Mind and matter: aspects of the implicate order described through algebra*

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Abstract

Bohm has argued that the fundamental problems in quantum mechanics arise because we insist on using the outmoded Cartesian order to describe quantum processes and has proposed that a more coherent account can be developed using new categories based on the implicate order. This requires that we take process as basic and develop an algebra of process. In this paper we discuss some aspects of the basis of this algebra and show how it accommodates some of the algebras fundamental to quantum mechanics. We also argue that this approach removes the sharp division between matter and mind and hence opens up new possibilities of exploring the relationship between mind and matter in new ways.

1 Introduction

Over the years there has been considerable interest in the question as to whether quantum mechanics would be of any help in understanding the nature of mind. One of the earliest suggestions of a possible connection between mind and quantum mechanics was made by von Neumann (1955). In his approach to quantum mechanics there are distinct processes. One is the continuous evolution of the wave function in time determined by the Schrödinger equation. The other is the collapse of the wave function that occurs during measurement, a process that cannot be incorporated into the Schrödinger equation. Both von Neumann (1955) and Wigner (1968) argued that to complete quantum mechanics, the mind is needed to account for this second non-unitary process.

This approach has been dismissed by many physicists who have argued that we have given up too easily on the attempt to find a physical explanation for the collapse. Indeed a number of interesting possibilities along these lines are still under consideration. Notable among these are the proposals of Ghirardi, Rimini and Weber (1986) who suggest that

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there is a new physical process that spontaneously collapses the wave function, a process that becomes magnified in the presence of many particles. Thus in the presence of a measuring apparatus, a spontaneous collapse occurs rapidly.

There is also the more recent proposals of Penrose (1994) who argues that when gravitational effects are introduced, the non-linearity of general relativity takes over and, under appropriate conditions, a collapse of the wave function occurs. These processes still lack experimental verification but offer a way out that does not introduce mind.

A more subtle reason for a possible connection between quantum mechanics and mind starts with the recognition of the key role played by the notion of *indivisibility* or of the *wholeness* of quantum processes that was stressed again and again by Bohr (1961). Indeed the notion of wholeness forms an essential part of the Copenhagen interpretation. When quantum phenomena are considered in this approach, there appears to be a number of analogies with thought processes. Some of these have been discussed by Bohm (1951) and he has even suggested possible reasons for this connection. If these are correct, the connections become more than mere analogy. He suggested that although much of the brain may be acting in a classical way, there may be key points where the control mechanism is so sensitively balanced that they might be controlled by quantum processes.

Likewise Stapp (1993) in extending this idea goes even further. He argues that in Heisenberg's approach, the nature of atoms are not "actual" things. The "primal stuff" represented by the wave function has an "idealike" character rather than being simply "matterlike". To quote Stapp (1993, p. 221):

> Indeed, quantum theory provides a detailed and explicit example of how an idealike primal stuff can be controlled in part by mathematical rules based in spacetime. The actual events in quantum theory are likewise idealike: each such happening is a choice that selects as the "actual", in a way not controlled by any known or purported mechanical law, one of the potentialities generated by the quantum-mechanical law of evolution.

For Stapp actual events occur in nature whether the observer is present or not. In other words the collapse process is a real actualisation, the nature of which is still unknown. When such an actualisation occurs in the brain, it becomes intimately related to thought and consciousness. Thus in the brain these events can be actualised within a large-scale metastable state of a collection of neurons and it is these actual events that correspond to a conscious experience.

What both Bohm and Stapp are implying is that there is no longer a sharp distinction between mind and matter in the quantum domain. However as far as I am aware neither exploit this connection in detail although through the notion of the implicate order Bohm was attempting to lay the foundation for exploring these relations further. The purpose of this paper is to bring out these connections in new ways.

2 Quantum mechanics and mind

To begin the discussion of a possible relationship between quantum mechanics and the mind I would like to briefly review some of the important developments that have taken place. The thesis that mind has a crucial role to play in the final stage of any observation of a quantum system has been proposed by von Neumann (1955), Wigner (1968), Everett (1973), Lockwood (1989) and others. These authors do not relate the collapse to specific properties of the brain or of the mind. Rather they focus on the gap between what the formalism predicts and what is actually observed and suggest that it is the mind that, in some unspecified way, bridges the gap. It is not that the formalism is wrong, but rather it is not complete in the sense that the formalism contains all the possible outcomes of the experiment, whereas only one is actual. The actualisation is not accounted for within the formalism and it is this feature that has generated many debates and has produced many explanations.

For example, von Neumann (1955) who contributed so much to the mathematical foundations of quantum mechanics, argued quite clearly that the human observer must play an active and essential role in the final stage of any measurement process. For him this intercession cannot be further analysed and it is this feature that is the source of the indeterminism that is assumed to underlie all quantum processes.

Many physicists feel that the mind should not enter in this way and there are a number of alternative proposals to complete quantum mechanics. One such idea is that when the system is sufficiently "complex", it is possible to replace the human observer by a machine and then one can argue, as does Everett (1973), "the machine has perceived a particular result". Unfortunately, as far as I am aware, the question of how a machine can perceive is not discussed. In the hands of DeWitt (1973), Everett's original proposals were sanitised and became the "Many Worlds Interpretation". Rather than have a single machine actualise the result, the Universe itself splits into branches, each branch corresponding to one of the actualisations. In other words, all alternatives are actual, but exist in different universes. Apart from the extravagant multiplication of actual universes, there are other serious shortcomings, some of which have been discussed by Bohm and Hiley (1993).

The most recent development along these lines is what Murray Gell-Mann (1994) calls the "Modern Interpretation". This involves, among other things, introducing the notion of "information gathering and utilising systems" (IGUS) [see Gell-Mann and Hartle (1989)]. Again I find their discussion is not sufficiently developed to provide a clear account of precisely what new principles are involved in these IGU systems. Rather it is assumed that they exist and the consequences are then further elaborated.

