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Bohm on Order, Structure and Process

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Abstract. David Bohm's notion of implicate order, while relatively well-known, is often said to be difficult to understand, and is almost completely absent in contemporary discussions in philosophy of quantum theory and relativity. Yet one can argue that it is a key part of Bohm's and Basil Hiley's research programme which anticipates currently fashionable topics, such as the idea of space-time as emergent. In this paper my aim is to briefly review the origin of Bohm's focus on the notion of order, and the related notion that continuous space-time is an abstraction from a discrete structural process.

1. Introduction

David Bohm is commonly acknowledged to be one of the most important physicists of the second half of the 20th century. He made major contributions in mainstream physics, such as plasma and the Aharanov-Bohm effect (see Freire 2019). His 'ontological' interpretation of quantum theory (Bohm 1952), while ignored for a long time, has during recent decades (in a minimalist form known as 'Bohmian mechanics') become one of the main interpretations actively discussed in the philosophy of quantum theory (see e.g. Albert 1992; Ney and Albert eds 2013; Maudlin 2019, Goldstein 2025). Yet Bohm's (and his long-time colleague Basil Hiley's) major aim was to develop a more comprehensive world view, based on a notion of 'discrete structural process' (and later 'implicate order') from which continuous space-time can be abstracted and into which even 'Bohmian mechanics' could be accommodated (see Bohm 1980; Bohm and Hiley 1993, ch 15; Pylkkänen 2007). One can argue that these ideas are much more fundamental and radical than the ideas (such as 'Bohmian mechanics') that are currently the focus of discussion among philosophers of physics. They are also more tentative and speculative. The aim of this paper is to review and explicate the origin of these more general ideas, and in this way also to help to understand the underlying motivation of the algebraic work of Basil Hiley (see e.g. Hiley 2005; for a recent discussion see Hiley and Dennis 2024).

Bohm first presented his more general programme in a 1965 article "Space, time and quantum theory understood as a discrete structural process" (Bohm 1965). This idea of a structural process (or 'structure process') was the one that Basil Hiley often used when referring to his own research programme. I will thus in the next section try to explain what Bohm meant by 'structural process' in this early paper. I will also suggest that the paper contains the seeds of Bohm's later 'implicate order' programme, including the way he thought we should think about the place of mental processes and consciousness in the physical world. People often say that the

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implicate order is a very difficult concept to grasp. I suggest that this early paper helps to understand the concept. It contains ideas that Bohm did not repeat in the later papers, but which form a background to them. My discussion will be entirely non-mathematical, as Bohm's 1965 article also was. There is a great contrast between this approach and Basil Hiley's algebraic work. What I want to emphasize is that there is a philosophical and conceptual ground to the at times very technical algebraic approach which Basil Hiley was developing with great passion. This short paper can only begin to explore this conceptual ground, but hopefully this kind of exploration can attract and motivate philosophers of physics to give a closer look at the more technical programme as well.

2. Bohm's 1965 article "Space, time and quantum theory understood as a discrete structural process": a summary

I will start by providing a brief summary of Bohm's 1965 paper in this section and then discuss some key aspects in more detail in later sections. The aim of his paper is to propose a radical new foundation for physics in order to eventually resolve the fundamental contradictions between relativity and quantum theory. He argues that the concept of a continuous space-time continuum must be abandoned at a fundamental level and suggests instead that physics should be built upon the notion of a *discrete structural process* — a dynamic, hierarchical network of discrete actions whose order is prior to continuous space and time.

The idea that the universe is fundamentally a discrete structural process is meant to do justice to both relativity and quantum theory. For Bohm the major implication of relativity is that we have to give up the idea that particles (whether extended or point-like) are fundamental and instead see structures and processes as fundamental. But this is not enough, for relativity still presupposes a continuous space-time. In contrast, quantum theory strongly suggests that there is a fundamental discreteness ('quantum jumps') in processes at the currently most fundamental level of reality known to us. Putting these ideas together we end up with the notion of the universe as a discrete structural process. Continuous space-time is then an abstraction from this underlying discrete structural process.

Bohm argues that simply dropping space-time (as in S-matrix theory) is insufficient. What is needed is a new principle of *order*, one that is discrete on a small scale but approximates continuity on a large scale. He introduces already in this paper his idea of order as 'similar differences' and 'different similarities,' and argues that all of reality is a process built from such nested orders (e.g., bricks can be ordered to make up walls which can be ordered to make houses, streets, and so on).

