HYLOMORPHIC FUNCTIONS

ANTONY VAN DER MUDE

Abstract. Philosophers have long pondered the Problem of Universals. Socrates and Plato hypothesized that the Universals exist independent of the real world in a universe of their own. The Doctrine of the Forms was criticized by Aristotle, who stated that the Universals do not exist apart from things — a theory known as Hylomorphism. This paper postulates that Measurement in Quantum Mechanics is the process that gives rise to the instantiation of Universals as Particulars, a process we refer to as Hylomorphic Functions. Measurements of fundamental properties of matter are the atomic Universals of metaphysics. These atomic Universals in turn combine to become the whole range of Universals. This leads to a type of metaphysical Realism. We look at this hypothesis in relation to two different interpretations of Quantum Mechanics. The first is the Copenhagen Interpretation, which we consider a version of Platonic Realism based on wave function collapse. The other interpretation is Pilot Wave Theory of Bohm and de Broglie, where particle–particle interactions take the place of measurement, leading to an Aristotelian metaphysics. This interpretation of metaphysical realism makes the instantiation of Particulars a physical process grounded in Quantum Mechanics. This view of Universals explains the distinction between pure information and the medium that instantiates it, the arrow of time and the existence of qualia.

1. Introduction

In contemporary research on the relationship between Quantum Mechanics and Metaphysics, the analysis of ontology mostly focuses on objects that have a physical reality. This leaves out the nature of Universals. As an example, Allori [2] analyzes which components of Quantum Mechanics form a primitive ontology but excludes the mathematical objects from consideration:

> Why the qualification ”primitive ontology,” instead of just ”ontology” simpliciter? First, the idea is that the primitive ontology does not exhaust all the ontology — it just accounts for physical objects. Other things might exist (numbers, mathematical objects, abstract entities, laws of nature, and so on), and some of them (like natural laws) might be described by other objects in the ontology of a fundamental physical theory.

It is fair to ask if the abstract entities can be considered to be part of a primitive ontology in their own right. If the distinction is to be made between physical objects and abstract entities such as mathematical objects, the question arises: where are abstract objects found in reality — if at all — and regardless, how do they interact with the physical objects?

John Stewart Bell, in his article entitled “The Theory of Local Beables” [5] makes the distinction between beables and observables, where observables are objects derived from the beables and beables are entities that have a physical existence. He questions the physical reality of observables, in that he thinks that the beables form a primitive ontology from which the observables can be derived:

> The concept of ‘observable’ lends itself to very precise mathematics when identified with“self–adjoint operator” But physically, it is a rather woolly concept. It is not easy to identify precisely which physical processes are to be given status of ’observations’

> and which are to be relegated to the limbo between one observation and another. So it could be hoped that some increase in precision might be possible by concentration on the beables, which can be described in 'classical terms', because they are there. The beables must include the settings of switches and knobs on experimental equipment, the currents in coils, and the readings of instruments. 'Observables' must be made, somehow, out of beables. The theory of local beables should contain, and give precise physical meaning to, the algebra of local observables.

These observations relate to one of the most important topics of metaphysics and ontology that deals with abstract objects: the Problem of Universals. This is the question of how universal concepts come to be associated with the different objects of reality. The notion of Universals — sometimes known as Forms — came from Aristotle's teacher Plato and Plato's teacher Socrates. This question also applies to mathematics: why 1 plus 1 always equals 2 is a question of Universals. There have been many viewpoints related to Universals through history (Realism, Conceptualism, Nominalism, for example) but we shall be primarily concerned here with metaphysical Realism.

When it comes to the ontology of mathematics, Plato's Doctrine of the Forms was updated for arithmetic in what has been referred to as Mathematical Platonism [13]. Mathematical Platonism maintains that the objects of mathematics, such as numbers, exist in an ideal world independent of time and space, separate from their individual instantiations in reality. This theory does not have all of the properties of classical Platonism, but it does postulate a separate realm of existence for the

Universals. This viewpoint was originally expressed in the modern form by Frege, especially in his book“The Foundations of Arithmetic” [21]. For a discussion of Frege’s Platonism, see Reck [44]. Other famous mathematicians such as Kurt Gödel have expressed a Mathematical Platonism [43].

Aristotle gave an alternative to Platonism. In his Metaphysics [3], he analyzed the Doctrine of the Forms, and concurred with Plato in the belief that the Forms are real: they provide a conceptual framework that we use to understand the objects of reality, and these concepts exist in their own right. But he had criticisms of the doctrine as Plato described it. The idea that the Forms exist in a separate plane of existence leads to questions about how the world of Forms and the world of reality interact. The Metaphysics ends with some arguments applied to mathematical objects in particular. Aristotle discusses the relationship between the mathematical Forms and reality, and the question of their independent existence. He concludes:

> And it is evident that the objects of mathematics do not exist apart; for if they existed apart their attributes would not have been present in bodies. [Book N, Section 3]

That means that the Forms do not exist apart from things. So Aristotle has an ontology whose existence is different from that of Plato and later Frege. Although he acknowledges the existence of Universals — ideal Forms — they do not have a separate existence in an ideal world.

The idea that the Forms do not exist apart from things has been termed Hylomorphism, from the concept hylo — wood or matter — and the concept morph — form or spirit. This terminology arose out of the Nineteenth Century’s appreciation of St. Thomas Aquinas' analysis of Aristotle's thought as it applied to Christian philosophy [38].

Although metaphysical Realism has gone through many stages of development, the groundwork was laid in Platonic Realism and Aristotle's Metaphysics. We shall use these two alternatives as the basis of discussion of the Problem of Universals in Quantum Mechanics.

2. Universals as Abstract Objects

First, we need to define what a Universal is.

E.J. Lowe describes Universals versus Objects as follows [35]:

> Objects are entities which possess, or 'bear', properties, whereas properties are entities that are possessed, or 'borne' by objects. Matters are complicated by the fact that properties can themselves possess properties, that is, so–called 'higher–order properties' as, for example, the property of being red, or redness, has the second–order property of being a colour–property. In view of this, one may wish to characterize an 'object' more precisely as being an entity which bears properties but which is not itself borne by anything else.
>
> ...
>
> An object is a property–bearing particular which is not itself borne by anything else: in traditional terms, it is an individual substance. A Universal (at least, a first–order Universal) is a property conceived as a "repeatable" entity, that is, conceived as something

> that may be borne by many different particulars, at different times and places.

So, in this viewpoint entities do not necessarily have a physical existence — there can exist abstract entities. Universals are such entities. Universals, in that they do not refer to a single object are sometimes termed “Abstract Objects” [34]. Lowe gives three main conceptions of abstract objects. First, an abstract object is an object that does not have a specified space–time location. The second conception is that an abstract object does not exist by itself, but is an abstraction of one or more concrete objects. Either of these two conceptions lead to some problems. The non–spatial description of abstract objects leads to problems in an attempt to arrive at a hylomorphic characterization of Universals that ties them to the physical things that an instantiation of a Universal refers to. The “morphic” aspect of a Universal may be without coordinates, but the “hylo” instantiation does involve the coordinates of any number of concrete objects that exemplify this property, even though each instantiation is different. The second concept is problematic as an attempt to establish a metaphysical realism for the Universals, since this implies they have no causal power – they lack the ability to enter into causal relationships. This viewpoint does not adequately specify how abstract and concrete objects are related.

Lowe credits Frege with the third major conception of abstract objects through the use of equivalence relations. Hale and Wright describe it this way [25]:

> Standardly, an abstraction principle is formulated as a universally quantified biconditional — schematically: $(\forall a)(\forall b)(\Sigma(a) = \Sigma(b) \iff E(a,b))$, where a and b are variables of a given type

(typically first- or second–order), Σ is a termforming operator, denoting a function from items of the given type to objects in the range of the first–order variables, and E is an equivalence relation over items of the given type.

Frege gives an example [21] in terms of the concept of parallel lines. Line a is parallel to line b if the directions of the two lines are identical. The two lines qua lines each have a direction, and the directions are the same: $Dir(a) = Dir(b) \iff a$ and b are parallel. This way of considering abstract objects applies naturally to numbers. Frege, citing a principle of Hume, then describes the concept of number through this type of equivalence relation: The number of F's = the number of G's if and only if there are just as many F's as G's.

The first two definitions are not as easy to relate to the mathematical formulation of quantum mechanics, whereas the equivalence relation gives a mathematical definition. Although all three definitions have their critics and detractors, the relational definition shall suffice for the purposes of this paper.

This gives us a notion of an abstract object in terms of a functions. A Universal, in accordance with Frege, is a function U from a domain D to a range R where the equivalence relation E is as follows: for any two elements of $x, y \in D$, xEy is true if and only if $U(x) = U(y)$. In accordance with the discussion above a *Property* could refer to either a Universal or an instantiation of a Universal. In what follows, I will use the term *Particular* to refer to an element of a set $r \in R$ that is the range of a given Universal, and *an instantiation of a Universal* to refer to some application of the Universal that yields a Particular: $U(x) = r$. The term *Property* will be limited to referring to the instantiation of the Universal — in effect, a Property refers to one of the equivalence classes defined by the Universal.

In discussing metaphysics in relation to quantum mechanics, the entities under consideration are often limited to those which have a physical existence. This is referred to as a "primitive ontology". Allori [2] describes the primitive ontology this way:

> The main idea is that all fundamental physical theories, from classical mechanics to quantum theories, share the following common structure:
>
> (1) Any fundamental physical theory is supposed to account for the world around us (the manifest image), which appears to be constituted by three–dimensional macroscopic objects with definite properties.
> (2) To accomplish that, the theory will be about a given primitive ontology: entities living in three–dimensional space or in space–time. They are the fundamental building blocks of everything else, and their histories through time provide a picture of the world according to the theory (the scientific image).
> (3) The formalism of the theory contains primitive variables to describe the primitive ontology, and nonprimitive variables necessary to mathematically implement how the primitive variables will evolve in time.

