Pilot-wave theory, Bohmian metaphysics, and the foundations of quantum mechanics Lecture 8

Bohmian metaphysics: the implicate order and other arcana



Mike Towler

TCM Group, Cavendish Laboratory, University of Cambridge www.tcm.phy.cam.ac.uk/~mdt26 and www.vallico.net/tti/tti.html

mdt26@cam.ac.uk

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www.tcm.phy.cam.ac.uk/~mdt26/pilot_waves.html

MDT

More philosophical preliminaries

Positivism: Observed phenomena are all that require discussion or scientific analysis; consideration of other questions, such as what the underlying mechanism may be, or what 'real entities' produce the phenomena, is dismissed as meaningless.

Truth begins in sense experience, but does not end there. Positivism fails to prove that there are not abstract ideas, laws, and principles, beyond particular observable facts and relationships and necessary principles, or that we cannot know them. Nor does it prove that material and corporeal things constitute the whole order of existing beings, and that our knowledge is limited to them.

Positivism ignores all humanly significant and interesting problems, citing its refusal to engage in reflection; it gives to a particular methodology an absolutist status and can do this only because it has partly forgotten, partly repressed its knowledge of the roots of this methodology in human concerns.

Instrumentalism: Regards scientific theories purely as tools to calculate experimental results; non-observable theoretical concepts may be potentially useful, but are always disposable.

Fair enough, but has tense relationship with realism.

Realism: The view that the observations we make in science are related to a real world existing independently of our observations.

Fair enough, but has tense relationship with instrumentalism.



What if things are pretending to be what they really are...?

Conclusions about interpretations

- So the quantum formalism predicts probabilities of experimental results. Sticking to that is *instrumentalism* and is fine for most people and for all applications (this is *not* Copenhagen, note..).
- We know metaphysical speculation can result in new concrete results and experiments (e.g. Bell/Aspect) so instrumentalists should be happy to encourage such speculation. Sitting on a self-appointed lofty perch taking the piss is boring for all concerned. Try to have more fun!
- Main message of this course: the 'weirdness industry' that has grown up around QM is unnecessary. Idea that nature *must* be intrinsically probabilistic; it is impossible to understand two-slit experiment; conscious observers are required; things don't exist till you look at them; there are an infinite number of constantly-splitting universes; macroscopic superpositions like Schrödinger's cat exist; solution of PDE represents 'observer's knowledge'; etc. are all slightly barking ideas which are not required. But this is how QM is presented to the public - and to most scientists..
- Bell said there are two ways to solve measurement problem: "*Either the wave function, as given by the Schrödinger equation, is not everything, or it is not right.*'[Bell, Speakable and Unspeakable, Ch. 22 (1987)].

First option gives us pilot wave theory (waves and particles). Second option gives us GRW and related 'objective collapse' theories (Schrödinger equation not right due to small nonlinear terms giving nonunitary evolution of Ψ - see http://plato.stanford.edu/entries/qm-collapse/). Other options either incomplete, unmathematical, lead to inconsistency/paradox, or are inescapably bizarre. Choice between two fundamentally aesthetic. I like pilot waves since complete purely-mathematical theory, reduces to older theories in suitable limit (statistical mechanics with novel dynamics..), and it does what standard QM patently fails to do; it attempts to tell us what the world is like.



[&]quot;Do the particles actually travel along such paths? I don't know but in the absence of any information to the contrary I am quite happy to imagine they do. As is well-known we cannot 'see' the particles travelling along a trajectory, hence Zeh's criticism. But equally can we claim that it does not travel along a trajectory? I feel that it is better to adopt a position that understands the particle to travel along such a trajectory, unless it leads to some contradiction, than to confess that one has no idea how particles get from A to B." [Basil Hiley, 2002].



Bohm was bored of this by 1957..

...and found bigger game to hunt..

"One thus sees that a new kind of theory is needed which drops these basic commitments and at most recovers some essential features of the older theories as abstract forms derived from a deeper reality in which what prevails is unbroken wholeness."

Thus far pilot-wave theory presented as QM interpretation and practical way of doing calculations (direct connection with current physics) but in many ways this is a very limited perspective. Today we briefly survey Bohm's other more ambitious projects between late 1950s and his death in 1992.

- Bohm was looking to capture what is essential about the more *fundamental architecture of the physical world*, as revealed in quantum, relativistic and mental phenomena.
- Basic concepts of relativity and QM in complete contradiction. Relativity emphasizes continuity, locality and determinism. QM emphasizes discontinuity, non-locality and indeterminism. Customary to talk about 'elementary particles' but these also have wave properties and properties that strongly violate any mechanistic scheme (non-locality, discontinuity of movement, etc..). New ideas required...

"Dave said he also felt like that when he talked with Einstein, that the two of them were exploring together and there was no sense of one being superior to the other. And I think many people who worked with Dave felt that too. You were aware of course that Dave was far smarter than you were - he could run rings around you - but when you worked with him you didn't get the sense that Dave was the boss, but that you were exploring together." F. David Peat

Disclaimer: Bohm essentially did not succeed in connecting his ideas to the established body of theoretical physics.. This may bother you, and the ideas are hard to grasp. Nevertheless, his approach is highly interesting - both historically and philosophically - and well worth a look.