Not all physicists are satisfied with this type of solution and numerous attempts have been made to produce a collapse by some other more specific means. This usually involves introducing some form of non-linear term, either directly or indirectly, into the Schrödinger equation. Among the more notable attempts in this direction have been those of Bohm and Bub (1966), of Bialynicki-Birula and Mycielski (1976), of Zurek (1981, 1989), of Ghirardi, Rimini and Weber (1986), of Petrosky and Prigogine (1994), and of

Penrose (1994). Unfortunately all of these present problems of one form or another.

3 Does quantum mechanics have any role to play in understanding mind?

The previous section shows the difficulty of resolving the problem of the collapse of the wave function, but it gives little indication of how quantum theory will help in understanding brain/mind function. Any positive evidence for this must come from another direction. In the introduction I pointed out that both Bohm (1951) and Stapp (1993) were trying to build on the analogies between quantum processes and thought processes. Central to both their approaches was the notion of "indivisibility" or "quantum wholeness". These notions are rather difficult to deal with in the way we currently think about physical processes. We insist on dividing processes into parts in an attempt to get a clear picture as to "what is going on". If we are told that two particles that are in different regions of space, are inseparable, we have great difficulty in thinking about this. To be spatially separate is to be "actually" separate. Is there any intermediate way of looking at this indivisibility that might help to bridge this gap? My work on the Bohm interpretation of quantum mechanics has convinced me that there is and when we go down this road, we find nature is not mechanistic but has new features that are in some sense "mind-like".

In Bohm and Hiley (1993), we tried to bring this point out although I fear we did not succeed! In the book we show that a re-formulation of quantum mechanics allows us to explore new notions that help to provide new insights into the way quantum processes are structured. I do not want to argue that these notions are *forced* on us by the quantum formalism, but by adopting them we are led to new ways of exploring quantum processes in a more coherent way. What I want to do here is to consider whether some of these new notions will be of any use in exploring the nature of thought and mind. To do this I will need to briefly highlight some of the relevant features of the Bohm interpretation.

In this approach, a detailed study of the properties of the quantum potential indicated that this potential is qualitatively different from all known classical potentials, a point that is often missed by some supporters of this approach. The reason for missing this point is because the potential appears alongside the classical potential in an equation that has the same form as Newton's equation of motion. Attempts to derive this potential from a deeper *mechanical* sub-structure have not been successful. My own feeling is that this attempt will always fail for reasons that I will not discuss here.

One feature that is of particular importance is that, unlike potentials derived from classical waves, the quantum potential is independent of the amplitude of the quantum wave. This means that a wave of very small amplitude can produce a large effect on the particle. Equally a wave of large amplitude can produce a small effect. In fact the force depends only on the form of the wave profile. To help understand this idea recall how an audio signal is carried by a radio wave. The audio signal modulates the profile of the high frequency carrier. Here the audio energy can be quite small, but its form can be amplified to produce a large effect in the radio itself. By analogy we have argued that the small energy in the quantum wave can be magnified by some as yet unknown internal process so as to produce a large effect on the particle. We have carried this idea further and proposed the quantum wave carries information about the environment to the particle.

In making this proposal it should be noted that we are using the word "information" in a different way from its usual use. It is not information in the sense of a passive list of instructions. Rather it is used in the sense of a dynamical process giving new form to the activity we call the particle. In Bohm and Hiley (1993) we have suggested that there are three types of information, active, passive and inactive which should be distinguished. With these new categories of information we have shown how all quantum processes can be accounted for.

All of this is very different from what we would expect from a physical theory. Instead of giving rise to a mechanical model, the properties of the quantum field suggest that its main role is to organise particles or groups of particles into co-ordinated movement which is shaped by the environment in which they find themselves. The appearance of nonlocality in such co-ordinated movements supports the idea that a mechanical interpretation of such movements is not adequate. In fact the structure that begins to emerge is very reminiscent of the proposals of Whitehead (1939) who suggested that matter should be regarded as "organic" rather than mechanistic.

Throughout my discussions with David Bohm on this interpretation, it seemed as if the differences between mind and matter were being eroded. Not only is thought organised and structured by active information, but particles and fields could be better understood if one regarded them as being influenced by active information. In the former case, it is information for us, while in the latter it is information for the particle or the field.

There is another factor that helps to make these ideas more plausible. The particles themselves emerge as structures in the field itself. This suggests that what we regard as the "solid" substance out of which all macroscopic matter emerges is in some sense "illusory". By this I do not want to suggest that in order to understand nature we have to resort to some sort of medieval mysticism, or ultimately attribute all existence to "pure spirit". This would mean a return to pre-science in which a kind of irrationality would dominate. Pauli (1984) has suggested such a position, but I reject it. I look at these new features as an extension of science into regions where the old categories are not adequate.

The real problem is that we do not have the correct categories with which to discuss quantum processes adequately. It is not clear as to precisely what these categories are at present and therefore it will be necessary to explore new categories which will be sensitive to the kind of changes that are needed to accommodate both matter and mind so that we do not have to resort to extreme mysticism or return to Cartesian dualism. Of course in embarking on such an undertaking it will be necessary to go beyond quantum mechanics and to explore more radical approaches that will ultimately enable us to deal with both mind and matter in one theory. I do not pretend this will be an easy matter, but I feel that if we are not radical we will remain engaged in a series of fruitless arguments.

4 New concepts

With this background in mind, I want to explore a different approach to physical processes. Let me motivate this by making the following comments. One of the basic assumptions that we have inherited from Decartes is the sharp distinction between matter, *res extensa*, and thought, *res cogitans*. Matter is defined as existing in space in the form of separated extended objects. It is further assumed that matter is rational, obeying immutable laws of physics. Newtonian physics assumes various local interactions between these objects which govern their movement. This movement is continuous and, more importantly, it is deterministic. For convenience, I call the categories necessary to carry through this programme “Cartesian categories”.

Mind, on the other hand, does not exist in space. It does not, therefore have any notion of locality. Furthermore it can appear to be irrational, jumping all over the place! It certainly does not appear to be deterministic although it can become mechanical, going through routines that have been programmed in at some stage.