> (4) Once these ingredients are provided, all the properties of macroscopic objects of our everyday life follow from a clear explanatory scheme in terms of the primitive ontology.
>
> Thus in this sense the primitive ontology is the most fundamental ingredient of the theory. It grounds the "architecture" of the theory: first we describe matter through the primitive variables, then we describe its dynamics, implemented by some nonprimitive variables, and that's it. All the macroscopic properties are recoverable. This summarizes the explanatory role of the primitive ontology. This is also connected with the "primitiveness" of the primitive ontology: even if the primitive ontology does not exhaust all the ontology, it makes direct contact between the manifest and the scientific image. Because the primitive ontology describes matter in the theory (the scientific image), we can directly compare its macroscopic behavior to the behavior of matter in the world of our everyday experience (the manifest image). Not so for the other nonprimitive variables, which can only be compared indirectly in terms of the ways they affect the behavior of the primitive ontology.

In contrast, we shall attempt here to expand the number of objects in the primitive ontology to include the Universals, considered as abstract objects. The Universals will be as fundamental to the theory as physical entities. The reason for this is to close the gap between the primitive ontology and the concepts in the scientific theory. This is how theory arises from the basic objects of existence in such a way that the theory forms a universal description of reality. We extend the ontology as follows. The Universals are abstract objects defined relationally in Frege's sense. They become part of the primitive ontology. The Particulars are instantiations of these primitive ontological objects. These are the basic facts upon which the scientific theory is grounded.

Related to the question of Universals is the notion of Information. We shall consider information from a metaphysical standpoint. Note that, although information requires a physical medium to be transferred, it exists as a configuration of abstract objects. That is, information is composed of the Particular instantiations of collections of Universals.

This is an abstract definition of information, in that it does not address how information is stored or transmitted, nor how it is quantified. Describing information in terms of metaphysics, we are focusing on the information itself and, depending on the Universal being instantiated as a Particular, what the information means on a microscopic level. How these fundamental units of information are combined is not in the scope of this discussion.

Aristotelian metaphysics requires a physical medium to be associated with this information, in that Forms do not exist apart from things. In a Platonic interpretation, the relationship is more fraught. When it comes to the different interpretations of quantum mechanics, we will discuss the relationship between the information and its means of transmission.

3. Quantum Mechanics: Copenhagen Interpretation, Pilot Wave Theory and Decoherence

The way the Abstract Objects are related to physical objects depends on the possible interpretations of quantum mechanics. Two of the most successful formulations are the Copenhagen Interpretation and the Pilot Wave Theory, also known as Bohm–de Brogle Mechanics. Although there are other well–regarded interpretations, such as Everett's Many Worlds Theory and Ghirardi-Rimini-Weber Theory, among others, we will limit ourselves to these two.

3.1. **The Copenhagen Interpretation.** The Copenhagen Interpretation (and its variants) is generally regarded as the most popular interpretation of quantum mechanics. This viewpoint started with Bohr and Heisenberg who were working together in Denmark. There is some question as to how much Bohr actually agreed with the Copenhagen Interpretation as it came to be known [24]. The term was first used by Heisenberg [27]. The major principles of the Copenhagen Interpretation are as follows:

- A system is described by a state vector in a Hilbert space. The state vector changes in one of two ways:
  - The state vector changes continuously through the passage of time, according to the Schrödinger wave function.
  - The state vector changes discontinuously, according to probability laws, if a measurement is made. This is termed wave function collapse.
- The Born Rule: The probability of the outcome of a measurement is given by the square of the modulus of the amplitude of the wave function.

- The Uncertainty Principle: It is not possible to know the value of all the properties of the system at the same time if the properties do not commute.
- The Complementarity Principle: The result of an experiment must be given in classical terms. Evidence obtained under different experimental conditions cannot be comprehended within a single picture, but must be regarded as complementary in the sense that only the totality of the phenomena exhausts the possible information about the objects. For example, in the double slit experiment, an electron could show either a particle or wave–like nature depending on the setup of the experiment.
- The Correspondence Principle: The quantum mechanical behavior reproduces classical behavior in the limit of large quantum numbers.

The main concept we shall consider here is the Measurement Problem.

A measurement was defined by Dirac [16] as:

> A measurement always causes the system to jump into an eigenstate of the dynamical variable that is being measured, the eigenvalue this eigenstate belongs to being equal to the result of the measurement.

A measurement is related to an observable. An observable, such as momentum or spin can be represented as an operator in a vector space [45]. A measurement collapses the wave function of a system which is a superposition of states into one of the eigenstates of the system. This results in an observable eigenvalue related to that eigenstate.

To relate measurement to metaphysical Universals, recall that we are defining Universals in terms of equivalence relations. Equivalence relations for quantum mechanical measurements require conjugacy classes: equivalence relations based on eigenvalues are insufficient because many measurements yield the same values [53]. Therefore when we relate measurements as eigenvalues to a Particular instantiation of a Universal we need to refer to the conjugacy classes associated with the operator the measurement is derived from.

The process of wave function collapse has been subject to debate from the time they were first formulated. One interpretation came from Heisenberg, von Neumann and Wigner.

Heisenberg, in his original 1927 paper "The Physical Content of Quantum Kinematics and Mechanics" [51] describes wave function collapse as as an act of observation:

> I believe that one can fruitfully formulate the origin of the classical "orbit" in this way: the "orbit" comes into being only when we observe it. For example, let an atom be given in a state of excitation n = 1000. The dimensions of the orbit in this case are already relatively large so that ... it is enough to use light of relatively low wavelength to determine the position of the electron. If the position determination is not to be too fuzzy then the Compton recoil will put the atom in some state of excitation, say, between 950 and 1050. Simultaneously, the momentum of the electron can be determined from the Doppler effect with a precision given by $(Err(p)Err(q) \geq \hbar)$. One can characterize the experimental finding by a wave–packet, or, better, a probability–amplitude packet, in q–space of a spread given by the wavelength of the light used,

> and built up primarily out of eigenfunctions between the 950th and 1050th eigenfunction — and by a corresponding packet in p–space.

This concept was further incorporated into the mathematical formulation of quantum mechanics by John von Neumann, in his 1932 work *The Mathematical Foundations of Quantum Mechanics.* He separates the observer from the observed system as follows, using the example of a person reading a temperature using a mercury thermometer [50]:

> But in any case, no matter how far we calculate — to the mercury vessel, to the scale of the thermometer, to the retina, or into the brain, at some time we must say: and this is perceived by the observer. That is, we must always divide the world into two parts, the one being the observed system, the other the observer. In the former, we can follow up all physical processes (in principle at least) arbitrarily precisely. In the latter, this is meaningless.
>
> The boundary between the two is arbitrary to a very large extent. In particular we saw in the four different possibilities in the example above [measuring a temperature with a mercury thermometer], that the observer in this sense needs not to become identified with the body of the actual observer: In one instance in the above example, we included even the thermometer in it, while in another instance, even the eyes and optic nerve tract were not included. That this boundary can be pushed arbitrarily deeply into the interior of the body of the actual observer is the content of the principle of the psycho–physical parallelism — but this

> does not change the fact that in each method of description the boundary must be put somewhere, if the method is not to proceed vacuously, i.e., if a comparison with experiment is to be possible. Indeed experience only makes statements of this type: an observer has made a certain (subjective) observation; and never any like this: a physical quantity has a certain value.

This viewpoint was extended by Wigner in the argument that has come to be called "Wigner's Friend". To paraphrase *Remarks on the Mind-Body Question*' [51] Wigner makes the argument that if he asks a friend if that friend has seen a physical phenomenon or not, such as a flash of light from an atomic process, then since that event was in the past and the person has made the observation, the interaction of the friend and physical object is either in one or the other state corresponding to the observational outcome, and not a superposition of the two outcomes. Wigner contrasts this with the substitution of the friend for a measuring apparatus. In this case he states that the joint system of physical object and measuring apparatus is a superposition of states. He goes on:

> If the [measuring apparatus] is replaced by a conscious being, the wave function [as a superposition] appears absurd because it implies that my friend was in a state of suspended animation before he answered my question.
>
> It follows that the being with a consciousness must have a different role in quantum mechanics than the inanimate measuring device.

So, according to Wigner, consciousness must play a role in quantum mechanics different from that of inanimate objects.

3.2. **Bohr's Interpretation of Quantum Mechanics.** Other physicists did not agree with the necessity of consciousness. Bohr is a case in point. Don Howard [27] and Ravi Gomatam [24] have looked at Bohr's alternative viewpoint. Howard makes the case that Heisenberg coined the term "Copenhagen Interpretation" and that this interpretation is mostly his. Bohr's viewpoint was different.

In Bohr's view, the process of going from the quantum realm to the classical realm must be considered in the context of both the object being measured and the measuring apparatus. The concept of wave function collapse still plays a part in this interpretation, and is considered a fundamental process. The measurement of the object will result in a change of state of the object. But there is no need to postulate an observer: the wave function undergoes a discontinuous change which transfers information from the object to the measuring apparatus.

The value being measured is a consequence of the complete system, both measurement apparatus and object being measured. In this viewpoint, there is no effect from outside on what is measured, and thus no need for an observer. Instead, the phenomenon being measured is a result of the interaction of the measurement apparatus and the object being measured, no more.

Niels Bohr in his 1928 paper *The Quantum Postulate and the Recent Development of Atomic Theory'* [51] says it this way:

> Now, the quantum postulate implies that any observation of atomic phenomena will involve an interaction with the agency of observation not to be neglected. Accordingly, an independent reality in

> the ordinary physical sense can neither be ascribed to the phenomena nor to the agencies of observation. After all, the concept of observation is in so far arbitrary as it depends upon which objects are included in the system to be observed. Ultimately every observation can of course be reduced to our sense perceptions. The circumstance, however, that in interpreting observations use has always to be made of theoretical notions, entails that for every particular case it is a question of convenience at which point the concept of observation involving the quantum postulate with its inherent "irrationality" is brought in.