Bohm then introduces 'function' as the active principle that carries out the structural process. A function is a transformation from an input to an output, and complex functions are built from ordered chains of sub-functions. Importantly, this is a physical notion of function which he then connects with the mathematical one, arguing that mathematically formulated physical laws describe functional relationships within nature itself.

Bohm next expands the concept to show how the entire universe, including human perception and thought, operates through 'reflective function' — the process by which the structure of the whole is mirrored in its parts. This unifies the observer, the measuring apparatus and the observed system into a single field. This strongly anticipates the notion of implicate order which he then develops in the 1970s, together with Basil Hiley.

Finally, Bohm proposes that the ultimate 'elements' of this process are binary, 'all or nothing' functions. These are the discrete building blocks from which all higher-order structures, including geometric space and even logical thought, are to be constituted.

In the discussion section Bohm hints at a mathematical implementation using the conformal group and spinors, where the fundamental discrete elements are intersecting light rays. He suggests that this approach naturally leads to a fundamental length. He finally notes that in his approach conformal invariance (specifically invariance under inversion through a hypersphere) can be physically represented by the operation of charge conjugation. This invariance implies that the entire large-scale structure of the universe is reflected or contained within each elementary point or region, like a spherical mirror. As a result, the vast outer cosmic horizon inverts to create an incredibly small inner horizon, on the scale of 10^{-33} cm, providing a conceptual model for understanding charge conjugation invariance. This radical 'holographic' suggestion clearly resonates with Bohm's later idea of the implicate order, where one key aspect is that the whole universe is in some way enfolded in each region.

The conclusion of Bohm's 1965 paper is that the continuous space-time of relativity and the objects within it (including elementary particles) are not fundamental. They are approximate, abstracted 'maps' and entities derived from a deeper, unbroken reality. This deeper reality is a discrete structural process, an infinite hierarchy of ordered levels, whose most basic activity is a network of 'all or nothing' functions. This new foundation, he argues, might help us to resolve the infinities of quantum field theory, naturally explain the discrete properties of particles, and even help to unify the physical world with the phenomena of mind and perception by seeing both as different aspects of the same universal reflective process. Again, this anticipates his later implicate order framework where he likewise proposes that the implicate order is common to both matter and consciousness.

3. Order vs. fundamental length

Let us now move on to examine some aspects of Bohm's 1965 paper in more detail. By 'structural process' he refers to "…a set of 'space-like' elements which are discrete structures, undergoing discrete or discontinuous changes as they move and unfold in a *process* of development" (1965, 252). As we already mentioned, continuous space-time should then be seen as an abstraction from the underlying discrete structural process.

Bohm emphasizes that this approach is fundamentally different from simply introducing a 'fundamental length' into a continuous background. He argues that the concept of order is much deeper than the concept of measure or length:

> In every theory of measure or length, order is tacitly assumed and taken for granted, because without knowing what is to be meant by the order of points, the measure of the distance between them, whether this be limited by a fundamental length or not, can have no significance. (Bohm 1965, 253)

What Bohm means is that when we try to think of length or measure, we much watch out that we do not tacitly put the order of the points in from our intuitive ideas of continuous space.

Instead, the order of the points must be defined as a part of the structure of the theory (Bohm 1965, 285). But to do this we must have some idea of what we mean by order. He thus says that a fundamental theory must start by going *axiomatically* into the notion of order. The strategy is to explicate the notion of order itself and then derive concepts like distance or measure, and continuous space as approximations. Continuous space-time is thus like a 'map' which works well on large scales but breaks down at very small scales, where we must refer directly to the discrete process itself.

4. Order and structure

To clarify his point of view Bohm thus needs to say what he means by 'order' and how he understands the notions of structure and process in terms of his notion of order. His strategy is to first explicate what everybody already implicitly knows about order, structure, and process, and then to try to make these common notions more precise, in a mathematical way. He illustrates what he means by order by discussing how the concepts of order and structure are related:

> …if one wishes to build a structure (such as a house) one must in general, start with similar elements (such as bricks) which are, however, also different in certain ways (such as the different location, and orientations of different bricks). These differences must be suitably ordered or else there will be no structure, but instead, only an arbitrary aggregate of elements. (1965, 261-2)

Bohm thus introduces a criterium for something to be a structure: we need similar elements, which are also different (thus 'similar differences'), and these 'differences' must be suitably ordered. In other words, structure presupposes order, underlining the primacy of order over measure and structure.