Let us now consider quantum mechanics from the standard view point. At the particle level it appears indeterministic. There are “quantum jumps” which cannot be accounted for in terms of a continuous process in space-time, and there is a kind of non-separablity or “wholeness”. It is further assumed that it is impossible to analyse the behaviour of a particle in a way that is independent of the means of observation. But if we pay attention only to the wave function, then everything is local because all the wave functions are local. Continuity and determinism also hold in the sense that wave functions follow a well-defined differential equation, namely, the Schrödinger equation. In other words we have successfully embedded quantum mechanics into the Cartesian categories at the level of the wave function, but not at the level of the individual particle or field.

To carry this through successfully we must now place the emphasis solely on the mathematical equations, allowing these equations to take us into new areas where we are even further from finding any connection with the physics. Thus it is assumed that only through abstract equations can we begin to understand physics. I would like to claim that the implicit assumption that lies behind this approach is that science is only possible using Cartesian categories. It is this assumption that I would like to challenge.

Before making some specific proposals, I would like to comment on the Bohm interpretation. At first sight it seems that in this interpretation we can maintain the Cartesian categories at the level of the individual particle. We have trajectories along which the individual objects travel in a continuous and deterministic way, but we are forced to introduce nonlocality. Nonlocality is not a notion that can be maintained within the Cartesian categories. So even in this interpretation we are forced to abandon these categories. The main role of the Bohm interpretation is to show that it is possible to provide an ontology for quantum phenomena, i.e. an objective structure lying behind the appearances that are revealed in measurement. It is this possibility that is denied by the standard interpretation and its many variants all of which are based on the Cartesian categories.

These remarks may be surprising to some. After all in my book with David Bohm, we showed that the Bohm interpretation is internally consistent and contains no contradictions with experiment. However the interpretation uses the differential manifold as a basic descriptive form. This assumes that space-time is continuous and local. In spite of this it is necessary to introduce nonlocality and it can be argued that this nonlocality introduces an incoherent feature into the description. It is as if the nonlocality is "plastered on" as an afterthought and does not arise naturally from within the basic structure.

Nonlocality in itself does not lead to any conflict with experiments in the non-relativistic domain, but will problems aries in the relativistic domain? In attempting to answer this question we were able to extended the Bohm interpretation to the Dirac equation and to a quantum field theory of boson fields. In the former, particle trajectories could still be maintained, while in the latter, particle trajectories have to be abandoned and their place taken by the field configurations which are treated as the "beables". These configurations have since been evaluated and they are found to evolve in a deterministic way, being controlled by a "super-quantum potential" [see Lamm and Dewdney (1994)].

In both field throey and the Dirac theory nonlocality is still present in the generalised quantum potentials associated with each case. However the presence of this nonlocality did not lead to any conflict with experiment as it is not possible to use these effects to transfer energy across space-like connections. The remarkable feature of these theories was that while at the level of the beables, locality and Lorentz invariance are not maintained, at the level of observables, i.e. the statistical level, both locality and Lorentz invariance are maintained. What this seems to suggest is that the invariances that are assumed to be immutable laws of physics at the fundamental level, emerge as statistical features of a yet more fundamental domain of process. We are thus led to seriously consider whether space-time itself may be a statistical feature of this deeper underlying process.

One can begin to see the necessity of raising such a question by considering a different problem, namely, the problem of quantising gravity, a problem that presents many conceptual difficulties [see C. Isham (1987)]. When a field is quantised (such as the electromagnetic field) it is subjected to fluctuations. If general relativity is a correct theory of gravity then we know that the metric of space-time plays the role of the gravitational potential. If the fields fluctuate, the metric must fluctuate. But the metric is intimately related to the geometry of space-time. It enables us to define angle, length, curvature, etc. In consequence if the metric fluctuates, the geometric property of space-time will also fluctuate. What does it mean to have a fluctuating space-time?

Let me propose that at a deeper level, let us say at the sub-quantum level, space-time has no meaning so that space-time itself is merely a statistical display at a higher level. Thus space-time with its local relations and Lorentz invariance are all statistical features and that underlying this is a structure that does not find a natural expression in the space-time continuum. The nonlocal features, which appear also in the standard approach to quantum theory, are then a macroscopic reflection of this deeper structure. In other words, this pre-space is not merely a curiosity manifesting itself at distances of the order of the Planck length ($\sim 10^{-33}$ cm). It has much more immediate consequences at the macroscopic level.

I am not alone in making a proposal to start from this position. Penrose (1972) writes:

> I wish merely to point out the lack of firm foundation for assigning any physical reality to the conventional continuum concept... Space-time theory would be expected to arise out of some more primitive theory.

John Wheeler (1978) puts it much more dramatically.

> It is NOT
>
> Day One: Geometry
> Day Two: Quantum Physics
>
> But
>
> Day One: The Quantum Principle
> Day Two: Geometry.

But if we deny that space-time is a fundamental descriptive feature, where do we start to develop a new theory?

5 Beyond space-time

Let us begin the discussion by asking what space-time enables us to do. Essentially it allows us to co-ordinate the positions of particles and fields, and to place them in a certain order, that order being mapped onto R^4. This order enables us to describe the way particles and fields evolve under the classical laws of physics. In doing this we have put the order of physical processes in one-to-one correspondence with a Cartesian co-ordinate grid. Our emphasis is then is on a linear, local order and we require forces to produce deviations from this linear order.

There is another way to order physical structures and that is to use barycentric co-ordinates. Here it is not the linear order that is emphasised, but a more complex order. We order processes in terms of a set of elementary units called simplexes. The 0-simplex is a point, the 1-simplex is a section of a line, the 2-simplex is a triangle, the 3-simplex is a tetrahedron and so on. Using these elementary building blocks we construct a simplicial complex which we assume will enable us to order physical processes in a new way.

This mathematics enables us to describe physical structures that emphasise topological properties of the structure which involves questions such as what is on the boundary of a given sub-structure. Of course, all of this can also be done on the space-time manifold. Indeed if this is done then these structures give rise to the Grassmann algebra which finds considerable use in modern physics.