The notion of complementarity is important because it describes the interface between the quantum level and classical measurements. But this leaves open the question of what the classical measurements mean. Bohr claims that they are derived from sense perceptions. But there is more to it than that, since the bare fact of being a sensation does not provide the meaning of the sensation. When Bohr refers to classical observations, they are usually in terms of the parameters that make up classical physics — e.g. mass, motion, charge and position — abstract objects that may have begun as sense perceptions, but are now part of a mathematical framework that has been built up since the time of the ancient Greeks, and systematized in the Enlightenment.

An example of this is the result of the two slit experiment. There may be different observations, depending on the different experimental setups, in accordance with Bohr's viewpoint of the entangled nature of the object and measuring apparatus.

But more than that, there is a conceptual interpretation of what the senses actually observe. With sensation comes interpretation.

Bohr stresses the physical basis of our sensory observations:

> In using an optical instrument for determination of position, it is necessary to remember that the formation of the image always requires a convergent beam of light...
>
> In measuring momentum with the aid of the Doppler effect ... one will employ a parallel wave–train...
>
> In tracing observations back to our sensations, once more regard has to be taken to the quantum postulate in connection with the perception of the agency of observation, be it through its direct action upon the eye or by means of suitable auxiliaries such as photographic plates, Wilson clouds, etc.

So instead of a separation between observer and that which is observed, there is a causal chain that proceeds from the quantum phenomenon to its interpretation in the mind.

3.3. **Pilot Wave Theory.** In contrast to the Copenhagen Interpretation, there is the Pilot Wave Theory of Bohm and de Broglie. Although de Broglie came up with a Pilot Wave theory, which he presented at the Solvay conference in 1927, he was met with objections and soon abandoned this approach. David Bohm developed the theory independently in 1952 [6] [7] and extended it in subsequent papers.

Bohm's pilot wave is a type of "hidden variables" theory. That is, he postulates that the Schrödinger Wave equation is an incomplete description of reality at the quantum mechanical level. In Bohm's viewpoint, each particle in the universe has a particular position. The motion of each particle from one position to another is guided by the Schrödinger Wave equation. This is the “pilot wave” in that it guides the particle. One of the main proponents of the Pilot Wave Theory was John Bell.

Besides the Schrödinger wave equation for N particles:

$$i\hbar\frac{\partial}{\partial t}\psi = -\sum_{k=1}^{N}\frac{\hbar^2}{2m_k}\Delta_k^2\psi + V\psi$$

we have the “hidden variables”, the position of the particles $Q_1, ..., Q_n$

$$\frac{dQ_k}{dt}(t) = \frac{\hbar}{m_k}Im(\frac{\Delta_k\psi}{\psi})(Q_1, Q_2, ..., Q_n, t)$$

Similar to Schrödinger with the Copenhagen interpretation, Bohm considered the wave function as information:

> The first of these new properties can be seen by noting that the quantum potential is not changed when we multiply the field intensity ϕ by an arbitrary constant. (This is because ϕ appears both in the numerator and the denominator of Q.) This means that the effect of the quantum potential is independent of the strength (i.e.. the intensity) of the quantum field but depends only on its form. By contrast, classical waves, which act mechanically (i.e., to transfer energy and momentum, for example, to push a floating object) always produce effects that are more or less proportional to the strength of the wave.
>
> To give an analogy, we may consider a ship on automatic pilot being guided by radio waves. Here too, the effect of the radio waves is independent of their intensity and depends only on their form. The essential point is that the ship is moving with its own energy,

> and that the information in the radio waves is taken up to direct the much greater energy of the ship. We may therefore propose that an electron too moves under its own energy, and that the information in the form of the quantum wave directs the energy of the electron.

The main difference between Pilot Wave Theory and the Copenhagen Interpretation is that Pilot Wave Theory is deterministic, whereas the Copenhagen Interpretation appears to be essentially random when it comes to the wave function collapse. The two approaches, are thought to give identical results. The randomness of the Copenhagen Interpretation is replaced by an uncertainty in the initial conditions of the particles being measured in Pilot Wave Theory. This uncertainty makes the results of the measurement to appear random, even though the positions of the particles are fully determined at all time. Although the Pilot Wave Theory was criticized as resulting in surrealistic particle trajectories [20], recent experimental results show that these trajectories can actually be observed [30] [37].

What appears to be indeterminacy in the Pilot Wave Theory is the inability to predict the configuration of a collection of particles, as measured by an interaction. But this is due, not to randomness, but to two conditions. First, the complexity of the history that preceded the particular interaction under consideration makes the prediction of any outcome well nigh impossible. Second, the Schrödinger wave equation contains a non–classical component which Bohm terms the "quantum–mechanical" potential mentioned above:

$$U = (\frac{-\hbar^2}{2m})\frac{\Delta^2 R}{R}$$

This quantum mechanical potential can change rapidly with position and is therefore hard to predict.

Bohm discusses these differences with the Copenhagen interpretation in terms of the two slit experiment. The interference pattern exists for two slits, but changes when one of the slits is closed. In the Copenhagen interpretation, this discrepancy is resolved by appeal to the fact that the particles in the two slit experiment can be considered both as waves and as particles: any model of the experiment in the Copenhagen interpretation must include both wave and particle properties. Any attempt to measure the position of the particle would destroy the interference pattern, and lead to a pattern that represents the scattering of particles.

Bohm responds to this viewpoint by acknowledging the Schrödinger wave equation as the driving equation for the two slit experiment, but this represents the forces acting on the particle. The indeterminacy of the Copenhagen interpretation comes from the unknown initial conditions of the particle. The quantum mechanical behavior is determined by the quantum mechanical potential. This potential changes rapidly with position and determines the complexity of the particle location in the two slit system. Closing one of the slits changes the potential, which allows the particle to reach positions that would not be possible in the double slit case. An attempt to measure the location of the particle will create a disturbance that destroys the interference pattern, but this is done by changing the quantum mechanical potential. This measurement changes the wave equation, but is not inherent in a conceptual wave–particle structure. It could be possible to make a measurement that does not destroy the interference pattern, if done carefully.

This quantum mechanical potential can be very powerful in certain circumstances. Bohm describes the Franck–Hertz experiment where moving electrons interact with stationary atoms through elastic scattering:

> Here, we shall see that the apparently discontinuous nature of the process of transfer of energy from the bombarding particle to the atomic electron is brought about by the "quantum–mechanical" potential, $U = (-\hbar^2/2m)\Delta^2 R/R$, which does not necessarily become small when the wave intensity becomes small. Thus, even if the force of interaction between the two particles is very weak, so that a correspondingly small disturbance of the Schrödinger wave function is produced by the interaction of these particles, this disturbance is capable of bringing about very large transfers of energy in a very short time. This means that if we view only the end results, this process presents the aspect of being discontinuous.

In this context, the measurement problem is addressed in the case where the information transfer of the measurement is as a result of an interaction between particles as follows:

> While interaction between the two particles takes place then, their orbits are subject to wild fluctuations. Eventually, however, the behavior of the system quiets down and becomes simple again. For after the wave function takes its asymptotic form and the packets corresponding to different values of m [the hydrogen atom quantum number] have obtained classically describable separations ... because the probability density is $|\psi|^2$, the outgoing particle must

> enter one of these packets and stay with that packet thereafter (since it does not enter the space between packets in which the probability density is negligibly different from zero).

A final point to mention about Pilot Wave Theory that will come up in this discussion is the asymmetry between the particles and the Schrödinger wave equation. As Goldstein [23] puts it:

> While the wave function is crucially implicated in the motion of the particles, via [the guiding equation], the particles can have no effect whatsoever on the wave function, since Schrödinger's equation is an autonomous equation for ψ, that does not involve the configuration Q.

3.4. **Decoherence and The Preferred Pointer Basis.** Current interpretations of quantum mechanics use the phenomenon of decoherence to explain the measurement problem: why we see classical behavior (the eigenvalues of the quantum state) instead of the quantum superposition of states. This approach has been pioneered by H.D. Zeh [54] and W.H. Zurek [56]. A good introduction to decoherence can be found in Schlosshauer [46], Schlosshauer and Fine [47], Zeh [55], Zurek [57] and Hornberger [26].

Environmental decoherence comes about as a quantum system interacts with the environment in which it is situated. This process is termed "einselection" (environmentally induced superselection), where superselection is the condition that eigenstates can be selected [22] by any observable, not just a Hamiltonian operator.

Zurek describes decoherence as follows:

> Decoherence and einselection are two complementary views of the consequences of the same process of environmental monitoring. Decoherence is the destruction of quantum coherence between preferred states associated with the observables monitored by the environment. Einselection is its consequence – the de facto exclusion of all but a small set, a classical domain consisting of pointer states – from within a much larger Hilbert space. Einselected states are distinguished by their resilience – stability in spite of the monitoring environment.

This state of affairs leads to two problems. First, the problem of measurement outcomes.

The consequence of Einselection is that, given the joint density matrix for the system and the environment, the off–diagonal elements of the matrix go to zero after interactions with the environment, regardless of the environmental basis. Although the system started out as a superposition of states, the interaction with the environment leads to the superposition being part of the system–enviroment joint state, and the appearance of the system alone is as if it were a classical ensemble of states.

Note that the problem of measurement outcomes is only partially solved — the density matrix contains only classical terms, but it is still unknown *which* eigenstate is the result. In the Pilot Wave Theory, the answer is obvious. It is the value that is measured that corresponds to the wave packet containing the particle after the measurement interaction is completed.

Adler [1] makes this plain. Although decoherence may be a mechanism where the off–diagonal terms go to zero, it does not explain why one eigenstate results from a measurement instead of another. Zeh [55] discusses this difference.

> Environment–induced decoherence means that an avalanche of other causal chains unavoidably branch off from the intermediary links of the chain as soon as they become macroscopic. This might even trigger a real collapse process (to be described by hypothetical dynamical terms), since the many–particle correlations arising from decoherence would render the total system prone to such as yet unobserved, but nevertheless conceivable, nonlinear many–particle forces ...
>
> Even "real" decoherence in the sense of above must be distinguished from a genuine collapse, which is defined as the disappearance of all but one component from reality (thus representing an irreversible law). As pointed out above, a collapse could well occur much later in the observational chain than decoherence, and possibly remain less fine–grained. Nonetheless, it should then be detectable in other situations if its dynamical rules are defined.