Let's interview Bohm's biographer and friend F. David Peat



(Courtesy of 'What is Enlightenment?' magazine)

Why did so many scientists - why do so many scientists even now - seem to have so much trouble accepting or respecting [Bohm's] ideas?

"Well, I suppose in some cases it's because people like small little bits of work - 'resultlets,' as David called them, not results but 'resultlets.' When Dave did his work he really dealt with ideas, with concepts, and in very broad brush strokes; whereas the fashion in physics today is that it should all be hyper-mathematical, and he always mistrusted mathematics. Mathematics to him was a good tool, but it was a tool and no more. The thing with mathematics, even the most beautiful and elegant mathematics, is that somewhere in there a lot of assumptions have been hidden, and when we speak together, using ordinary language, it's a little bit easier to discover what those assumptions are. Mathematics tends to conceal a lot. He was also suspicious of other aspects of the way physics was being done - for example, all this reliance in particle physics on breaking things apart rather than seeing them in an all-embracing fashion. You see, Dave felt there had been a major revolution in this century in quantum mechanics and relativity, but that our thinking hadn't really caught up with it. In the old order you could fragment things, you could define everything on a Cartesian grid of space and time. Now we needed an entirely new order, and the implicate order, which is inherently infinite, was one of the approaches he was working on. But of course, that's asking too much of physicists. They like to see things small and finite, and Dave was too much of a global thinker, I think, for many of them except the very good ones, who were sympathetic to Dave because they realized that something new was called for."

Interview II

But to most of the fraternity of physicists it seemed that he had gone beyond the bounds of science? "Yes. And it is ironic that now, after his death, his hidden variable work - which is the work that caused so much controversy - is now being picked up on by physicists because they see it as a way of making calculations. To Dave it was a completely new way of looking at quantum mechanics, but they are just using it as a way of making calculations. They have left the meat behind and just taken the juice."

'Bohmian mechanics' they're calling it?

"Yes, the Bohmian mechanics, that's right. That would have shocked Dave somewhat. It's ironic that that's what they have extracted from his theory. But similar things have happened in the past. He and Basil Hiley realized at one point that the new order they were looking for had already been anticipated by mathematicians like Grassman, Hamilton and Clifford. And in that case too, what had happened was that people had left the real deep stuff behind and just extracted some of the facile ways of doing calculations; the truly deep ideas had always been ignored."

Do you think his humility played a role in his ability to draw the conclusions that he did or to have the perspective that he had?

"You know, there's always an easy way out, isn't there? You could take your ideas and say, 'I'll present them in a way that the public will find pleasing,' or, 'I won't take them too far.' You can search for approval or for promotion - all of those things which lead inevitably to compromise. If you want to be successful you might find some little field and try to carve it out. But right from the beginning Dave never wanted to do that. He had the honesty and the modesty to do what he really wanted to do, which was to ask the biggest questions. I mean, what makes it possible to ask the biggest questions? You are either very arrogant or you freely admit that you don't know very much."

Interview III

"He also made a point of rejecting this idea of geniuses, of saying that you don't have to be a genius. Anybody can do it who has the energy to question and to face things, to keep working on something. That's an important point to make. Otherwise a lot of people will give up and say, 'Well, I'm not a genius.' This is what was said to me when I was doing research, 'Well, you're not a genius, so why bother doing those things? Pick something small.' Whereas Dave made the point that anybody can do this work. You have to have some training of course, but the main thing is to keep asking those questions. Anybody can ask those questions."

This advice you were given about not being a genius - is it routine for graduate students in physics to hear that kind of thing?

"Yes. Yes it is. It happens quite a lot. Another piece of advice I was given was, 'Find a very, very small area in physics and then just publish about ten or fifteen papers on it; then you'll get a reputation. Then you can go and do this other stuff.' In fact - another little story - when I did go and spend a sabbatical with Bohm, a very senior physicist in England asked me to come visit him for a few days. He took me out to dinner one night and, very fatherly, said he wanted to give me some advice. He said he knew I was working with Bohm and that it probably wasn't a very good thing to be doing. It would be bad for me, and really I should try to dissociate myself from him and go back to doing small pieces of physics. 'Do small problems,' he said. 'That's the way that physics is going to progress, by people doing little bits of things.'

Another person told me that his ambition was to be just a footnote in a textbook. Now Dave never thought that way. Dave felt that was a deeply false modesty, when people said that sort of thing, and that really the only important thing was to ask the big questions - otherwise, why do physics? I think this idea was expressed in one of the letters between Dave and Einstein. Einstein wrote, 'If this is the way things are going, then there's no point in my doing physics anymore.""

Order in physics

The term 'order' - in Bohm-speak - refers to a sort of paradigm which dominates our perception/thought.

- Our usual concept of order which we shall call the *Cartesian order* or *mechanistic order* derives from Cartesian coordinate systems where concept of 'local point' is fundamental. Einstein's curved spacetime is a classic 'point theory' which clashes with non-local QM.
- In classical physics explanation must be deterministic, continuous, and local. In QM we find the opposite, but attempt to restore this classical paradigm the Cartesian order through Schrödinger, Dirac, Klein-Gordon equations and wave functions evolving in space-time and so on..
- The Cartesian order is essentially *mechanistic* i.e. all natural phenomena exist in a strictly *external* relationship[†] to one another, and exhibit precise and discernible chains of cause and effect. (In a world of externalized entities like this it can only be a matter of time before the basic stuff of which the universe is made will be discovered and explained(!)).

