HYLOMORPHIC FUNCTIONS

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ABSTRACT. Philosophers have long pondered the Problem of Universals. One response is Metaphysical Realism, such as Plato's Doctrine of the Forms and Aristotle's Hylomorphism. We postulate that Measurement in Quantum Mechanics forms the basis of Metaphysical Realism. It is the process that gives rise to the instantiation of Universals as Properties, a process we refer to as Hylomorphic Functions. This combines substance metaphysics and process metaphysics by identifying the instantiation of Universals as causally active processes along with physical substance, forming a dualism of both substance and information. Measurements of fundamental properties of matter are the Atomic Universals of metaphysics, which combine to form the whole taxonomy of Universals. We look at this hypothesis in relation to various different interpretations of Quantum Mechanics grouped under two exemplars: the Copenhagen Interpretation, a version of Platonic Realism based on wave function collapse, and the Pilot Wave Theory of Bohm and de Broglie, where particle–particle interactions lead to an Aristotelian metaphysics. This view of Universals explains the distinction between pure information and the medium that transmits it and establishes the arrow of time. It also distinguishes between univerally true Atomic Facts and the more conditional Inferences based on them. Hylomorphic Functions also provide a distinction between Universals and Tropes based on whether a given Property is a physical process or is based on the qualia of an individual organism. Since the Hylomorphic Functions are causally active, it is possible to suggest experimental tests that can verify this viewpoint of metaphysics.

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. As an example, Allori (Albert & Ney, 2013) describes which components of Quantum Mechanics form a primitive ontology but excludes the abstract 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 there are universals that 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, the question arises: where are abstract objects found in reality — if at all — and, assuming they exist, how do they interact with the physical objects? This is the Problem of Universals.

People who believe that Universals actually exist are called *Metaphysical Realists*. The two classical versions of Realism are Platonism and the more moderate Realism of Aristotle. Modern Platonism does not have all of the characteristics of classical Platonism, but it does postulate a separate realm of existence for the Universals. This viewpoint was expressed by Frege, especially in his book "The Foundations of Arithmetic" (Frege & Austin, 1953). Other famous mathematicians such as

Kurt Gödel have expressed a Mathematical Platonism (Parsons, 1995). Carmichael (Carmichael, 2016) advocates a type of Platonism he calls “Deep Platonism”.

Aristotle gave an alternative to Platonism. In his *Metaphysics* (Aristotle & Ross, 1924), 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. He argues this way:

> ”But suppose the Form to be different in each species. Then there will be practically an infinite number of things whose substance is ‘animal’; for it is not by accident that ‘man’ has ‘animal’ for one of its elements. Further, many things will be ‘animal-itself’. For (i) the ‘animal’ in each species will be the substance of the species; for it is after nothing else that the species is called; if it were, that other would be an element in ‘man’, i.e. would be the genus of man. And further, (ii) all the elements of which ‘man’ is composed will be Ideas. None of them, then, will be the Idea of one thing and the substance of another; this is impossible. The ‘animal’, then, present in each species of animals will be animal-itself. Further, from what is this ‘animal’ in each species derived, and how will it be derived from animal-itself? Or how can this ‘animal’, whose essence is simply animality, exist apart from animal-itself?

So Aristotle has an ontology 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 hyle — wood or matter — and the concept morphe — 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 (Manning, 2013). Aristotle's viewpoint has been termed a "Moderate" or "Immanent" Realism (Armstrong, 2005),

Although Metaphysical Realism has gone through many stages of development, the groundwork was laid in Platonic Realism and Aristotle's Metaphysics. Although a case can be made for either approach, the main thesis of this paper — that Universals exist as the result of causally active physical processes — allows for either view of Universals. The type of Metaphysical Realism advocated here will be termed *Causally Active Metaphysical Realism.*

In the Twentieth Century we have seen the development of Process Metaphysics especially the work of Whitehead (Whitehead, 2010). Seibt (Seibt, 2009) and Rescher (Rescher, 1996), among others, have different versions of Process Metaphysics. In contrast to Substance Metaphysics, Process Metaphysics has processes as the foundation of its ontology, rather than objects. The type of Process Metaphysics discussed here is the more generic type as described by Rescher.

Process Metaphysics is often discussed as an alternative to Substance Metaphysics, but it is certainly possible to combine the two viewpoints. But, as Rescher notes: "The mixed – and thereby more complicated – option of a theory of things-in-process has not found much favor since the hey-day of Aristotelianism."[1] In this paper, abstract objects will be considered as contingent upon the more fundamental process of instantiation of a property of an object. The process of instantiation is considered part of the basic ontology — it creates information. It also forms the basis of sensation as a prerequisite to mental acts. This also preserves the viewpoint that the world consists of a duality of both substance and information.

In contemporary metaphysics, philosophers such as Armstrong and Lowe are considered Realists when it comes to the problem of Universals. Lowe, in his *Four Category Ontology* (Lowe, 2006) establishes a framework in which both Universals and Tropes coexist. The arguments made here are in that spirit: we will try to make the case that Universals exist, while still allowing for the coexistence of abstract particulars like Tropes. We will not make an exclusive commitment between Universals versus Tropes in the ontology.

In claiming that there exist Universals that are causally active, it is incumbent upon us to discuss what experimental tests can be applied to prove that this is actually true. We shall begin by discussing the definition of Universals in Quantum Mechanics, the philosophical implications of their existence, and then the physical implications of their existence, in a testable fashion.

2. Universals, Properties and Particulars

First, we need to define what a Universal is.

[1]Ellis (Ellis, 2005) considers a combination of substance and process metaphysics, in the context of scientific essentialism, but a process is limited to be a sequence of physical events, which are defined as some change of energy distribution in the universe.

E.J. Lowe describes Universals versus Objects as follows (Lowe, 2003):

> 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.

It is important to note that Universals, as Lowe defines them, are causally inert. Lowe says:

> ... it seems that only particulars can participate in causal relationships and that an object participates in such relationships in different ways according to its different properties.

Therefore, entities do not necessarily have a physical existence — there can exist objects that exist as abstract entities. Universals are such entities. Universals, in that they do not refer to a single object are sometimes termed "Abstract Objects" (Lowe, 1995). 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 are instantiated as a physical process. 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, since 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 (Hale & Wright, 2009):

> 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 (Frege & Austin, 1953) 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, 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 the desired mathematical definition. Although all three definitions have their critics and detractors, the relational definition shall be used here.

This gives us a notion of an abstract object in terms of a function. In accordance with the discussion above, a *Universal* is the equivalence class of the output of 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 the first order case, *Particulars* form the domain of the function. The application of the function is termed an *Instantiation of that Universal*. Each Universal instantiates a *Property*, which is the range of the function. And a *Fact* refers to the output of the function for that given instantiation, where these Facts impose an equivalence relation on the set of Particulars[2].

Using this formalism, we claim that instantiation is more fundamental than the Universal that it instantiates. The act of instantiation is prior the existence of

[2]Note that Properties are often considered to be possessed by an object or not, such as saying "the ball is red". In the formalism of this paper, this is a Boolean function whose Fact is either the Boolean value *True* or *False*.

the Universal and the existence of the Universal is contingent on the process of instantiation. This is not an unusual position in metaphysics: a number of people such as Armstrong (Armstrong, 1989) (Armstrong, 2004), Lowe (Lowe, 2006) and Juvshik (Juvshik, 2017) have expressed the idea that truth-makers and states of affairs are ontologically prior to the Universals that they instantiate.

Considering the process of instantiation as fundamental leads to the inclusion of process metaphysics in combination with substance metaphysics as a better way of describing the world than substance metaphysics or process metaphysics alone. The resultant ontology contains both static substances and dynamic processes, where the action of instantiation can be considered to be an "object". Although Frege's notion of an equivalence relation is an abstract object, the equivalence is only established through the act of instantiation, since by definition, the objects $x, y \in D$, are equivalent by the relation xEy only if the instantiation process $U(x) = U(y)$ has been executed.

Seibt's General Process Ontology (Seibt, 2009) (Seibt, 2002) (Seibt, 2015) is an example of this viewpoint. She writes "General processes are independent, individual, concrete, spatiotemporally extended, non-particular, non-countable, determinable and dynamic entities". She applies General Process Ontology to Quantum Field Theory, but in a fashion different from the approach given here. In particular, Seibt describes the "Myth of Substance", instead of considering a combination of both substance and process.

The combination of substance and process ontology can be seen in formal systems. The Predicate Calculus (Kleene, 1967) is a formalization of mathematical reasoning in terms of substance metaphysics. The Universe of Discourse is a set of concrete objects, where both Predicates and Functions are abstract objects (Properties) expressed as subsets of the Universe of Discourse (or its Cartesian products). In contrast, the General Recursive Functions (Rogers, 1967) have both objects (the integers) and processes (functions)[3]. Both formalisms are effectively equivalent, but their expression and application are completely different.

Combining substance and process metaphysics also preserves the notion of mind–body dualism, and gives a conceptual framework in which to consider how the two interact. We will expand upon this later.

A further point is that including the concept of process into the formal system also introduces the concept of time. Formal proofs in the predicate calculus use the set of integers as an ordinal notation to express time as a static property. In contrast, the General Recursive Functions capture the notion of time directly. They also make clear the arrow of time as an irreversible process. Many–to–one functions are not invertible by their very nature, and trap door functions are asymmetric in their computational cost.

What about tropes? According to Trope Theory (Williams, 1953), (Maurin, 2011), there are no Universals, only abstract Particulars. Considering the process of instantiation as primary, we can allow for both Universals and Tropes, depending on what got instantiated. Tropes are often grouped according to their resemblance,

[3] For example, in computer science the formalisms equivalent to the General Recursive Functions are Turing Machines or the specification of computers as collections of silicon gates. It is interesting to note that Complexity Theory discusses space-time tradeoffs in the costs of computation, which is essentially trading off substance (memory size) and process (computation time).

which in the simple case[4], would be expressed in a manner similar to the formal definition given above. In this case, a Trope is instantiated, with the equivalence relation redefined by replacing the term "Universal" with "Resemblance". The distinction between a Universal and a Trope will be discussed further in Section 8.

The first part of this paper, though, will focus on Universals. In contrast to philosophers like Armstrong (Armstrong, 1983) (Armstrong, 1989) and Lowe (Lowe, 2006), we claim that there can exist uninstantiated Universals. For example, it is common in mathematics to have "existence proofs" where it is proved that a mathematical object having certain properties exists, but with no way to provide an example of such an object[5]. This is common for proofs involving classes of objects such as the Cantorian sets, sets in the Arithmetic Hierarchy or the Medvedev Lattice (Rogers, 1967). That leaves us open to a Platonic Realism, which we shall discuss later. Note that having the process of instantiation as part of the fundamental ontology avoids some difficulties with abstract mathematical objects such as infinities. For example, the sequence of integers ω is expressed nicely by referring to a process that generates the sequence using the induction axiom of Peano Arithmetic, as noted by Hale and Wright (Hale & Wright, 2002).

In discussing metaphysics in relation to quantum mechanics, the entities under consideration are often limited to those which have a physical existence. This is

[4]Resemblance is typically more than an equivalence relation. Resemblance can also be expressed as clusters of similar Particulars, where overlap between clusters could be allowed (reddish-green as being both red and green), or having the clusters defined in terms of some "centroid".

[5]Carmichael (Carmichael, 2010) considers the concept of "necessarily true" propositions and claims that they are Universals that are mind independent. The distinction is that a necessarily true proposition is true whether or not minds exist. Mathematical concepts can be considered necessarily true Universals.

referred to as a "primitive ontology". Allori (Albert & Ney, 2013) 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.

> 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 classes of objects in the primitive ontology to include the instantiation of some Universals as processes. These processes will be as fundamental to the theory as the concrete entities of standard physics. We extend the ontology as follows. The instantiation of Universals will be used as the fundamental explanation of the Measurement Problem. The act of measurement, at this fundamental level, makes the abstract objects of metaphysics — expressed as process — into causal participants, as much a part of the primitive ontology as concrete objects. This extends the primitive ontology, the basic variables and functions, upon which 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 for its transmission, it exists as a configuration of abstract objects. That is, information is composed of Facts that are the instantiation of Universals (or Tropes).

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 Property being instantiated, what the information means, on a fundamental level. How these fundamental units of information are combined and interpreted will not be gone into detail in this paper[6]. But we will discuss why information has meaning, and how that meaning is structured.

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. We will not make a choice between these two versions of Metaphysical Realism as to which is right, but demonstrate that quantum mechanics provides an answer to the Problem of Universals for Metaphysical Realists, regardless of the choice of Platonic or Aristotelian realism.

