combined into sets of events, which have a joint causal past, hence each set of events also has a joint view. There is a natural algebra for combining views. This remind us of surgery joining topological two surfaces. Some laws act together on sets of events and their views, we call these law-bound. Entangled states and coherent states will require this treatment. These must be dealt with irreducibly.

¹¹Among the classical constraints satisfied is the energy-momentum relation.

The event creation dynamics knows about the views only through their differences, $D(I, J)$. It is specified by requiring that the diversities of views is maximal.

In a “continuum limit” in which a spacetime emerges, together with an embedding of the discrete causal structure into it, a view must become approximated by a cross-section of a backwards light cone, (ie a sphere of some dimension) on which are found punctures or (coarse grained) fields, which carry energy-momentum and other conserved quantities[27]. In our universe, $d = 2$. Thus a view physically is a full or partial S^2 , on which live, depending on the level of description, punctures labeled by energy, momentum and other conserved charges, or pull backs of fields (into the light cone’s cross-section) carrying those conserved quantities.

The real ensemble theory is a realist completion of QM, which, in its most general formulation, is based on the principle that the dynamical variables of the theory are differences of views of subsystems. This can be thought of as a norm or distance function $D(I, J)$.

On a theory with many subsystems, S_I , each of which has a view of the others: v_I^J represents the view of the subsystem J from the subsystem I . The subsystems may also be composites and have internal degrees of freedom y_I^α , that also are seen in the views.

In this world a fundamental role is played, not by distances in a background space, but by differences between pairs of views. We will then employ $D(I, J)$ as a measure of difference of two views, I and J , ie a distance function on a space of views, \mathcal{S} .

The dynamics has two parts. There is the event generator, which picks the parents of each newly create event. Then there is an action principle which determines how the energy and momentum are distributed to the recently formed events. This is of the rough form

$$S = \mathcal{K}[\Delta D(I, J)] - \mathcal{U}[D(I, J)] \quad (1)$$

where the potential energy is a functional of difference between views and the kinetic energy, \mathcal{K} is a functional of the rates of change of the differences between views, $\Delta D(I, J)$. The kinetic energy comes from the energetic causal set models, while the potential energy is taken from the real ensemble models[50], and is chosen so that there is a strong repulsive interaction when two views are very similar. A good choice is a measure of complexity called the variety, \mathcal{V} .

The variety, \mathcal{V} of a system of relations is a useful measure of the diversity present in the set of views[51, 50, 27], and is a function of the $D(I, J)$ ¹².

$$\mathcal{V} = \frac{1}{N^2} \sum_{J < K} \frac{1}{\mathcal{D}(J, K)} \quad (2)$$

where N is the number of subsystems. The potential energy \mathcal{U} will be proportional to the negative of \mathcal{V}

$$\mathcal{U} = -\alpha \mathcal{V} \quad (3)$$

¹²To eliminate coordinate dependent effects, which arise from fictional “outside observers”, the distance functional, $D(I, J)$, is sometimes defined through a best matching procedure (see [73]).

This has the consequence that the forces are strongest-and are repulsive-between two views whose difference is small.

The constant α will turn out to be related to $\frac{\hbar}{m}$.

We intend something like an ensemble interpretation of quantum mechanics, but rather than being an interpretation of the usual formulas this is a construction of Schrodinger quantum dynamics for a function of variables which describes a real ensemble, by which I mean that, rather than being a mathematical description of an imaginary ensemble, each and every member of this ensemble exists somewhere in the universe. That is, the wave-function of a water molecule at the tip of my cat's left whisker is built from information about an ensemble of water molecules in similar conditions scattered through out the universe.

This general framework is presented in [49, 50]. We are interested here in the application to the energetic causal sets, which is the main subjects of [27]. Then the whole system is an energetic causal set, constructed up to some step. The elementary subsystems are the events, and we have already said that their views are extracted from the information in their past causal neighbourhoods; these will generally be truncated a finite number of causal links. Thus, we have a graded structure in which the p 'th past causal neighborhood of the event E , which we will also call the p 'th view, is the past of E truncated p steps into the causal past.

As we sketched above for the first view, the information in these views can be represented as a 2-sphere with labeled punctures.

At each step in the construction, there is a present set of events and their views.

For each event, we ask if there are other events in the present which are similar to it. We make the arbitrary distinction that a set of M events $E_\alpha \{E\}$ have views which are all within some small number ϵ of each other:

$$\forall \alpha, \beta \quad D(E_\alpha, E_\beta) < \epsilon, \quad (4)$$

We note that these are, by the assumptions stated above, all strongly interacting with each other. We hypothesize that the result is that the views of the members of the ensemble may be changing their values often, but in a way that can be expressed by a static probability function,

$$\rho(V_I) \quad (5)$$

Now let us consider two opposite cases, first a set of many similar events, so $M \gg 1$. The individual values are rapidly changing within a narrow range, due to the strong interactions within the ensemble, but there can be an equilibrium, in which the probability distribution is slowly changing, and becomes uniform on the ensemble. We are able to show that the probability distribution represents the modulus of a wave-function that satisfies the Shrodinger equation.