Bohm then moves on, using the example of a city's construction to illustrate that complex structures are built through a hierarchy of orders. The key idea is that a structure is an 'order of orders.' This means that

1) Basic, similar elements (like bricks) are arranged in a specific order to form a new, higher-level entity (a wall).
2) This new entity then becomes a basic element itself, which can be ordered with other similar elements (other walls) to form the next level of structure (a house).
3) This process repeats through multiple levels, so that houses can be organized to create streets, and streets can develop into cities.

Therefore, every complex structure is not just a single order, but a *nested system* where each level of order provides the foundation for the next.

The next step is to argue that such principle of hierarchical order is a universal foundation for all structures, not just human-made ones. Bohm demonstrates this through two examples.

In biology, nucleotides are ordered into DNA/RNA and amino acids are ordered into proteins; these complex molecules form cellular components, then cells, and finally the whole organism. In physics, nucleons form atomic nuclei, which join with electrons to form atoms, which form molecules. On a cosmic scale, stars are ordered into galaxies. The core idea is that complex

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structures at every scale are built through multiple, nested levels of order, where each level serves as the building blocks for the next.

Having discussed the notion of order in terms of familiar examples, Bohm feels that it is now possible to provide a more precise notion of what order is. He starts by saying that "…order is based on a set of similar differences leading to different similarities" (1965, 262) It is not immediately obvious or intuitive what this definition means – which might partly explain why Bohm's notion of order is not widely discussed in the philosophy of physics community. So let us try to make sense of it. Rather than relying on Bohm's 1965 article it is better to use the discussion he provided in an article that was published in 1971 (Bohm 1971, republished in his 1980 book *Wholeness and the Implicate Order*).

In the second section of the 1971 paper ("What is order?"), Bohm expands the common, restricted notion of order (like a grid or a neat row) into a vast, fundamental concept that cannot be strictly defined but only pointed to through examples. His central thesis is that order can be understood in terms of similarities and differences.[1]

He breaks this down into two key concepts. First, there are 'similar differences'. This is the simplest form of order. It can be illustrated by a sequence where the way things differ from one step to the next remains the same. The simplest example is the straight line which we can analyse in terms of segments of equal length, A, B, C etc. The difference between segment A and B is a spatial displacement that is similar to the difference between B and C, and so on.

Then there are 'different similarities'. This is a higher, more complex level of order. Here, the rule or 'similarity' that was governing the steps itself changes over the sequence. As an example, consider a chain of straight lines in different directions. The first line has a similarity S1 (a constant direction). The next line has a different similarity S2 (a new direction). The third has S3 (e.g., a rotation), and so on. The similarities themselves are different from each other – thus 'different similarities'.

Bohm then uses geometric curves to illustrate a hierarchy of order. A straight line is a 1st-degree order (only similar differences in position). A circle is a 2nd-degree order (similar differences in both position and direction). And a helix is a 3rd-degree order (adds a third dimension of change). By extending this idea to curves where the 'similarity' changes in increasingly complex ways, we can eventually describe what is commonly called a 'random' curve (like in Brownian motion).

This leads to Bohm's central claim: there is no such thing as true 'disorder.' Instead, there is only a spectrum of different degrees of order (Bohm and Peat 2000, ch 7). What we call randomness or disorder is simply an order of such a high and complex degree that it is not predictable from a few initial steps.

So, what Bohm does is to redefine order as a universal principle based on the dynamic relationship between similarity and difference, paving the way for him to later analyze the

[1] This is an idea that was suggest to him the Americal artist Charles Biederman in the course of their extensive correspondence (see Bohm and Biederman 1999).

specific orders implied by classical physics, relativity, and quantum theory, ultimately leading to the notions of implicate and explicate order, central to his later thinking.

5. Process understood in terms of similar differences and different similarities

Going back to Bohm's 1965 paper, he next moves on to discuss process, again appealing to common sense examples. There is a key distinction between an *orderly process* as opposed to an *arbitrary succession of changes*.