Bohm's idea is to supplant Cartesian order with an '*implicate order*' - a propositional template for plotting emergence and dynamics of both matter *and* consciousness. Proposes dynamic 'structure process' from which our coordinate-based experience of 3D space and time just a derivative, temporary projection. We experience only this '*explicate order*' but never consider that coordinate frame for our experiences is itself a projection, another experience arising from this deeper 'implicate' order.

[†] **Definition**: *External relationships* between things occur if x stands in some relation to y but neither its identity nor nature depends on this (e.g. table and stuff on it). *Internal relationships* occur if x could not be same item or item of same kind without standing in that relation to y (e.g. cell in body).

Propose electrons are internally related: the way an electron relates to the whole then thought to be essential to what it is, in way very different from classical physics, where particles are what they are (i.e. particles) regardless of kind of environment they happen to be located in.

Bohm's big question

Bohm was concerned with providing a description of reality - at the quantum level, and more generally, a **unified description of matter, life, and consciousness**, all adding up to a general concept of reality or a metaphysical theory. Not ambitious at all then..

Unfortunately, suggesting an answer to this question involves *all three* topics whose discussion was effectively forbidden for most of the 20th century, namely:

- metaphysics study of most basic general features of reality and our place in it[†].
- the study of conscious experience
- interpretation of quantum mechanics and of relativity

Though eyebrows may still be set in motion by these topics, one is no longer - in the 21st century - generally assumed to be a *gibbering lunatic* on asking such questions (well, maybe sometimes). Bohm may have been the right man in the wrong time..

Note all these topics very difficult when considered *separately*! Bohm nevertheless advocated a *joint* approach since while it seems clear mind must be based on post-classical physics, the post-classical physics we have does not provide us with a commonly accepted coherent notion of matter. Thus he looks for a more fundamental ontology - with the emphasis on understanding, not prediction and control.

†Most physicists think 'metaphysics' is a term of abuse implying fanciful speculation or mysticism.. 🧐



Mind and matter

How do we understand nature of mind and its relationship to matter?

Mind and matter seem very different in their basic qualities and yet they seem intimately related, so much so that many have tried to reduce mind to matter, suggesting mental processes identical with some neurophysiological processes in the brain.

This attitude has some problems, since conscious experience has many features that seem very different from objective neurophysiological processes:

- Qualitative character of conscious states ('raw feels' or qualia taste of Cavendish canteen coffee)
- Subjectivity (only you have direct access to your inner conscious states such as experience of pain)
- Meaningfullness, or 'intentionality'. How can anything mean anything to anything in a purely physical system?
- Experiencing. We are conscious that 'experiencing' goes on, but what is it and how does it arise? How can objective physical processes give rise to experiencing, which at least *seems* to be something altogether different from objective physical processes?

Obvious that 'experiencing' correlated with neural processes, but not at all obvious that it is *nothing but* neural processes. In fact it seems clear that experiencing *cannot* be identical with sorts of mechanical neurophysiological processes that modern neuroscience talks about.

Why should mechanical interaction between physical parts (neurons) make you conscious? (I say 'mechanical' since almost all neuroscience is done implying neural processes that obey classical physics). If given mechanical components structurally equivalent to neurons and bind them together in functionally equivalent way, will this artificial system be conscious? It seems obvious that it will not.

Other difficult issues in consciousness

The problem of mental causation

Mind seems to be very different from matter, but also seems obvious that our mental states - both conscious or unconscious - influence behaviour of our body. How are we to make sense of this influence?

For example if minds are not described by the laws of physics, should laws of physics be modified to allow for causal influence of minds upon bodily behaviour?



Phenomenonal structure of conscious experience

'Phenomenonal organization' covers all kinds of order and structure found within domain of experience i.e. within domain of world as it appears to us. Richer concept than 'raw feels' (qualia): involves not only sensory ideas and qualities but complex representations of time, space, cause, body, self, world and organized structure of lived reality in all its conceptual and nonconceptual forms.

The **temporal structure of conscious experience** is particularly interesting. Usual view of time says only present and what is in it exists. But for example how can we then - when listening to music - *perceive*, as opposed to just remember, a structure that includes notes heard a little time ago and anticipates perception of future notes? The previous notes - according to the usual view of time - no longer exist. We nevertheless perceive melody as a whole structure that is in some sense 'timeless'.

One of Bohm's ideas attempts to explain this 'time consciousness'.

Mental strategy



How will we get to the relationship between mind and matter?

- 1. First describe the notion of implicate order as it applies to matter...
- 2. .. then consider how it applies to mind.
- 3. Note implicate order framework needs to be extended to provide better view of relationship between mind and matter.
- 4. Consider Bohm's notion of *soma-significance* as one such extension.
- 5. Finally consider how *pilot-wave theory* can be used to extend implicate order framework to provide a better mind-matter theory.

Quantum theory and the mechanistic order

Recall notion of mechanistic or Cartesian order, which assumes world is:

- constituted of entities (particles and/or fields) which are *outside* of each other, in sense that
- they exist independently in different regions of space (and time) and
- interact either via direct push and pull or else through forces that do not bring about any changes in their essential natures.