This quick summary leaves out many steps, to mention just one-we are able to extract from the information in the views, phases, which are correlated with the energy in the views and which become the phases of the wavefunction.

Thus, events whose views have many near copies define ensembles of views, whose evolution is, in a certain limit, defined to leading order (in $1/M$), described by the Schrodinger equation.

But what of events whose views have no near copies? Most likely these will be composite events of sufficient complexity and numbers of degrees of freedom that they would be associated with a history made up by a mesoscopic or macroscopic process or system.

When a subsystem is too complex or large, it will not have any copies in the universe, so it is not a part of such a large ensemble. Hence they do not correspond to pure quantum states. These are the novel states. Their evolution law is not the Schroedinger equation, but a more complex non-linear equation, governed by the full dynamics of the completion. The dynamics is specified by the same theory, but without taking the large M limit or constructing an ensemble and its probability distribution.

Some first steps towards exploring this anti-quantum limit are taken in [49, 50]. To leading order in the inverse of the number of copies, this can be expressed as a non-linear extension of the Schrodinger equation, that conserves probability but is not unitary. This then falls into a class of modifications of quantum mechanics that is very vulnerable to experimental tests.

This is, we may note, a solution to the measurement problem, because macroscopic devices, clocks, ourselves and our cats all are unique and have no copies, hence are not described by a wavefunction.

More generally, we see that there are naturally three classes of views: views which have many near copies, views which have a small number of near copies and views that are unique. Thus, this completion of quantum mechanics is also an extension of quantum physics. In the first class we find a derivation of ordinary quantum mechanics, in the second, a new class of nonlinear quantum phenomena. The third, unique views, will play a special role in the following.

3.1.3 From views to correlates of consciousness

We are now ready to state my first hypothesis about the physical correlates of consciousness. This is related to what we will call the first observation regarding consciousness.

- *First observation:* There are no "atoms of experience", ie experiences of nothing but a shade of red or blue or a pure high c. *Each conscious perception comes as a complex but irreducible unity, which may contain a number of qualia, thoughts, sounds, smells, all together, defining a (thick)moment of time, always in a frame, which is often experienced as a two-sphere, or a piece of one. We call this a framed conscious perception.*
- *First hypothesis:* *Each framed conscious perception corresponds to the view of a physical event or law-bound sets of events.*

The framing of a conscious perception is another way of stating the self problem: there are no elementary qualia which are pure colors or pure tones. Each view is

experienced as a whole, with colors or tones bound into a frame defined by the two-sphere. That is it suggests there is something or someone whose bundled or framed complex perception this is.

The first hypothesis answers the self-problem: it is the conscious perception correlated to the view of a particular event or law-bound set of events. This addresses how qualia are bound into a single frame.

The “presentist problem” is addressed because each framed conscious perception is associated to a single event or, to a law-bound set of events. In the latter case, the moment may be thick.

The uniqueness of the self-problem is not yet addressed¹³.

- We notice that the bundled qualia are each associated with beables, so there is no ambiguity, as beables always have definite values. This explains the fact that we experience a world in which all variables have definite values.

If we look ahead at how the theory we are sketching may, we hope, be a completion of QM in two senses—that it resolves the foundational issues of quantum theory, and that it gives a home to qualia and framed perceptions in a physical theory. These two issues must relate, because we want the perceived (ie selected) events to arise at the level where we experience beables, which take on definite values, not observables. We do not perceive superpositions, hence the events whose views are perceived must be limited to those events where the superpositions are resolved. These events must be rare, within a framework in which possible or potential histories are summed over. This then underlies the hypothesis that the rare events associated with conscious experience are expressions of the mechanism by which the real beables are defined, in a completion of quantum mechanics.

3.2 Common and unique views

I have proposed that the PCC are views, and that this addresses the “self” or bundled problem.

In the last section, we saw that the real ensemble formulation gives a special role to unique views, which have no present near copies. We also saw that these are sometimes the views of large or complex composite events. This makes it natural to propose the following two hypotheses:

- *Second hypothesis: Common events, which are those whose views have many near copies, are those described to good approximation by quantum mechanics as formulated presently. These are not correlates of conscious perceptions.*

¹³To do that we need to be able to define a hierarchy of inclusions of events, which in turn dictates an algebra of views. The problem may be solved if there is a property like entanglement, which can serve as a selection principle, which will be present up to a top level. [See Markopoulou et al [71, 72].]

- *Third hypothesis: Only views of unique events or unique law-bound sets of events are correlates of conscious perceptions.*

3.3 The hierarchy problem

Nature is full of hierarchies of composite systems, which are quantum at several levels. Furthermore they may be entangled at a succession of levels as well. A quark is part of a quantum system, entangled with two other quarks, to make a proton. That proton is in turn bounded and entangled with other protons, making a nucleus. The nucleus is bound and entangled into an atom, which is entangled into a molecule, and so on.

In the real ensemble formulation, each of these is part of an ensemble. There is an ensemble of nuclei, many- but not necessarily all, are member of ensembles of their own.