> …process is in general an ordered series of developments of structure. Each kind of process is abstracted (i.e., taken out in a purely conceptual sense) from its total context, when one makes a fundamental structural assumption about such a process. This assumption asserts a range of similar but different structures that are to be regarded as basic in the analysis of processes of this kind. But the key factor which gives rise to an orderly process instead of an arbitrary succession of changes, is that one must correctly abstract the similar differences in various phases of development, leading on the next level to the proper set of different similarities. Therefore, (as happened with the geometric curve), the orders of various phases of a process will follow from some basic and relatively simple law. (Bohm 1965, 264)

Bohm thinks that he can develop a general framework for understanding natural processes through the interplay his two principles already familiar to us: 'similar differences' (consistent, repeating changes) and 'different similarities' (variations that introduce complexity). For a freely moving particle, the 'similar differences' are its constant velocity in equal time intervals, which directly leads to Newton's first law. However, when constraints are added, as with a particle that is not free, the pattern becomes more complex, described by contact transformations in mechanics.

In biology, the growth of a plant illustrates both principles: the 'similar differences' produce exponential growth as the plant gets consistently larger, while the 'different similarities' are the varying growth rates in different parts (roots vs. stems) that shape its specific form. This dynamic tension between repetition and variation is what allows for the lawful yet complex development of any structure, ultimately leading to its completion and ending in death. Bohm suggests this kind of analysis is a natural and widely applicable way to understand processes of lawful development across many different fields.

It is important to note that Bohm often uses the word "process" to refer not to a continuous change but rather to a discrete, step-by-step change. He points out that the word "process" is based on the verb "to proceed", which means "to step forward". It originally thus refers to a particular kind of movement, which goes step by step, with one step following another (Bohm 1976, pp. 40–41). This perhaps makes it easier to grasp what he means by 'discrete structural process'.

6. Function as a key aspect of all process

Bohm now thinks that he has been able to show that the notion of a structural process is a universally applicable one. He proposes that it is fruitful

> …to start with a very general notion of this kind as the fundamental in physics rather than to start with more specialized mathematical hypotheses on space,

> time, the nature of elementary particles, the laws of quantum theory, etc. (1965, 265)

However, he acknowledges that in physics one typically emphasizes certain limited features of the structural process while ignoring others. A very important feature is *function* which Bohm sees as a key aspect of all process.

> If we abstract some limited domain of possibilities and denote the totality of them by the term "the field of structure under consideration", then a function in the domain of this field is a certain specifiable kind of change or development of structure within that field. (1965, 268)

Note how Bohm emphasizes that he is not talking about functions in THE fundamental level of reality, but rather about functions that take place in some limited domain that we have (conceptually) abstracted. This way he wants to leave room for the possibility that there exists a creative process, if we consider broader domains.

As examples of function, he gives the function of organs in a living organism (such as the function of the heart and the brain), the function of a bridge and a motor in engineering, and the function of speech in communications. He then proceeds to a rough definition:

> …every function in a certain field is carried out by some substance, object, entity, system or element, having a structure that is in the field under consideration. The function itself is … the action of taking a certain domain of possible structures in … the 'input' and changing or transforming these structures, or else constructing new ones, in the range of … the 'output'. (1965, 268)

He also uses the notion that functions apply in limited domains to justify his use of discrete elements:

> Since physics always abstracts in some limited context, the basic elements of that context can be taken as discrete, and yet in principle sub-divisible in terms of qualitatively new functions. Thus, we justify the approach which begins with some countable set of discrete elements in a physical theory, though we know that beneath and beyond them may well be an inexhaustibly deep and non-countable infinity of further elements, which can, however, correctly be ignored in the level of abstractions under consideration. (1965, 269)

This shows that the 'discrete elements' which Bohm takes as fundamental in his theory are only relatively fundamental. It is a pragmatic choice to call them 'fundamental' in the current theory. In principle Bohm admits that there is always the possibility of further, more fundamental elements *ad infinitum*, or 'turtles all the way down' as it were. This point is important later when we consider the philosophical interpretation of Bohm's view.

7. Reflective function: the parts reflect the whole

Bohm next draws attention to the nature of visual information. Its possibility is "…based on the fact that all the light rays passing through each point of space possess an order and structure that reflectively corresponds in a certain rather indirect way to the order and structure of the whole environment" (1965, 274).

