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Concerning Multiple Context-Dependence, Uncertainty, and Understanding

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ABSTRACT. Recent discourse in the philosophy of scientific explanation involves an account known as the Kairetic account[10]. I proposed implementing a complementarity view involving a mapping scheme to the Kairetic account and similar models[8]. There are two natural concerns related to this mapping. The first concern is the treatment of multiple mappings required for an explanation: phenomena may involve two complementarity features. The second concern is regarding the acquisition of understanding and whether context-dependence facilitates understanding. This article aims to address the first thought through an example involving interference and photon detectors in a telescope. I claim that context-dependent mapping is on a particle basis, accommodating the wave-particle duality for every single particle without generalization. I further introduce the implications of mathematical developments of a complementarity relation grounded in the uncertainty principle. In addition, I will offer the stance that context-dependence facilitates understanding because it ensures that explanations are logically consistent, precise, relevant, and comprehensive.

KEYWORDS: Philosophy of Science, explanation, Kairetic account, DNP account, complementarities, Understanding.

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1. A Brief Introduction to the Mapping Scheme

The complementarity principle posits that entities/systems can display contradictory properties depending on the manner in which they are observed. These complementarity properties are mutually exclusive but are equally necessary for a consistent description of the system with our current physical laws. Consider the following description of the wave-particle duality:

> In wave-particle duality, [any] featured quantum entity can manifest either wave or particle-like properties depending on the experiment. For instance, in the double-slit experiment, light manifests itself as a wave and produces interference patterns; however, in the case of the photoelectric effect, where light is shined onto a metal, light behaves as a particle, which scatters and interacts with the metal as though it in itself is an energy-carrying particle. Depending on the experimental context, light appears in different forms. The identity of a particle is two-fold: it is a particle and a wave in various contexts. The nature of the observation of the wave-particle duality (whether it reveals wave or particle behavior) is not probabilistic in the sense of a quantum superposition. Instead, the experimental apparatus used unequivocally influences the nature of the observed phenomena: depending on the experiment, there seems to be a set of relevant physical laws corresponding to waves or particles[8].

This wave-particle duality is well established in experimentation, particularly with various iterations of slits, meshes, and scattering trials[3][13][5][9][1]. If one wishes to consider the entirety of scientific developments, this complementarity principle is difficult to ignore. Specifically, because this property exists in the realm of our fundamental physics, any explanation will have its roots in one of the complementarity features being manifested for every entity of a system. In consideration of the complementarity view, I proposed a mapping between a set of contexts and a set of physical principles[8]. It is imperative to discuss first the notion of a similarity space: a set of physical laws with a relation between them that identifies the degree of similarity between those laws. Consider the following construction of the context space:

> [We] begin with a context space C, which is a set of phenomena that

> we know (from our models of physics) involve paradoxes. The phenomena of C can be grouped up into context subsets c_i that contain all phenomena in which the experimental condition corresponds to a single feature in a complementarity[8].

This will then be mapped onto a subset of the similarity space called S_i such that the set of laws involved in the Kairetic account (or other accounts with an entailment structure) is consistent—there are no contradictions. Without taking any similarity subset (or complementarity feature) for granted, one can show a manifestation of a feature through this mapping as it identifies the relevant laws. Accordingly, the outcome that is unequivocally influenced by the experimental apparatus is said to be a "context-dependent" outcome. The following section will discuss the notion of a standalone explanation and will depict examples of utilizing the context-dependent mapping scheme for phenomena with multiple cases of complementarity features.