Ascending the hierarchy, there are ensembles connected with each level of the hierarchy of bound systems. There are then beables associated with each level.

More formally, in quantum mechanics there is a way to build composite systems out of components, by taking the direct products of the Hilbert spaces representing the parts. Depending on the formulation of quantum physics one subscribes to, this process never stops till you get to the last composite which is the universe as a whole, or it stops at some level at which the Hilbert space description is no longer relevant.

In the real ensemble formulation, the process alters as we go up the levels, and the number of near copies in the ensembles fall rapidly, till it gets. to a level where the subsystem is unique and has no near copies. Let us call this the top level. There will still be a process of composing parts into wholes that continues for some number of levels, but above the top level, these will be only composites of individuals, without their being members of ensembles.

In the causal theory of views the real ensemble framework is applied to views. There must then be ways to construct composites of views, which are themselves views. This part of the theory is not yet fully worked out, but let us for a moment proceed as if it is, assuming that at each level of a hierarchy of composites, there is an ensemble of nearly- but not precisely-similar views. This then also stops at a top level, at which the view is unique, so it is not a member of any ensemble of nearly similar views.

This affords us a final step in the selection principle for conscious perceptions:

- *Fourth hypothesis: Only the top level of each hierarchy of ensembles of views are correlates of conscious perceptions. These are the first levels in the hierarchy which are unique single views, with no near copies.*

4 Principle of precedence

I now want to introduce an alternative selection principle which also vastly reduced the set of views that will be candidates for PCC. This is connected with the principle of precedence I introduced in [28]. This leads to a similar second and third hypothesis.

Let me begin with the idea that the laws of physics, or at least their dimensionless parameters, must change and evolve, if they are to be explainable[31, 32]. I have made the case for this at length in several books and papers[31, 32, 33, 58, 59, 21], here I will simply work with the simplest proposal so far made for laws to evolve, which I called the principle of precedence[28].

The principle of precedence is a mechanism by which the dynamics of a quantum system (ie the unitary evolution operator, U), could evolve in time. More specifically the dynamical law is replaced by a principle of precedence, which I describe below[28].

But first I want to introduce some language to frame this and other proposals.

4.1 Routine and novel events

I propose we divide events and law-bound sets of events into *routine events* and *novel events*.

Routine events are the vast bulk of events where the laws act as on those in the past, so that no mechanism of law-change is acting.

Novel events are those that have no near¹⁴ precedents in their causal past.

Similarly, we can speak of routine states and novel states, a novel state is one that has no precedents in its causal past, Those that have many precedents are routine.

I now make two alternative hypotheses:

- *Second' hypothesis: Routine events are those described to good approximation by quantum mechanics as formulated presently. Novel events will require a realist completion of quantum physics. Thus, the PCC will be associated with the completion of QM.*
- *Third' hypothesis: Only views of novel events or novel law-bound sets of events are correlates of conscious perceptions.*

This addresses the unique self problem.

4.2 Principle of precedence: details [28]

Let me now describe the principle of precedence, after which I will give a second example of a completion of quantum mechanics where a distinction between routine and novel events or states could arise.

The *Principle of Precedent* is an idea about the origin of laws, or rather how the notion of dynamical law could be replaced by a simpler hypothesis.

One context in which it has an especially clear presentation is an operational formulation of quantum mechanics. In such a formulation, each quantum process is broken up into three stages: i) a preparation, by which the experimenter picks out an initial state,

¹⁴we say near-precedents because complete precedents are we hope ruled out in respect for the PII

$\rho_{initial}$ initial time, t_{in} ; ii) a unitary evolution generated over an elapsed time T by a Hermitian hamiltonian, $U(T)$, and iii) a measurement made at $t_f = t_{in} + T$. Given a set of possible output states, the result is a set of numbers, $p(output, input) = Tr \rho_{final} U \rho_{initial}$.

The probabilities $p(output, input)$ for the different possible outcomes depend only on the elapsed time, T , and not on the initial time, t_{in} , so that the probabilities measured in the next year will converge with those measured over the last N years. Given this we could posit a precedence law:

Law of precedence: *Given a preparation for a physical system, chose the output state by picking it randomly from the set of past precedents.*

The routine states are those that have a large number of precedence. The novel states are those without precedents.

How does the universe choose the outcomes of preparations which have no or few precedents?

This question might require a completion of quantum mechanics to answer. The causal theory of views and the real ensemble theories are candidates.

But so far as the question of consciousness is concerned we have here a striking suggestion:

The novel states are the physical correlates of conscious events!

That is, experience is made up of those moments where the universe is not guided by the law of precedents. At these moments, the universe has perhaps some degree of freedom to choose what happens next. It is these moments of freedom which make up conscious experience.

Those unprecedented moments are presumably common near the universe's origin, and spread throughout the universe. As the universe ages, it takes a higher degree of complexity for a state to be unprecedented. But we can wonder whether complex biomolecules might serve as a reservoir of novel states. Might the biosphere and the brain have evolved, to make use of the special properties of novel states, including the freedom present at those moments to choose a small part of the future. It is not difficult to see that this access to novel states might be a selective advantage.