This leads him to introduce the notion of 'reflective function':

> Such a function takes place … in external nature, when for example, the structure of the whole universe is reflected in the light through each point, in the radio waves that come from the most distant galaxies. … The senses and brain then constitute functions that reflect even higher level abstractions from this overall structure. One sees in this way that the structure of thought is itself an extension of the whole structure, which is, like everything else, similar in certain key ways, and different in others. (1965, 277)

This 'holographic' feature of reflective function where information about the whole universe is contained or 'enfolded' at each local region clearly anticipates Bohm's later notion of 'implicate order' for which such 'enfoldment' is one of the key defining factors. Reflective function is also what the 'object' (external nature) and the 'subject' (the operation of scientific instruments, the brain and cognition) have in common. It is not, however, trivial to understand how these reflective functions work. One way of expressing the measurement problem in quantum mechanics is to say that we do not understand how the reflective function of the measuring apparatus operates to produce a single outcome out of the many possibilities implied by the wave function (cf. Bohm 1965, 278).

8. The significance of the 'all or nothing' elementary functions

We saw above that Bohm introduced the notion of 'function' as the active principle that carries out the structural process. He further argued that the entire universe, including human perception and thought, operates through 'reflective function' — a process by which the structure of the whole is mirrored in its parts.

Having established this he then raises the question of whether there might exist some basic structural feature that is general enough to apply in the whole field of function. In other words, might there exist some 'element' that is common to all levels of function, both in external nature, and in its reflection in perception, thought and consciousness? Such elements (or 'atoms') could then ground the similar differences and different similarities that constitute the orders and structures that we discover in our experience (in line with Bohm's general notion of order).

Bohm's proposal for such elements is what he calls the 'all or nothing' function. He starts by noting how this underlies the reflective function of the nervous system: nerve cells produce impulses by firing in bursts, with an 'all or nothing' response to some structural feature. A given cell will give a positive structure in the presence of certain structures, while there is a different type of cell which fires when this same structure is absent and which is 'inhibited' or prevented from firing by a certain range of structures.

Bohm sees a similar mode of functioning in the higher levels of thought. He notes that a set of structures can give rise to specific words, images, or feelings that match them. Meanwhile, a different set of structures—which those same words, images or feelings do *not* match—will either not produce those mental symbols or will actively inhibit them:

> Thus it follows that the elementary structure of logical thought is similar to that of nervous impulses, in the key respect that it is based on the possibility for a structure either to evoke or to negate a corresponding symbolic reflection with an 'all or nothing ' response. (1965, 283)

Note that Bohm is drawing attention to a similarity or analogy between the operation of the nervous system and the higher-level functioning of cognition. He is not claiming that the higher-level cognition is reducible to, or 'nothing but' the neural functioning. The idea is to discover the 'all-or-nothing' response at different levels, not to claim that the levels are the same in all respects.

What about external nature? Can we find 'all or nothing' responses there as well? Here Bohm mentions a number of examples. First of all, there are the quantum jumps: "…the 'all or nothing' response at the foundation of the whole known field of natural law, in the discrete action of all quantum processes" (1965, 283). This indeed suggests that 'all or nothing' responses are fundamental in external nature. But he also mentions the interference properties (or 'wave-like aspects') of quantum processes, which "…reveal something like the 'negative' response that can 'inhibit' what would otherwise be a 'positive' response at certain places" (1965, 283). This underlines the importance of destructive interference, in the sense that waves that have opposite phase cancel out.

Finally, he refers to the discrete properties of elementary particles, such as charge, mass and isospin. Elementary particles have all these discrete features in common, but why? Bohm speculates that to explain this we must assume that there is some corresponding 'rhythm' in basic natural processes. He notes further that the possibility for negative charges to 'annihilate' positive charges suggests some pair of functions similar in relationship to excitatory and inhibitory function, pointing to an analogy between quantum field theory and neural functioning.