We want to use this algebra in a different way. In an earlier paper Bohm, Hiley and Stuart (1970) showed how all the basic equations of physics could be given very simple expression in terms of the vanishing of boundary operators of differential forms. John Wheeler's (1990) beautiful book *A Journey into Gravity and Spacetime* took these ideas much further in general relativity and showed that this theory could be summarised in the sentence: "The boundary of a boundary: where the action is! "

Again all of this can still be embedded in a local continuous space-time manifold which may or may not contain topological features such as "wormholes" and "handles". However the point I want to make is that all of this can be made independent of any underlying continuous manifold. If we could give physical meaning to these simplexes in a way that is independent of space-time, then we would have begun to do what we set out to do, namely, order physical processes independently of space-time. This will not leave us too isolated from space-time because we always have the possibility of recovering the space-time structure by exploiting the isomorphism between the de Rahm cohomology and the abstract cohomology defined by these general simplexes. The de Rahm cohomology is the cohomology defined by the Grassmann algebra using differential forms. This isomorphism will enable us to make direct contact with space-time.

The key question that remains is: "What physical processes could these simplicial complexes represent?" To answer this question, it is clear that we must give up the notion of the particle and the field as basic descriptive entities. They are relevant only when giving rise to the order of physical processes within the Cartesian framework.

To many this may be asking too much and in order to make this suggestion a little more palatable, let us ask the question: "Where is the 'substance' of matter?" Is it in the atom? The answer is clearly "no". The atoms are made of protons, neutrons and electrons. Is it then in the protons and neutrons? Again "no", because these particles are made of quarks and gluons. Is it in the quark? We can always hope it is, but my feeling is that these entities will be shown to be composed of "preons", a word that has already been used in this connection. But we need not go down that road to see that there is no ultimon. A quark and an antiquark can annihilate each other to produce photons (electromagnetic energy) and the photon is hardly what we need to explain the solidity of macroscopic matter such as a table. Thus we see the attempt to attribute the stability of the table to some ultimate "solid" entity is misguided. We have, in Whitehead's words, a "fallacy of misplaced concreteness".

I would like to suggest there is no ultimate "solid" material substance from which matter is constructed, there is only "energy" or perhaps we should use a more neutral term such as "activity" or "process" or even "flux". This is implicitly what most physicists assume when they use field theory. But field theory depends on continuity and local connection. As I have remarked above it is local continuum from which I want to breakaway.

I am suggesting that what underlies all material structure and form is the notion of activity, movement or process. I will use the term "process" as part of my minimum vocabulary to stand for pure activity or flux and regard all matter as being semi-autonomous, quasi-local invariant features in this back ground of continual change. Bohm preferred to call this fundamental form "movement" and he called the background from which all physical phenomena arose the "holomovement". [See Hiley (1991) for an extensive discussion of this notion in the present context.] I have since learnt that the word "movement" invariably invokes the response "movement of what?" But in our terms, movement or process cannot be further analysed. It is simply a primitive descriptive form from which all else follows, but to avoid ambiguities we could refer to it as the "holoflux" Here process replaces the term "field" as a primitive descriptive form of present day physics. Thus in our approach, the continuity of substance, either particle or field, is being replaced by the continuity of form within process.

6 Grassmann's contribution

While I was talking about the possibilities of developing a description of physical processes in terms of process and activity in the late seventies, my attention was drawn to Grassmann's (1894) own account of how he was lead to what we now call a Grassmann algebra. [See Lewis (1977) for a discussion of Grassmann's work.] To begin with, Grassmann argued that mathematics was about thought not about material reality. Mathematics studies relationships in thought, not a relationship of content, but a relationship of forms within which the content of thought is carried. Mathematics is to do with ordering forms created in thought and is therefore of thought. Now thoughts are clearly not located in space-time. They cannot be co-ordinated within a Cartesian frame. They are "outside" of space.

Thought is about becoming, how one thought becomes another. It is not about being. Being is a relative invariant or stability in the overall process of becoming. What I would like to suggest is that there is a new general principle lying behind Grassmann's ideas, namely, "Being is the outward manifestation of becoming".

Bohm and I exploited this principle in *The Undivided Universe* (1993). There we argued that in the Bohm interpretation, the classical level is to be regarded as the relatively stable manifest level (literally that which can be held in the hand or in thought), while the quantum level is the subtle level that is revealed in the manifest level. In the first part of the book we showed how these notions could be applied to matter.

We also showed how similar arguments go through for thought. Thought is always revealed in thought. One aspect of thought becomes manifest and stable through constant re-enforcement, either by repetition or learning. New and more subtle thoughts are then

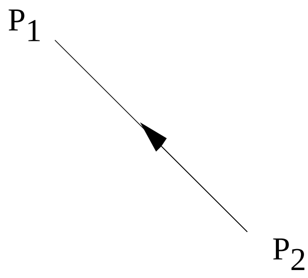

Figure 1: Elementary process

revealed in these older re-enforced thoughts. The newer subtler thoughts can, in turn, became stable and form the basis for revealing yet more subtle thoughts. In his way a hierarchy of complex thought structures can be built up into a multiplex of structure.

What I want to suggest in this paper is that both material process and thought can be treated by the same set of categories and hence by the same mathematics. They appear to be very different, thoughts being ephemeral, whereas matter is more permanent. For me it is a question of relative stability and that stability in the case of material process is compounded to produce the appearance of permanence to us. I want to suggest is that if we can find a common language for matter and thought, then it will be possible to remove the Cartesian barrier between them and we will have the possibility of a deeper investigation into the relation between matter and mind.

7 The algebra of process

How are we to build up such a mathematical structure? I believe that Grassmann has already begun to show us how this might be achieved in terms of an algebra which we now find very useful for some purposes in physics, but the full possibilities have been lost because Grassmanns original motivation has been forgotten. With this loss, the exploitation of its potentially rich structure has been stifled.