Note that large molecules are made up of smaller subsystem, such as atoms. The component atoms will not be novel. What I want to suggest is that if there are entangled or coherent states which are made of many atoms which are sufficiently large and complex to be without precedent, these may serve as novel states.

The freedom in choosing the unitary evolution operator acting on such states will not impinge on the microscopic local dynamics governing each routine component, it will have to act non-locally, on the whole molecule, and be sufficiently weak so as to not have been discovered. Such a term might, for example, favour one folding of a protein over others.

4.3 The principle of precedence applied to an energetic causal set theory

Ideally we would like to derive relativistic quantum mechanics from the causal theory of views, along the lines of the derivation of non-relativistic QM we give in [27]. But in the absence of such a derivation we can anticipate the outcome. This is a quantum theory built on a causal set, somewhat analogous to a discrete version of a quantum field theory built over a fixed classical spacetime.

This is an example of a class of theories invented by Fotini Markopoulou called *Quantum causal histories*[71, 72] They are defined as follows.

- Generate a causal set. There is then a map which assigns to the causal link connecting event K with an event I in its immediate future, a Hilbert space \mathcal{H}_I^K .

Associated with the sky of I is a joint Hilbert space constructed by direct product.

$$\mathcal{H}_I = \otimes_{K < I} \mathcal{H}_I^K \quad (6)$$

- Associated with the same event I there also is the anti-view, which consists of all the information sent out by I . In classical general relativity the anti-view of an event I is a cross section through the future light cone of I . If $L > I$ is in the immediate future of I then

$$\bar{\mathcal{H}}_I = \otimes_{I < L} \mathcal{H}_L^I \quad (7)$$

- Let us assume that the view and anti-view have the same dimension. The quantum dynamics is constructed to give a unitary evolution from the quantum view to the quantum pre-view.

$$\mathcal{U}_I : \mathcal{H}_I \rightarrow \bar{\mathcal{H}}_I \quad (8)$$

- To construct the quantum casual histories associated to an energetic causal set (which we may call an energetic quantum causal history (EQCH)), replace the energy-momentum vector p_I^K associated to the link from K to I by the free-particle Hilbert space

$$p_I^K \rightarrow \mathcal{H}_I^K \in \psi(p_I^K) \quad (9)$$

subject to the usual mass shell constraint and norm.

$$C(p) = 0 \rightarrow C(p)\psi(p) = 0 \quad (10)$$

Now we can apply the principle of precedence, as follows.

- Now let us choose a basis for the space of views, \mathcal{H}_I given by $|a \rangle$. These are the preparations. A dual basis for the anti-views is given by $\langle w|$. Then as usual

$$\mathcal{T}(I, \langle w|, |a \rangle) = \langle w| \mathcal{U}_I |a \rangle \quad (11)$$

is the probability that the sky preparation $|a \rangle$ evolves by the event I and yields, the output state $\langle w|$. (in a fixed basis).

- Now, let $\mathcal{D}(I, J)$ be the distant operators on the past causal sets of events I and J .
- Let us consider for an event I , and preparation, $|a \rangle$, the set of causally past events J which share the same preparation, $|a \rangle$, and which are close in the space of views. We will define $\mathcal{P}^\epsilon(I, |a \rangle)$ be the past set of event I consisting of events $J \ll I$, such that,

$$\mathcal{D}(I, J) < \epsilon \tag{12}$$

We call the members of this set the precedents of $(I, |a \rangle)$. Let there be $N(I, |a \rangle)$ elements in the set of precedents and let this number be very large. Each event in this set has an output which is one of the $\langle w |$. This gives us an ensemble of outputs, called $\mathcal{O}(\mathcal{P}^\epsilon(I, |a \rangle))$.

Then we apply the principle of precedence, which says that to find the output of I pick a random element of the ensemble of outputs.

This will agree with the quantum prediction given by (11).

- The interesting question is what to do if the event generator builds an event, N that has no precedent; the set $\mathcal{O}(\mathcal{P}^\epsilon(I, |a \rangle))$ is empty.

In the case of no precedent, the universe must make a choice of output that is not determined by past data; in a certain minimal sense of the word freedom, the universe makes a free choice.

- I now propose that, *The correlates of conscious perceptions are the smallest views which are unprecedented.*

4.4 Energy and qualia

To go further we would like to address the structural problem, we mentioned above and put the most basic properties of views in correspondence with aspects of conscious perceptions. In the case of visual perception a rather obvious structural similarity suggests itself. A view consist of a framing two-sphere, corresponding to incident direction, on which are punctures or fields, labelled by incident energy. The experience of visual perception is a portion of a two-sphere, on which are colours.

This suggests an identification between a range of energies and perceived colours. A similar argument could be made for the perception of tones.

- *Fifth hypothesis: Different qualia of the same modality (ie colours, tones) correspond to differences in energy.*

5 Conclusions

I close with a brief summary of the main assumptions and hypotheses.