[6]This viewpoint is intermediate between information as defined by Shannon (Shannon, 1948) which is more about how information is carried by a medium, and Generalized Representational Information Theory of Vigo (Vigo, 2011) (Vigo, 2012) which is about how information is structured and combined.

As Lowe mentioned above, Universals are considered to be causally inert. We are claiming that some Universals are causally active, in the sense that their instantiation is a physical process independent of a mental act, a process that causes other things to happen. A causally active Universal is one that is spontaneously instantiated without the necessity of having a mind present — it is information that is independent of a mind to process that information. It is the output of a process — the information generated by that process. This information then proceeds to affect other things as a consequence.

The next section gives some salient points of a variety of major interpretations of Quantum Mechanics.

3. Quantum Mechanics: The Measurement Problem

The way that abstract objects are related to physical objects depends on the possible interpretations of quantum mechanics. Two of the earliest formulations are the Copenhagen Interpretation and the Pilot Wave Theory, also known as Bohm–de Brogle Mechanics. There are other well–regarded interpretations we shall consider: Everett's Many Worlds Theory, Decoherence, Decoherent Histories, Ghirardi–Rimini–Weber Theory, the Transactional Interpretation, and Quantum Bayesianism. For the purposes of this paper, we will use the Copenhagen Interpretation and Pilot Wave Theory as exemplars, since they address the Measurement Problem in fundamentally different ways. We shall classify the other interpretations in terms of these two.

This is not to say that the other interpretations are variations on these two exemplars – they are not. As shall be seen, these exemplars deal with abstract objects in two fundamentally different ways. The other interpretations, notwithstanding their differences from these exemplars, have similar viewpoints when it comes to abstract objects.

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 (Gomatam, 2007). The term was first used by Heisenberg (Howard, 2004). 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*: "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."

Bohr (Wheeler *et al.*, 1983) 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 Quantum to Classical Divide*: "However far the phenomena transcend the scope of classical physical explanation, the account of all evidence must be expressed in classical terms." This generalization of the Correspondence Principle was mentioned by Bohr as part of Complementarity, and is considered as such[7], but it comes from a different aspect of Metaphysical Realism than the Complementary Principle. So it is listed separately and given its own name.

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

A measurement was defined by Dirac (Dirac, 1981) (the *Projection Postulate*) 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 (Sakurai & Napolitano, 2011). A measurement collapses the wave function of a system which is a

[7]for example (Kastner, 2017a)

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 (Wilson, 2015). Therefore when we relate measurements as eigenvalues to an instantiation of a Universal as a Fact we are referring to the conjugacy classes associated with the operator the measurement is derived from.

The interpretation of wave function collapse has been subject to debate from the time it was first identified. One interpretation came from Heisenberg, von Neumann and Wigner.

Heisenberg, in his original 1927 paper *The Physical Content of Quantum Kinematics and Mechanics* (Wheeler *et al.*, 1983) describes wave function collapse as an act of observation. 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.* Von Neumann defines two processes in Quantum Mechanics: the first process is the collapse of the wave function during a measurement and the second process is the development of the wave function in time according to the Schrödinger equation. During the process of measurement, he separates the observer from the observed system as follows, using the example of a person reading a temperature using a mercury thermometer (von Neumann, 1996):

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* (Wheeler *et al.*, 1983) 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.

Other physicists did not agree with the necessity of consciousness. Bohr is a case in point. Howard (Howard, 2004) and Gomatam (Gomatam, 2007) 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 the 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 just 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'* (Wheeler *et al.*, 1983) 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 Quantum to Classical Divide addresses the problem of 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 perception does not provide the meaning of the perception. 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 physical theory 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 perceive. With perception 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 perceptions, 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.

3.2. **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 (Bohm, 1952a) (Bohm, 1952b) 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 defined 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 (Bell, 2004).

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 ψ by an arbitrary constant. (This is because ψ 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 though, 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 by Englert, Scully and Süssmann (Englert *et al.*, 1992) as resulting in surrealistic particle trajectories, recent experimental results by Kocsis *et al.* (Kocsis *et al.*, 2011) and Mahler *et al.* (Mahler *et al.*, 2016) show that these trajectories can actually be observed.

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, incomplete knowledge of the initial particle positions that preceded the interaction under consideration makes the prediction of any outcome well–nigh impossible. Second, the equations of motion contain 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 idea 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. In Pilot Wave Theory, 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 (Goldstein, 2010) 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.

3.3. **Other Responses to the Measurement Problem.** There have been a wide variety of differing interpretations of Quantum Mechanics and most of them have something to say about the Measurement Problem. We shall present a number of them, in approximate order of when they were first published. Although these interpretations give different explanations of the measurement problem in terms of physical processes and/or physical intuition, there are some underlying metaphysical properties of quantum mechanics that are inherent in the measurement process and therefore common to all interpretations. These properties will be discussed in the next section. These interpretations will be grouped under the two exemplars, depending on whether the interpretation acknowledges the existence of the process of wave function collapse separate from the Schrödinger wave equation, or whether the interpretation explains measurement through some physical means without having to postulate a separate process.

3.3.1. *Everett's Many Worlds Interpretation.* Soon after Bohm presented his interpretation of Quantum Mechanics, Everett presented a PhD Thesis at Princeton

(Everett III, 1957). In this interpretation Everett argued that there was no Process 1 (wave function collapse). Instead of the wave function being collapsed, the state of the system becomes entangled with the observer. This interpretation was revived in the 1970's by DeWitt as the Many Worlds interpretation, where different possible outcomes of a measurement produce different copies of the universe[8].

Everett writes "Thus with each succeeding observation (or interaction), the observer state 'branches' into a number of different states. Each branch represents a different outcome of the measurement and the corresponding eigenstate for the object-system state. All branches exist simultaneously in the superposition after any given sequence of observations." This is reflected in the memory of the observer: "The 'trajectory' of the memory configuration of an observer performing a sequence of measurements is thus not a linear sequence of memory configurations, but a branching tree, with all possible outcomes existing simultaneously in a final superposition with various coefficients in the mathematical model."

Although Everett's interpretation denies that wave function collapse occurs, it is still true that there is a measurement. These measurements are recorded by observers that are purely physical systems with memories to record the measurement.

Everett's approach is similar to Pilot Wave Theory in its denial of wave function collapse and the explanation of measurements in terms of physical principles. Therefore we categorize it under the Pilot Wave exemplar.

[8]It is interesting to compare Everett's interpretation to Lowe's Modal Realism. (Lewis, 1986). Whereas Lowe postulates that the different worlds exist independently, Everett provides a mechanism where they branch off from each other. We shall not consider modal metaphysics in this paper.

3.3.2. *Decoherence.* A number of 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 (Zeh, 1970) and W.H. Zurek (Zurek, 1981). A good introduction to decoherence can be found in Schlosshauer (Schlosshauer, 2005), Schlosshauer and Fine (Schlosshauer & Fine, 2007), Zeh (Zeh, 2003), Zurek (Zurek, 2002) and Hornberger (Hornberger, 2009). Schlosshauer (Schlosshauer, 2006) discusses how a variety of experimental results can be interpreted through decoherence.

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 (Giulini, 2009) by any observable, not just a Hamiltonian operator.

To quote Zurek (Zurek, 2003):

> The understanding of how the environment distills the classical essence from quantum systems is more recent. It combines two observations: (1) In quantum physics "reality" can be attributed to the measured states. (2) Information transfer usually associated with measurements is a common result of almost any interaction with the environment of a system.

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–environment 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 (Adler, 2003) makes this plain: "One might then attempt to show that the discrete choice of experimental outcome is tied to details of the initial state, giving a sense in which 'decoherence', as understood more generally to mean environmental influence, could be said resolve the measurement problem. A calculation showing how this might happen has never been given..." Although decoherence may be a mechanism where the off–diagonal terms go to zero, it does not explain why one eigenstate results from one measurement instead of another. Zeh (Zeh, 2003) discusses this problem in terms of superselection.

> 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.

Quantum Darwinism (Zurek, 2009) (Riedel *et al.*, 2016) has been proposed as the mechanism of einselection. According to Zurek "Quantum Darwinism leads to appearance, in the environment, of multiple copies of the state of the system... This insight captures the essence of Quantum Darwinism: Only states that produce multiple informational offspring – multiple imprints on the environment – can be found out from small fragments of $\mathcal{E}$ [the environment]. The origin of the emergent classicality is then not just survival of the fittest states (the idea already captured by einselection), but their ability to *procreate*, to deposit multiple records – copies of themselves – throughout $\mathcal{E}$."

A related issue is the preferred pointer basis. Schlosshauer (Schlosshauer, 2005) 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.

It is interesting to note that one of the first appearances of the concept of decoherence and einselection in the scientific literature was Bohm's articles on Pilot Wave Theory (Bohm, 1952a) . The way he presented decoherence is different from the current use of the term and is useful to consider. He said:

> [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.

The question of the preferred basis will play an part in the following discussion. Although there has been some attempts to provide a physical explanation for the preferred basis problem, the metaphysical implications have not been addressed.

In classifying decoherence under the two exemplars, this process comes under the Pilot Wave exemplar. Decoherence is an explanation of measurement without the need to postulate a wave function collapse as a separate process.

3.3.3. *Consistent Histories and Decoherent Histories.* Consistent Histories is an approach introduced by Griffiths (Griffiths, 1984). Although measurements do not play a part in this interpretation, there are “events”. Joint probabilities are computed on a series of events (a history). It is required that the events be consistent, in the sense that they commute.

Consistent Histories was developed further by Gell-Mann and Hartle (Gell-Mann & Hartle, 1996), in what is termed Decoherent Histories. Dowker and Kent (Dowker & Kent, 1996) review the two approaches and compare and contrast them. Gell-Mann and Hartle’s approach uses decoherence in the context of consistent histories to explain the emergence of classicality from quantum mechanics. The fine-grained history of the full set of operators is grouped into a coarse-grained structure upon which the process of decoherence applies, leading to our concept of a classical domain. They suggest that human observers are examples of an “information gathering and utilizing system” (IGUS) that evolved to exploit the quantum regularities in some particular quasi-classical domain, giving a predictive power to observations.

Although there is no reference to measurement, there still is the notion of an event, which is not further defined. Similarly, the notion of an IGUS is similar to the notion of the observer in the Copenhagen Interpretation. Because of this, Dowker and Kent suggest that “There is an alternative which cuts through all these problems. It is to accept, once and for all, that quantum theory is not sufficient to describe the world, and that it should be augmented by a further axiom which takes the form of a selection principle.” Therefore, Decoherent Histories is placed with the Copenhagen Interpretation for the purposes of this paper.

3.3.4. *Ghirardi, Rimini, Weber Collapse Theory.* The Collapse Theory of Ghirardi, Rimini and Weber (Ghirardi *et al.*, 1986) takes the process of wave function collapse literally, and attempts to quantize it. Given that a quantum system can be a collection of particles in a superposition of states, collapse theory postulates that individual particles sometimes collapse to a particular location out of a superposition of possible locations. Although the chance of an individual particle collapsing is very low, this will happen in a macroscopic system almost instantaneously, leading to a measurement.

One method of Collapse is known as Trace Dynamics (Bassi *et al.*, 2013) This approach postulates that the collapse occurs when the wave packet macroscopic mass spreads out sufficiently, due to space-time haziness. This causes a stochastic reduction of the extended wave function to one of its smaller, coherent parts.

In terms of the two exemplars, Collapse Theories are more like the Pilot Wave Theory than the Copenhagen Interpretation, because the collapse is described as a physical process from the regular evolution of the Schrödinger wave equation, but without recourse to an observer.

3.3.5. *Transactional Interpretation.* The Transactional Interpretation was developed in the late 1980's by John Cramer. In this interpretation, the ψ and ψ^* wave functions are presumed to move in opposite directions in time. According to Cramer (Cramer, 1988), "Any quantum event is a 'handshake' executed through an exchange of advanced and retarded waves". These are referred to these as the Offer Wave and the Confirmation Wave. Kastner points out (Kastner, 2016c): "In TI, these Offer Wave/Confirmation Wave encounters are called incipient transactions. If we add all the incipient transactions, we clearly have the density operator representation of von Neumann's Process 1." Cramer notes (Cramer, 1986) "It should be emphasized that the transactional interpretation is an interpretation of the existing formalism of quantum mechanics rather than a new theory or revision of the quantum-mechanical formalism. As such, it makes no predictions that differ from those of conventional quantum mechanics. It is not testable except on the basis of its value in dealing with interpretational problems." Following criticisms by Maudlin, Kastner provided a relativistic version of the Transactional Interpretation and an account of the measurement problem (Kastner, 2016b) (Kastner, 2017b).