To begin the discussion, let us ask how one thought becomes another? Is the new thought independent of the old or is there some essential dependence? The answer to the first part of the question is clearly "no" because the old thought contains the potentiality of the new thought, while the new thought contains a trace of the old thought.

Let us follow Grassmann and regard P_1 and P_2 as the opposite poles of an indivisible process of a thought. To emphasise the indivisibility of this process, Grassmann wrote the mathematical expression for this process between a pair of braces as $[P_1P_2]$ which we can represent a line as shown in figure 1. The braces and the arrow emphasise that P_1 and P_2 cannot be separated. It has the potentiality of being subdivided and if it is actually subdivided it becomes another process altogether. When applied to space, these braces were called extensives by Grassmann. For more complex structures, we can generalise the basic processes which are shown in figure 2. In this way we have a field

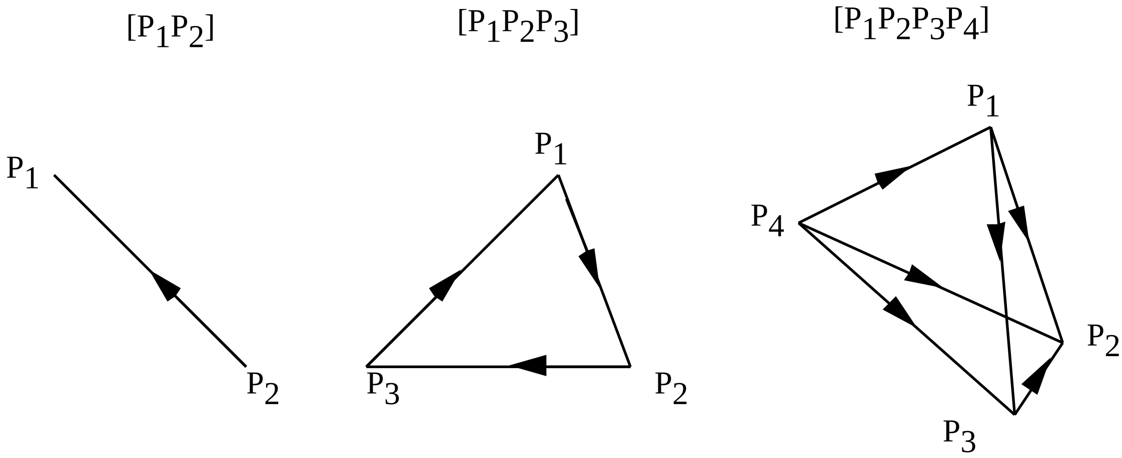

Figure 2: Higher order processes

of extensives from which we can construct a multiplex of relations of thought, process, activity or movement. The sum total of all such relations constitutes the holoflux.

For Grassmann then, space was a particular realisation of the general notion of process. Each point of space is a distinctive form in the continuous generation of distinctive forms, one following the other. It is not a sequence of independent points but each successive point is the opposite pole of its immediate predecessors so that points become essentially related in a dynamic way. In this view space cannot be a static receptacle for matter. It is a dynamic, flowing structure.

The structure of process can be regarded as an algebra over the real field in the following sense:

1. multiplication by a real scalar denotes the strength of the process;

2. the process is assumed to be oriented. Thus $[P_1P_2] = -[P_2P_1]$.

3. the addition of two processes produces a new process. A mechanical analogy of this is the motion that arises when two harmonic oscillators are vibrating at right angles are combined. This produces an elliptical motion if the phases are adjusted appropriately. In Leibnitizian terms this addition process can be regarded as an expression of the order of co-existence.

4. to complete the algebra there is a inner multiplication of processes defined by

$$[P_1P_2]\,[P_2P_3] = [P_1P_3]$$

This can be regarded as the order of succession.

8 The Clifford Algebra of process

Let me now illustrate briefly how this algebra can carry the directional properties of space within it, without the need to introduce a co-ordinate system. I will only discuss the ideas that lead to what I call the directional calculus.

I start by assuming there are three basic movements, which corresponds to the fact that space has three dimensions. The process can be easily generalised to higher dimensional spaces with different metrics.

Let these three movements be $[P_0P_1]\,,[P_0P_2]\,,[P_0P_3]$. I then want to describe movements that take me from $[P_0P_1]$ to $[P_0P_2]$, from $[P_0P_1]$ to $[P_0P_3]$ and from $[P_0P_2]$ to $[P_0P_3]$. This means I need a set of movements $[P_0P_1P_0P_2]$, $[P_0P_1P_0P_3]$ and $[P_0P_2P_0P_3]$. At this stage the notation is looking a bit clumsy so it will be simplified by writing the six basic movements as $[a], [b], [c], [ab], [ac], [bc]$.

We now use the order of succession to establish

$$\begin{aligned}[ab]\,[bc] &= [ac]\\ [ac]\,[cb] &= [ab]\\ [ba]\,[ac] &= [bc]\end{aligned}$$

where the rule for the product (contracting) is self evident. There exist in the algebra, three two-sided units, $[aa], [bb]$, and $[cc]$. For simplicity we will replace these elements by the unit element 1. This can be justified by the following results $[aa][ab] = [ab]$ and $[ba][aa] = [ba]$; $[bb][ba] = [ba]$, etc. Now

$$\begin{aligned}[ab]\,[ab] &= -\,[ab]\,[ba] = -\,[aa] = -1\\ [ac]\,[ac] &= -\,[ac]\,[ca] = -\,[cc] = -1\\ [bc]\,[bc] &= -\,[bc]\,[cb] = -\,[bb] = -1\end{aligned}$$

There is the possibility of forming $[abc]$. This gives

$$\begin{aligned}[abc]\,[abc] &= -\,[abc]\,[acb] = [abc]\,[cab] = [ab]\,[ab] = -1\\ [abc]\,[cb] &= [ab]\,[b] = [a]\,,\text{etc.}\end{aligned}$$

Thus the algebra closes on itself and it is straightforward to show that the algebra is isomorphic to the Clifford algebra C(2) which we was called the Pauli-Clifford algebra in Frescura and Hiley (1980).