- We propose a new ontology according to which the universe consists of a dynamically evolving collection of partial views of itself.
- The view of an event contains information about its recent causal past neighbourhood. The view also represents flows of energy, momentum and other conserved quantities. The views are the only beables of this theory.
- The dynamics which creates the events and guides the flow of energy on the causal links depends only on differences amongst views, and expresses a principle of maximizing the diversity, or variety of views[51]. There is no fixed background space or spacetime.
- The replacement of locality (in a background space) with similarity (in a space of views) has striking consequences. Since space is emergent, so is locality, and the mechanism by which that happens is that much of the time the world is arranged so that locality in the emergent space tracks similarity of views. (Come here and look at what I see!) But locality, being emergent, will have defects, where two very similar views represent two events which are very far from each other in the emergent spacetime geometry[63]. In [62, 50, 27] I show that this leads to the recovery of quantum mechanics. The key point is that a small composite system, like an atom or a small molecule, will have *copies* which are scattered across the universe. These nonetheless interact strongly with each other. When there are many copies, the evolution develops sufficient coherence and the result is unitary Schroedinger dynamics.

But what of the subsystems that have no copies? How does it evolve? This is addressed in detail by the real ensemble theory[49], showing that it is indeed a good candidate for a completion of quantum mechanics.

This suggests a new picture of evolution in quantum physics, which I called the principle of precedence[28]. A quantum state evolves because the underlying dynamics being local in the space of views, it is coupled to the members of an ensemble of similar states in its causal past. These are its precedents, and the proposal is that quantum dynamics is simply the copying of random precedents from a state's causal past.

A state without precedents can be called a novel state-one that has not so far existed in the history of the universe. A key question to be addressed by a completion of quantum theory is then, how is an unprecedented state to chose what next to do?

Within this framework for a relational physics, we make five hypotheses about the physical correlates of consciousness.

1. *First hypothesis: Each framed conscious perception corresponds to the view of a physical event or law-bound sets of events.*

2. *Second hypothesis: Common events, which are those whose views have many near copies, are those described to good approximation by quantum mechanics as formulated presently. These are not correlates of conscious perceptions.*
3. *Third hypothesis: Only views of unique events or unique law-bound sets of events are correlates of conscious perceptions.*
4. *Fourth hypothesis: Only the top level of each hierarchy of ensembles of views are correlates of conscious perceptions. These are the first levels in the hierarchy which are unique single views, with no near copies.*
5. *Fifth hypothesis: Different qualia of the same modality (ie colours, tones) correspond to differences in energy.*

Thus, while standard panpsychism proposes that there are qualia (or proto-qualia) associated with all physical states or processes, this new view proposes that there are framed or bundled conscious perceptions, associated to a very restricted subset of views—those that are novel, and maximal in the sense described.

These first four hypotheses explain together the self problem, the presentist self problem and the unique self problem.

How do we proceed from here?

Of course, the most urgent question is to make contact with neurobiology. To do that we need a suggestion as to actual physical processes acting in specific neural tissues that have the needed characteristics. Principally, they have to be novel in the sense of having no or few precedents or copies. One way to build such unprecedented states would be to entangle a large enough number of qubits that simple combinatorial complexity could guarantee uniqueness. But this seems like pure fantasy, where in the brain's warm environment are we to find large sets of entangled qubits? Under present evidence, there would seem to be little chance the brain constructs protected channels, topological or otherwise?

One way to look for coherently entangled qubits in the brain is to make use of the suggestion of Mathew Fisher that sets of the nuclear spins of phosphorus shielded in phosphate and randomized to project out protected noise free channels might provide a source of qubits in biological systems[77]. One place they are found is in the bilayers of phospholipid molecules, which form the membrane of the neuron. Each such molecule has a "head", which is composed of a phosphate group, possibly linked to other groups. Two chains or tails extend downward, each composed of carbon-hydrogen units. The prospects for there being significant quantum effects involving these spins will be discussed separately[78].

ACKNOWLEDGEMENTS

I would like to thank Shan Gao first of all for the invitation to contribute a paper to this book. I am grateful for correspondence and conversations with Sean Carroll, David Chalmers, Philip Goff, Jenann Ismael, Jaron Lanier, Stuart Kauffman, Kristoff Koch, George Northoff and Galen Strawson. I am especially grateful to Marina Cortes, Rodolfo Gambini, Philip Goff, Jaron Lanier, Andrew Liddle, Galen Strawson and Steve Weinstein for detailed critical comments on drafts. Also extremely helpful were many comments at a workshop at *NYU* where a draft of this paper was critiqued; I am very grateful to David Chalmers for the invitation to that workshop as well as to the members for their acute comments. Jaron Lanier has been insisting to me for many years—till I finally got it—that there are no isolated qualia.

This research was supported in part by Perimeter Institute for Theoretical Physics. Research at Perimeter Institute is supported by the Government of Canada through Industry Canada and by the Province of Ontario through the Ministry of Research and Innovation. This research was also partly supported by grants from NSERC and FQXi. I am especially thankful to the John Templeton Foundation for their generous support of this project.