The Transactional Interpretation, like Pilot Wave Theory, gives a physical explanation for measurements.

3.3.6. *Relational Interpretation.* The Relational Interpretation was introduced by Rovelli (Rovelli, 1996). This interpretation considers that the analysis of quantum mechanical systems can only be analyzed relative to other quantum mechanical systems. This interpretation rejects the notion of an observer-independent measurement of physical quantities. As Rovelli puts it:

> If different observers give different accounts of the same sequence of events, then each quantum mechanical description has to be understood as relative to a particular observer. Thus, a quantum mechanical description of a certain system (state and/or values of physical quantities) cannot be taken as an "absolute" (observer independent) description of reality, but rather as a formalization, or codification, of properties of a system relative to a given observer. Quantum mechanics can therefore be viewed as a theory about the states of systems and values of physical quantities relative to other systems.

The relative interpretation makes the events of a quantum system relative to an observer, but how are they ever reconciled? Is it possible, in one system, for a particle to be spin-up and in another system to be spin-down at the same time? Dorato (Dorato, 2013) refers to these properties as "intrinsic properties". Rovelli notes that the attempt to reconcile any discrepancies about the values of properties is itself relative: "you can inquire about the value of q with respect to me, but this is (in principle) a quantum measurement as well."

Laudisa (Laudisa, 2017) criticizes Relational Quantum Mechanics as follows:

> Rovelli as a matter of fact seems to assume that the sequence of events in the measurement does not include the apparatus as a quantum system ... This looks like a sort of Bohrian approach: in principle it is not an immediately inconsistent approach in itself but, as is well known, it leads to very serious problems in deciding (i) where the classical/quantum divide is supposed to be located,

> and (ii) when an interaction is supposed to be a 'measurement'- or
> a 'non-measurement'-interaction.

Winter (Winter, 2017) critiques Relational quantum mechanics as follows: "Relational quantum mechanics is therefore incompatible with the philosophical tenet that there is an objective or real cause for the correlation between the measurements of the two observers." This objection is easily refuted by pointing out that entanglement itself is the cause of the correlation between measurements. So one observation does not cause the other observation to be a certain way in the classical sense.

Trassinelli (Trassinelli, 2018) analyzes the Relational Model using a probabilistic analysis. He demonstrates that the two postulates: "there is a maximum amount of relevant information that can be extracted from a system." and "it is always possible to acquire new information about a system" are sufficient to build a Hilbert space and derive Born's rule.

Like Decoherent Histories, there is a notion of a quantum event, which is not simply explained by reference to the Schrödinger wave equation. Therefore, this interpretation is classified with the Copenhagen exemplar.

3.3.7. *Quantum Bayesianism.* Quantum Bayesianism was introduced by Christopher Fuchs. According to QBism, (Fuchs, 2002) Quantum Mechanics is more about information – a measurement is the updating of subjective probabilistic beliefs about a system. Fuchs says (Fuchs, 2017): "QBists opt to say that the outcome of a quantum measurement is a personal experience for the agent gambling upon it. Whereas Bohr always had his classically describable measuring devices mediating between the registration of a measurement's outcome and the individual agent's experience, for QBism the outcome just is the experience."

QBism makes no non–local statements such as found in the Einstein–Podolsky–Rosen paradox (Einstein *et al.*, 1935). Instead, Fuchs, Mermin, and Schack (Fuchs *et al.*, 2014) say:

> Therefore when any agent uses quantum mechanics to calculate "[cor]relations between the manifold aspects of [her] experience", those experiences cannot be space-like separated. Quantum correlations, by their very nature, refer only to time-like separated events: the acquisition of experiences by any single agent. Quantum mechanics, in the QBist interpretation, cannot assign correlations, spooky or otherwise, to space-like separated events, since they cannot be experienced by any single agent. Quantum mechanics is thus explicitly local in the QBist interpretation.

Quantum Bayesianism allows for the notion of wave function collapse, but does not explain it beyond categorizing it as a subjective event. Therefore it is placed with the Copenhagen exemplar.

3.3.8. *Summary.* In summary, the different interpretations of Quantum Mechanics can be grouped under the two exemplars, as shown in Table 1.

We will now discuss the Problem of Universals in terms of the Measurement Problem of Quantum Mechanics.

Exemplar	Copenhagen	Pilot Wave
Measurement	Wave function collapse	Physical process
Similar Interpretations	Decoherent Histories Relational Interpretation Quantum Bayesianism	Everett Many Worlds Decoherence Ghirardi, Rimini, Weber Transactional Interpretation

Table 1. Quantum Mechanical Interpretations

4. Universals in the Ontology of Quantum Mechanics

There are two parts to the question of Universals in the context of Causally Active 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. We shall answer these questions through the process of Measurement in Quantum Mechanics.

Given the definitions of Universals and Properties, which map Particulars to Facts as described in Section 2, we can state the following principles about Facts that are true about physical objects:[9]

- A Fact occurs at some discrete point in space. It is not continous, but localized.
- A Fact comes into being relatively quickly. It is localized in time.
- A Fact is universal for all space and time.
- A Fact is universal for all observers.

[9]These claims certainly cannot be applied to Universals that are pure concepts, such as truth and beauty. We will argue that these other Universals arise from concepts about physical objects.

- A Fact captures only one aspect of a state of affairs. It is conceptually localized.

This is the nature of a Universal in Metaphysical Realism. A Universal generates Facts about physical objects that are eventually the same for all observers. Otherwise, the physical evidence of the result would not be fixed in time and space: the photodetectors of a physics experiment would give different readings for different observers, despite the fact that the record is fixed and universal. But different observers do not have to know the same Facts at the same time. We are limited by the speed of light and the bandwidth limitations of our information systems. It should also be mentioned that Universals appear to be quantized in some sense. For example, although it is possible to attach real numbers to a position of a particle, the concept of position itself cannot be subdivided.

Regardless of the particular interpretation of the Measurement Problem, it is obviously true that what the interpretations have in common is that a measurement occurred. Measurements record some property of the system – they generate information that has meaning. So if a measurement has been made, it results in a Universal Fact. That is, the particular value of this Fact is universal to all observers, at different times and places. It is still a Fact even if there were no observers, as long as there was some physical record of its particular value, even if it is just a transient record. Otherwise, there can be no possibility of any kind of universal information or knowledge in the universe. This must be true regardless of the interpretation — the measurement may be due to wave function collapse, decoherence, Many Worlds, or any other process, but it must result in a Fact.

The existence of universal Facts cannot be explained purely by the deterministic process of the wave equation, which only explains the substance of the Universe and how it is arranged. We still have to explain the existence of Universals – how ideas arise as abstract objects.

Regardless of how to explain the Measurement Problem, any Fact that is true about some physical event in the Universe is based on a measurement. That is, measurements have the following properties:

- A measurement is made of a system localized in time and space.
- A measurement is an event that yields a Fact as its outcome.
- A measurement captures only one aspect of a Quantum Mechanical state.
- A measurement is universally true, eventually.

The main claim of this paper is that Causally Active Metaphysical Realism gives a physical basis to the existence of the Facts that are generated by metaphysical Universals. This physical basis can be found in the process of measurement in Quantum Mechanics. The two realms – physics and metaphysics – form a dualism where both substance and process form an interdependent part.

This is neither an epistemological nor an ontological view of Quantum Mechanics as they are currently understood. It is not epistemological, in the sense that an epistemological state is not presumed to have an actual physical existence (Zinkernagel, 2016). On the other hand, the ontological view presumes that an ontological existence is limited to a physical objects, not abstract ones. These viewpoints refer primarily to the wave equation, not to a measurement. But the emphasis here is on the process of measurement. Causally Active Metaphysical Realism means that the epistemic state of a Fact instantiated by a measurement has a real existence, but ontologically that Fact exists as an abstract object, not a physical one.

This means that the Measurement Problem needs to be addressed in terms of both physics and metaphysics. The essential problem with the measurement problem is that a quantum mechanical system is a thing but a measurement is an idea. The measurement problem is usually discussed in terms of experimental measurements of properties of objects but it is deeper than that. The object exists and has properties regardless of whether they are measured or not. But we have no knowledge about the properties of the object without measurements.

So what is the meaning of measurement in terms of Universals? Qualitatively, measurement is the process of abstracting some Property from an object. The instantiation of Universals as the output of a measurement means that these Properties are not fundamental objects — they are the results of processes that are themselves fundamental. This is the justification for considering measurement as an ontologically fundamental process. The resultant abstract object supervenes on the process. Put another way, the measurements are the fundamental truthmakers for the class of Universals that instantiate physical Facts, the ground truth of physics. These Universals supervene on the states of affairs that are the subject of the act of measurement.

Rephrased in terms of Quantum Mechanics, a measurement is a process of instantiating a Universal, which will be termed a *Hylomorphic Function.* Each measured property can be considered as the output of a hylomorphic 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 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 instantiates a metaphysical Universal. The act of measurement executes the Hylomorphic Function, collapsing the wave function into a Fact — a particular instantiation of the Universal at that time and place.

So the instantiation of Universals as Properties are the results of quantum measurements. This gives a physical explanation for Causally Active Metaphysical Realism.

John Stewart Bell, in his article entitled *The Theory of Local Beables* (Bell, 2004) gives a viewpoint of the Quantum to Classical Divide. He 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.

In Bell's terms, the hylomorphic functions are the process of generating an observable from a beable. Bell prefers to focus only on beables (Bell, 2004):

> 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.

Instead, we can have both. In terms of Bell's distinction between observables and beables, Causally Active Metaphysical Realism implies that observables do not exist because of beables, but exist in their own right. The beables are composed of physical entities, as Bell states, and the observables are composed of the instantiation of Universals that are the results of quantum measurements. Thus, hylomorphic functions do not supervene on physical objects — they are processes that result in abstract objects.

So observations and observables exist as much as beables do. If they were dependent upon beables, the question can be reasonably posed: how does the mere fact that beables exist give rise to observables? There is nothing in modern physics that describes how beables create observables. Admittedly, the claim that observables, as the output of hylomorphic functions, exist independently of beables also does not, by itself, answer how observables come to be. This is a problem that physics has yet to definitively address. But establishing hylomorphic functions as independent physical processes brings this problem into relief.

This leads to the dichotomy of substance and process metaphysics. Substance metaphysics is captured in Schrödinger's equation. Process metaphysics is the process of measurement. This takes the place of the system and the observer in many interpretations of quantum mechanics. Instead of an observed physical entity and an observing physical entity, there is a single physical entity – the *System* – and an abstract, ideal entity – a *Fact* about the System.

Facts are created by a process, a Hylomorphic Function, that is independent of the System – they are not substance. The different interpretations of Quantum Mechanics give a different physical explanation for how the Fact is generated, but they do not explain the Fact itself. They do not explain the creation of abstract objects.

To quote The Stanford Encyclopedia of Philosophy (Myrvold, 2017): "These two interpretations of the collapse postulate, as either a real change of the physical state of the system, or as a mere updating of information on the part of an observer, have persisted in the literature." Hylomorphic functions connect these two interpretations. The measurement is the creation of information, associated with a physical record of this information. The separate nature of hylomorphic functions from the time symmetrical laws of physics leads to a type of dualism. That is to say, the substance of reality must be acknowledged equally with the process of knowledge creation in reality. Duality comes out of the fact that both substance and process are co–equally fundamental in the basic ontology. This view of dualism does not imply two separate realms of substance and spirit — instead, they are two aspects of physics.

With this viewpoint of Hylomorphic Functions, we see the resolution of certain puzzles bedeviling different interpretations. First, there is no need to split the universe into a system and observer, or the tripartite system, observer and environment, For example, Smolin (Smolin, 1995) says this about the system – observer split: "The interpretational difficulties with quantum cosmology arise because the conventional interpretations of quantum theory require that the quantum state description be applied only to subsystems of the universe. The interpretation of the theory requires the existence of things which are in the universe but outside of the system described by the quantum state, including the measuring instruments, the clocks that give meaning to the Schrödinger evolution and the observers." The notion of Hylomorphic Functions does away with that. Instead of two subsystems, there is a System (a substance) and a Hylomorphic Function (a process) that generates a Fact about the System without reference to an observer. Facts exist by themselves as causally active abstract objects. They do not require an observer to exist. There can be zero, one, or many observers of the same Fact.