A second problem is that of the preferred pointer basis.

Schlosshauer [46] describes the preferred basis problem this way: Let $|\psi\rangle$ be:

$$|\psi\rangle = \sum_n c_n |s_n\rangle |a_n\rangle$$

The preferred basis problem arises because it is possible that, given a new set of basis vectors $|s'_i\rangle$ and $|a'_i\rangle$, $|\psi\rangle$ is also:

$$|\psi\rangle = \sum_n c'_n |s'_n\rangle |a'_n\rangle$$

such that the same post measurement state could appear to correspond to two different measurements of observables $\hat{A} = \sum_n \lambda_n |s_n\rangle\langle s_n|$ and $\hat{B} = \sum_n \lambda'_n |s'_n\rangle\langle s'_n|$ even though $\hat{A}$ and $\hat{B}$ do not commute. But the simultaneous measurement of two non–commuting observables is not allowed in quantum mechanics.

This problem is also resolved in decoherence through einselection. The interaction between the apparatus and the surrounding environment singles out a set of mutually commuting observables. The preferred pointer basis is the basis in which the system–apparatus correlations $|s_n\rangle|a_n\rangle$ are left undisturbed by the subsequent formation of correlations with the environment.

Laura and Vanni [49] argue that the basis of any measurement is uniquely identified by the physical process involved in the measurement without recourse to decoherence.

One of the first appearances of the concept of decoherence and einselection in the scientific literature was Bohm's articles on Pilot Wave Theory [6] . The way he presented decoherence is different from the current use of the term and is useful to consider it here in detail. This will be a basis for the metaphysical realism of Pilot Wave Theory that we will present.

> [We need] to show that if the outgoing packets are subsequently brought together by some arrangement of matter that does not act on the atomic electron, the atomic electron and and the scattered particle will continue to act independently. To show that these

> two particles will continue to act independently, we note that in all practical applications, the outgoing particle soon interacts with some classically describable system. Such a system might consist, for example, of the host of atoms of the gas with which it collides or of the walls of a container.

In the later work of Bohm, Hiley and Kaloyerou [9], this topic is revisited:

> We have not, as yet, brought into the theoretical description anything that would assign a special role to the state of the measuring apparatus as something that was actually capable of being known by a human being. It was here that we introduced our second stage of the measurement process, which contained a detection or registration device capable of amplifying the distinctions in the states of the "apparatus particles" to a large scale level that is easily observable by ordinary means. Such a registration device will contain a very large (macroscopic) number, N, of particles. When this device interacts with the "apparatus particles", y, its wave function $\lambda(Z_1, ...Z_N)$ will have to be brought into the discussion. To each distinct state, n, of the "apparatus particles", there will be a corresponding state, $\lambda_n(Z_1, ...Z_N)$ of the registration devices. The wave function of the relevant system will then be
>
> $$\Psi = \sum_n C\phi_n(y)\psi_n(x)\lambda_n(Z_1, ...Z_N).$$
>
> Each of the λ_n will also not overlap with the others, so that even if the $\phi_n(y)$ should later come to overlap, this would still not

> affect the quantum potential. as the particles of the registration device will now be in distinct channels.

Could the channels of the registration device in turn be made to overlap again? In Bohm and Hiley [8] it was emphasized that this would have essentially zero probability, because in registration, there has occurred a thermodynamically irreversible process. (So that, for example, to have overlap here would be as improbable as for a kettle of water placed on ice to boil.)

4. Universals in the Ontology of Quantum Mechanics

There are two parts to the question of Universals in the context of metaphysical realism. The first part is the process by which the Universals come to be associated with physical objects. The second part is the nature of the existence of Universals themselves.

Essentially, a Universal is a concept. In quantum mechanics, individual instances of concepts are measurements. The basic idea is that measurement is a process of instantiating a Universal, which is what I term a Hylomorphic Function. So the instantiation of Universals as Particulars are the results of quantum measurement. This gives a physical explanation for metaphysical realism.

Each measurement can be considered as the output of a function. That is because each individual measurement can be considered to have a unique input — a quantum state at a given time and place — and has an outcome that is an eigenstate with an associated eigenvalue.

A measurement has an associated observable operator. The measurement collapses the quantum state into one of a number of eigenstates. The operator associated with the measurement forms an conjugacy class on the set of possible measurements. Using the definition of a Universal as Frege's concept of an equivalence relation, the operator that specifies the measurement is a metaphysical Universal — a hylomorphic function. The act of measurement executes the function, collapsing the wave function into a Particular instantiation of the Universal.

This distinction is made by Bell with the notion of beables and observables. The hylomorphic functions are the process of generating an observable from a beable [5]:

> In particular, we will exclude the notion of "observable" in favour of that of "beable". The beables of the theory are those elements which might correspond to elements of reality, to things which exist. Their existence does not depend on 'observation'. Indeed observation and observers must be made out of beables.

An example of a beable that Bell gives is that of a fermion number density which is related to the charge density of a given volume [14].

In terms of Bell's distinction between observables and beables, metaphysical realism implies that observables are not derived from beables, but exist in their own right. The beables are composed of physical entities, as Bell states, and the observables are composed of the particular instantiation of Universals that are the results of quantum measurements.

So what is the meaning of measurement in terms of Universals? Qualitatively, measurement is the process of abstracting some property from an object. It is the act of observation itself. The equivalence of instantiations of Universals as the output of a measurement means that these Particulars are not fundamental objects — they are the results of operations which are themselves fundamental. So the Universals have existence, not as physical objects but as classes of functions that extract a measurable property from the quantum interactions. This identification of Universals as quantum mechanical operators shows that the Universals are real, and not just nominal terms or ideal concepts.

A measurement can be made of a quantum mechanical system of arbitrary complexity. We need to consider the notion of an "Atomic Universal". This is a fundamental physical observable, such as position, momentum, angular momentum or spin. An atomic Universal is a property that is fundamental in the sense that it cannot be reduced to another property or combination of properties. Here, the distinction made by Bell of a local beable is of value. What makes them local is that local beables can be assigned to some bounded space time region. This locality is one aspect of the notion of an atomic Universal. The atomic Universals form a primitive basis for the rest of the Universals that are composed of them.

So the hylomorphic functions complete the ontology started by Allori. The primitive ontology as currently conceived describes the objects of physical reality in their most basic units. The hylomorphic functions are the part of the theory describing the process by which the physical entities give rise to concepts, especially the atomic Universals that are fundamental to describing the conceptual, metaphysical layer of reality as the primitive ontology is to describing the physical layer. Together with the physical entities of the current primitive ontology, the atomic Universals extend the primitive ontology to encompass both physical and metaphysical entities.

This realist viewpoint of Universals as abstract objects can be expressed from either a Platonic or an Aristotelian viewpoint, since both consider the existence of abstract objects in reality. The Platonist considers the abstract objects to have a separate existence in a different plane of being from the physical world. The Aristotelian considers the abstract objects to exist as a part of physical things.

This brings up the question of more complex Universals. How universal are Universals such as Redness, Truth, or the Number One? It could be argued that the Universals we recognize are what they are because we are human and these are what humans recognize — they are just brute facts. Instead, we claim that Universals such as these can be considered to be composed of atomic Universals, similar to the way physical objects are composed of atoms. The atomic Universals are not contingent on human thought — they are part of the fabric of reality. But the Universals we recognize are formed from our existence as human beings. This means that there is a basic ground of metaphysical realism when it comes to the Universals, that results in a metaphysical nominalism when it comes to our everyday use of Universals.

This differs from the classical notion of Universals, where each Universal is a concept unto its own. In the hylomorphic conception of Universals, there are atomic Universals, instantiated through quantum measurements, that combine to form more complex Universals with their own properties. The operators that represent those measurements must be fundamental in the sense that they form an ontological basis by which all other more complex measurements and Universal concepts can be constructed.

This composition is constrained by physical necessity instead of a theoretical hierarchy, such as found in formal logic. So, for example, the hylomorphic hierarchy is constructed in the same sense that an electron is a parent of a transistor, and transistors combine to form electronic circuits. Each step of the way, there is the notion of electrons, but they can be combined to form more complex notions according to the constraints of the physical processes. The emergence of more complex Universals is not arbitrary, but based on the nature of the physical world.

In this sense, a more complicated measurement, such as that represented by Schrödinger's cat is not ontologically atomic. It is composed of the individual concepts that compose it, such as the concept of a cat and what alive or dead means, along with the complex of measurements that determine whether the cat is alive or dead. The measurement of a cat being alive or dead is based on simpler measurements, just like the cat's body is made up of molecules which are made of atoms.

This implies that even the mathematical objects are not fundamental, but are abstractions of the more fundamental Universals that are the different species of atomic observables. Wave–particle duality implies the existence of both integers and reals, but the concepts themselves are complex, multifaceted conceptual structures. They are human constructs more than they are fundamental properties of reality.

Although we have concentrated on metaphysical realism, one variant of nominalism — *Trope Theory* [52] — has seen some work relating tropes to primitive quantum mechanical concepts. Trope Theory is the idea that individual entities are characterized by abstract Particulars called tropes, and that entities are similar due to the similarity of their tropes. Some suggestions have been made on the relationship between tropes and aspects of quantum mechanics, such as summary statistics [42] or the fundamental forces or particles of physics [39]. Although these approaches have the virtue of grounding trope theory in actual physical phenomena, they instantiate their tropes indirectly through the objects of the primitive ontology, which requires a mechanism of instantiating the trope from the physical property. Appealing to the hylomorphic functions provides this instantiation directly.

The separate nature of hylomorphic functions from the time symmetrical laws of physics appears to lead to a type of dualism. Dualism seems to be exist because the observer is different from the physical waveform. But they could also be separate processes in a single reality.