2. Multiple Context-Dependent Mappings

The necessity of this mapping within the Kairetic account was underscored in cases of paradoxical explanandum, such as the wave-particle duality or the black hole information paradox. This is intended to serve as a kernel of a deeper standalone explanation. A ”standalone explanation” is a causal model that is created just for an event (E) and is made up only of components that have a direct impact on E's occurrence (you'll recall that these are called difference-makers). A sequence of ”explanatory kernels,” or more basic, abstracted causal models that gradually build upon one another, are the building blocks of this paradigm. Every subsequent model in the series rigorously follows the causal architecture set by its predecessors since each kernel in the series contains and meets the causal requirements of the previous model. The last kernel in this chain, which only captures the crucial causal elements that account for E, is directly connected with the event E. Consider the standalone explanation for a reading of an optical telescope:

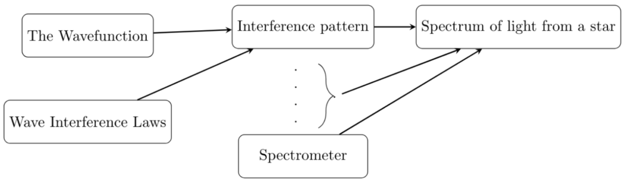

FIG. 1: *Optical Telescope Reading Standalone Explanation[8]*

This standalone explanation makes use of the similarity subset involving wave laws S_{wave} rather than particle laws. Overall, Context-dependent mapping serves to determine the set of laws that may be relevant to the phenomena. A natural avenue of further thought would be the specifics of the workings of the spectrometer, i.e. what functions and electronic parts were involved in such a reading. A typical spectrometer involves detectors (photomultiplier tubes, photodiodes, microchannels, etc.), all of which treat incoming light or electrons as scattering particles, even if they are photons associated as a result of the double slit. If this is the case, then it may be worthwhile to consider the mapping scheme to justify the behavior of the spectrometer using the relevant similarity subspace of particles. Such a scheme may involve the detector's enforcement of particle laws $S_{particle}$ from the context of the instrument of the detector and relevant electronics $c_{particle}$. Figure 2 depicts a sample standalone explanation involving both subsets:

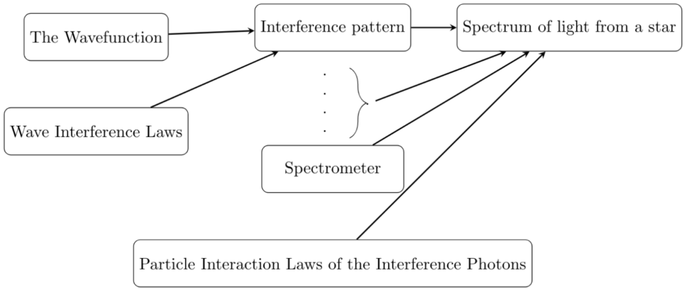

FIG. 2: *More Detailed Standalone Explanation*

In particular, it is the photons involved as inputs to the instrumentation, as well as the particle interaction laws of those photons treated as particles, that make the spectrometer behave in the manner that it does. In this case, we have effectively constructed a standalone explanation using both complementarity features in various parts of the explanation. It is important to note that the mapping may apply various complementarity mappings to several distinct entities within one entailment structure. It is an assignment on a particle basis - that is, there is no one mapping done for all particles on a system (though at times it may be so). Instead, wave-particle complementarity is accommodated for all particles: certain particles behave as waves, and other particles behave as particles depending on the nature of the system. This allows the interference pattern in Figure 2 to be based on wave laws and the detecting system (spectrometer) to be based on particle laws. If one were to generalize all involved particles into the wave scheme, then the particle-like behavior of photons in the presence of detectors would not be accounted for. In the following section, I investigate an objection involving the uncertainty principle as a probabilistic relation.