For many interpretations, this split has been so hard to define that sometimes it is argued away. Schlosshauer (Schlosshauer, 2005) says: "As long as the universe is not resolved into individual subsystems, there is no measurement problem." But measurement occurs all the time, regardless of the observer. The measurement problem exists because we have information with meaning.

If a Fact is never recorded, does it exist? Probably not – otherwise there would be no information. A measurement must be recorded somehow. But does this do away with the necessity of defining a process? No, because the process of creating Facts is not part of physics as we currently know it, since physics has no formal mechanism to define the meaning of information. Not the amount of information, or the physical manifestation of information, but the meaning.

A measurement is causally active because the value of a measurement affects other processes by transferring information to those other processes, such as in Heisenberg's description of a light measurement of an electron orbit (Wheeler *et al.*, 1983). This instantiation has a defined time and place, so any Fact that is the result of a hylomorphic function can only be true at that time and place.

Can there be knowledge without an observer? Dirac describes the Projection Postulate without reference to an observer. A measurement could simply be the recording of information. This can happen without a consciousness being present. For example, a Stern–Gerlach experiment could possibly arise naturally with suitably situated natural lodestones and a material that reacts to the particles passing through the lodestones. Consciousness is not required for wave function collapse – the act of measurement is sufficient, regardless of how the measurement came about. This is discussed further in Yu and Nikolić (Yu & Nikolić, 2011) where an experiment is described that has measurement without observers.

This is in contrast to Quantum Bayesianism. As Fuchs, Merman and Schack (Fuchs *et al.*, 2014) put it:

> "QBism personalizes the famous dictum of Asher Peres. The outcome of an experiment is the experience it elicits in an agent. If an agent experiences no outcome, then for that agent there is no outcome. Experiments are not floating in the void, independent of human agency... The disagreement between Wigner's account and his friend's is paradoxical only if you take a measurement outcome to be an objective feature of the world, rather than the contents of an agent's experience. The paradox vanishes with the recognition that a measurement outcome is personal to the experiencing agent."

This is just not so. For example, a measurement about a quantum system can be captured in the position or velocity of an electron traveling away from the system. This electron has taken on these properties because of some particular property of the system it is leaving. You do not need a human agency to make this possible. You don't even need an electron detector to make this possible. This particular property of the system is inherent in the electron. This is information that can be transferred to another quantum system, and can eventually become part of the information of a classical measurement apparatus. But the apparatus does not make the information come into being. It only transmits that information.

This identification of the instantiation of hylomorphic functions as abstract Universals is due to the fact that a measurement can occur by itself, not just as a mental act. A measurement does not require consciousness. It is an observation without an observer. There could be an observer measuring a quantum state, but there could also be an Analog to Digital (A/D) converter in a microprocessor or even a set of billiard balls being hit by a cue ball. In contrast to Bell (Bell, 1990) a measurement does not require an external intervention. It may be spontaneous, such as an electron/positron creation. If a set of measurements emerge as pointer positions in an experimental setup it is because the experimenter chooses the experiment in such a way as to elicit the measurement, not because we have the power to create a new type of fundamental measurement.

So, instead of the consciousness of the Copenhagen Interpretation, there is the generation of an abstract ideal Fact, existing at some point in space and time. That means that a measurement outcome is an objective event independent of an agent. That is inherent in Metaphysical Realism. What exists is the Fact itself, besides the consciousness of the Fact. This is in contrast to the Wigner's friend argument: the Fact was instantiated whether there was a consciousness there to experience it or not.

This Fact is generated as a Process of measurement that is manifest on the Substance of the universe, which can be gives meaning to information transmitted from one observer to another. Note that due to entanglement, Facts are not necessarily independent. Actually, since they are causally active, entanglement is always a possibility.

Garret (Garret, 2001) makes the claim that measurement and entanglement are really the same thing: "Under QIT [Quantum Information Theory], a measurement is just the propagation of a mutually entangled state to a large number of particles." Cerf and Adami (Cerf & Adami, 1998) put it this way: "it is recognized that the creation of entanglement (rather than correlation) is generic to a quantum measurement," As Garret says:

> So Mermin was on the right track, but he didn't get it quite right: not only is the moon is not really there when nobody looks, but it isn't really there even when you do look! "Physical reality" is not "real", but information–theoretical reality is. We are not physical entities, but informational ones. We are made of, to quote Mermin, "correlations without correlata." We are not made of atoms, we are made of (quantum) bits. At the risk of stretching a metaphor beyond its breaking point, what we usually call reality is "really" a very high quality simulation running on a quantum computer.

This viewpoint does not address the generation of a Fact. If Physical reality is not real, does this also apply to my identification of the moon as a physical entity? This viewpoint is essentially Process without Substance.

4.1. **Atomic Universals.** 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, velocity 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. Metaphysically, it is a quantum. Here, the distinction made by Bell of a local beable is worth noting. What makes them local is that local beables can be assigned to some bounded space time region. This locality is a fundamental aspect of the notion of an Atomic Universal. As mentioned, both Facts and measurements are localized. Facts are generated by the Atomic Universals. The Atomic Universals form a primitive basis for the rest of the Universals that are composed of them.

A Fact that is the instantiation of an Atomic Universal will be termed an *Atomic Fact*.

It can be argued that the Atomic Universals form the basis for natural classes, in the sense of Armstrong (Armstrong, 1989)[10]. Armstrong claims that natural classes are determined by scientific reasoning. The hylomorphic functions provide the physical explanation for this.

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 information. The Atomic Universals are as fundamental to describing the conceptual, abstract layer of reality as the primitive ontology of Allori 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 concrete and abstract entities.

This viewpoint makes the class of fundamental Atomic Universals 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 Facts. Also, the nature of the apparatus is dependent on our ability to conceive of it to construct it, which conception is based on Atomic Universals.

[10]Eddon (Eddon, 2013a) uses the term fundamental, or natural, properties

Contrast this to Kastner's Possibilist Transactional Interpretation and the concept of potentia (Kastner, 2016c) (Kastner *et al.*, 2017).

> If we think of the space–time realm as the realm of concrete, actualized events, then the quantum entities described by state vectors must have a different ontological status. In PTI they are viewed as physical possibilities or potentiae, just as Heisenberg suggested... For Heisenberg, potentiae are not merely epistemic, statistical approximations of an underlying veiled reality of predetermined facts; rather, potentiae are ontologically fundamental constituents of nature... In this way, the evaluation of an observable via a quantum measurement event entails the actualization of one of the potential outcomes inherent in a pure state (i.e. a given pure state embodies many potential outcomes). It is a fundamental feature of quantum mechanics that the object of observation is always an actual outcome, and never a superposition of potential outcomes. Thus, one cannot 'directly observe' potentiality, but rather only infer it from the structure of the theory.

Kastner recognizes the need to augment the primitive ontology with abstract objects to fully capture the physics behind quantum mechanics. The difference between this approach and hylomorphic functions is that PTI considers potential outcomes as ontologically basic, and with hylomorphic functions, the process itself is ontologically basic.

Consistent histories (Gell-Mann & Hartle, 1996) has the concept of coarse grained and fine grained histories to explain the emergence of quasi-classical domains. The

Information Gathering and Utilizing System chooses the coarse graining and thus the domain. Instead, we make the claim that coarse graining arises naturally out of the nature of Atomic Universals, which are the fine grain.

It is also necessary to emphasize that the mere existence of a Fact is only one aspect of a Quantum Mechanical system. A related problem is how we arrive at the selection of a particular Fact for a particular measurement. In “Against Measurement” (Bell, 1990) Bell says: “the measurement act ‘collapses’ the state into one in which there are no interference terms between different states of the measurement apparatus.” This process is the selection of an ideal. It is implied in the process of wave function collapse. But it also occurs in other interpretations: for example, in decoherence, the process of measurement is the reduction of the interference terms. The metaphysics of a measurement is that every Atomic Universal is an abstraction of some single concept, not the whole state of the system. It is possible to consider the wave function of the Universe containing all knowledge, but each measurement only contains a single universal. Otherwise it is impossible to have universals – everything would be metaphysically indistinguishable.

The Kochen–Specker theorem shows that it is not possible to instantiate all properties of a system simultaneously. This is consistent with the claim that only one hylomorphic function can be instantiated at a time. This means that complementarity is inherent in hylomorphic functions.

Note that complementarity is not just a duality, like that of wave and particle. There are as many possible properties as there are hylomorphic functions. A measurement is the choice of a single Property out of all of the possible Properties to instantiate. But the choice of one Property means the others are ignored[11]. The property instantiated may be because of the intentional setup of an experiment or it may be because of a naturally occurring situation. But we end up with a single Fact. The System that is characterized by the Fact keeps on developing according to the Schrödinger wave equation, so we will have other Facts at other times. But we also can only know a limited amount of knowledge about a system at any time. As we get new Facts, the system evolves and the old Facts become invalid. The Heisenberg Uncertainty principle quantizes this characteristic of hylomorphic functions.

This brings up the question of more complex Universals. How universal are Universals (or Tropes) 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 concepts 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 concepts we recognize are formed from our existence as human beings. This means that there is a basic ground of Causally Active Metaphysical Realism

[11]Cramer (Cramer, 1986) points out that in the classical regime, electrical pulses can be represented either in the time domain as a set of voltages varying continuously as a function of time, or in the frequency domain as a continuous set of Fourier components, i.e., a set of voltages varying continuously as a function of frequency. These representations of fast electrical pulses have exactly the Bohr–Heisenberg complementary relationship and exhibit their own "uncertainty principle". This reflects the point that the nature of Universals requires that a choice must be made of which Property to consider at any given time. This is part of the nature of metaphysics, not specific to a particular domain of physics.

when it comes to Universals, that also allows for a metaphysical nominalism, if Trope Theory (Williams, 1953) (Maurin, 2011) is true, and also gives a physical grounding to the Platonic Universals of a Metaphysical Realism.

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 the measurements of Atomic Universals 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 of Universals is constrained by physical necessity instead of a theoretical hierarchy, such as found in formal logic. So, for example, the taxonomy of Universals composed of hylomorphic functions is constructed in the same sense that an electron is part 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. Atomic Facts can arise spontaneously, but there must be some mechanism – or some observer – to combine them.

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 Universals. 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 characteristics of reality.

For example, Universals that are relational operators, such a *A is heavier than B* are not fundamental Properties. Atomic Universals can only be simple quantities. It is difficult to claim that the relationship between two Atomic Universals can come about without a mental act that compares the two. This is the case with Johannsen (Johansson, 2013) who considers relations that depend on collections of scattered quantities. Eddon (Eddon, 2013b) also discusses a definition of relation based on the work of Mundy, that involves predicates of variable degree. In both of these cases, the relation depends on the ability to keep a number of more fundamental concepts in mind – a problem that does not arise with hylomorphic functions that instantiate a single Property.

So, just like mathematical objects, laws of nature are not fundamental. To quote Armstrong (Armstrong, 1997): "It remains true, though, that your average law of nature that has some claim to be fundamental will be a functional law that connects two or more quantities. This in turn means that a scientific or a posteriori realism about Universals will have to concentrate particularly on Universals of quantity." Since laws of these types are relational, they can never be ontologically fundamental.

Trope Theory has seen some work relating Tropes to primitive quantum mechanical concepts. Some suggestions have been made on the relationship between Tropes and aspects of quantum mechanics, such as summary statistics (Orilia, 2006) or the fundamental forces or particles of physics (Morganti, 2009). Although these approaches have the virtue of grounding Trope Theory in actual physical phenomena, there is more to Tropes than that. We shall discuss the nature of Tropes in Section 8, in reference to qualia.

As mentioned above, the notion of the Quantum to Classical Divide 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 (Dürr *et al.*, 1996) 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 Causally Active 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 Causally Active Metaphysical Realism there is a circular argument in this view: the experiments represent Universals that are not necessarily Atomic, but they give rise to the Atomic Universals via quantum measurements. This problem is similar in character to the argument that Kant had used to claim that there must be *a priori* knowledge of physical reality that he defined in the *Prolegomena* (Kant, 2004).

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. We are not free to create fundamental properties from scratch through the setup of our experiments. Instead, the way we set up an experiment will elicit certain fundamental properties.

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 Metaphysical Realism, not just our conceptual structure.

The Quantum to Classical Divide comes out of the duality of substance and process. The Schrödinger wave equation is the expression of the physical ontology of the universe – its substance. But the hylomorphic functions are the process of measurement. Classical concepts such as position, time, velocity, spin, etc. are the basic building blocks of the process of measurement. The Atomic Universals form the basis of our knowledge of the real world in time and space. They are most likely classical in nature.