This viewpoint makes the class of fundamental atomic measurements that occur in the collapse of the wave function as ontologically basic — primitive ontological units — independent of the measurement apparatus used to make the measurement. The nature of the measuring apparatus is instead dependent on how the apparatus can be physically constructed to yield a measurement composed of these atomic hylomorphic functions. Also, the nature of the apparatus is dependent on our ability to conceive of it, which is based on atomic Universals.

Decoherence does not solve the problem of which eigenstate the system collapses to resulting in a given eigenvalue. The hylomorphic functions — the Universals — determine the eigenvalue that is instantiated from the system being measured. The Particular instantiation comes from the nature of the Universal being instantiated.

The Particular that results is an property of the quantum system seen as a metaphysical entity. It is only one aspect of the system — one of its properties — not a complete description of the system.

The concept of hylomorphic functions has implications when it comes to complementarity, especially the relationship between the ontological status of the measurement apparatus and the system being observed.

As mentioned above, the concept of complementarity originated with Bohr. He considers a quantum measurement to consist of both the phenomenon being measured and the apparatus measuring it. This viewpoint has been carried into Pilot Wave Theory. Durr, Goldstein and Zanghi [17] explain the physical properties of quantum observables as follows:

> The best way to understand the status of these observables — and to better appreciate the minimality of Bohmian mechanics is Bohr's way: What are called quantum observables obtain meaning only through their association with specific experiments. ... Information about a system does not spontaneously pop into our heads, or into our (other) "measuring" instruments; rather, it is generated by an experiment: some physical interaction between the system of interest and these instruments, which together (if there is more than one) comprise the apparatus for the experiment. Moreover, this interaction is defined by, and must be analyzed in terms of, the physical theory governing the behavior of the composite formed by system and apparatus. If the apparatus is well designed, the experiment should somehow convey significant information about

> the system. However, we cannot hope to understand the significance of this "information" — for example, the nature of what it is, if anything, that has been measured — without some such theoretical analysis.

But metaphysical realism brings this notion into question. This analysis does not explain why there are certain Universals and not others — it does not explain the source of the Universals. Seen from the viewpoint of metaphysical realism there is a circular argument in this view of complementarity: the experiments represent Universals that are not atomic, but they give rise to the atomic Universals via quantum measurements. This problem is similar in character to the argument that Kant used to claim that there must be *a priori* knowledge of physical reality that he defined in the Prolegomena [29].

We measure what we ask for. What we ask for is a property of nature. The properties of nature are what we measure. This is circular. Instead, what we ask for is composed of more fundamental physical measurements, and the hylomorphic functions associated with these fundamental measurements produce the result of our experiments.

The atomic Universals are fundamental. They form our ontological basis. From this basis our thoughts are constructed, and this determines what we ask for. Our knowledge of physics helps us to identify the atomic Universals which comprise the observables. Put another way, the reason we set up an experiment in a certain fashion is because we have an idea in mind about the nature of what we want to measure. But this idea has to come from somewhere. It arises out of the hylomorphic functions that form the basis of our conceptual structure.

The hylomorphic functions are the beginning of the process of observation and have an *a priori* existence. Insofar as the atomic Universals make up the basic ontological properties of physics, they also form the basis of our knowledge of the real world in time and space.

Another way of considering this is that the Universals are the essential preferred basis vectors for quantum measurements. The different types of Universals themselves are the different self–adjoint operators that are the fundamental observables. These operators have a preferred basis which arises out of the fundamental properties of nature, not as a result of the structure of the measurement apparatus. This could explain why quantum mechanical measurements yield instances of the same Universals: velocity, mass, charge or spin, instead of something new every time. Laura and Vanni [49] point out that the physical processes involved in the process of measurement determine the preferred basis. Considering the physical processes as fundamental, this recognizes that the instantiation of Universals is not arbitrary, but is the result of the physical things that they represent.

The problem is, why do we have the Universals we have and not others? Why are there some particular Universals and not just an arbitrary or infinite number of different Universals? Why we have the atomic Universals we have is a question that needs to be explored. The reason why there are what they are is unknown. Perhaps the Universals aren't discrete but live on some higher manifold [53].

We will further explore the nature of Universals in terms of the Copenhagen and Pilot Wave interpretations of quantum mechanics.

4.1. **Metaphysical Realism in the Copenhagen Interpretation.** Given that the Universals have a real existence in the process of measurement in quantum mechanics, when it comes to the nature of that existence there is a difference between the Copenhagen Interpretation and the Pilot Wave theory.

In the Heisenberg/von Neumann/Wigner interpretation of quantum mechanics, the ontology of Universals would seem to be reasonably simple. An instantiated Universal is whatever the Observer has observed. Of course, what the Universals are is a complex question in and of itself. But if the Universals are the process of conscious observation, this takes the existence of Universals out of the realm of physics and quantum mechanics and puts it into the phenomenological realm of what consciousness and observation are composed of. Wigner makes that distinction quite clear. The conscious observation collapses the wave function, which in the unconscious world is a superposition of states.

Bohr's interpretation is more nuanced. Although he discusses the classical observations and measurements in terms of sensations — a recognition that some observer is involved — the observations themselves are physical properties that have an independent meaning, at least in the sense that they are basic components of physical theories.

In either case, the measurement occurs at the moment of the wave function's collapse. Also, this collapse, as separate from the processes implicit in the Schrödinger wave equation, does not seem to be driven by the physical processes expressed by the wave equation but by some other principle. This implies a kind of Platonic realism which separates the existence of physical objects in the real world from that of Universals as the instantiators of the particular measurement. In this viewpoint, the Universals are instantiated by wave function collapse, and this creation and the resultant composition of complex Universals from these atomic Universals occur in the Platonic realm.

But this still leaves open the question of how the Universals interact with the objects of physical existence. In the Copenhagen Interpretation, it can be said that consciousness is what determines the measurements involved in the wave function collapse, but the question is, how does the Platonic realm interact with the physical world through this collapse? This is essentially the same as the problem of the interaction between consciousness and the world in Cartesian dualism.

In the Copenhagen Interpretation, the wave function is one aspect of reality and the act of measurement is a separate independent aspect of reality that gives rise to the Universals. The act of measurement is essentially Platonic — that is why it has been so hard to define. Even though measurement has been defined in terms of decoherence, this just describes the mechanism of collapse. The nature of the end product of the measurement has an essential reality that the decoherence cannot explain. The basic kinds of measurement are Platonic Universals in their own right.

It is interesting to note that in the Heisenberg/von Neumann/Wigner interpretation of quantum mechanics, consciousness causes the wave function collapse. But in terms of metaphysical realism, consciousness *is* the wave function collapse, in the sense that consciousness is a metaphysical process.

4.2. **Metaphysical Realism in Pilot Wave Theory.** With Pilot Wave Theory we have a more thoroughgoing Aristotelian hylomorphism, where the duality of physical objects and hylomorphic functions are interacting entities in a unified reality. Instead of the Universals arising from their relationship to the conceptual objects of physics as the end product of an observation or measurement in the

Copenhagen Interpretation, in the Pilot Wave interpretation they arise directly from the interaction between a system and its environment.

A measurement occurs through the interaction of the system and a measuring apparatus. But the measurement itself involves some sort of transfer of information from the system to the apparatus. This can only happen through an interaction between particles — those of the system and those that transfer the information to the measuring apparatus. In this sense a measurement is a hylomorphic function that instantiates a Universal.

For example, Bohm discusses the result of a particle–particle interaction in the Frank–Hertz experiment as leading to the creation of a number of wave packets, one of which will be the pilot wave for the particle in the interaction. Each of these wave packets is associated with one of the eigenvalues of the system. The Universal from which the measurement selected its value is determined by the basis vectors that define the eigenvectors of the measurement. This is essentially the selection of one Particular over another.

As mentioned before, these eigenvalues are not defined by the measurement apparatus, since the creation of a measurement apparatus is dependent on the Universals that define the apparatus. The Universals themselves are essential to the measurement and *a priori* to the whole process. The instantiation of the Universal exists in and of itself as part of reality, without having to postulate an observer or a separate plane of existence such as consciousness.

This means that the atomic Universals are simply the different possible particle–particle interactions. These form the basis of Pilot Wave theory. A particle in motion by itself does not instantiate a particular Universal since there is no change. But any interaction between two particles will lead to an instantiation.

The process of wave function collapse in the Copenhagen Interpretation cannot be explained solely through a physical process. This implies that the existence of Universals are manifest in a process that transcends the physical. In Pilot Wave theory, the Universals arise naturally from physical processes.

It has been mentioned by Ney [2], among others, that particle position is the only determinate observable — it is the single measurement that has metaphysical meaning. Or, stated another way, position is the only conceptual ontological primitive. This may be so, but it leaves open the question of where the other properties, such as charge, velocity, momentum, spin, etc. come from. It could be that, similar to the process where protons, neutrons and electrons combine to form the elements of the periodic table, the measurement of position gives rise to the atomic Universals that compose the Universals we as humans know. The claim that position is fundamental is unlikely, unless we can come up with a process by which we can show how the other atomic Universals are combinations of position measurements. In classical physics we do have a distinction between basic properties such as mass, distance and time and other observables such as velocity and force. This ontological hierarchy likely carries into the quantum realm in some sense.

5. Universals And Information

Using the concept of Hylomorphic Functions, we can discuss the metaphysical nature of information. Analogous to the particle/wave duality for particles as seen in the Complementarity Principle of the Copenhagen Interpretation, there is a similar duality in the information field of Schrödinger's equation and the instantiation of Universals through the act of measurement.

As mentioned by Bohm, it is useful to consider the Schrödinger Wave Equation as an information field. This information determines the behavior of the physical particles which in turn gives rise to the Particular instantiation of a given Universal. Given the metaphysical definition of information, this instantiation of a particular atomic Universal is an atomic unit of classical information.

Therefore an instantiation of a Universal is not outside of time and space. Although Particulars are abstract entities, they are actual events, just as physical interactions are. They are located in the space–time continuum and, as we shall see later, the process of instantiation actually defines time.