References

- [1] David Chalmers, **The Conscious Mind: In Search of a Fundamental Theory** (1996). Oxford University Press. hardcover: ISBN 0-19-511789-1,
- [2] Leibniz, in the *Monadology*.
- [3] F. Jackson, *Epiphenomenal qualia*, *Philosophical Quarterly*, 32 (1982) 127-36.
- [4] Philip Goff, *CONSCIOUSNESS AND FUNDAMENTAL REALITY* (2017) Oxford University Press.
- [5] Philip Goff, **Galileo's Error: Foundations for a New Science of Consciousness** Pantheon, to appear Nov 2019.
- [6] Galen Strawson, **Consciousness and Its Place in Nature: Does physicalism entail panpsychism?** (2006) ISBN 1-84540-059-3; (2006) *Realistic Monism: Why Physicalism Entails Panpsychism*. *Journal of Consciousness Studies*. Volume 13, No 10?11, Exeter, Imprint Academic pp. 3?31.
- [7] G. Strawson *NY Review of Books*, March 13, 2018, <https://www.nybooks.com/daily/2018/03/13/the-consciousness-deniers/>
- [8] Tom Nagles **Mind and Cosmos** Oxford University Press (2012).

- [9] Rodolfo Gambini (with the collaboration of Jorge Pullin), **A hospitable universe: Addressing Ethical and Spiritual Concerns in Light of Recent Scientific Discoveries**, Imprint Academic (Feb. 1 2018).
- [10] James, William. (1912). *Essays in Radical Empiricism*. New York: Longmans, Green, and Co.
- [11] Russell, Bertrand. (1921). *The Analysis of Mind*. London, G. Allen and Unwin; New York, Macmillan.
- [12] A Eddington, (1928), *The Nature of the Physical World*, Cambridge, Cambridge University Press
- [13] L. Smolin, *No matter, never mind, II*, (1974), Hampshire College, Division II paper, <http://leesmolin.com/wp-content/uploads/2019/07/No-Matter-Never-Mind-1.pdf>
- [14] Adrian Kent, *Quanta and qualia*, *Found Phys* (2018) 48: 1021 DOI: 10.1007/s10701-018-0193-9, arXiv:1608.04804 [quant-ph]
- [15] G. W. Leibniz **The Monadology**
- [16] G. W. Leibniz, **Leibniz's letters to Samuel Clarke**.
- [17] Albert Einstein, *Preussische Akademie der Wissenschaften, Sitzungsberichte*, 1916 (part 1), 688?696.
- [18] D. Chalmers, *Consciousness and its place in nature*, in his **Philosophy of Mind: Classical and Contemporary Readings**, Oxford University Press, New York (2002).
- [19] Mauricio Gonzalez-Forero and Andy Gardner, *Inference of ecological and social drivers of human brain-size evolution*, *Nature* volume 557, pages554?557 (2018)
- [20] Lee Smolin *The relational idea in physics and cosmology*, contribution to a book, *Structural realism and quantum gravity*, edited by Steve French. Preprint version: *The case for background independence*, hep-th/0507235.
- [21] Lee Smolin, *Temporal naturalism*, arXiv:1310.8539, Invited contribution for a special Issue of *Studies in History and Philosophy of Modern Physics*, on *Time and Cosmology*.
- [22] L. Smolin, *Temporal relationalism*, Invited contribution to a collection of essays on *Beyond spacetime*, edited by Nick Huggett, Keizo Matsubara and Christian Wuthrich. arXiv:1805.12468.
- [23] Luca Bombelli, Jooan Lee, David Meyer, Rafael D. Sorkin, *Spacetime as a Causal Set*, *Phys.Rev.Lett.* 59 (1987) 521-524.

- [24] J. Ambjorn, S. Jordan, J. Jurkiewicz, R. Loll, *Quantum Spacetime, from a Practitioner's Point of View*, arXiv:1302.2181, AIP Conference Proceedings 1514, 60 (2013); <https://doi.org/10.1063/1.4791726>.
- [25] Daniele Oriti, *Spacetime as a quantum many-body system*, arXiv:1710.02807, in "Many-body approaches at different scales: A tribute to Norman H. March on the occasion of his 90th birthday", edited by G. G. N. Angilella and C. Amovilli (New York, Springer, 2017.)
- [26] Carlo Rovelli and Francesca Vidotto, **Covariant Loop Quantum Gravity: An elementary introduction to quantum gravity and spin foam theory**, Cambridge University Press, 2015.
- [27] Lee Smolin, The dynamics of difference, arXiv:1712.04799., Foundations of Physics, DOI: 10.1007/s10701-018-0141-8;
- [28] Lee Smolin, Precedence and freedom in quantum physics, arXiv:1205.3707
- [29] Penrose, Roger. Conversation Chapter 14: Consciousness Involves Noncomputable Ingredients". Edge.com.
- [30] Lee Smolin, **Einstein's Unfinished Revolution** Penguin Press, April 2019.
- [31] Lee Smolin, Did the universe evolve? Classical and Quantum Gravity 9 (1992) 173-191.
- [32] Lee Smolin, The Life of the Cosmos, 1997 Oxford University Press (in the USA), Weidenfeld and Nicolson (in the United Kingdom).
- [33] Lee Smolin, A perspective on the landscape problem, Invited contribution for a special issue of Foundations of Physics titled: Forty Years Of String Theory: Reflecting On the Foundations, DOI: 10.1007/s10701-012-9652-x arXiv:1202.3373
- [34] Gerald Edelman and Giulio Tononi, A Universe of Consciousness: How Matter Becomes Imagination, (Basic Books, 2000, Reprint edition 2001). ISBN 0-465-01377-5
- [35] Gerald Edelman, Bright Air, Brilliant Fire: On the Matter of the Mind (Basic Books, 1992, Reprint edition 1993). ISBN 0-465-00764-3
- [36] Christof Koch, The Quest for Consciousness: a Neurobiological Approach, Roberts and Co., (2004), ISBN 0-9747077-0-8
- [37] Christof Koch, Consciousness: Confessions of a Romantic Reductionist, The MIT Press, (2012), ISBN 978-0-262-01749-7