Considering physical process as fundamental as physical substance, this recognizes that the instantiation of Universals is not arbitrary, but is the result of the physical processes that they represent. The different types of Atomic 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.

The problem is, why do we have the Universals we have and not others? Why are there some defined set of Atomic 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 they are what they are is unknown. Perhaps the Atomic Universals aren't discrete but live on some higher manifold (Wilson, 2015).

It has been mentioned by Ney (Albert & Ney, 2013), among others, that particle position is the only determinate observable — it is the single measurement that has metaphysical meaning[12]. 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 quarks form protons, neutrons and electrons which 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. But 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 taxonomy of abstract objects likely carries into the quantum realm in some sense.

You cannot assume that the Atomic Universals necessarily form a simple mathematical structure from which more complex Universals are constructed. Daumer et al (Daumer *et al.*, 1996) argue against a naive realism where the world is just what it seems, showing that it is possible to mathematically derive some properties, such as spin, from more fundamental properties, such as position. Yes, but this does not answer the question of why spin is a fundamental concept. There may be some underlying structure of the Atomic Universals that leads to this ability to

[12]It is sometimes stated that position is the universal preferred basis, such as for collapse theories like GRW (Schlosshauer, 2005)

reduce some properties from other more fundamental properties. That is to say, the Atomic Universals may have their own non–trivial taxonomy.

The Universals are the essential preferred basis vectors for quantum measurements. Barret (Barrett, 2005) analyzes this in some detail. Laura and Vanni (Vanni & Laura, 2008) argue that the basis of any measurement is uniquely identified by the physical process involved in the measurement without recourse to decoherence. As Schlosshauer notes: (Schlosshauer, 2005) "The appearance of 'classicality' is therefore grounded in the structure of the physical laws." This means that the physical processes involved in the process of measurement determine the preferred basis.

To illustrate this problem, consider the Atomic Universals in terms of the preferred basis. Schlosshauer (Schlosshauer, 2005) points out that the measurement problem consists of both the problem of definite outcomes — why one Fact and not a superposition of Facts — and the problem of the preferred basis — what singles out a preferred decomposition of a state vector (Galvan, 2010). The reason why a hylomorphic function is a process and physics is a substance is not due to the simple act of measurement, which is typically discussed in terms of substance physics. Instead, it is due to the fact that after the measurement, we end up with classical properties as abstract ideals. Substance physics alone is hard pressed to explain the abstract ontology: why we have the set of preferred bases that we do, or alternatively, why we have the set of hylomorphic functions we do. There is nothing in decoherence that allows us to derive a fundamental primitive ontology of measurements. For example, Quantum Darwinism discusses how certain states have a preferred basis, but not why the set of properties are such as they are. Physics just goes from state to state, but a hylomorphic function generates a Universal Fact. It is not the action alone that counts – it is the result. A process is composed of an input, a transformation and an output. The output is a fundamental part of the process. In physics, things just are. In metaphysics, things are known.

Schlosshauer (Schlosshauer, 2005) claims: "The clear merit of the approach of environment induced superselection lies in the fact that the preferred basis is not chosen in an ad hoc manner simply to make our measurement records determinate or to match our experience of which physical quantities are usually perceived as determinate (for example, position). Instead the selection is motivated on physical, observer–free grounds, that is, through the system–environment interaction Hamiltonian." But Kastner (Kastner, 2014) points out that the preferred basis is a circular argument, in terms of the Everett interpretation: "the whole point of the 'einselection' program is to demonstrate that the observed divisions arise naturally from within the theory. To assume the divisions we already see in the world and then demonstrate that, based on those assumed divisions, the divisions arise 'naturally,' is clearly circular." This is why there are a priori Atomic Universals, not arbitrary human choices.

Zurek (Zurek, 2003) talks of premeasurement, which begs the question. There is no one to set up the measurement, if there are no observers. How then, can an observerless measurement be set up initially? Most measurements are not chosen by an observer – they just happen. It is important to recognize that the only observations that can be prepared beforehand are experimental measurements, but in the real world most observations are made with no preparation. The setup of the measurement implies the knowledge of the preferred pointer, which, as discussed, is circular.

This problem also comes up in Quantum Information Theory. For QIT to work, we need an a priori definition of states. See for example, Cerf and Adami (Cerf & Adami, 1998) discuss the Stern–Gerlach experiment. The analysis is given in terms of spin states. Why these states and not others? QIT only works if there is a set of Atomic Universals. Without this, there would be no set of states to define and the whole world would be smeared out. Put another way, correlations are defined over a universe of discourse, which is the set of hylomorphic functions.

Decoherence is right in postulating a mechanism for the preferred basis, but it does not go far enough. Decoherence provides a possible mechanism for why the reduction of the wave function occurs in a burst of a short time, instead of happening continuously. But there is nothing in decoherence, or generally, in physics as we know it, that results in the choice of the Atomic Universals. There are only a select number of such preferred bases, and we don't know why.

Therefore, the hylomorphic functions have a separate component outside of substance physics. That is, physics generates information in a bit (or qubit) Shannon sense, but it does not generate meaning. I do not have an explanation of why we have the meaning that we do. That will be a task for an experimental metaphysics based on quantum mechanics,

Whether all abstract Universals are causally active is a matter of their logical distance from the Atomic Universals. Although all Universals are composed of Atomic Universals, this does not mean that they are all causally active. In classical physics, the Universals that form its ontological framework are higher level Properties that are derived from measurements of the underlying physical processes. These properties are the result of a process of logical deduction and mathematical computation. The conclusions that one observer makes can be different from that of another, in contrast to an Atomic Fact, which, being universal, is true for all observers. To distinguish a non–causal deduction from an Atomic Fact, we will refer to it as an *Inference*. Causally active Facts are the same for all observers. Inferences can differ between observers.

Whether or not a Universal is causally active is a binary property. A Universal is either causally active or it is not. Certain causal chains are easy to determine: Fact A causes Fact B, such as a photodetector converting a photon into a current which is sent to a display which converts that Fact into a photon again that reaches an observer's retina. Inferences, such as those composed of relational operators may have causally active Facts as their components, but are not themselves causally active. A case in point is Schrödinger's cat. Although it is possible to express the cat as a superposition of quantum states, this is an Inference that is subject to a measurement: looking in and observing the cat.

The Afshar experiment (Afshar, 2005) (Afshar, 2006) (Afshar *et al.*, 2007) is an example of an experiment that combines both causally active Facts and inactive Inferences. The direct observations force other observations to be constrained (pinhole 1 precludes pinhole 2), because the Atomic Universals are limited to a single Fact. The negative information of the wires come from Atomic Facts about the wires, which are causally active, but the negative conclusion is not active. It is an Inference in the mind. Note that the source of the information is different. The which–way determination of the particles is a direct measurement using a photosensitive surface and is causally active. The location of the wire mesh is determined in the setup of the experimental apparatus and is deduced by classical means, such as measuring the location of the wires. Note that these measurements must have some sort of quantum basis in Atomic Universals, which result in the Fact that the wires have a certain physical location. But the conclusion that the wires do not interfere with the laser light is a causally inactive negative Inference, that places no physical constraint on the direct observations made of the photodetector. This means that there is no violation of complementarity – most likely, the measurements of the wires were made even before the lasers were turned on.

This distinction between Fact and Inference must be clearly made. For example, Cramer (Cramer, 1986) describes Renninger's gedanken experiment where a sphere of radius R_1 composed of scintillation counters is occluded in part by another incomplete sphere of radius R_2 composed of scintillation counter inside the R_1 sphere. If a particle is randomly emitted from the origin, the initial state can be considered to be $|S(t)\rangle = p_1|E_1\rangle + p_2|E_2\rangle$ where p_1 and p_2 are related to how much the partial sphere occludes the outer sphere. The claim is made that after some time t_2 which would allow the particle to reach the inner partial sphere, if there is no scintillation, the state collapses to $|S(t)\rangle = |E_1\rangle$ for $t > t_2$.

The distinction to be made here is that both state representations are Inferences, and are not causally active, even though they are certainly true. What is missing here are the Facts. For example, what Facts allow us to infer that there was no scintillation? This would seem to imply that an observer of this system was monitoring an information channel connected to the inner scintillation counters, where the measurements received from that channel indicated a negative result. Otherwise, it is not possible to infer that no such scintillation has been received. You need Facts to base your Inferences on.

This is where the "shifty split" of the Quantum to Classical Divide occurs. It is the shift from causally active Facts to causally inactive Inferences. This split is a discontinuous jump, since there is nothing in between causally active and causally inactive information.

Recently, Frauchiger and Renner presented a gedanken experiment (Frauchiger & Renner, 2016) that involves a two–stage version of Wigner's Friend. Their analysis claims to show that single–world interpretations of standard quantum theory cannot be self–consistent. The setup involves two labs Alice and Bob and two super–observers Wigner and Friend. Alice begins by measuring a random number:

$$|\psi_c\rangle = \sqrt{1/3}(|head\rangle) + \sqrt{2/3}(|tail\rangle)$$

then preparing a spin state:

$$|\phi_s\rangle = |\downarrow\rangle \ if \ head, |\phi_s\rangle = \sqrt{1/2}(|\downarrow\rangle + |\uparrow\rangle) \ if \ tail$$

if the result is a tail, which is handed over to Bob who measures it. The Friend measures the state of Alice and Alice's lab in a Hadamard basis:

$$|ok\rangle_A = \sqrt{1/2}(|head\rangle - |tail\rangle), |fail\rangle_A = \sqrt{1/2}(|head\rangle + |tail\rangle)$$

and records the outcome, and Wigner does the same for Bob:

$$|ok\rangle_B = \sqrt{1/2}(|\downarrow\rangle - |\uparrow\rangle), \ |fail\rangle_A = \sqrt{1/2}(|\downarrow\rangle + |\uparrow\rangle)$$

In terms of hylomorphic functions, the Inferences drawn by Wigner and Friend do not have to be consistent. Laloë (Laloë, 2018) mentions that the states are "a pure state involving a coherent superposition of entire laboratories". Baumann, Hansen and Wolf (Baumann *et al.*, 2016) invoke the concept of a measurement as a "subjective collapse" with each agent assuming a collapse merely in their own measurement. A subjective collapse is an Inference that, although based in part on Atomic Universals, are also based on beliefs about the state of Alice and Bob and their laboratories. These states are postulated by the two observers and not themselves Facts.

This leads to inconsistencies for different observers. Bub (Bub, 2018) notes "If we interpret the quantum state probabilistically, we seem to be forced to QBism, ... The QBist rejects ... the self–consistency assumption. On this view, all probabilities, including quantum probabilities, are understood in the subjective sense as the personal judgments of an agent, based on how the external world responds to actions by the agent."

So we have hylomorphic functions generating Atomic Facts that are causally active. These Facts can be combined into more complex Inferences which are not causally active. This realist viewpoint of Universals 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. We will further explore the nature of Universals in terms of our two exemplars: the Copenhagen and Pilot Wave interpretations of quantum mechanics.

4.2. **Platonic Metaphysical Realism.** 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 exemplars.

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 perceptions — 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 hylomorphic functions as the instantiators of the given 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. Dualism seems to be exist because the observer is different from the physical waveform. 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.

This Platonic interpretation is also present in Decoherent Histories and Quantum Bayesianism. In Decoherent Histories, the notion of events that make up a history, and IGUS's are a fundamental part of the interpretation. They are more than physical processes. In Quantum Bayesianism, this reliance upon the conscious knowledge of an observer is explicit. The terms used are "personal experience" and "gambling".

In the Relational Interpretation, it is explicitly stated that the observer does not have to be conscious: "By using the word 'observer' I do not make any reference to conscious, animate, or computing, or in any other manner special, system. I use the word 'observer' in the sense in which it is conventionally used in Galilean relativity when we say that an object has a velocity 'with respect to a certain observer'." (Rovelli, 1996). "Information is a measure of the number of states in which a system can be... We do not need a human being, a cat, or a computer, to make use of this notion of information."

This is insufficient, though, because it measures the states of the *System* but not the *Facts* that the observer knows. In the Relational model everything is relative to an observer and despite the claims to the contrary, there is some interpretive character to the observer that implies a consciousness: "the fact that a certain quantity q has a value with respect to O is a physical fact; as a physical fact, its being true, or not true, must be understood as relative to an observer, say P. Thus, the relation between $O's$ and $P's$ views is not absolute either, but it can be described in the framework of, say, $P's$ view." (Rovelli, 1996)

4.3. **Aristotelian Metaphysical Realism.** With the Pilot Wave Theory exemplar, we have a 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 external environment.