This dichotomy between the information field and the Universals that instantiate it is like the distinction between any field and its quanta. The Universals are events in the information sea. The wave function of the universe contains all the information that has been and will ever be. The initial configuration of the wave function for the universe specifies all future events, including the results of measurements [18].

Since this field is information itself, and mathematics is the representation of information (the mathematical objects of Frege's Platonism) we establish the dichotomy between the integers and the reals. The information field represents the reals, so the quantized nature of information (bits, the excluded middle) represents the integers. The lack of any intermediate concept implies that the Continuum Hypothesis is true in our universe.

There is a distinction between information and the medium by which it is carried. The hylomorphic functions create the units of information that are carried by the medium. One of the essential properties of a measurement is that it conveys information from the observed to the observer. Consequently, the creation of a unit of information must start at one place and possibly end in another. These instantiations carry their information from place to place, until they take part in another interaction, which usually results in giving rise to new bits of information. This is a classical viewpoint of information, in that the information being transferred is usable in the sense that it is capable of creating new information. Although the wave function is the field that gives rise to all the information in the universe, both quantum and classical information, the information may not be usable until it is converted into classical information.

The hylomorphic functions are the atomic units from which mathematical Universals exist, even as expressed as part of a Platonic Universe. For example, the notion of *True*/*False* can be considered in terms of a particular instantiation of a Universal. If a particular Universal is instantiated as Particular X instead of Y, then the value of the Universal as X at that time and place is *True* but the value of the Universal as Y is *False*.

Hylomorphic functions are how information is created. But we also need to explain how information is used, transmitted and stored. Information is transmitted through cascading chains of Particulars: instantiations of Universals. The Particulars are generated by the transmitter, which gives rise to information. This information is propagated by chains of Particulars in the physical medium carrying the message and possibly received by a last creation of a Particular in the receiver.

If there is no further transmission, this information is lost or forgotten. All through this chain, the generation of the Particulars as a result of a wave function collapse (for the Copenhagen Interpretation) or the change in the position of particles (in Pilot Wave theory), which lead to physical changes in both receiver and transmitter, and all points in between during the process of transmission.

Information is not transferred if no Universals are instantiated. The transmission of information is necessary for us to actually know things. It is probably safe to say that a measurement — a wave function collapse — is unknowable unless there is a some sort of interaction with the outside world. If a measurement occurred and the result is not conveyed, then this information is lost to the rest of the universe.

Besides the transfer of information, we also need to address the meaning of the information transferred. The Universals provide the semantics of a Particular. This means that the hylomorphic functions are the basis of meaning. Meaning is a complex construction based on the atomic Universals that provide the fundamental units of information. The fundamental properties of physics ground the meaning of information in the universe, for example in the way that atomic Universals generate Particulars about some entity in the world, which are combined to give us knowledge in the form of our sensory input such as sight or sound.

The question also arises between the amount of usable information and the total information in the universe. In terms of the capacity of the usable information that can be held in a region of space–time, the Bekenstein bound describes the usable information.

The Bekenstein bound is the limit of the amount of information that can be contained in a finite volume of space [4]. A distinction can be made between the information carried as classical information in a given volume and the amount of information carried by the Schrödinger wave equation as constituted in this volume. If the Schrödinger wave equation contains all of the information possible, both classical and quantum, the amount of information is more than the Bekenstein bound, especially if the Schrödinger wave equation is not quantized in space and time, but is a real field. The Bekenstein bound limits the number of bits of information possible from the outputs of hylomorphic functions.

6. Universals And The Arrow of Time

The arrow of time has been considered since Eddington. It is generally agreed that, except for entropy, the laws of physics do not have a distinction between time going forward and backward. The reason is that time and entropy actually come about at the level of metaphysical realism, through the process of knowledge transfer.

The reason entropy is different can be considered essentially as a matter of information. If we have enough information to fully describe the current condition of all of the physical units in a particular volume of space, then we can make time go backward by using this information to reverse the interactions that had occurred in the past. The problem is how to retain and apply the information we have. Kupervasser, Nikolic and Zlatic [31] point out that even if it is possible for the arrow of time to point in either direction, whichever direction its takes must be universal over all space.

In the previous section we have discussed the amount of information in the Schrödinger wave equation, which contains all of the information available, both past and present, and the usable information, which was expressed in the hylomorphic functions as classical information. The information field may contain all of the information in the universe, but this information can only be manipulated through the instantiation of Universals. It is not possible through this instantiation to have enough Particulars to fully represent the information in the field.

Given any single measurement, the Particular instantiation of a Universal is transmitted as the measurement. But there are other properties that are part of the the system being measured that are lost to the measuring apparatus. They are retained only in the information field.

The arrow of time is due this loss of information. The generation of a Particular through a hylomorphic function gives us some knowledge through the instantiation of the Universal but not the complete knowledge of the system. The loss of knowledge about the other properties of the system other than what was measured results in a functional irreversibility. But we are left with a trail of information which Maccone points out [36] is the result of an increase in entropy.

The arrow of time can be discussed in terms of Maxwell's demon. The demon registers a certain piece of information, but not all of the information that can be collected. If this were possible, the demon would be not just an observer, but one of the particles in the system. As an observer, it only has access to the Particular instantiations of the Universal that comprise the measurements of the system. This means that Maxwell's demon contains incomplete information and cannot completely invert the mixture of hot and cold items. This extra information still exists in the wave equation, but it cannot be recovered through Maxwell's demon, which only recorded the information that was measured.

What about the Schrödinger wave equation itself? All information is preserved in it from the start of time. Theoretically, this means that the universe is symmetric in time. But the Bekenstein bound means that we cannot have the full history of an individual particle stored, only the amount of information that can be stored in a fixed volume of space. The information field contains all of the information, but we cannot possibly express as measurement all of the information field. So although time is symmetrical for the whole information field. there is not enough usable information to make this inversion possible.

The arrow of time is usually considered from a probabilistic standpoint. That is, given any ensemble of particles in the world we tend to go from a less probable state to a more probable state. But if all the information exists in the wave equation, then probability is a measure of ignorance. This means that we don't know all of the information that led us to the state we have: we only know the information we received through measurements, which are the results of hylomorphic functions. The incidental information remains as part of the wave equation and cannot be recovered. So, although the laws of physics are invertible, we are limited in the amount of usable information to reverse the actions of physics. This means that entropy increases just by the nature of this loss of information. The number of states increase, leading to an increase in entropy, because of the loss of information, which appears as randomness, but is actually ignorance.

7. The Arrow of Time In Pilot Wave Theory

The Implicate Order of Bohm [9] includes an attempt to define the arrow of time. Given a particle–particle interaction where an incident particle is driven by a wave packet, the interaction creates a family of wave particles, where each alternative wave packet out of the interaction represents an alternative value that the particle assumes dependent on the interactions. The packet that controls the particle actively steers it. As time goes on, other wave packets become inactive.

> Another analogy to the process in which information becomes inactive can be obtained by thinking of what happens when we make a decision from a number of distinct possibilities. Before the decision is made, each of these possibilities constitutes a kind of information. This may be displayed virtually in imagination as the sort of activities that would follow if we decided on one of these possibilities. Immediately after we make such a decision, there is still the possibility of altering it. However, as we engage in more and more activities that are consequent on this decision, we will find it harder and harder to change it. For we are increasingly caught up in its irreversible consequences and sooner or later we would have to say that the decision can no longer be altered. Until that moment, the information in the other possibilities was still potentially active, but from that point on such information is permanently inactive. The analogy to the quantum situation is clear for the information in the unoccupied wave packet becomes more and more inactive as more and more irreversible processes are set in train by the channel that is actually active. In the case of our own experience of choice, the inactive possibilities may still have a kind of "ghostly existence" in the activity of the imagination, but eventually this too will die away. Similarly, according to our proposal, the inactive

> information in the quantum potential exists at a very subtle level of the implicate order. We may propose, however, that perhaps this too will eventually die away because of as yet unknown features of the laws of physics going beyond those of quantum theory.

There may be a more straightforward explanation in Pilot Wave theory for information loss than what is described here. This has to do with what becomes of wave packets in the Schrödinger Wave equation that are not associated with a physical particle.

We claim that wave packets with no associated particle dissipate. Or more accurately, the converse is true: the particle keeps the wave packet from dissipating. If this did not happen then cases would arise where the unoccupied wave packets would have an effect equivalent to an occupied wave packet. Bohm discusses inactive particles, but only in the sense where they take part in the original interaction in which the packets were involved. But in a cascade of interactions, the dissipation of the unoccupied wave packets must occur.

Bohm and Hiley [9] discuss a case where an inactive packet becomes active again, by interfering with the system/apparatus.

> At this point, however, one may ask what is the role of the "inactive" packets, not containing the particles. Can we be sure that they must necessarily remain permanently inactive? The answer is that in principle, it is in fact still possible to bring about activity of such packets. For example, one may apply an interaction Hamiltonian to one of these inactive packets, say $\psi_r(x)$, such that it comes to coincide once again with $\psi_m(x)$, while leaving

> $\phi_m(y)$ unchanged. The two packets together will then give us $\phi_m(y)(\psi_m(x) + \psi_r(x))$. If $\psi_m(x)$ and $\psi_r(x)$ overlap, there will be interference between them, and this will give rise to a new quantum state, in which the previously inactive packet, $\psi_r(x)$, will now affect the quantum potential, so that it will once again be active.

But what about a packet that goes off and interacts with something entirely different? This causes all sorts of ghost interactions. Therefore, an inactive packet must dissipate after some time. This shows that, besides the wave function piloting the particle, the particle sustains the packet.

An example of this is the Franck–Hertz experiment. In the original Franck-Hertz experiment an electron undergoes an inelastic collision with a mercury atom, transferring energy to one of the electrons in the atom, moving it into the next energy level. Bohm performed the calculations for this experiment using the Pilot Wave theory, but to simplify the calculations, he assumed a hydrogen atom. He described the process where the electron approaches the hydrogen atom and one of two packets leave based on whether or how the electron transferred energy to the electron in the hydrogen atom.