Clearly emphasizes *external relationships* between things. May sound obviously correct - usually presupposed in neuroscience - but modern physics challenges this as fundamental description; suggests non-mechanical or more holistic order more appropriate. Bohm liked to use the following metaphor:

"The machine gives a typical illustration of such a system of [mechanistic] order. Each part is formed (e.g. by stamping or casting) independently of the others, and interacts with the other parts only through some kind of external contact. By contrast, in a **living organism**, for example, each part grows in the context of the whole, so that it does not exist independently, nor can it be said that it merely 'interacts' with the others, without being essentially affected in this relationship." D. Bohm (1980)

QM (discontinuities, wave particle duality, and nonlocality) seems to require fundamentally a holistic rather than a mechanistic concept of reality. Experimental results clearly suggest there is *internal relationship* between electron and its environment, or between two electrons in non-local relationship.

Familiar macroscopic reality obeys principles of mechanistic order - with external relationships - but only approximately. In more accurate description, new holistic order seem to prevail. What kind of holistic order? Bohm set out to find out - led him to notion of *implicate order*.

Interview IV

"Then there was his theory of the implicate order. The world we seem to live in - the world of classical objects, the world of Newtonian physics - Dave referred to as the 'explicate order.' He felt that what we take for reality is only one particular level or perception of order. And underneath that is what he called the 'implicate order,' the enfolded order, in which things are folded together and deeply interconnected, and out of which the explicate order unfolds. The explicate is only, you could say, the froth on top of the milk and the implicate order is much deeper. It includes not only matter, but consciousness; it's only in the explicate order that we tend to break them apart, to see them as two separate things. Dave spent a great deal of time in the last decades of his life trying to find a mathematical expression for this vision of reality." F. David Peat

Bohm's philosophical problem

- For Bohm, discontinuous quantized movement, context-dependent form, and non-local action require new holistic order that both incorporates and goes beyond the order of mechanism.
- He believed requirement for this order understood by majority of physics community only via highly abstract mathematical algorithms, with little or no concern for what these rather shocking assaults on common sense might *mean*. As we have seen, instrumentalists maintain that any search for meaning or structure is in fact pointless.
- Thus the three quantum discoveries with their potentially vast implications are shoehorned into a tacit metaphysical commitment to mechanism, in spite of the fact that such a commitment is philosophically inconsistent with experimental fact.

Implicate order

Basic idea: "the whole universe is in some way enfolded in everything and each thing is enfolded in the whole. This implies that in some way, and to some degree, everything enfolds or 'implicates' everything. However, this takes place in such a manner that under typical conditions of ordinary experience, there is a great deal of relative independence of things."

So we propose the whole is in a deep sense internally related to the parts. Since the whole enfolds all the parts, the parts are internally related to each other, though in a weaker way than they are related to the whole.

Implicate order: where everything is enfolded into everything else.

Explicate order: where things are unfolded in the sense that each thing lies in its own particular region of space (and time). This is what you see.

Concepts of *unfoldment* characterises processes in which the explicate order becomes relevant, and *enfoldment* when it is ploughed back into the implicate order.

For the moment these ideas are best illustrated with *analogies* (Bohm had several favourite ones). Beware these analogies are all flawed in one way or another - usually by having some *mechanistic* explanation. They do no more than *hint at* overall conception. Important to 'kick away the ladder' afterwards!

Night sky analogy



Idea of 'enfoldment' of the whole universe in each part (Blake poetry, anyone?) may seem counterintuitive, exotic and strange.

But enfoldment is taking place in a wide range of domains, and actually right there in front of you.

Think of small region of space in front of your eye. In this region, there is a movement of electromagnetic waves that carries the information you use as the basis for constructing your visual experience. This movement somehow contains or 'enfolds' information about the whole room..

..or if you happen to be on top of a mountain on a clear night - maybe drawing on a cigarette - watching the night sky, then the movement contains or 'enfolds' information about the whole universe of space and time. This enfolded information is then *unfolded* by the lens of your eye, and later in a very complex process by your brain, resulting, when combined with information supplied by your brain, in your visual experience of a three-dimensional world with objects in it[†].

Just as light waves in a small region can enfold information about the whole universe, so the waves that underlie each 'elementary particle' can similarly enfold information about the whole universe.

† Of course we do not really understand how the objective physiological process becomes a conscious visual experience - we shall discuss that problem later.





Hologram analogy

Draws our attention to undivided wholeness.. where the whole is in some sense contained in each part and each part is enfolded throughout the whole.



Each part of a hologram contains information about the whole object in such a way that there is no point-to-point correspondence of object and recorded image (unlike a *lens*). The hologram records interference pattern of light waves that come off an object. Form and structure of entire object can thus be said to be *enfolded* within each region of photographic record. When you shine light on any region, this form and structure are then *unfolded*, to give recognizable image of whole object again.



If hologram torn in half and light passed through new halves then still see whole object albeit with some loss of overall definition.

So hologram helps to illustrate idea of implicate order in a sensibly perceptible way, but in the end it is only an instrument for making a *static record* or snapshot of this order.