- [38] P. Pearle, Reduction of the state vector by a nonlinear Schrodinger equation, *Phys. Rev. A* 113, 857 (1976); G. C. Ghirardi, R. Grassi and A. Rimini, Continuous-spontaneous-reduction model involving gravity, *Phys. Rev. A* 42, 1057 (1990).
- [39] Roger Penrose and Stuart Hameroff (4 July 1992). "Consciousness in the Universe: Neuroscience, Quantum Space-Time Geometry and Orch OR Theory". *Journal of Cosmology*; "Consciousness in the universe: A review of the 'Orch OR' theory". *Physics of Life Reviews*. 11 (1): 39?78 (2014).
- [40] Tegmark, Max (2000). *Importance of quantum decoherence in brain processes*. *Physical Review E*. 61 (4): 4194?4206. arXiv:quant-ph/9907009. Bibcode:2000PhRvE..61.4194T. doi:10.1103/PhysRevE.61.4194; McKemmish, Laura K.; Reimers, Jeffrey R.; McKenzie, Ross H.; Mark, Alan E.; Hush, Noel S. (2009). "Penrose-Hameroff orchestrated objective-reduction proposal for human consciousness is not biologically feasible" (PDF). *Physical Review E*. 80 (2): 021912. Bibcode:2009PhRvE..80b1912M. doi:10.1103/PhysRevE.80.021912. PMID 19792156; Georgiev, D.D. (2007). "Falsifications of Hameroff?Penrose Orch OR model of consciousness and novel avenues for development of quantum mind theory". *NeuroQuantology*. 5 (1): 145?174. doi:10.14704/nq.2007.5.1.121; Koch, Christof; Hepp, Klaus (2006). "Quantum mechanics in the brain". *Nature*. 440 (7084): 611. Bibcode:2006Natur.440..611K. doi:10.1038/440611a. PMID 16572152; Hepp, K. (27 September 2012). "Coherence and decoherence in the brain". *J. Math. Phys.* 53 (9): 095222.
- [41] R. Gambini and J. Pullin, *The Montevideo Interpretation of Quantum Mechanics: a short review*, *Entropy* 2018, 20(6), 413 DOI: 10.3390/e20060413, arXiv:1502.03410
- [42] D. Dennett, **Consciousness Explained**, (Back Bay Books 1992) (ISBN 0-316-18066-1)
- [43] Giulio Tononi, Melanie Boly, Marcello Massimini and Christof Koch, *Integrated information theory: from consciousness to its physical substrate* *Nature*, 450 — JULY 2016 — VOLUME 17; Oizumi, Masafumi; Albantakis, Larissa; Tononi, Giulio (2014-05-08). "From the Phenomenology to the Mechanisms of Consciousness: Integrated Information Theory 3.0". *PLoS Comput Biol*. 10 (5): e1003588.
- [44] Kobi Kremnizer, Andr Ranchin, *Integrated Information-induced quantum collapse*, arXiv:1405.0879, quant-ph cs.IT doi10.1007/s10701-015-9905-6, *Foundations of Physics* 45 (2015) 889-899.
- [45] E.P. Wigner, *Remarks on the mind-body question*, In I.J. Good (ed.) *The scientist speculates* (1961).
- [46] H. Stapp, *Mind, Matter and Quantum Mechanics*, (1993) Springer.