The significance of this algebra is that it carries the rotational symmetries and this is the reason I call it the directional calculus. The movements $[ab]$, $[ac]$ and $[bc]$ generate the Lie algebra of SO(3), the group of ordinary rotations. For good measure this structure contains the spinor as a linear sub-space in the algebra, which shows that the spinors arises naturally from an algebra of movements. The background to all of this has been discussed in Frescura and Hiley (1984).

The generalisation to include translations has recently been carried out but the formulation of the problem is not as straight forward as we have to deal with an infinite dimensional algebra [see Frescura and Hiley (1984) and Hiley and Monk (1994)]. It would be inappropriate to discuss this structure here. I will merely remark that our approach leads to the Heisenberg algebra, strongly suggesting that our overall approach is directly relevant to quantum theory.

9 The multiplex and neighbourhood

Let us now return to consider structures that are not necessarily tied to space-time. For simplicity let us confine our attention to structures that can be built out of 0-dimension simplexes $\sigma_{(0)}$ and 1-dimension simplexes$\sigma_{(1)}$ only. Since we do not insist on continuity, any structure in the multiplex is constructed in terms of chains, i.e.

$$C_{(0)} = \sum_i a_i \sigma^i_{(0)} \quad \text{and} \quad C_{(1)} = \sum_j b_j \sigma^j_{(1)}$$

where we will assume the coefficients a_i and b_j are taken over the real or complex numbers.

To those unfamiliar with the mathematics, it might be useful to have a simple example of a chain. Consider a newspaper photograph. Here the 0- simplexes are the spots of print, while the real weights a_i are the degree of blackness of the dots. Notice this description does not locate the positions of the dots. To do that we need to introduce the notion of a neighbourhood. This requires us to ask what is on the boundary of each simplex. The usual mathematical term that contains information about the neighbourhoods is called an incident matrix. This can be defined through the relations

$$\mathbf{B}\sigma^{\mathbf{i}}_{(\mathbf{1})} = \sum_{\mathbf{j}} {}_{(\mathbf{1})}\eta^{\mathbf{i}}_{\mathbf{j}}\sigma^{\mathbf{j}}_{(\mathbf{0})}$$

Here $\mathbf{B}$ is the boundary operator and ${}_{(1)}\eta^i_j$ is the incident matrix. Since we have no absolute neighbourhood relation, we can define different neighbourhood relations. Here again an illustration might help to understand the rich possibilities that this descriptive form may have. In one of his experiments on the development of concepts in young children, Piaget describes how, when children are asked to draw a map of the local area around their home and are asked to position the playground, school, ice cream shop, dentist etc., they place the ice cream shop and the playground close to home, but will place the dentist and the school far from home, regardless of their actual physical distance from their home. The children are using a neighbourhood relation which has to do with pleasure and not physical distance.

Thus by generalising the notion of neighbourhood, it is possible to have many different orders on the same set of points depending on what is taken to be the relevant criterion for the notion of neighbourhood in a particular context. Thus our description becomes context dependent and not absolute. This is very important both for thought and quantum theory.

In thought the importance of context is very obvious. How often do people complain that their meaning has been distorted by taking quotations out of context? The importance of context in quantum theory has only recently begun to emerge, although it was always implicit in Bohr's notion of wholeness. However in the Bohm interpretation context dependence becomes crucial. Indeed the famous von Neumann "no hidden variable" theorem only goes through if it is assumed that physical processes are independent of context. Exploration using hidden variables was held up for a long time before the full significance of context was appreciated.

The new approach that I am suggesting has another interesting feature. It may be possible to have many different orders on the same set of points, or it may even be possible to define a different set of points, i.e. 0-simplexes, since the points themselves are to be regarded as particular movements, i.e. of a movement into itself. Thus it may be possible to abstract many different orders from the same underlying process. To put it another way, the holomoflux contains many possible orders not all of which can be made explicit at the same time.

This general order has been called the "implicate order" by Bohm (1980). The choice of one particular set of neighbourhood relations enables one to make one particular order manifest over some other. Any order that can be made manifest is called an "explicate order", so we have emerging from this approach a new set of ideas which fit the categories that Bohm was developing. It is in terms of these categories that we can give a similar order to both physical and mental processes.

As we have already remarked one feature of this new description is that it is not always possible to make manifest all orders together at one time. This is an important new idea that takes us beyond the Cartesian order where it is assumed that it is always possible to account for all physical processes on one level, namely, in space-time. The new order removes the primacy of space-time allowing other orders to be given equal importance. Thus in quantum mechanics, the use of complementarity is now seen as a necessity arising out of the very nature of physical processes, rather than being a limitation on our ability to account for quantum processes.

Mathematically this new idea can be expressed through what we have called an "exploding " transformation. This is brought about by considering a structure built out of a set of basic simplexes $\sigma^i_{(0)}$ and $\sigma^j_{(1)}$ and then transforming the structure to one built out of a different set of basic simplexes $\sum^i_{(0)}$ and $\sum^j_{(1)}$. For simplicity we will call these basic simplexes "frames". Suppose these frames are related through the relations

$$\sigma^i_{(0)} = \sum_j a^i_j \Sigma^j_{(0)} \quad \text{and} \quad \sigma^i_{(1)} = \sum_j \beta^i_j \Sigma^j_{(0)}$$