The measurement involves some sort of transfer of information from the system to some sort of record of the Fact. This can only happen through an interaction between particles — those of the system and those that transfer the information away from the system. 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 Fact 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 Universal since there is no transmission of information. But any interaction between two particles will lead to an instantiation.

In Decoherence, the GRW interpretation and the Transactional Interpretation, the physical process is also explicitly laid out. A measurement occurs because of a physical event, regardless of whether it is consciously understood. Note, though, that in Aristotelian terms, this instantiates an Atomic Universal through the hylomorphic function associated with the process. The process itself is not the Fact, the process is the transformation of the state of affairs that results in the Fact.

This extends to the Everett Many Worlds interpretation. Everett is explicit in describing the branching event in terms of a record, which is independent of its interpretation. This is in contrast to the Relational Interpretation which was described in the previous section, where interpretation of the observer is necessary. Here, the branches become manifest through the hylomorphic functions. As Everett originally considered it, a model consisting only of Process 2 is substance physics without the metaphysics. No observers, no ideal knowledge.

The process of wave function collapse in the Copenhagen Interpretation and the other Platonic interpretations 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 are naturally associated with physical processes of necessity.

But even for Aristotelian interpretations, a purely physical explanation is not sufficient. The Atomic Universals have an independent existence a priori to any measurement. Any attempt to explain Universals through physical properties is at best circular. That is to say, one can come up with a theory of physical processes that account for the Atomic Universals and their taxonomy, but that only indirectly describes abstract objects that are better described in their own terms. For example, the attempt to explain the measurement of spin in terms of the measurement position is contrived — the fact remains that spin is a basic concept. All that has been accomplished is to create a theoretical scaffolding on the physical level that covers the underlying structure on the conceptual level.

5. Universals And Information

Using the concept of Hylomorphic Functions, we can discuss the metaphysical nature of information. As mentioned by Bohm, Hiley and Kaloyerou (Bohm *et al.*, 1987), 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 Fact that is the instantiation of a given Universal. Given the metaphysical definition of information, this instantiation of a given Atomic Universal is an atomic unit of classical information.

Therefore an instantiation of a Universal is not outside of time and space. They are instantiated by actual events, located in the space–time continuum and, as we shall see later, the process of instantiation actually defines the arrow of 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 (Dürr *et al.*, 2012).

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. This is due to the duality of substance and process in metaphysics. A measurement is the creation of a Fact, not a transfer of information. The hylomorphic functions create the units of information that are carried by the medium. So, 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 units 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 is not usable until it is converted into classical information.

Information is transmitted through cascading chains of Properties: instantiations of Universals. The Properties are generated by the transmitter, which gives rise to information. This information is propagated by these instantiations in the physical medium carrying the message and possibly received by a last instantiation of a Property in the receiver. If there is no further transmission, this information is lost or forgotten. All through this chain, the generation of the Properties as a result of a wave function collapse (for the Copenhagen Interpretation and related interpretations) or the change in the system state (in Pilot Wave theory and related interpretations), which leads to physical changes in both receiver and transmitter, and all points in between during the process of transmission[13].

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 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.

This description of information transfer emphasizes that information has meaning, which is implicit in the Universals being transferred. Bohm's metaphor of a pilot wave emphasizes this distinction. The pilot wave is causally active because of its inherent meaning. This should be distinguished from the method of information transfer, a physical process which is expressed in Shannon's Information Theory (Shannon, 1948) and further developed in quantum mechanics by the Clifton – Bub – Halvorson Theorem (Clifton *et al.*, 2003) and (Bub, 2005).

Besides the transfer of information, we also need to address the meaning of the information transferred. The Atomic Universals provide the semantics of a Property. 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 processes of physics ground

[13]Collier (Collier, 1999) defines causation as the transfer of information: "P is a causal process in system S from time t_0 to t_1 iff some part of the information of S involved in stages of P is transferred from t_0 to t_1." This viewpoint is consistent with the viewpoint expressed here that the hylomorphic functions are causally active because they generate information, which affects other systems. In contrast to Collier though, this generation of information is a physical process, not an abstract mathematical concept.

the meaning of information in the universe, for example in the way that Atomic Universals generate Properties 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.

It is worth noting that the creation of information in quantum mechanics is often discussed in a negative sense by "tracing over" the off–diagonal terms of the state matrix. For example Cerf and Adami (Cerf & Adami, 1998) says: "the quantum system and the ancilla are entangled as a result of the measurement, and that the measurement simply becomes the 'act' of ignoring – or tracing over – the quantum system Q which is to be measured." Describing a measurement in this negative sense ignores the fact that a measurement is the selection of a particular property of a quantum system. The tracing out is the recognition that there exist different properties other than the one that was selected, even an unobserved degree of freedom (Cerf & Adami, 1996). The point is that measurement is more than just entanglement. It is not a negative – it is the creation of a positive Fact.

Using the concept of hylomorphic functions, it may be possible to express the essentials of a quantum mechanical system by creating a graph of the Facts involved in the information flow, while leaving out the details of the physical substance. This *Fact Graph* captures the events that lead to the creation of actual information, including the Facts that lead to Inferences. It is a method of formally expressing the structure of knowledge transfer. It is similar to the Relational Model of Rovelli (Rovelli, 1996) and Filk (Filk, 2006). Rovelli says: "the direct question 'Do observers O and P have the same information on a system S?' is meaningless, because it is a question about the absolute state of O and P. What is meaningful is to rephrase the question in terms of some observer." Note also that Consistent

Histories and Decoherent Histories are thought of in terms of graphs that connect histories throughout time.

In a Fact Graph, each observer is represented by a timeline. A measurement is represented as a *Fact Node*. This node is placed on an observer's timeline if the measurement occurred at the position of the observer at that time. Otherwise, there is an edge from the measurement to the observer's timeline indicating when the observer became aware of the measurement through information transfer. An *Inference Node* is a node on an observer's timeline where an Inference has been drawn from the causally active Facts known to that observer. There needs to be a Fact node or nodes that represent the Atomic Facts that gave rise to that Inference. They would appear on the observer's timeline prior to the Inference. The information transfer from one observer's Fact Nodes to another observer's Fact Node records the process of information transfer and the resultant composition into Inferences.

The Fact Graph diagrams how an observer eventually receives information about a measurement and connects observers by their information transfer. The Fact Graph can only connect measurements of Atomic Universals, because that is the only way to accumulate knowledge. It is not absolutely necessary to describe the state of the system in between, because knowledge about it will not have changed. The observer may have an idea of the state of the system, but that is just speculation until a measurement is made. We can, though, annotate a Fact Graph with what a particular observer believes about the state of the system at a given time. This is in contrast to Rovelli, who allows for statements of the knowledge of one observer observing another observer observing a system as a tensor product of

$H_{SO} = H_S \otimes H_O$. The importance of this distinction is that, the Facts generated by Atomic Universals are eventually universal for all observers, but speculation about a quantum mechanical system may be different for different observers, until this speculation is resolved by a measurement.

Note that some observers, for example, a complete human brain, have a spatial dimension, whereas a hylomorphic function is a fixed spatiotemporal point. The usage here is for an observer that is, for all practical purposes, a point in space. If it is necessary to consider a system that has a spatial dimension, this would have to be represented as a bundle of lines.

Kastner's Possibilist Transactional Interpretation (Kastner, 2016a) (Kastner, 2017b) arrives at a similar structure, referred to as a *causal set*: "If a transaction involves a photon, the interval is null; if it involves a quantum with finite rest mass, the interval is time-like. The intervals have a causal relationship in that an absorption event A can, and generally does, serve as the site of a new emission event B. Thus the set of intervals created by actualized transactions establish a causal network with a partial order, much like the causal set structure proposed by Sorkin." The main differences with Fact Graphs are that the causal set only represents the measurements (or transactions), not the inferences, and of the transactions, there is only knowledge that a transaction occurred, not its meaning.

As an example of how to consider quantum processes using a Fact Graph, consider the delayed choice quantum erasure experiment (Kim *et al.*, 2000) (Gaasbeek, 2010). This is seen in Figure 1.

Atoms are excited by a laser pulse and go through either slit A or B. A pair of entangled photons are then emitted by a type-II phase matching nonlinear optical crystal BBO. A pair of orthogonally polarized signal-idler photons is generated. The first photon is registered by a photon counting detector D_0, which can be scanned by a stepper motor along its x–axis for the observation of interference fringes. The other photon is injected into one of two beamsplitters, depending on whether the photon came from the atom that went through slit A or B. If the photon came from the atom going through A, it will be detected by detector D_1 or D_3, depending on how it came out of the beamsplitter. For photons from the atom going through slit B, then the second beamsplitter will send the photon to either D_2 and D_4. Detectors D_1 and D_2 provide which–path information (A or B), while D_3 and D_4 only counts the presence of the photon[14].

By using a coincidence counter, the experimenters were able to isolate the entangled signal from photo–noise, recording only events where both signal and idler photons were detected. The electronic output pulses of detectors D_1, D_2, D_3, and D_4 are sent to coincidence circuits with the output pulse of detector D_0, respectively, for the counting of joint detection rates R_{01}, R_{02}, R_{03}, and R_{04} . When the experimenters looked at the signal photons whose entangled idlers were detected at R_{01} or R_{02}, they detected interference patterns. However, when they looked at the signal photons whose entangled idlers were detected at R_{03} or R_{04}, they detected a simple diffraction pattern with no interference.

The four wave functions $\psi(t_0, t_j)$, correspond to four different joint detection measurements, having the following different forms:

$$\psi(t_0, t_1) = Amplitude(t_0, t_1^A) + Amplitude(t_0, t_1^B)$$

$$\psi(t_0, t_2) = Amplitude(t_0, t_2^A) - Amplitude(t_0, t_2^B)$$

[14] In the original experiment, D_4 was omitted, because it gives the same output as D_3

$$\psi(t_0, t_3) = Amplitude(t_0, t_3^A)$$

$$\psi(t_0, t_4) = Amplitude(t_0, t_4^B)$$

There are nine timelines, the *Slit* (including the BBO crystal), detector D_0, the *Beamsplitter*, detectors D_1, D_2 D_3 and D_4, the *CoincidenceCircuit* and the *Experimenter*. Since the detectors D_1 through D_4 are only detecting the existence of a photon, they will be collapsed into $D_{1,2,3,4}$ to reduce clutter. As the timelines go on, the data is recorded. Note that the measurements from the detectors and the coincidence counters are Atomic Facts, but the wave functions of the *Slit*, *Beamsplitter* and the *Experimenter* are Inferences.

Figure 2 shows a similar setup where the *Slit* appears after the *Beamsplitter*. Since the states of the *Slit* and the *Beamsplitter* are Inferences, they do not causally affect the Facts that are the result of the actual measurements.

Fact Graphs relativize. That the relational approach to quantum mechanics relativizes was pointed out by Rovelli (Rovelli, 1996) and Laudisa (Laudisa, 2001). This is also true for Fact Graphs. The information transfer between observers can be represented in a way that makes explicit when different observers become aware of an Atomic Fact. So the information transfer is more easily relativized than the wave function itself. Dorato (Dorato, 2013) claims that the Relational Model "provides time with an objective although local and worldline–dependent arrow of time," but we actually end up with a graph structure that, as Kastner (Kastner, 2016a) points out, represents all timelines in terms of a "growing universe".

It is difficult to define a space–time metric using these types of graphs. This is something that Kastner (Kastner, 2016a) analyzes in detail. The problem is that a graph has no assumption of continuity or neighborhood that is necessary

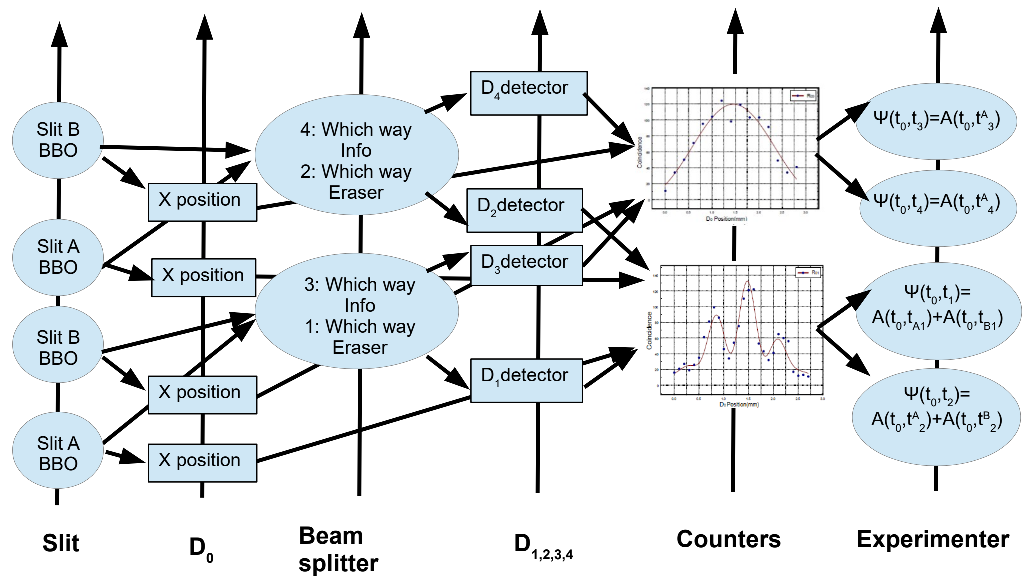

Figure 1. Delayed Choice Quantum Eraser Fact Graph

for a metric, such as a metric tensor or Minkowski space. The graph connects measurements. The direction of the edges is past and future and each edge has a time length. But these lengths are not differentiable.