The above considerations lead him to make a more general and fundamental assumption:

> …all functions have the basic property of being constituted out of ordered structures of 'elementary functions'. These functions are similar in that they give an 'all or nothing' response (either 'positive' or 'negative') to everything in the field in which they operate. They are different in that their 'inputs' and 'outputs' are of many different orders, and consist of structures existing on many different but related levels. (1965, 283)

As an example that illustrates 'all or nothing' operation in the field of reflective function he mentions the pictures printed in a book in the form of an array of little dots:

> Each place for a dot has two possibilities. Either it is printed or it is not. So for each place, there is a corresponding 'all or nothing' function. The total set of such functions evidently determines the reflective function of the picture as a whole. (1965, 283)

It is clear that in this example the reflective function at a higher level (the ability of the picture as a whole to reflect some aspect of the world) depends on the operation of the elementary 'all or nothing' functions at a lower level (which latter do not themselves reflect that aspect in the same way). Analogously Bohm seems to assume that physical functions at more macroscopic levels are in the end constituted by a set of 'all or nothing' functions, and at the most fundamental level known to us by the 'quantum jumps' which either take place or they do not. This may give an appearance of a kind of reductionism, where all functioning in the physical world is in the end reducible to binary 'all or nothing' functions. We will return to this issue later.

Bohm then considers an important way in which sets of 'all or nothing' functions can be related on different levels, namely a situation in which one kind of such functions determines the order of another.

> Consider for example, a segment of a very fine line, printed out of a single ordered row of dots. Beginning with the dot at one end of the line, we can define higher order 'all or nothing' functions belonging to that dot which operates 'positively' for the next dot in order in the line, and fails to operate for all the other dots. A further example of such a function can be defined with each successive dot. It seems clear that the totality of these functions determines the order of dots on the line segment. And these 'ordering functions' form a functional (or function of a function) of the original 'place elements' that determine the line. (1965, 283)

Remember how we noted at the beginning of the article the emphasis Bohm gave to defining what we mean by the 'order of the points' when considering measure or length – according to him this has to come from the theory and not projected from our implicit assumptions of continuity. Using his idea of 'all or nothing' functions, Bohm thinks he can show how the order of points in a line is determined. By using the same method, we can generate more complex figures. For example, in case of a printed image of a square. Bohm suggests that we start with one of the boundary lines, and consider the order of lines that are parallel to it. This is determined by a set of 'all or nothing, functions of the lines, similar to those that determined the order of the points on a line. In a similar way, we can move on to build up all sorts of figures with geometrical relationships. Bohm is quick to underline the more general implications:

> What this means is that the order that underlies geometry corresponds to a certain structure of 'all or nothing' functions, and these latter correspond, as we have seen, to the general structure of all logical thinking. So we are able thus to develop a fundamental relationship between geometry and logic. (1965, 284)

In summary, we have seen that Bohm proposes that the ultimate 'elements' of the universal structural process are binary, 'all or nothing' functions. These are supposed to provide the discrete building blocks from which all higher-order structures, including geometric space and even logical thought, are constituted.

How exactly do 'all or nothing' functions support the notion of the universe as a discrete structural process? By positing that the most basic 'acts' or 'functions' of the universe are binary — they either happen or they don't, they are 'on' or 'off' — Bohm builds discreteness directly into the fabric of reality. He argues that this is a more radical proposition than just having a 'fundamental length.' It is not that space is pixelated; it's that *the structural process itself and its basic actions are in a sense digital in nature*. Bohm thinks that this might help to avoid the infinite divisibility of continuous fields and the resulting infinities that plague quantum field theory.

Regarding particles, Bohm proposes that they are "…*abstracted* as relatively constant and invariant features of the overall order of action." (1965, 282) Also, fields (like the electric field) are not continuous entities. We can think of an electric field in terms of a vast, ordered network of discrete 'electric functions' of an extended region of space and time. This function, Bohm says, is to accelerate and deflect charged particles that pass through the region in question. The 'value' of a field at a point is then an abstraction from the collective 'input-output' physical functioning of that region on test particles.

Finally, as was pointed out in the beginning, space-time itself is an approximate, continuous 'map' abstracted from the overall order of these fundamental events. The geometry of this space-time corresponds to a specific, stable structure of 'all or nothing' functional relationships (as when we generate lines and shapes from ordered dots in the way that was described above).

We saw above also that Bohm emphasizes that the 'all or nothing' concept isn't just 'on-off'; it also contains the possibility of a 'negative' or 'inhibitory' function. This is crucial for explaining wave-like interference in quantum mechanics, where possibilities can cancel each other out. For example, opening the second slit in a two-slit experiment can prevent an electron arriving at a region where it could arrive if only one slit were open. If the electron only had particle properties, we would expect the opening of a second slit *increase* it possibilities. But because the electron also has wave properties, these waves can cancel each other out in such a way as to *decrease* the possibilities of the electron.