Consider two more hydrogen atoms, both down–range from the original atoms, that interact with the two packets (one with the traveling electron and one without). The two packets should affect the two down–range atoms equally. But since there is only one electron in only one of the packets, in actuality only one of those atoms should be affected. The other packet must have dissipated.

Bohm's analysis of Pilot Wave theory made this phenomenon explicit. Given a particle driven by a wave packet that interacted with another wave particle, the interaction caused the creation of wave packets that resulted from the interaction. One packet contained the particle after the interaction, the rest dissipated, since they did not hold that particle.

If it is true that the other wave packets dissipate, then the particles do have an effect on the wave function. This effect is different from the propagation of the wave function where no interactions are involved. Just as in the Copenhagen Interpretation, where there are two separate processes controlling the state vector, one a continuous process and the other the wave function collapse, in Pilot Wave theory, there are two separate processes, one which controls the movement of a particle through space and the other that controls the dissipation of wave packets that are not associated with particles. One process gives rise to the standard laws of physics. The other process controls how Particulars are instantiated in Pilot Wave theory, in the dissipation of the other wave packets that represent the Particulars that were not instantiated.

Decoherence is usually used to describe the arrow of time, but it is not sufficient. Decoherence is given as the reason for the appearance of irreversibility due to interactions with the environment, because it is virtually impossible to reverse any given interaction. But each action is potentially reversible nonetheless. So this does not define the arrow of time as an irreversible process. In Pilot Wave theory the arrow of time is the dissipation of empty packets. An instantiation of a Universal as a Particular comes from the measurement of an interaction and the it defines the packet with the particle. But the packets that do not hold the particle are the alternative Particular values for that Universal. Once a Universal is instantiated, the alternatives cease to exist and cannot be recovered through time symmetry, making the holomorphic functions many to one and therefore not invertible. This means that they define the arrow of time.

8. Hylomorphic Functions and Qualia

The hylomorphic functions can also explain subjectivity. The hard problem of consciousness is the attempt to explain subjective reality as it relates to the physical properties that make up thought — the objective world. It has been argued that consciousness can be entirely explained through physical processes [15]: that consciousness is purely physical or at best an epiphenomenon. But this feels unsatisfactory to those who believe that conscious reality is something more than the processes of physical interactions. This is true even for those who argue that sensations are contingent on physical processes [33]. A famous paper by Nagel [40] pointed out the difficulty of knowing what it feels like to be something different than a human, for example, a bat.

Qualia, first coined by Clarence Irving Lewis in 1929, are considered to be the fundamental units of thought. Although they can be anything from the sensation of light and sound to the expression of an emotion, qualia always involve some functional change.

The term qualia is given to the basic components of subjective reality. A qualia is considered to be a single irreducible unit of consciousness. Qualia seem to be more than just the result of physical interactions, but instead the components of a consciousness that cannot be reduced to purely physical interactions. Chalmers [12] makes the distinction between third person and first person data to illustrate this point. The physical processes of neurological action are third person data, but the subjective reality of thought is first person data. First person data is the hard problem of consciousness, which we shall address here.

At one extreme are those who argue that thought and physical processes inhabit two separate worlds. Plato, in the Phaedo, with his Doctrine of the Forms, considered these two realms to be separate. Descartes also expressed this same principle in his Meditations. In both cases, the question arose about how the two separate realms could interact.

This led to theories that expressed the other extreme — the universe is monist; there is only a unified reality from which both the physical and the mental arise. This physicalist response has been contrasted with functionalism, which define consciousness as functional processes that are more than simple physical processes.

We argue that qualia are not purely physical, arising out of the beables. Instead, the hylomorphic functions generate qualia. That is, the instantiation of atomic Universals are the basic units that make up the functional mental processes. A consequence of Aristotelian hylomorphism is that the hylomorphic functions operate in tandem with the physical processes of the mind, but the hylomorphic functions, and their instantiations of the Universals, are not purely physical. This is, as Jackson argues [28] what makes qualia different from pure physical reality, not just an epiphenomenon.

Chalmers [11] has argued against quantum mechanics as being the answer to the hard problem of consciousness. The problem he has is with a mind–body dualism that seems to affect the results of what appears to be an essentially probabilistic phenomenon. But whether or not the phenomenon is probabilistic (as in the Copenhagen interpretation) or deterministic (as in Pilot Wave theory), the action of measurement that gives rise to an instantiation of a Universal is different from, but related to, the physical process. Chalmers worries about the nonlocal effects that are present in theories such as the Pilot Wave theory, but the instantiation of a Universal is essentially local (although affected in a nonlocal fashion by the wave equation) and this can be argued as being the building blocks that make up the qualia of subjective experience.

But there is some underlying conceptual hierarchy that defines the structure of what we know. It is unlikely that a single qualia is a single instantiation of an atomic Universal. It is more likely that a qualia is like a molecule — it is a simple combination of even simpler atomic events that are the instantiation of atomic Universals. The combination of atomic Universals is not arbitrary, though. The nature of the atomic Universals are such that they will only admit to a limited combination of concepts that are expressed as qualia. These rules are yet to be defined, but probably they are similar to the composition of more complex structures in physics and chemistry. This conceptual hierarchy may someday be constructed that begins with the atomic Universals that lead to the construction of the different types of qualia which then make up the thoughts that living organisms experience.

This means that the conscious experiences we humans have are due to the components of thought and subjective experience which are the result of the combinations of the instantiations of Universals. These qualia do not exist as purely physical phenomena, although organisms with identical physical processes will have identical qualia [10]. As discussed earlier, in Aristotelian philosophy, the Universals are separate from physical things, even though they do not exist apart from things. Because they are not purely physical, they feel different.

One of the most basic sensations of qualia is the sense of the arrow of time. This comes about because hylomorphic functions define the arrow of time. This means that the sense of time is an essential feature of qualia.

Qualia seem to have a dual existence. Just as information is separate from the medium that carries it, so qualia are separate from the physical processes that lead to the qualia. Mental functions can describe the objective reality of what thoughts, feelings and sensations we experience, but they can not describe the subjective reality of these experiences.

Although qualia are basic sensations, this does not imply that there is always a corresponding perception — let alone an awareness — that can react to the sensation, nor need there be a consciousness that is self–aware. Like atoms that can be combined to form more complex structures from molecules up to things like rocks or animals, qualia can be combined to form more complex mental constructs. But individual qualia are like individual molecules. They only become part of perception and consciousness if they are part of a larger conceptual structure.

This concept is somewhat similar to Leibniz's Monadism [32], although there are significant differences. One major difference is that Leibniz considered consciousness to consist of a single monad. The theory of hylomorphic functions postulates that consciousness is a complex construct built out of qualia which in turn are composed of hylomorphic functions.

Hylomorphic functions can be considered to be a type of panpsychism, but only in the simplest sense. The universe does not consist of atomic consciousness, no more than a single machine instruction in a computer is a computer program. This attitude is similar to that expressed by Chalmers [11] in that the world can be considered as having some elementary proto–consciousness, but this does not have any larger implications, except when it comes to beings with more complex decision–making processes.

This also implies that a measurement in quantum mechanics does not imply a conscious observer, just as an elemental Platonic observer (in the case of the Copenhagen Interpretation) or an elemental observation (in the case of Pilot Wave theory) implies a conscious observer. A measurement is the end result of a hylomorphic function, but there may be no conscious observer to take note of this measurement. Hylomorphic functions are the basis of perception, but the sensation of that perception or the awareness of it requires some higher order processing. Self–awareness and consciousness are not fundamental — they arise out of these fundamental functions.

A metaphysical realism leads to the existence of qualia separate from the physical process of sense perception. This resolves the hard problem of consciousness. Qualia are composed of metaphysical Particulars that have an existence different from the neurological processes that give rise to them. This is similar to the distinction between packets of information and the medium that carries them.

9. Conclusions

In conclusion, hylomorphic functions can be characterized in a number of interesting ways.

- Hylomorphic functions are the observer in the Copenhagen Interpretation of quantum mechanics or the particle interaction of the wave function in Pilot Wave theory.

  - The observer simply observes a measurement. For example, a measurement in physics can be a real value, such as a position, or an integer, such as the event of a positron–electron annihilation. In all cases, they are functions that instantiate observations from the beables that constitute the physical states of a system.
  - Hylomorphic functions collapse the wave function into a single measurement, but this does not make the wave function deterministic from then on. The measurement of a Universal is a property that characterizes the wave function at this time, but the wave function still maintains its non–determinacy due to its other properties.
  - Hylomorphic functions give a physical interpretation to metaphysical realism.
- Hylomorphic functions are the basic units of information.
  - The hylomorphism functions explain why information seems to be independent of the medium carrying the information. Information is an instantiation of a Universal property, not a property of matter itself. Since these Particulars are the outputs of measurements, they require a medium to carry the information, but being abstract, they are essentially different from the medium.
  - Informational entropy, a measure of the randomness of a system, is also a measure of the carrying capacity of a communication medium. But the information — the message carried by the medium — is made up of the Particular values that the medium carries. These values

comes from the instantiation of a hylomorphic function or functions, and are therefore the result of abstract Universals.

- Hylomorphic functions define the Arrow of Time.
  - In both the Copenhagen Interpretation and Pilot Wave theory, the hylomorphic functions are many to one and therefore not invertible. This means that they define the arrow of time. The many to one property also implies that they increase the number of accessible states, and therefore increase entropy.
  - In Pilot Wave theory the arrow of time arises from wave packet dissipation.
- Hylomorphic functions are the atomic units that make up qualia.
  - All other sensations and experiences that form subjective reality are composed of qualia. Similar to the objects of our experience being composed of molecules which are in turn composed of atoms, our sensations composed of qualia which are in turn made up of the instantiations of atomic Universals.
  - Sensations and perceptions are like molecules — they are composed of hylomorphic functions but are themselves components of larger things.
  - This is why nominalism seems to be true because although the Universals are are based on quantum mechanical phenomena, the higher level concepts we deal in are part of our nature as humans.