This idea is scientifically respectable, just like warp drives and stuff; it must be since it's in New Scientist (see 'Our world may be a giant hologram!!', January 2009) though interestingly everyone seems to have forgotten Bohm thought of it first.. See also 'Information in the Holographic Universe', J.D. Bekenstein, Scientific American, August 2003, and 'The Illusion of Gravity', J. Maldacena, Scientific American, November 2005. Even the string theorists like it (see 't Hooft and Susskind's 'Holographic Principle' on Wikipedia.)

Cubes



A Necker cube

A hypercube

- Viewing Necker cube gives a very good intuitive sense of an implicate order, in this case a *perceptual* implicate order. Generally speaking it is only possible to perceive one of the two possible cubes at a time while one is enfolded in perception (an implicate order), the other is unfolded in perception (an explicate order).
- This phenomenon is significantly amplified when one views the hypercube many possible geometric orders remain enfolded in perception (a complex implicate order), while only one is unfolded at any given moment (an explicate order).

Propagators and the implicate order







As we remarked in Lecture 6, Bohm used to discuss the implicate order and his concepts of enfolding and unfolding in terms of **propagators** (Green's functions for the Schrödinger equation) which in pilot-wave theory we can compute using a single quantum trajectory.

Laws of movement in QM correspond to *enfoldment* and *unfoldment*. In particular, relation between wave function at one time and its form later determined by propagator or Green's function K through $\Psi(\mathbf{x}, t) = \int K(\mathbf{x}, t; \mathbf{x}', t') \Psi(\mathbf{x}', t') dx'$. Simple picture of movement is that waves from whole space enfold into each region and waves from each region unfold back into whole space. Propagator ultimately derived from Cartesian order by solving differential equations. But if we question this order holds fundamentally can adopt view that propagator is more basic than the differential equation.

See Bohm and Hiley's "The Undivided Universe", p.354.

Nonlocality and entanglement in the implicate order



In Bohm-speak, entangled particles apparently remain in contact regardless of separation not because of 'signalling' but because their separateness is an illusion. The particles are not individual entities but are extensions of a fundamental something in the implicate order.

"Imagine a fish swimming in an aquarium. Imagine also that you have never seen a fish or an aquarium before and your only knowledge about them comes from two television cameras - one directed at the aquarium's front and the other at its side. When you look at the two television monitors you might mistakenly assume that the fish on the screens are separate entities. After all, because the cameras are set at different angles, each of the images will be slightly different. But as you continue to watch you will eventually realize there is a relationship between the two fish. When one turns, the other makes a slightly different but corresponding turn. When one faces the front, the other faces the side, and so on. If you are unaware of the full scope of the situation, you might wrongly conclude that the fish are instantaneously communicating with one another, but this is not the case. No communication is taking place because at a deeper level of reality, the reality of the aquarium, the two fish are actually one and the same." [Bohm]



The ink-in-fluid device

Impossible to read about Bohm without encountering this damned device, but still.. Tank made of two concentric glass cylinders filled with viscous fluid (glycerine). Place drop of ink in fluid (negligible diffusion). Turn outer cylinder slowly; fluid elements at large radii move faster than those at small radii and so droplet drawn out into fine thread that eventually becomes invisible. Turn outer cylinder in opposite direction, and drop reforms.

So we have localized 'unfolded' entity (drop containing ink particles) which can become 'enfolded' and this is reversible. Thus have distinguishable set of elements (ink particles) which retains its identifiability even in the enfolded state (imagine separate red and blue drops - enfolded particles intermingle apparently at random but can still reconstitute separate drops).

- In general any object can exist in either explicate (unfolded) mode or implicate (enfolded) mode (different 'ways of being'). Implicate resembles 'potentiality' while explicate resembles 'actuality'.
- **Pre-existent explicate order**: add *N* drops in line, turning enfolds entire linear order into fluid.
- Intrinsically implicate order: Add drop (colour A), turn cylinder N times. Add second drop (colour B) at same place, turn N times. Repeat. When reverse motion, ensembles successively come together to form droplet in order D,B,C,A.. In general when any one is unfolded, rest are still enfolded. Have an order that can't be made explicate all at once which is nevertheless real..
- Motion: Add drop A, turn. Add drop B in *slightly different position*, turn. Repeat. Reversing, apparently see 'particle' moving continuously.

Only analogy - device has mechanical explanation, but illustrates some features going beyond mechanistic order (kick away ladder i.e. glycerine!).

Implicate order as fundamental architecture of matter

- Instead of focussing on relationships of unfolded elements in explicate order (particles and/or fields) should explore relationships between enfolded structures in the implicate order. What happens in observable arena of explicate order determined by relationships at level of implicate order. Currently physics concerned with explaining regularities in nature at level of explicate order only.
- Think of electron as set of fields in movement of unfoldment and enfoldment. Electron is *total set* of enfolded ensembles which are generally not localized; the continued existence of a particle can be approximated by a rapid recurrence of similar forms.
- Unfoldment-enfoldment is more fundamental mode of existence, while continuous existence as a particle is something attributed for convenience in situations where order of unfoldment is recurrent and stable. Can account for central non-mechanistic features of quantum phenomena i.e. discontinuity of movement, wave particle duality, non-locality.