9. Comparison between Bohm's 'all or nothing' and Wheeler's 'bit makes it'

One interesting question is whether Bohm's binary notion of 'all or nothing' might be related to Wheeler's famous notion 'bit makes it', which also implies a that a binary feature is fundamental in physics.[2] Wheeler proposed that every physical quantity ('it') derives its ultimate significance from binary yes-no questions, or 'bits.'

There are some similarities. Both posit a binary, yes-no, all-or-nothing element at a fundamental level of reality. For Wheeler, 'bits' are the primary information; for Bohm, 'elementary functions' are the primary actions. Both are also attempts to move beyond the concept of an infinitely continuous space-time. Wheeler suggests that we need to consider a notion of 'prespace' or 'pregeometry' at the Planck length, while Bohm and Hiley developed the notion of 'implicate order' to serve the same purpose (see Wheeler 1980; Bohm 1986; for a mathematical treatment see Bohm and Hiley 1984).

However, there are also some important differences between Bohm and Wheeler in emphasis and in ontology. For Bohm, a function is something that *does* something — it transforms an input into an output. For example, we saw above that Bohm understands the electric field in terms of the 'electrical function' of an extended region of space and time, where the function is to accelerate and deflect charged particles that pass through the region. In contrast, a bit is a piece of knowledge, an answer to a question. So, Bohm's notion of function is clearly ontological, while Wheeler was somewhat agnostic about whether 'it from bit' was about reality itself or our knowledge of it. Regarding observation, for Bohm the observer (and their instruments) are high-level, complex structures *within* the total field of function. Reflection is a universal property, not one unique to conscious observers. For Wheeler the act of observation or measurement is what *creates* the 'bit' and thus gives rise to the 'it.' One interpretation of this is that the universe can be seen as a self-excited circuit arising from observation. This clearly gives observation a more powerful role that it has in Bohm's view.

In summary, while both Bohm and Wheeler identified a binary, 'all-or-nothing' principle as the key to a new foundation for physics, they framed it differently. Wheeler's 'bit' is more

[2] This possible connection between Bohm and Wheeler was suggested to me by Alyssa Ney, in the discussion session after my talk "Undivided Wholeness in Flowing Movement: David Bohm's Concept of Nature" in the International Ontology Congress, University of San Sebastian, October 9, 2025.

informational and epistemological, emphasizing how reality is brought into being by measurement, while Bohm's 'function' is more process-oriented and ontological, emphasizing how reality is a dynamic, structured network of actions, which includes the actions of the observer and the measuring apparatus as a special case.

10. Is the universe mechanistically computable in the Bohmian digital 'all-or-nothing' universe?

We saw above how Bohm presents in a sense a 'digital' notion of reality with his emphasis on the central role of 'all-or-nothing' functions at different levels of the hierarchy of the discrete structural process, including at the quantum level. This raises the question of whether the Bohmian digital reality might be completely understandable in terms of mechanistic computability. This would go against the non-mechanistic spirit we find in almost all of Bohm's other writings, starting from his 1951 text-book *Quantum theory,* moving on to his notion of the qualitative infinity of nature in his 1957 book *Causality and Chance in Modern Physics*, and culminating in the work on the ontological interpretation of quantum theory and the implicate order that was presented in the 1993 book *The Undivided Universe* with Basil Hiley. Bohm typically emphasized the holistic nature of consciousness and intelligence, but the question arises whether these, too, might be seen as reducible to mechanistic computability in the digital universe sketched in his 1965 paper. Roger Penrose for one has strongly argued that human intelligence and insight must be grounded on non-computable processes in the brain (more specifically in the orchestrated, gravity-induced, non-computational reductions of the quantum wave functions in neural microtubules; see Penrose 1994). Can Bohm deal with genuine intelligence and creativity in his 'all-or-nothing' digital approach?

A careful study of Bohm's 1965 article shows that his 'digital' notion does *not* imply that nature is mechanically computable. In fact, his framework is an argument *against* such a mechanistic view. So how does he reconcile a discrete foundation with genuine creativity and non-computability?

The key point is that Bohm uses the 'all or nothing' functions to build an inexhaustibly rich and open-ended hierarchy of levels. He assumes that each new level of order (built from the 'all or nothing' functions of the level below) has genuinely new qualities that are not reducible to the lower level. Because of this, even if you could compute the behavior of the fundamental 'bits,' you could not thereby necessarily compute the behavior of the higher-level structures they form. The higher levels have a kind of autonomy and their own 'laws,' which are the expression of their specific order.