We may now ask how the neighbourhood relations are related under such a transformation. Suppose we have

$$\mathbf{B}\sigma^{\mathbf{i}}_{(\mathbf{1})} = \sum_{\mathbf{j}} {}_{(\mathbf{1})}\eta^{\mathbf{i}}_{\mathbf{j}} \sigma^{\mathbf{j}}_{(\mathbf{0})} \quad \text{and} \quad \mathbf{B}\sum_{(\mathbf{1})}^{\mathbf{i}} = \sum_{\mathbf{j}} {}_{(\mathbf{1})}\eta'^{\mathbf{i}}_{\mathbf{j}} \sigma^{\mathbf{j}}_{(\mathbf{0})}$$

and then ask how the incidence matrices are related. We have

$$\mathbf{B}\sigma^{\mathbf{i}}_{(\mathbf{1})} = \mathbf{B}\left(\sum_{\mathbf{j}} \beta^{\mathbf{i}}_{\mathbf{k}} \boldsymbol{\Sigma}^{\mathbf{j}}_{(\mathbf{1})}\right) = \sum_{j,k} a^i_{k(1)} \eta'^k_j \Sigma^j_{(0)} = \sum_{\ell} {}_{(1)}\eta^i_\ell \sigma^\ell_{(0)}$$
$$= \sum_{\ell} {}_{(1)}\eta^i_\ell a^\ell_n \Sigma^n_{(0)}.$$

So that

$${}_{(1)}\eta^i_\ell = a^i_{k(1)} \eta'^k_j \left(a^\ell_j\right)^{-1}.$$

Or in matrix form

$$\eta = \alpha \eta' \alpha^{-1}.$$

This is the exploding transformation so called because the original structure can look quite different after such a transformation. Furthermore what is local in one frame need not be not local in any other. Mathematically these transformations are similarity transforms or automorphisms. In the algebraic approach we have tried to exploit these automorphisms in our aljebraic description of pre-space. [See Hiley and Monk (1994).]

10 The unmixing experiment

A specific example of such a transformation was given by Bohm (1980). I would briefly like to recall this example to show how it fits into my argument.

Consider two concentric transparent cylinders that can rotate relative to each other. Between these cylinders there is some glycerine (see figure 3). If a spot of dye is placed in the glycerine and the inner cylinder rotated, the spot of dye becomes smeared out and eventually disappears. There is nothing surprising about that, but what is surprising is that if we reverse the rotation, then the spot of dye reappears (figure 4).

This device actually works in practice and is easily explained in terms of the laminar flow of the glycerine under slow rotation. What we want to illustrate here is that in the

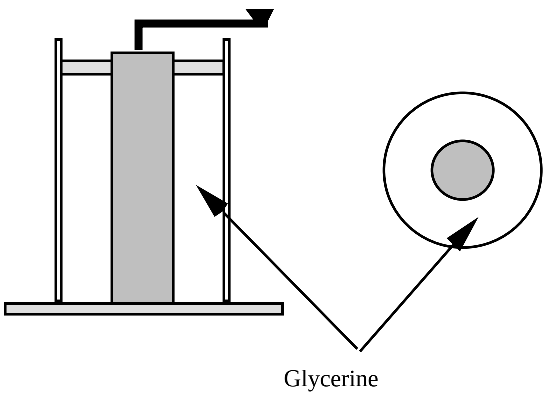

Figure 3: The unmixing experiment.

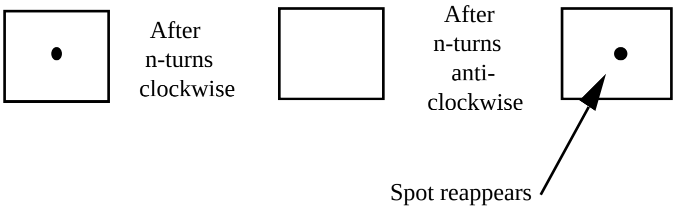

Figure 4: The reappearing spot.

"mixed" state, there does not seem to be any distinctive order present. Yet the order is, as it were, *implicit* in the liquid and our activity of unmixing, i.e. unwinding, makes manifest the order that is implicit in the glycerine.

To carry the idea further, we can arrange to put in a series of spots of dye, displaced from one another in the glycerine. Place one spot at x_1 and then rotate the inner cylinder n_1 times. Then place another spot at x_2 and rotate the inner cylinder again a further n_2 times and so on repeating N times in all. If we were then to unwind the cylinder, we would see a series of spots apparently moving through the glycerine. If the spots were very close together we would have the impression of the movement of some kind of 'object' starting from position x_1 and terminating at position x_N (see figure 5). But no object has actually moved anywhere! There is simply an unfolding and then enfolding movement which creates a series of distinguished forms that are made manifest in the glycerine. So what we have taken to be the continuous movement of substance is actually a continuous unfoldment of form.

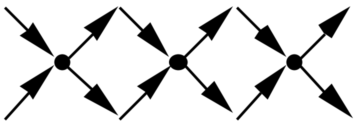

Figure 5: The morphology of stuff.

Recalling my earlier remarks concerning the ephemeral nature of material processes, we can follow Whitehead (1957) and suggest that a quantum particle could be understood within the framework of these ideas. As Whitehead (1939) puts it: "An actual entity is a process and is not describable in terms of the morphology of a stuff."

In this view, the cloud chamber photograph does not reveal a "solid" particle leaving a track. Rather it reveals the continual unfolding of process with droplets forming at the points where the process manifests itself. Since in this view the particle is no longer a point-like entity, the reason for quantum particle interference becomes easier to understand. When a particle encounters a pair of slits, the motion of the particle is conditioned by the slits even though they are separated by a distance that is greater than any size that could be given to the particle. The slits act as an obstruction to the unfolding process, thus generating a set of motions that gives rise to the interference pattern.

11 Evolution in the implicate order

I would now like to show how we can arrive at an equation of unfoldment using the ideas of the last two sections. We assume that we have an explicate order symbolised by $\mathbf{e}$. This could have considerable inner structure, but for simplicity we will simply use a single letter to describe it. We want to find an equation that will take us to a new explicate order $\mathbf{e}'$ as a result of the unfolding movement.

Let us again use the order of succession to argue that the explicate order is enfolded via the expression $\mathbf{eM_1}$. Here M_1 is an element of the algebra that describes the enfolding process. The next unfolded explicate order will be obtained from the expression $M_2\mathbf{e}'$. Here M_2 is the process giving rise to the unfoldment. To express the continuity of form, we equate these two expressions to obtain

$$\mathbf{e}\ M_1 = M_2\mathbf{e}'$$

or

$$e' = M_2^{-1}\mathbf{e}M_1.$$

Thus the movement is an algebraic automophism, analogous to the transformation that we called the exploding transformation.