Analogy of implicate order with living matter

"When inanimate matter is left to itself the above-described enfoldment and unfoldment just reproduces a similar form of inanimate matter, but when this is further 'informed' by (say) a seed, it begins to produce a living plant instead."

- Parts of living organism *internally related to each other* (each part grows in context of whole no independent existence). In this context life defined as particular kind of 'well-informed' process of unfoldment and enfoldment. No fundamental difference between inanimate/animate matter; difference is rather in nature of enfoldment and unfoldment which is fundamental to both.
- No separation of mind and matter (Descartes' *res extensa/res cogitans*) anymore different aspects of same thing. Implicate order typically involves co-presence of elements or ensembles of elements at different degrees of enfoldment seems relevant to problem of 'time-consciousness' (later).

Living matter and back-action

In certain dark corners of the internet, can find speculation of the following nature:

- Propose the wave function/pilot wave is intrinsically 'mental' and capable of qualia.
- Equate the pilot wave with the mental aspect of the universe, generally: the particles are 'matter', and 'mind' the pilot wave.

OK, who cares, except..

- 'Mental' aspect of universe upgradeable to life/consciousness by *self-organization*. Happens when a physical system uses its own nonlocality in its organization.
- In this case a feedback loop is created, as follows: system configures itself so as to set up its own pilot wave, which in turn directly affects its physical configuration, which then affects its non-local pilot wave, which affects the configuration etc..
- Normally in QM this 'back-action' is not taken into account. The wave guides the particles but back-action of particle onto wave not systematically calculated. Of course, the back-action is physically real since particle movement determines initial conditions for next round of calculation. But there is no systematic way to characterize such feedback. One reason this works in practice is that for systems that are not self-organizing the back-action may not exert any systematic effect.

Well, it's not obviously wrong..!

[see p.346, Bohm and Hiley's Undivided Universe).]

Holomovement

Implicate order not static but basically dynamic in nature, in a constant process of change and development. Thus Bohm called its most general form the holomovement.



"All things found in the unfolded, explicate order emerge from the holomovement in which they are enfolded as potentialities, and ultimately they fall back to it. They endure only for some time, and while they last, their existence is sustained in a constant process of unfoldment and re-enfoldment, which gives rise to their relatively stable and independent forms in the explicate order." [Bohm, 1990]

- Term 'holomovement' describes *totality of movement of enfoldment and unfoldment*. It is a general metaphysical or ontological concept that goes beyond what is observed today. Characterizes physical reality at a fairly fundamental level movement *per se* is fundamental and gives rise to the essential properties of fields.
- Essential qualities of fields exist only in their movement. It is not that there is a field with some essential qualities, which then may or may not move. Rather, it is movement that is more fundamental, and the essential qualities (whether those of fields or particles) are derivative.
- Bohm thus suggests inanimate matter, life, and consciousness all of which have their ground in the holomovement have a similar *causal architecture*.

The algebra of process

How can we represent the implicate order scheme mathematically? One suggestion is in terms of *non-commutative algebra*.

- In QM cannot construct exact phase space in *x* and *p* as we can in classical mechanics; main novel mathematical feature is non-commutative structure of its algebra of operators. If regard eigenvalues as labelling properties of things, non-commutativity does not seem to make any sense (e.g. objects should have position and momentum simultaneously but in QM they do not).
- However, we see some features of the implicate order: measurement simply makes manifest one particular partial view of nature and it is not possible to make manifest all aspects of reality in one single universal picture. Different measurements produce different explicate orders; structure of underlying implicate order captured by the algebra.
- Basic underlying assumption of this general approach is that the ontology is based on *process*, a process not explicitly describable. Can only be described implicitly (hence 'implicate order'). The implicate order is a structure of relationships, and this order of structures is described by an algebra, the *algebra of process*. This process only allows partial views because nature is basically *participatory*.
- The ink-in-fluid machine has the advantage of suggesting how we may describe the evolution of process mathematically without the need of a space-time manifold. 'Tracks' can be understood as the evolution of a quasi-stable form, evolving within the unfolding process.

Quantum algebraic approach beyond scope of the course but very interesting! See the following:

Non-commutative geometry, the Bohm interpretation, and the mind-matter relationship, B.J. Hiley (2000).

Non-commutative quantum geometry: a reappraisal of the Bohm approach to quantum theory, B.J. Hiley (2005).



Bohm's views on mind

Bohm believed implicate order concept applies even more directly and obviously to mind than it does to matter. In the mind, he says, there is:

"...a constant flow of evanescent thoughts, feelings, desires and impulses, which flow into and out of each other, and which in a certain sense, enfold each other (as, for example, we may say that one thought is implicit in another, noting that this word literally means 'enfolded'). "

- Bohm concerned with order prevailing in this 'constant flow' (the 'stream of consciousness'). If assume only explicate order prevails in the mind, then natural to think that thoughts, feelings etc. are some sort of separate entities in mechanical interaction. Limited domain of applicability however as our thoughts flow into and out of each other. Suggests some kind of *enfoldment* and *unfoldment* are primary processes taking place in stream of consciousness.
- Seems implicate order prevails as primary order of thoughts, feelings, desires etc.. However in certain kinds of phenomenal consciousness, such as the visual experience of a static scene, it seems that the explicate order dominates.
- But there are aspects of even phenomenal consciousness where implicate order prevails. In particular, structure of conscious experience over a period of time (recall analogy with listening to music). Usual mechanistic view of time says only things in explicate order at present instant exist, and other things (e.g. notes heard some time ago) don't exist anymore. With notion of enfoldment Bohm allows for new kind of existence. Past notes can exist as enfoldments, as active tranformations of original notes, and in this way can be present and perceived in conscious experience.