Also, Bohm repeatedly emphasizes that all our knowledge, including any specific set of 'all or nothing' functions we might define, is an abstraction from an immeasurably broader and deeper 'unknown.' Any computable system is a closed, finite, and well-defined set of rules and elements. In contrast, Bohm's structural process is supposed to be inherently open, infinite in depth, and creative. He states that assuming that we could one day know the 'complete set of all the laws of nature' is a useless notion, because there is no way of proving that we have discovered such a set. The process of abstraction itself is creative and it is a valuable working hypothesis to assume that there is always the possibility to uncover new, deeper levels of order that were not contained in the previous framework. The history of the science so far shows that this assumption is reasonable.

A Turing machine or any computational model typically operates within a fixed, predefined state space. In contrast, Bohm's universe is constantly generating *new state spaces* — new levels of order with new qualities — through its creative process. This is fundamentally non-computable, although it may be possible to describe a given level up to a point in terms of mechanistic computability (such as the unitary evolution of the Schrödinger equation in quantum mechanics).

Now, there is room in Bohm's universe for mechanical function which operates within a fixed, definable domain of possibilities. This is the kind of process that a computer can, in principle, simulate. Bohm notes that physics, at any given stage, purposely restricts itself to such domains to make progress. However, such pragmatic restrictions should not make us blind to the possible role of what we might call 'creative process'. This for Bohm is the broader reality from which mechanical domains are abstracted. It involves the possibility of a fundamental alteration of the basic structural possibilities themselves. In other words, the 'rules of the game' can change.

In summary, for Bohm the 'digital' elementary functions are the basis for our *mechanical abstractions*, but the total structural process, which is creative, continually transcends these abstractions. The birth of a new theory in science, the evolution of a new species, the emergence of consciousness, and the act of genuine artistic or intellectual insight are according to Bohm all examples of this creative process breaking through the limits of a previously defined, more rigid functional domain.

What is the relation of Bohm's views to Penrose's views about the role of non-computability? Penrose focuses on the idea that human understanding and insight are non-computable, and he tries to explain that in terms of non-computable physics, the gravity-induced collapse of the wave function. In contrast, Bohm's view is more general and metaphysical. For him the entire natural world, including mind, has a creative, non-mechanical aspect. He thus proposes a non-mechanistic ontology; a discrete process whose infinite depth and hierarchical nature make it non-computable.

So, it is fair to say that Bohm's 'all or nothing' functions are not the seeds of a giant cosmic computer. They are the seeds of a creative, unfolding reality, which he later articulates in terms of the notion of implicate order. Their discreteness is meant to help to develop a way to avoid the infinities of continuous fields and to ground a theory of order. However, the assumption of the infinite hierarchy of levels, the emphasis on the 'unknown,' and the primacy of the creative process over any limited functional domain suggest that his worldview goes beyond mechanism, even if he acknowledged the value of mechanistic theories as long as we are aware of their limitations.

11. Concluding remarks

We have above briefly considered some key aspects of Bohm's 1965 article "Space, time and quantum theory understood as a discrete structural process" which is a seminal but a relatively little-known article which lays the foundation for Bohm and Hiley's research programme, which Basil Hiley developed until early 2025. It is interesting that the paper contains the seeds of the implicate order programme which was later given a rigorous mathematical formulation by Hiley and others. The style of Bohm's paper is very philosophical, not at all a typical physics paper, and it is thus perhaps not surprising that it is not widely discussed among physicists. The same can be said of some of Bohm's other articles about the implicate order, especially his 1971 paper we referred to earlier. But Bohm was very aware of the fact that he was developing ideas in an intuitive, somewhat hazy way. This, he argues in the 1965 paper, is the only way to create something genuinely new, such as a new notion of order which then can be made exact and mathematized only later. He argues that if we start with well-defined notions, it is very likely that we end up making small modifications into our existing paradigm. Bohm's rather hazy and general reflections did in fact lead to a highly mathematical programme, as anyone who has interacted with Basil Hiley will know. This programme still needs to be evaluated and hopefully will sooner and later attract the interest of philosophers of physics more broadly. Here it may help to go to the very conceptual roots of the programme – something that I have here tried to do in a preliminary way.

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