Depending on the interpretation of quantum mechanics, metaphysical realism could be either a Platonic duality or a single reality, where the laws of physics determine the objects of reality and the hylomorphic functions instantiate the conceptual qualities of these objects. Whether these two interpretations represent different experimentally distinguishable descriptions of the nature of the universe has yet to be determined.

There are a number of concepts that are fundamental to physics and mathematics, such as the existence of integers and reals and the reality of the universal basis of effective computation that is expressed in Church's Thesis. These concepts should be considered to have a hylomorphic basis — their universality has not been disproved, so they probably have a real ontological existence.

Up till now, there was the problem that the physical world and the objects of cognition seem to be different. The hylomorphic functions provide an answer to this. But this still leaves open the question of how the concepts and ideas we think about are composed of atomic hylomorphic functions. Although the objects of our perception are composed of atomic observations, such as when light impinges on the retina, these make up the total experience of an object such as a chair. But there is still the identification of an object like a chair as its Universal. This, of course, is a combination of hylomorphic functions — observations — that become the end product of this identification.

Current physics as we know it only describes objective reality, not the subjective reality of consciousness. The recognition that there is a metaphysical realism is a start in the attempt to give a formal description of what consciousness is, which will lead to an scientific approach to the Hard Problem of Consciousness. This approach will probably lead to a new set of scientific laws that extend physics from objective reality alone to encompass both subjective and objective reality. This will lead to a unification of both subjectivity and objectivity as natural phenomena, without the need to consider any supernatural processes.

10. Acknowledgments

Thanks to Kevin Wilson, Patrick Boyle, John Batali, Nick Orton and an anonymous referee of an early version of this paper for helpful comments.

References

[1] Stephen L Adler. Why decoherence has not solved the measurement problem: a response to pw anderson. *Studies in History and Philosophy of Science Part B: Studies in History and Philosophy of Modern Physics*, 34(1):135–142, 2003.

[2] David Albert and Alyssa Ney. *The Wave Function: Essays on the Metaphysics of Quantum Mechanics*. OUP USA, 2013.

[3] Aristotle and W.D. Ross. *Aristotle's Metaphysics, a Revised Text with Introduction and Commentary by WD Ross,...* Clarendon Press, 1924.

[4] J.D. Bekenstein. Black holes and the second law. *Lettere Al Nuovo Cimento (1971–1985)*, 4(15):737–740, 1972.

[5] John Stewart Bell. *Speakable and Unspeakable in Quantum Mechanics: Collected papers on quantum philosophy*. Cambridge University Press, 2004.

[6] David Bohm. A suggested interpretation of the quantum theory in terms of" hidden" variables. i. *Physical Review*, 85(2):166, 1952.

[7] David Bohm. A suggested interpretation of the quantum theory in terms of" hidden" variables. ii. *Physical Review*, 85(2):180, 1952.

[8] David Bohm and Basil J Hiley. Measurement understood through the quantum potential approach. *Foundations of Physics*, 14(3):255–274, 1984.

[9] David Bohm, Basil J Hiley, and PN Kaloyerou. An ontological basis for the quantum theory. *Physics Reports*, 144(6):321–375, 1987.

[10] David J Chalmers. Absent qualia, fading qualia, dancing qualia. *Conscious experience*, pages 309–328, 1995.

[11] David J Chalmers. *The conscious mind: In search of a fundamental theory.* Oxford University Press, 1997.

[12] David J Chalmers and M Gazzaniga. How can we construct a science of consciousness. *The cognitive neurosciences III*, pages 1111–1119, 2004.

[13] J.C. Cole. Platonism, mathematical. *Internet Encyclopedia of Philosophy*, 2010.

[14] Samuel Colin. A deterministic bell model. *Physics letters A*, 317(5):349–358, 2003.

[15] Daniel C Dennett. *Consciousness explained.* Penguin UK, 1993.

[16] Paul Adrien Maurice Dirac. *The principles of quantum mechanics.* Number 27. Oxford university press, 1981.

[17] Detlef Dürr, Sheldon Goldstein, and Nino Zanghi. Bohmian mechanics as the foundation of quantum mechanics. In *Bohmian mechanics and quantum theory: an appraisal*, pages 21–44. Springer, 1996.

[18] Detlef Dürr, Sheldon Goldstein, and Nino Zanghì. *Quantum physics without quantum philosophy.* Springer Science & Business Media, 2012.

[19] Albert Einstein. *Albert Einstein: philosopher-scientist*, volume 7. Library of Living Philosophers, 1949.

[20] Berthold-Georg Englert, Marian O Scully, Georg Süssmann, and Herbert Walther. Surrealistic bohm trajectories. *Zeitschrift für Naturforschung A*, 47(12):1175–1186, 1992.

[21] Frege and Austin. *The Foundations of Mathematics. A LogicoMathematical Enquiry into the Concept of Numbers.* Harper Torchbooks, 1953.

[22] Domenico Giulini. Superselection rules. In *Compendium of Quantum Physics*, pages 771–779. Springer, 2009.

[23] Sheldon Goldstein. Bohmian mechanics and quantum information. *Foundations of Physics*, 40(4):335–355, 2010.

[24] Ravi Gomatam. Niels bohrs interpretation and the copenhagen interpretation - are the two incompatible? *Philosophy of Science*, 74(5):736–748, 2007.

[25] Bob Hale and Crispin Wright. The metaontology of abstraction. *Metametaphysics. Oxford University Press, Oxford*, 2009.

[26] Klaus Hornberger. Introduction to decoherence theory. In *Entanglement and Decoherence*, pages 221–276. Springer, 2009.

[27] Don Howard. Who invented the copenhagen interpretation? a study in mythology. *Philosophy of Science*, 71(5):669–682, 2004.

[28] Frank Jackson. Epiphenomenal qualia. *The Philosophical Quarterly*, pages 127–136, 1982.

[29] Immanuel Kant. Prolegomena to any future metaphysics that will be able to present itself as a science. 2004.

[30] Sacha Kocsis, Boris Braverman, Sylvain Ravets, Martin J Stevens, Richard P Mirin, L Krister Shalm, and Aephraim M Steinberg. Observing the average trajectories of single photons in a two-slit interferometer. *Science*, 332(6034):1170–1173, 2011.

[31] Oleg Kupervasser, Hrvoje Nikolić, and Vinko Zlatić. The universal arrow of time. *Foundations of physics*, 42(9):1165–1185, 2012.

[32] R. Latta. Leibniz: The monadology and other philosophical writings, 1898.

[33] Joseph Levine. Materialism and qualia: The explanatory gap. *Pacific philosophical quarterly*, 64(4):354–361, 1983.

[34] E Jonathan Lowe. The metaphysics of abstract objects. *The Journal of philosophy*, 92(10):509–524, 1995.

[35] EJ Lowe. Recent advances in metaphysics. *Facta philosophica*, 5:3–24, 2003.

[36] Lorenzo Maccone. Quantum solution to the arrow-of-time dilemma. *Physical review letters*, 103(8):080401, 2009.

[37] Dylan H Mahler, Lee Rozema, Kent Fisher, Lydia Vermeyden, Kevin J Resch, Howard M Wiseman, and Aephraim Steinberg. Experimental nonlocal and surreal bohmian trajectories. *Science advances*, 2(2):e1501466, 2016.

[38] Gideon Manning. The history of" hylomorphism". *Journal of the History of Ideas*, 74(2):173–187, 2013.

[39] Matteo Morganti. Tropes and physics. *Grazer Philosophische Studien*, 78(1):185–205, 2009.

[40] Thomas Nagel. What is it like to be a bat? *The philosophical review*, pages 435–450, 1974.

[41] Michael A. Neilsen and Isaac L. Chuang. *Quantum Computation and Quantum Information: 10th Anniversary Edition*. Cambridge University Press, 2011.

[42] Francesco Orilia. Quantum-mechanical statistics and the inclusivist approach to the nature of particulars. *Synthese*, 148(1):57–77, 2006.

[43] Charles Parsons. Platonism and mathematical intuition in kurt gödel's thought. *The Bulletin of Symbolic Logic*, 1(1):44–74, 1995.

[44] E.H. Reck. Frege on numbers: Beyond the platonist picture. *Harvard Review of Philosophy*, 13(2):25, 2005.

[45] J.J. Sakurai and J. Napolitano. *Modern Quantum Mechanics*. Addison-Wesley, 2011.

[46] Maximilian Schlosshauer. Decoherence, the measurement problem, and interpretations of quantum mechanics. *Reviews of Modern Physics*, 76(4):1267, 2005.

[47] Maximilian Schlosshauer and Arthur Fine. Decoherence and the foundations of quantum mechanics. In *Quantum Mechanics at the Crossroads*, pages 125–148. Springer, 2007.

[48] Claude E. Shannon. A mathematical theory of communication part i. *The Bell System Technical Journal*, 27:379–423, 1948.

[49] L Vanni and R Laura. Preferred basis without decoherence. *arXiv preprint arXiv:0812.0093*, 2008.

[50] J von Neumann. *Mathematical foundations of quantum mechanics*. Princeton university press, 1996.

[51] J.A. Wheeler, W.H. Zurek, et al. *Quantum Theory and Measurement*, volume 10. Princeton University Press Princeton, NJ, 1983.

[52] Donald C Williams. On the elements of being: I. *The review of metaphysics*, pages 3–18, 1953.

[53] Kevin Wilson. personal communication, 2015.

[54] H Dieter Zeh. On the interpretation of measurement in quantum theory. *Foundations of Physics*, 1(1):69–76, 1970.

[55] H Dieter Zeh. Basic concepts and their interpretation. In *Decoherence and the Appearance of a Classical World in Quantum Theory*, pages 7–40. Springer, 2003.

[56] Wojciech H Zurek. Pointer basis of quantum apparatus: Into what mixture does the wave packet collapse? *Physical Review D*, 24(6):1516, 1981.

[57] Wojciech H Zurek. Decoherence and the transition from quantum to classical-revisited. *Los Alamos Science*, 27:86–109, 2002.

32 Second Avenue #332, Burlington MA, 01803

E-mail address: `vandermude@acm.org`