- [47] D. J. Chalmers and K. J. McQueen, *Consciousness and collapse of the wave function* (2019) <http://consc.net/qm>, to be published in the volume *Quantum Mechanics and Consciousness*, edited by Shan Gao, forthcoming from Oxford University Press most likely in 2020.
- [48] R. Gambini and J. Pullin, *Physical requirements for models of consciousness*, <http://philsci-archive.pitt.edu/16405/>
- [49] L. Smolin, *A real ensemble interpretation of quantum mechanics*, *Foundations of Physics*, 2012, DOI 10.1007/s10701-012-9666-4 arXiv:1104.2822
- [50] L. Smolin, *Quantum mechanics and the principle of maximal variety*, arXiv:1506.02938, *Foundations of Physics*, *Foundations of Physics*, 46(6), 736-758 DOI 10.1007/s10701-016-9994-x
- [51] J. Barbour and L. Smolin, *Variety, complexity and cosmology*, hep-th/9203041.
- [52] M. Cortês and L. Smolin, *The Universe as a Process of Unique Events*, arXiv:1307.6167 [gr-qc], *Phys. Rev. D* 90, 084007 (2014).
- [53] M. Cortês and L. Smolin, *Energetic causal sets*, arXiv:1308.2206 [gr-qc], *Physical Review D*, volume 90, eid 044035.
- [54] M. Cortês and L. Smolin, *Spin foam models as energetic causal sets*, arXiv:1407.0032, *Phys. Rev. D* 93, 084039 (2016) DOI: 10.1103/PhysRevD.93.084039.
- [55] M. Cortês and L. Smolin, *Reversing the Irreversible: from limit cycles to emergent time symmetry*, arXiv:1703.09696.
- [56] W. M. Wieland, *New action for simplicial gravity in four dimensions*, arXiv:1407.0025, *Class. Quantum Grav.* 32 (2015) 015016.
- [57] Eliahu Cohen, Marina Corts, Avshalom C. Elitzur, Lee Smolin, *Realism and causality II: Retrocausality in Energetic Causal Sets*, arXiv:1902.05082
- [58] L. Smolin, *Time Reborn*, Houghton Mifflin Harcourt, Penguin and Random House Canada, (2013).
- [59] Roberto Mangabeira Unger and Lee Smolin, *The Singular Universe and the Reality of Time: An essay in natural philosophy*, Cambridge University Press, November 2014.
- [60] Lee Smolin, *Derivation of quantum mechanics from a deterministic non-local hidden variable theory, I. The two dimensional theory*, IAS preprint, August 1983. — *Stochastic mechanics, hidden variables and gravity in Quantum Concepts in Space and Time* ed. C.J. Isham and R. Penrose (Oxford University Press, 1985).
- [61] Lee Smolin, *Matrix models as non-local hidden variables theories*, hep-th/0201031.

- [62] Fotini Markopoulou and Lee Smolin, *Quantum theory from quantum gravity*, arXiv:gr-qc/0311059, Phys.Rev. D70 (2004) 124029.
- [63] Fotini Markopoulou, Lee Smolin, Disordered locality in loop quantum gravity states, arXiv:gr-qc/0702044, Class.Quant.Grav.24:3813-3824,2007.
- [64] Lee Smolin, Could quantum mechanics be an approximation to another theory?, arXiv:quant-ph/0609109.
- [65] Lee Smolin, *Nonlocal beables*, International Journal of Quantum Foundations, 1 (2015) 100-106, arXiv:1507.08576.
- [66] E. Nelson, Phy. Rev., 150, 1079 (1969); E. Nelson, Quantum Fluctuations, Princeton University Press (1985).
- [67] S. Alder, *Quantum theory as an emergent phenomenon*, 2004 - Cambridge University Press New York; *Statistical dynamics of global unitary invariant matrix models as pre-quantum mechanics*, hep-th/0206120.
- [68] Artem Starodubtsev, *A note on quantization of matrix models*, arXiv:hep-th/0206097, Nucl.Phys. B674 (2003) 533-552
- [69] G. Amelino-Camelia, L. Freidel, J. Kowalski-Glikman and L. Smolin, "The principle of relative locality," Phys. Rev. D **84** (2011) 084010 [arXiv:1101.0931 [hep-th]].
- [70] L. Freidel and L. Smolin, *Gamma ray burst delay times probe the geometry of momentum space*, arxiv:hep-th/arXiv:1103.5626
- [71] Fotini Markopoulou, *Quantum causal histories*, Class.Quant.Grav. 17 (2000) 2059-2072 DOI: 10.1088/0264-9381/17/10/302, arXiv:hep-th/9904009
- [72] Eli Hawkins, Fotini Markopoulou, Hanno Sahlmann, *Evolution in Quantum Causal Histories*, Class.Quant.Grav. 20 (2003) 3839 DOI: 10.1088/0264-9381/20/16/320, arXiv:hep-th/0302111
- [73] J. Barbour and B. Bertotti, *Mach's principle and the structure of dynamical theories*. Proceedings of the Royal Society (London) A 382, 295 (1982).
- [74] Criscuolo A and Waelbroeck H, 1998, ?Causal Set Dynamics: A Toy Model?, arXiv:gr-qc/9811088, Class.Quant.Grav. 16 (1999) 1817-1832
- [75] Cohl Furey, *Notes on algebraic causal sets*, unpublished notes (2011); *Cambridge Part III research essay*, (2006).
- [76] D. Bohm, A suggested interpretation of quantum theory in terms of hidden variables, I, Phys. Rev. 85, 166179 (1952).

- [77] M.P.A. Fisher, *Quantum Cognition: The possibility of processing with nuclear spins in the brains*, *Annals of Physics* 362, p. 593-602 (2015), arXiv:1508.05929.
- [78] Lee Smolin, *Design for a bionic, hybrid silicon and biological quantum device*, unpublished draft (2016).