3. The Uncertainty Objection

When it comes to complementarity, there have been mathematical formulations, an instance being the work of Björk et al.[2], that discuss the connections between Heisenberg's uncertainty principle and the observed wave-particle complementarity. The initial complementarity relation derived by Englert[4] is expressed as so:

$$P^2 + V^2 \leq 1 \tag{1}$$

where P symbolizes predictability and V symbolizes visibility. Since the derivation, there has been numerous constructions and testing of more general models involving multiple slits and continuous-variable systems[6][7]. Nevertheless, we focus on the double-slit case. The thought is that if P is 1, then we have certainty of a particle's path, and 0 is complete randomness. Similarly, V is the measure of how visible the interference pattern is. A possible interpretation is that P is 1 when we have particle features, and V is 1 when we have wave features. One can alter the P and V values based on the experiment or conditions of the system, thereby achieving context dependence. This formulation has connections to other quantum mechanical laws, as discussed by Björk et al[2]. It may be of concern that this complementarity is related in this manner to a probabilistic law: if this is the case, then the mapping is not necessary for wave-particle phenomena. This would be because there would not be any contradictions. Each particle would have to abide by the uncertainty (or similar statistical) principle. Hence, there would be no need to include a mapping necessarily—each particle's manifested feature would be a result of the probabilities.

It would be of natural concern to one who aims to accommodate the complementarity principle of quantum mechanics to incorporate this law and examine whether the mapping is necessary. I grant that the connection serves to ground this particular complementarity within the realm of probabilistic laws. It connects well to the thought of a particle-basis mapping; this complementarity relation will hold different (depending on the case) P and V values for all particles. I make the claim that even if we have relations of visibility and predictability (and position, momentum, energy, and time from the uncertainty principle), it is nonetheless the case that we need a form of mapping to address this specific complementarity. The reasoning I will cover will be two-fold:

- There is no collapse mechanism within these relations.
- There are no connections to any of the similarity subspaces.

Consider the complementarity relation or any uncertainty principle when addressing the first point. It is difficult to see any mechanism that takes one from an equation describing the constraint of our measurements to a determinate manifested feature. One may consider the wavefunction, which has a collapse and measurement function that determines an energy value, for instance. There is no analogous mechanism within these uncertainty relations. The second point follows from the first—if there is no mechanism for which the P and V collapse onto a manifested feature, be it particle or wave features, then there is no analogous collapse onto a similarity subspace with just this relation. This is the case analytically based on the definition of the similarity subspace as a set of purely wave or particle laws. These similarity subspaces contain laws that describe the quantum entity. If we do not know what the feature is, we do not know the set of laws that it obeys. Hence, without a determiner for wave or particle-like properties, there is also no determiner for wave or particle laws and, hence, no connection to any relevant similarity subspace. The natural concern would then be P and V's roles in the context-dependent mapping. I suggest that they are elements of a context subset depending on their specific values. For instance, a P value closer to 1 would be in $c_{particle}$, whereas a V value closer to 1 would be in c_{wave}.

In the following section, I discuss the notion of understanding and the implications of context dependence.

4. On The Notion of Understanding and Context-Dependence

Philosophers often involved in the discussion of explanation consider the notion of understanding rather than knowledge. Proponents of the philosophy of explanation often suggest that there is a connection between explanatory structures and the notion of understanding in science. As Strevens[11] puts it:

> To understand something, I propose, is to grasp a correct explanation of that thing (Strevens 2008, 3). This is a view that is so simple and obvious that it might fittingly be called the naive view of the connection between explanation and understanding. Nothing called the "naive view" survives for the duration of a philosophy paper, and this one won't quite make it to the end of the present section, but the basic idea—that understanding consists in grasping correct explanations—will endure.

To grasp an explanation, according to Strevens, to grasp the truth of these propositions and also to grasp that they stand in the relations required by the "correct" theory of explanation[12]. I will follow Strevens' notion of understanding and attempt to make a case that context-dependent mapping facilitates it. I will also discuss the shortcomings of the Kairetic account with respect to understanding modern physics.