Let us now assume for simplicity that $M_1 = M_2 = M$, where $M = \exp[iH\tau]$. Here H is some element of the algebra characterising the enfolding and τ is the enfolding parameter. For small τ we have

$$e' = (1 - iH\tau)\,\mathbf{e}\,(1 + iH\tau)$$

so that

$$i\frac{(e'\text{-}\mathbf{e})}{\tau} = H\mathbf{e} - \mathbf{e}H = [H, \mathbf{e}]\,.$$

Therefore in the limit as $\tau \to \infty$, we obtain

$$i\frac{\mathrm{d}\mathbf{e}}{\mathrm{d}\tau} = [H, \mathbf{e}]\,.$$

This equation has the same form as the Heisenberg equation of motion.

If we represent the explicate order $\mathbf{e}$ by a matrix and assume it is factorisable, i.e. $\mathbf{e} = \boldsymbol{\psi}$ we find

$$i\frac{\mathrm{d}\psi}{\mathrm{d}\tau}\phi + i\psi\frac{\mathrm{d}\phi}{\mathrm{d}\tau} = (H\psi)\phi - \psi(\phi H).$$

If we regard ψ and ϕ as independent, we can separate the equation into two

$$i\frac{\mathrm{d}\psi}{\mathrm{d}\tau} = H\psi \quad \text{and} \quad -i\psi\frac{\mathrm{d}\phi}{\mathrm{d}\tau} = \phi H.$$

If H is identified with the Hamiltonian, then the first equation has the same form as the Schrödinger equation. If ϕ is regarded as $\psi^\dagger$ then the second equation has the same form as the complex conjugate of the Schrödinger equation. Thus the Schrödinger equation arises in a very simple way from the unfolding process.

12 Conclusion

In this paper I have tried to motivate a new way of looking at physical processes in which the sharp Cartesian division between mind and matter can be removed. We began by showing that it is possible to explore new ways of describing material process that does not begin with an *a priori* given space-time continuum. Instead by starting with the notion of activity or process which is taken as basic, we are able to link up with some of the mathematics used in algebraic geometry. In fact in the particular example we used, we were able to recover the Clifford algebra, implying that some aspects of the symmetries of space can be carried by the process itself, albeit in an implicit form. By extending these ideas to include Bohm's idea of the enfolding process, we are also able to construct an algebra similar to the Heisenberg algebra used in quantum theory.

The motivation for exploring this approach came from two different considerations. Firstly, it came from the problems of trying to understand what quantum mechanics seems to be saying about the nature of physical reality. Using the Cartesian framework we find that, rather than helping to clarify the physical order underlying quantum mechanics, we are led to the well-known paradoxes that make quantum theory so puzzling and often unacceptable to many. It seems to me that these difficulties will not be resolved by tinkering with the mathematics of present day quantum mechanics. What is called for is a radically new approach to quantum phenomena.

The second strand of my argument was inspired by the work of Grassmann who showed how by analysing thought, one could be led to new mathematical structures. In other words, by regarding thought as an algebraic process, Grassmann was led to a new algebra which we now call the Grassmann algebra. The scope of this algebra has become rather limited by being grounded in space-time essentially because, unfortunately, the original motivations have been largely forgotten. By reviving these ideas, I have been exploring whether the similarities between thought and quantum processes which I have tried to bring out in this paper.

What this means is that if we can give up the assumption that space-time is absolutely necessary for describing physical processes, then it is possible to bring the two apparently separate domains of *res extensa* and *res cogitans* into one common domain. What I have tried to suggest here is that by using the notion of process and its description by an algebraic structure, we have the beginnings of a descriptive form that will enable us to understand quantum processes and will also enable us to explore the relation between mind and matter in new ways.

In order to discuss these ideas further we must use the general framework of the implicate order introduced by Bohm (1980). An important feature within this order is that it is not possible to make everything explicit at same time. This feature is well illustrated in the unmixing experiment described above. Here when there are a series of spots folded into the glycerine, only one spot at a time can be made manifest. In order to make manifest another spot, the first spot must be enfolded back into the glycerine and so on. If we now generalise this idea and replace the spots by a series of complex structure-processes within the implicate order, then not all of these processes can be made manifest together. In other words, within the implicate order there exists the possibility of a whole series of non-compatible explicate orders, no one of them being more primary than any other.

This is to be contrasted with the Cartesian order where it is assumed that the whole of nature can be laid out in a unique space-time for our intellectual examination. Everything in the material world can be reduced to one level. Nothing more complicated is required. I feel this implicit dependence on the Cartesian order is the reason why it is such a shock when people first realise that quantum mechanics requires a principle of complimentarity. Here we are asked to look upon this as arising from the limitations of our human ability to construct a unique description, this ambiguity having its roots in the uncertainty principle. But it is not merely an uncertainty; it is a new ontological principle that arises from the fact that it is not possible to explore complementary aspects of physical processes together. Within the Cartesian order, complimentarity seems totally alien and mysterious. There exists no structural reason as to why these incompatibilities exist. Within notion of the implicate order, a structural reason emerges and provides a new way of looking for explanations.

Finally I would like to emphasise that it is not only material processes that require this mutually exclusivity. Such ideas are well known in other areas of human activity. There are many examples in philosophy and psychology. To illustrate what I mean here, I will give the example used by Richards (1974, 1976). He raises the question: "Are there ways of asking the question 'what does this mean?' which actually destroys the possibility of an answer?" In other words can a particular way of investigating some statement make it impossible for us to understand the statement? In general terms what this means is that we have to find the appropriate (explicate) order in which to understand the meaning of the statement. Context dependence is vital here as it is in quantum theory and this is ultimately a consequence of the holistic nature of all processes.

Such ideas cannot be accommodated within the Cartesian framework. If we embrace the notions of the implicate-explicate order proposed by Bohm, we have a new and more appropriate framework in which to describe and explore both material processes and mental processes

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