Soma-significance

Implicate order is general framework potentially helpful in removing gulf between mind and matter, but it "lacks a well-defined set of general principles that would determine how the potentialities enfolded in the implicate order are actualized as relatively stable and independent forms in the explicate order." Nor does it have such a set of principles on the mental side, in particular no clear idea of just how mental and material sides are to be related. Necessary to extend implicate order framework.

Bohm's first attempt at this is a general theoretical notion called '*soma-significance*'. (*Soma* = Greek word for body \Rightarrow *somatic* = 'Of, relating to, or affecting the body, especially as distinguished from a body part, the mind, or the environment; corporeal or physical.').

Basic idea: Matter and meaning are not separate entities, but rather aspects of one overall reality. Thus each particular significance or meaning is always based on some somatic order, arrangement, connection, and organization of distinguishable elements.

Further suggestion: Reality (though strictly speaking an undivivided totality or 'holomovement') can for convenience be thought of as constituted out of relatively autonomous levels organized into a hierarchy. There are manifest levels ('matter') and there are more subtle levels ('mind') and each level has a somatic side and a significant side. Think of relation between levels as bidirectional process:

Soma-significant refers to process in which significance of a particular somatic order is carried over to higher levels, sometimes resulting in an apprehension of meaning in consciousness. Similar to 'enfoldment' i.e. information is gathered from the world and enfolded.

Signa-somatic refers to reverse process in which significance that is apprehended acts 'downwards' and organizes the less subtle levels i.e. on apprehension the meaning of the information is 'unfolded', and as it unfolds it can have an effect upon lower levels.

Nowhere is there anything 'purely physical' or 'purely mental'.

The role of pilot-wave theory

- Soma-significance notion does not say how manifest levels (explicate order) arise from subtle levels (implicate order). And is it plausible that, say, matter at quantum level has a significant side?
- Bohm suggests *pilot-wave theory* goes even further in extending implicate order in way required (i.e. gives better view of how potentialities are actualized, and how mind and matter are related). Also provides way of making notion of soma-significance more specific at quantum level of matter.
- For example, apply PWT to electromagnetic field; explicate order is the photon now seen as a momentary particle-like manifestation, rather than as a continuously existing particle.
- According to PWT, individual quantum system (e.g. electron) always combination of a particle aspect and a field aspect, and field exerts a 'force' on the particle (describable in terms of 'quantum potential' $Q = -\sum_{i} \frac{\hbar^2}{2m_i} \frac{\nabla_i^2 |\Psi|}{|\Psi|}$ if you like).
- Striking point: effect of field on particle only depends on *form* of field unusual since effect of other fields in physics depend on field *intensity*. What does this mean? Bohm says look at field as containing *information* that literally *informs* or puts form into energy of particle ⇒ new notion of active information. General concept referring to situation in which a form carrying very little energy enters into and directs a much larger energy.
- Active information examples: form of DNA molecule active in shaping growth of organism; form of radio waves informs energy of radio receiver so we hear sound; form of radar waves guides movement of a ship; information in a computer acts with various consequences, etc.
- Information content in conscious thought constitutes subtle level of information that acts signasomatically 'downwards' in hierarchy of levels, ultimately reaching quantum level of information. This in turn acts on particles (ions in synapses) or electromagnetic field (e.g. in dendrites). Effects can be amplified and result in more classically describable process (e.g. you kick a sleeping student).

Two-way traffic

Important to note that pilot-wave theory does not take into account any effect of individual particle on its own quantum field (though Bohm and Hiley briefly sketch some ideas about how this might happen, see e.g. Undivided Universe pp. 345-346).

- Idea that particles collectively affect quantum field of a single particle is contained in the standard notion that shape of quantum field of a particle is determined by shape of environment (which consists of many particles, and is part of the boundary conditions put into the Schrödinger equation before solving it, even in conventional QM).
- Celebrity nutjob Jack Sarfatti (see e.g., er.. www.stardrive.org) in particular has emphasized the need for an explanation of how the individual particle influences its own field and has proposed mechanisms for such 'back-action', also emphasizing its importance in understanding the mind-matter relationship and how consciousness arises (see earlier slide).
- Assuming that notion of such an influence of the particle on its field can be coherently developed, we can then have *two-way traffic* between the mental and the physical levels without reducing one to the other. Role of Bohm's model of the quantum system then would be that it provides a kind of *prototype* that defines a more general class of systems in which a field of information is connected with a material body by a two-way relationship.
- Quantum theory is currently our most fundamental theory of matter and Bohm suggests that, when ontologically interpreted, it reveals a *proto-mental* aspect of matter. This is the quantum field, described mathematically by the wave function, which is governed by the Schrödinger equation. Bohm's suggestion is known as *panprotopsychism*.. so at least you learned a new word today..!