Note that without information transfer there is no way to measure relativity. You can't compare reference frames without information and information is transferred only through hylomorphic functions. The information received for any given frame does not match any other frame, since simultaneity is different for different inertial frames. Despite the different times that something is known, we still have the notion that an Atomic Fact is universal for all observers regardless of when it becomes known to them — even though the Inferences differ. This is an aspect of reality that relativity must contend with. Knowledge is in some sense absolute.

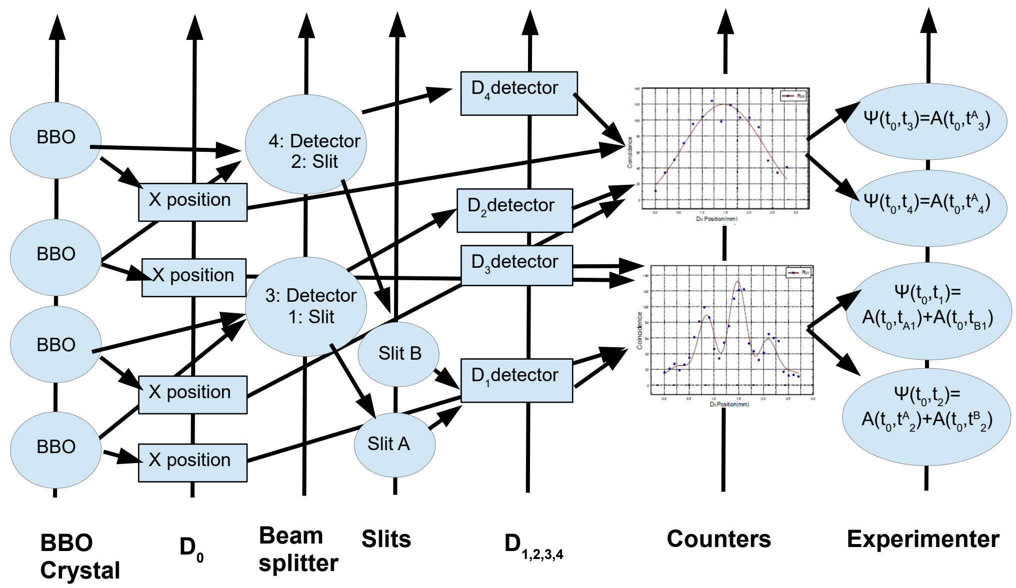

Figure 2. Non-Delayed Choice Quantum Complementarity Fact Graph

6. Universals And The Arrow of Time

It is generally agreed that, with some exceptions, the laws of physics do not have a distinction between time going forward and backward. The reason is that the arrow of time actually comes about through the process of information creation.

Take the example of entropy. If we have enough information to fully describe the current condition of all of the physical units in a given volume of space, then we can make time go backward by using this information to reverse the interactions that had occurred in the past. Stapp (Stapp, 2011) points out that letting the Schrödinger wave equation proceed naturally without a wave function collapse does not increase entropy. Entropy increases through the process of instantiating a hylomorphic function.

The problem is how to retain and apply the information we have. 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 transmitted through the instantiation of Universals. It is not possible through this instantiation to have enough Properties to fully represent the information in the field.

The arrow of time is due to this loss of usable information. The instantiation of a Fact through a hylomorphic function gives us some knowledge through the instantiation of the Universal but not the complete knowledge of the system. Given any single measurement, the Property instantiated by a Universal is transmitted as the measurement. But there are other characteristics that are part of the the system that are lost to the measuring apparatus, since they are not part of the measurement. They are retained only in the information field. The loss of knowledge about the other characteristics of the system other than what was measured results in a functional irreversibility. But we are left with a trail of information which Maccone (Maccone, 2009) points out is the result of an increase in entropy.

This notion of time is consistent with the Possibilist Transactional Interpretation (Kastner, 2016a) (Kastner, 2017b). Although PTI views space–time as emerging from a static block world whose causal set structure has an underlying quantum substratum, it can also be argued that both views exist simultaneously. One does not supervene on the other – instead, the two views form a duality of substance and process.

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 Properties that were the instantiations of the Universal that comprise the measurements of the system[15]. 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[16] 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

[15]Hartle's discussion of time (Hartle, 2005) in Decoherent Histories has the problem of having the sense of time specific to Information Gathering and Utilizing Systems. The notion of time presented here is inherent in the universe.

[16]The Bekenstein bound is the limit of the amount of information that can be contained in a finite volume of space (Bekenstein, 1972). 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.

although time is symmetrical for the whole information field, there is not enough usable information to make this inversion possible.

Contrast this to Trassinelli's analysis of the Relational Interpretation (Trassinelli, 2018). Trassinelli (and originally Rovelli) maintain that there is a maximum amount of relevant information about a system. A problem with this claim is that you cannot specify what constitutes the maximum amount of relevant information. Not only is it not possible to specify the amount of information, you cannot specify what knowledge the information is composed of. Relational Quantum Mechanics defines information transfer in terms of Shannon's information theory: the meaning of the information is ignored. This makes it relatively easy to define some sort of information quantity, by stating how much information can be transferred. But it makes it much harder to make a claim of maximality, unless it has been predetermined that all of the meaning has been captured. Now it is possible that there are only a finite number of Atomic Universals, and this could limit the amount of information. But a proof of this statement will be difficult to make.

The arrow of time can be 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 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.

Hylomorphic functions can also be used to explain the difference between A–time (time has a past, present and future) and B–time (time is tenseless) (McTaggart, 1908). Many physicists and philosophers consider that modern physics can be expressed in terms of B–time[17], but where does A–time come from? Note that the concept of past, present and future are implicit in the notion of a process: if the application of a function to some arguments is the present, the values of the input arguments came from the past and the result of the process exists in the future. A–time views time as a process, B–time views time as a parameter of objects in a substance metaphysics. The more extreme case of presentism (Zimmerman *et al.*, 2011) compounds the problem because the passage of time determines how concepts are built from Atomic Facts. A–time has implicit in it the arrow of time due to the fact that hylomorphic functions can be one–way or many to one functions.

7. The Arrow of Time In Pilot Wave Theory

The Implicate Order of Bohm (Bohm *et al.*, 1987) 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 packets, where each alternative wave packet out of the interaction represents an alternative value that the particle can assume is dependent on the interaction. The packet that controls the particle actively steers it. As time goes on, other wave packets become inactive. To quote Bohm, Hiley and Kaloyerou (Bohm *et al.*, 1987):

[17] For example, see Sider's (Sider, 1997) defense of four–dimensionalism

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 (Bohm *et al.*, 1987) 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 would cause 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 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. This is also known as Permanent Spatial Decomposition (Galvan, 2010).

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 Properties are instantiated in Pilot Wave theory, in the dissipation of the other wave packets that represent the Properties 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 Fact comes from the measurement of an interaction and it is associated with the packet controlling the particle. But the packets that do not hold the particle are the alternative Facts for that Universal. Once a Universal is instantiated, the alternatives cease to exist and cannot be recovered through time symmetry, making the hylomorphic functions many to one and therefore not invertible. This means that they define the arrow of time.

8. Qualia and Tropes

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 characteristics that make up thought — the objective world. It has been argued that consciousness can be entirely explained through physical processes: that consciousness is purely physical or at best an epiphenomenon [18]. 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 perceptions are contingent on physical processes (Levine, 1983). A famous paper by Nagel (Nagel, 1974) pointed out the difficulty of knowing what it feels like to be something different than a human, for example, a bat.

Qualia 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. They are the basic components of subjective reality, 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 (Chalmers & Gazzaniga, 2004) 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

[18]See for example Dennett (Dennett, 1993)

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. This issue also arises in the Copenhagen interpretation, at least where consciousness is concerned. In these 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 a process that is distinctly different from the substances of physical interactions. This is, as Jackson (Jackson, 1982) argues, what makes qualia different from pure physical reality, not just an epiphenomenon. The duality of substance and process metaphysics leads to the duality of body and mind.

Chalmers (Chalmers, 1996) 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 associated with, the substances of physics. Chalmers worries about the non-local 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 non-local 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. To use an analogy, a qualia is like a molecule — it is a simple combination of even simpler Atomic Facts. The formation of qualia 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. A conceptual hierarchy may someday be defined 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 Atomic Universals. These qualia do not exist as purely physical phenomena, although organisms with identical physical processes will have identical qualia (Chalmers, 1995). 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.

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 substances that lead to the qualia. Qualia are formed from the processes of hylomorphic functions. The mind, as substance, can represent the objective reality of what thoughts, feelings and perceptions come from, but it cannot be the subjective reality of these experiences.

Rescher (Rescher, 1996) nicely expresses how process metaphysics captures the notion of qualia:

> In particular, colors, say, or numbers or poems lend themselves naturally to a processual account. Take phenomenal colors, for example. A mental process such as perceiving or imagining a certain shade of red is simply a way of perceiving redly or imagining redly – that is to say, in a certain particular way. And here, the relevant universal is not the abstract quality *red*, but the generic process at issue in perceiving (seeing, apprehending) something *redly*.

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 (Latta, 1898), 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.

Qualia can help us make a distinction between Universals and Tropes in the context of Causally Active Metaphysical Realism. First, note that qualia are different for different organisms, and can even differ from organism to organism based on their ability to perceive the world[19]. What it is like to be a bat is different from what it is like to be a human because the two organisms do not share the same set of qualia. But the Atomic Universals are necessarily true for everyone, because they are the result of quantum mechanical processes. They are the same for each mind regardless — they exist as information alone, only secondarily as perceptions. Tropes are Particulars. They are different due to the qualia that give rise to them. They are specific to the organisms that have those qualia that they are based on.

The difference forms a continuum, though, from Universals to Tropes. For example, relational properties of Atomic Universals are themselves universal, but even there, they are dependent on the ability of the organism to perceive that relation.

[19]It could be argued that computers have their own qualia, such as inputs from analog to digital converters, or communication ports.

Relations such as "heavier than" or "faster than" are dependent on the ability of an organism to perceive mass or location (and speed). This cannot be assumed to be universal for all organisms in terms of their expression. For example, sharks can sense electric fields. That implies that they can recognize relations such as "more charged than" that a typical human cannot.

This continuum is also true for the laws of nature. Laws of nature, being relational and not fundamental, are not pure Universals. Because the perception of the world as qualia defines the Particulars in which the law is based, the expression of the laws of nature as defined by two different organisms will diverge the further their qualia are from Atomic Facts and the more that the fundamental units that make up the law are perceived as more and more complex qualia.

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 a universal sensation of all minds. Concepts involving mass and velocity are also likely to be universal, but perceptions of sound and light may differ, since their qualia will differ.

Properties of objects must defined in terms of the qualia of the observer who instantiates the Properties. That is, the ontological taxonomy of an organism that senses one region of the light spectrum is different from another ontological taxonomy of an organism whose sensation of light is different. Because of this, resemblance of Tropes is due to the fact that Tropes are dependent on qualia that fall into the same part of the ontological taxonomy. This gives rise to similarity classes the way molecules composed of the same type of atoms behave similarly. It also means certain Tropes do not exist for some organisms. Something like the moral identification of "goodness" would not exist for organisms with no social structure that recognizes such moral Properties.