Architecture of consciousness and the process of thought

'Mind' can thus be seen as a fairly subtle level in the brain, with an internal relationship to the whole universe (through the implicate order). But like all levels, this level has both physical and mental aspects. Bohm assumed that - for 'mind' - physical aspect very subtle (more subtle than the quantum field - while in some respects similar to it). Important point that mind still assumed to have physical aspect - can thus influence other such levels (e.g. already known neural levels). Might sound facile in some ways, but stating things in this way avoids usual philosophical traps (dualism, idealism, reductive materialism - look them up..).

- 'Intelligence' for Bohm is ability to respond coherently to new situation. We act always on basis
 of certain level of understanding, related to our tacit and explicit knowledge (i.e. information
 content). When we encounter new situation, may not be able to respond adequately from our
 current information content. The activity of intelligence thus typically means that we 'survey' our
 existing mental activities and see if we can go beyond them.
- 'Hard problem of consciousness': How is an experiencing physical system possible? Why should a purely physical or neurophysiological process, however complex a computation it may be implementing, have consciousness associated with it?
 - In pilot-wave scheme, conscious experience involves interplay between explicate and implicate orders. Explicate order of one's visual experience unfolds from overall implicate order prevailing in the various levels of the brain/mind. One possibility is that unfolded, explicate order is somehow apprehended or surveyed by some more subtle level of activity at more implicate levels, and that conscious experience arises from such apprehending.

Seems clear Bohmian universe is more 'consciousness friendly' than mechanistic universe of classical physics and contemporary neuroscience. And with a better framework, who knows what might happen?

There's more..



That concludes our (inevitably) brief survey of Bohm's ideas regarding the implicate order concept. There is of course a large literature.. The best survey to read is Paavo Pylkkänen's *Mind*, *Matter*, *and the Implicate Order* (2007), available at a good book store near you.



Paavo Pylickänen received his masters degree from the University of Sussex and his doctorate from the University of Helsinki. He was an Academy of Finland researcher 1990–1995 and became associate professor in theoretical philosophy at the University of Skövde, Sweden in 1996. Since 2001 he has also been an adjunct professor at the Department of Philosophy, University of Helsinki. He lives in Stockholm.

Opinion Poll (second chance..)

In this course we shall claim that all the interpretative problems raised in non-relativistic quantum mechanics are essentially solved by the *pilot-wave approach*.

What is your current opinion on pilot-wave theory? (a.k.a. *de Broglie-Bohm theory*, *Bohmian mechanics*, the *causal* or *ontological interpretation of QM*).

- A: I have never heard of it.
- B: I have heard of it and..
 - B1: ...believe it is the best available formulation of non-relativistic QM.
 - B2: ...believe is interesting and stands equal with one or more other formulations.
 - B3: ...believe while internally self-consistent it is pointless metaphysical speculation.
 - B4: ..understand that it has been shown to be incorrect or impossible.
 - B5: ...don't know enough details to have an opinion.
 - B6: ...have come to this lecture course just to have fun and slag off Mike.

B7: ..am a paid assassin sent by the orthodox physics inquisition to torture and liquidate everyone who attends this filthy heretical course. Viva Bohr!

Peat interview: final thought

Picking up a thread we left behind, having more to do with your own perception of things: For you, what is the most important thing in life?

"Hmm... An easy question! The most important thing in life... You know, maybe I don't think about it. Maybe I don't think about that sort of thing. I mean, it's been nice finding a village on a hilltop [in Italy], surrounded by beauty, where people live in a sort of traditional way, where you can lead a life that's balanced - a little bit of walking, good food, warmth. And, I suppose, being able to express yourself creatively, maybe that's the important thing - whatever it might be, writing or painting or doing something. And having relationships with people...

I don't know. I don't know. It's not something that worries me. Maybe if it worried me I wouldn't be doing this. In the past I was more worried about things. Maybe I'm not worried at the moment... but nothing lasts forever!"



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End of the course

I hope you've enjoyed it!



Of course I agree with Peat's sentiment about 'finding a village on a hilltop in Italy'. In the future I hope to have some events focussed on Quantum Foundations at my monastery in Vallico Sotto - see the web page at www.vallico.net/tti/tti.html. Let me know if you would like to be involved, or if you have any suggestions along these lines. Sammy, Saska and I would be happy to welcome you.

Any questions, comments, or suggestions - please email me at mdt26@cam.ac.uk

P.S. Thanks to the girls for their infinite patience while I was typing all these damned slides..

Some points for discussion

- 1. Did you enjoy the course? If so, why? If not, why not..?
- 2. This was a very experimental course, and I was not able to get it listed on the list of offical graduate lectures. There is in fact a tremendous resistance to this sort of thing being taught at all. Do you think graduate students should be taught about quantum foundations?
- 3. I concentrated on pilot-wave theory for reasons that I have repeatedly outlined. Do you think I should have been 'fairer' and given equal treatment to all the various alternatives?
- 4. What is your favourite interpretation/formulation of QM?
- 5. Why is pilot-wave theory a complete load of rubbish/a wonderful revelation (delete as appropriate)?
- 6. Do you think Bohm's metaphysical speculations about the implicate order and so forth (which go beyond the basic pilot-wave theory) have any value?
- 7. Anything else..