Hylomorphic functions can be considered to be a form of panprotopsychism — a term coined by Chalmers (Chalmers *et al.*, 2003) — but only in the simplest sense. This comes out of having processes as a fundamental part of ontology. The operations of the mind are inherent in the hylomorphic functions that give rise to the Atomic Universals. But 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 (Chalmers, 1996) 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 means that a measurement in quantum mechanics does not imply a conscious observer, either as an elemental Platonic Universal (in the case of the Copenhagen Interpretation) or an elemental interaction (in the case of Pilot Wave theory). A Fact is the end result of a hylomorphic function, but there may be no conscious observer to take note of this Fact. Hylomorphic functions are the basis of sensation, but the perception of that sensation or the awareness of it requires some higher order processing. Self–awareness and consciousness are not fundamental — they arise out of these fundamental functions.

In the Heisenberg/von Neumann/Wigner interpretation of quantum mechanics, consciousness causes the wave function collapse. Put more strongly, Stapp (Stapp, 2011) makes the claim that wave function collapse *is* consciousness. This is unlikely, since consciousness involves these types of higher order processing. In terms of Causally Active Metaphysical Realism, consciousness is derived from the wave function collapse, in the sense that consciousness is a process composed of more primitive processes. The hierarchical viewpoint that starts with hylomorphic functions as information, then qualia and the Tropes derived from them, gives a reductionist basis for the nature of consciousness, and the basic units that consciousness is composed of. An undifferentiated "consciousness" is like postulating an atomic monad of thought — a basic unit of physical reality as difficult to isolate as the luminiferous ether.

Hylomorphic functions are not the act of consciousness affecting quantum systems, such as the double slit experiment. It is the other way around: instead of consciousness affecting the experiment, hylomorphic functions are the informational basis of consciousness.

A Causally Active Metaphysical Realism that involves processes as fundamental objects in the basic ontology leads to the existence of qualia separate from the substance metaphysics of physical objects. This resolves the hard problem of consciousness. This is similar to the distinction between packets of information and the medium that carries them.

9. Experimental Tests

Experimental verification is important because it gives an objective justification about which view of metaphysics is correct. A metaphysics tested by experimentation forms the conceptual underpinning of science.

Since we have made the case that the instantiation of Universals can be causally active, then the process of instantiation and the existence of the resultant Universal is subject to experimental verification, with implications for an expanded viewpoint of physics that involves both the concrete objects usually thought of as making up the physical world, but also the addition of processes as ontological objects in their own right. Here are some experimental tests that can give credence to this viewpoint.

9.1. **Discovery of Atomic Universals.** A new Atomic Universal is as likely as a new law of nature. This happened with atomic theory and the nuclear forces. New Atomic Universals are typically classical concepts and new ones would only come about if we were to have new situations that give observations that we would have no way of experiencing up till now. To find new ones, we would have to explore places in the universe that are unfamiliar to us now, which can only be described in terms of new concepts.

Note that Atomic Universals are a priori to experience – they are essentially a part of nature and cannot be manufactured. This implies that most common Atomic Universals have already been found, and that any we don't know of yet will be discovered in unknown and surprising ways.

One possible method of discovering new Atomic Universals is through the careful analysis of decoherence. Typically, the matrix representation of the state of a system is established prior to an experiment and contains our expectations of what the experiment will reveal. If the off–diagonal matrix terms do not behave in the way we expect, it may be due to our not knowing that the system had other eigenvalues that we did not take into account, and that the expression of the experimental system needs to be reformulated. This reformulation may result in the identification of previously unknown Atomic Universals. Deutsch (Deutsch, 1985) suggests some techniques in terms of determining the preferred basis that could be used to construct some experimental tests of this kind.

9.2. **Definition of Information.** The claim is made that information is exclusively based on hylomorphic functions. This means that the capacity of an information channel is based both on the capacity of the medium in terms the number of measurements and the specificity of the Facts for each measurement. Therefore, to increase the bandwidth of a channel you can either increase the number of possible outcomes of a measurement or increase the number of measurements in time and space. This gives a measure of the channel capacity of a medium as a function of the probability distribution of the Facts generated by the measurement times the number of measurements in a given time period. This also means that Inferences, both positive and negative, do not affect the capacity of the channel.

9.3. **The Arrow Of Time.** The analysis given here challenges the claim often made in quantum mechanics that, as Cerf and Adami (Cerf & Adami, 1996) say: "It is practically impossible, although not in principle, to undo this observation, i.e., to resuscitate the cat, or, more precisely, to come back to the initial decaying atom, with a living cat and an ignorant observer." A consequence of hylomorphic functions is that this is not *practically* impossible, it is *completely* impossible — the particular fact (that Schrödinger's cat is alive or dead) is likely to have already been transmitted throughout space and cannot become unknown again. Once a Fact has been instantiated by a measurement, it is no longer possible to revert back to an ignorant observer because there is a whole cone of space–time aware of this Fact. The claim that an observer *could* revert back to being ignorant can't even be tested by experiment, because the experimenter knows.

An experimental test of hylomorphic functions and the arrow of time will be difficult to bring about, but this aspect of the theory can be subject to disconfirmation. If a case can be found where the cat can be resusitated, this would provide a counter–example to this view of quantum mechanics. But such an example would likely appear to be almost miraculous.

9.4. **Entropy as Information.** We claim that entropy changes because the instantiation of a hylomorphic function loses some information of a state. This implies that entropy does not change solely because of a measurement, but it is also necessary for the associated hylomorphic function to be a many to one result. A hylomorphic function that does not lose information is capable of producing the same distribution of states as before the instantiation of the function and thus no increase in entropy. A hylomorphic function such as this is essentially a statement of existence: "System S is here".

9.5. **Bohmian Mechanics and the Measurement Problem.** As mentioned in Section 7, after a particle interaction, the wave packets with no associated particle dissipate. If this dissipation takes time, then the dissipating packets could interfere with nearby measurements. This could be measured. If the dissipation is instantaneous, the only way it can be detected is by showing that the calculation of a particle interaction in Bohmian mechanics yields extraneous wave packets that are not detected physically.

9.6. **Afshar Experiment.** Regarding the Afshar experiment: with the distinction between causally active Facts and inactive Information, it is possible to create a whole family of experiments where the causally active Facts force a choice of a particular measurement that procludes another measurement, as in complementarity, but there can be associated, causally inactive Information that can be derived from the Facts but do not further constrain these measurements.

For example, the wires in the Afshar experiment could be replaced by electron beams, which could be shifted from one place to another, based on the which way information from the two pinholes. If the photon comes through pinhole A, the electron beam would be in one of the areas where it is most likely to interfere, and would be moved to be least likely to interfere if coming from pinhole B. The photon could be sent through a mirror to give the circuitry time to shift the beam. This might lead to a situation where complementarity would play a part.

Care must be taken to identify what are true Facts and what are Inferences. It is also important to note that, if an Inference has been made, what actual Facts are used to derive it?

9.7. **Fact Graphs and Relativity.** In Section 5 we discussed the concept of Fact Graphs. If the concept of hylomorphic functions is useful, then the analysis of quantum mechanical systems using Fact Graphs would yield insights into quantum mechanical processes, especially the flow of information.

Hylomorphic Functions may make it possible to come up with a simpler way of relativizing Quantum Mechanics. We make the claim that all information comes from hylomorphic functions. Therefore the concept of a clock in special or general relativity is expressed solely through instantiations of hylomorphic functions. Stapp and Jones (Stapp & Jones, 1977) say: "Kurt Gödel (Gödel, 1949) has remarked that all cosmological solutions of the Einstein gravitational equations have preferred systems of space–like surfaces that can be used to define an absolute order of coming into existence." An alternative to considering a foliation of space–time in relativity is to formalize space–time as a Fact Graph.

Simultaneity or the lack of it depends on the transmission of information. The determination of relative velocity depends on this transfer – you cannot tell a relative velocity without information from the other object. In a graph of information flow through space–time, the nodes would be specific measurements, and the edges would be the information transferred to a particular event from previous events. The edges would be labeled with the time in the past that the information was received that affected this event along with the Fact instantiated. This replaces the geometric representation of space–time as a foliation.

Although Atomic Facts are universal, relativity plays havoc with the process of instantiating Inferences shuch as qualia or Tropes. Things that are round may look oval to another observer. An object in transition, such as a bar of metal being uniformly heated, may appear a nonuniform temperature in another reference frame. A test of hylomorphic functions would be the use of Fact Graphs to distinguish Facts and Inferences in situations where relativity plays a significant role.

9.8. **Proof of Church's Thesis.** The concept of effective computation is formally different from formal logic and set theory. In terms of Causally Active Metaphysical Realism, computation is a process that is a fundamental part of the basic ontology, whereas a set–theoretic definition of property defines predicates on different substances.

Church's thesis is the claim that all formal systems that express effective computation are identical in their computational and expressive power. With an exhaustive enumeration of the Atomic Universals, as currently known, it should be possible to derive effective computation from the basic fundamentals of quantum mechanics. The work of Sulis (Sulis, 2014) can serve as a theoretical basis for this proof.

9.9. **Qualia.** We have described the difference between Universals and Tropes as determined by their source: hylomorphic functions instantiate Universals while Tropes arise from qualia. There is a continuum from Universals to Tropes depending on the complexity of the composition of qualia from hylomorphic functions. Therefore the hylomorphic functions are the criteria that define this continuum. This means that it is impossible to draw a bright line between Universals and Tropes.

Psychological studies should show that Universals, especially time, but also mass and velocity, are truly universal, but Tropes dependent on sensory input such as sight and hearing will differ to the degree that they are closer to the hylomorphic functions.

The types of qualia for different organisms are not arbitrary. It should be possible to demonstrate for each type of qualia how they are derived from the hylomorphic functions. This derivation will also determine how the resemblance of Tropes is defined.

It is impossible to ask a bat what their Tropes are and how they differ from that of a human. But it is possible to ask different humans, such as someone who is deaf or blind, or someone with synesthesia, about their Tropes. They will differ in quality depending on qualia.

The determination of single quantities will be universal, but relationships will differ depending on how the differences are perceived. This also applies to the basic units of scientific laws versus the functional relationships of these laws in terms of the perception of these relationships.

10. Conclusions

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

- Hylomorphic functions are the process of wave function collapse in the Copenhagen Interpretation of quantum mechanics or the particle interactions in Pilot Wave theory.
  - This establishes both observables and beables as essential to the basic ontology of Quantum Mechanics. The beables are the physical entities of the basic ontology. The observables are the process of instantiation of Universals.
  - Hylomorphic functions are a separate process from the wave function, a measurement that instantiates a Property. But this does not make the wave function deterministic from then on. The instantiation of a Universal is a Fact that characterizes the wave function at this time and place, but the wave function still maintains its non–determinacy due to its other properties.
  - Hylomorphic functions give a physical interpretation to Causally Active Metaphysical Realism. This gives us a duality between substance metaphysics and process metaphysics.
- Hylomorphic functions are the basic units of information.
  - The hylomorphic functions are not just the generators of mere bits or qubits, but the instantiators of abstract objects with meaning.

  - 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 physical aspect of matter itself. Since these Facts 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 Facts 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 fact that the function is many to one also implies that this increases the number of accessible states, and therefore increases 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 perceptions 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

are composed of qualia which are in turn made up of the instantiations of Atomic Universals.

– This is why both Universals and Tropes exist. Although the Universals are are based on quantum mechanical phenomena, the higher level concepts we deal in as part of our nature as humans are Particular Tropes.

It is important to note that, regardless of whatever particular interpretation of quantum mechanics you choose, hylomorphic functions are a reality. It is true that, depending on the interpretation of quantum mechanics, Causally Active Metaphysical Realism could be either a Platonic dualism or an Aristotelian 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 versions of Metaphysical Realism 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.

Dualism is the recognition that the objects of the physical world and the objects of cognition seem to be fundamentally 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 Universals. Although the objects of our perception are composed of Atomic Facts, 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 question of how the identification of an object like a chair is done. This results from a basis of hylomorphic functions — Atomic Facts that combine to form qualia as observations — that become the end product of this identification as a Trope.

To quote Weinstein(Weinstein, 2001): "Although many seem to think that the ultimate physical theory will be a quantum theory, it seems to me that it is worth seriously considering the idea that quantum theory is joined at the hip to classical theory, and that further progress in understanding quantum theory will come, not by probing quantum theory proper, but by coming to understand how to move beyond it." This theory is an attempt to combine both quantum and classical theory. The classical theory is composed of Atomic Universals. The quantum theory is the wave function.

Current physics as we know it only describes objective reality, not the subjective reality of consciousness. The recognition that there is a Causally Active Metaphysical Realism that combines both substance and process 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 result in a new set of scientific laws that extend physics from objective reality alone to encompass both subjective and objective reality. Hopefully, this will culminate in a unification of both subjectivity and objectivity as natural phenomena, as two separate aspects of a physical duality.

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