One benefit of the context-dependence is the avoidance of misrepresenting modern physics. Context-dependence arises from the denial of Strevens' method for reconciling multiple realizers, known as frameworking, as a solution to contradicting laws. In particular, we have the following issue:

> In quantum mechanics, wave-like and particle-like behaviors are two facets of the same underlying reality; the aim is to express the

> potential to manifest different properties under different conditions (almost like a disjunction, as it must either manifest as a particle or a wave). An attempt to explain the duality would involve invoking two separate regions of similarity space, which would amount to utilizing a form of frameworking. Frameworking (in the manner of Strevens) these realizers/characteristics would mean taking one of these for granted, which misrepresents the context-dependent and simultaneous nature of quantum mechanics[8].

The main concern with regard to understanding is that the relations of these propositions (of waves and particles within the Kairetic structure) can not quite be determined because our physical theories do not deny either feature; the duality in itself is a part of our (current) physical theory. Such a complementarity can not be resolved or frameworked and is misrepresented through frameworking. This poses a problem when it comes to deducing the "correct" explanation: specifically, the concern is of the "correctness" of an explanatory model that may have no functionality that explicitly determines which feature and relevant laws will be involved without ignoring the other. Within a causal model that aims to stay true to our scientific foundations, it is plausible to consider "correct" to partly be contingent upon representing our theories to the best of our abilities. A more lenient view is that a correct explanation involves a set of difference-makers and their causal relations. As Strevens[11] puts it:

> Grasping the correct explanation of a state of affairs means grasping the dependence relations that make a difference to whether or not that state of affairs holds.

If correctness refers solely to the determining of difference makers, then it may be excusable with respect to this definition to take for granted the particle feature of a double slit interference pattern, for instance. However, it may be worthwhile to consider the representation of our physical theories when making scientific explanations. In addition, there is some difficulty in concluding that only wave-like features of photons in the double slit experiment are difference-makers. As mentioned before, the complementarity relation involving predictability and visibility exists in degrees, whether it may be 0 or 1 or anywhere in between. In an ideal double-slit experiment, it must be the case that there is only visibility, but that would involve the predictability (or knowing the path of the photons) to be 0. In a non-ideal double-slit experiment, however, even if there is so much as a hint of the particle's path, P and V are altered accordingly. Hence, this alters the visible interference pattern. The degree to which there is predictability (or particle-like features) makes a difference in whether the specific pattern is observed or not. This critique extends to the DNP account and other similar accounts. Context-dependent mapping does not take for granted any feature. It embraces the duality and difference in observations based on the context. Overall, frameworking does not represent quantum mechanics and does not provide accurate difference-makers. It is not a sufficient mechanism in an endeavor to construct a correct account of explanation in the sense of determining difference-makers and grounding fundamental physics.

Another benefit of context-dependent mapping is the mitigating of contradictory laws within the beginning kernels of a standalone explanation. This aspect of the DNP and Kairetic account, in particular, is dangerous to its entailment structure.

> Without frameworking, if one were to utilize the DNP account's entailment structure, then the physical laws that we have regarding the wave-like and particle-like features will produce contradictions as both features can not hold at once: only one manifests itself. Similarly, when involving relativistic laws, the entailment structure of the DNP account would lead us to the paradoxes involving the Unruh effect or the black hole information paradox, as we would have conflicting theories as the premises[8].

This ties into our discussion of understanding because the physical theories that we have as a basis for attempting to explain our phenomena seem to be contradictory within the structure of the Kairetic account. The frameworking mechanism is not sufficient to remove this conflict. Recall that understanding (in the sense of Strevens) involves grasping the truth of the propositions and ensuring that they stand in the relations of (in this case) the Kairetic account. It follows that if one were to evaluate the standings of these laws in the deductive structure required by the Kairetic account, then one can see that it is difficult to grasp the truth of these propositions as the very structure will produce a contradiction, not an entailment. One may wish to ignore one aspect, such as the wave or particle aspect, yet this would be taking one feature to be granted over the other - which again misrepresents quantum mechanics.

It is clear then that one has to sacrifice one of these two factors for a sense of understanding in the Kairetic account:

- A "correct" explanation in the sense of representing the current physical theories and determining difference-makers
- The notion of understanding, as discussed prior.

Accordingly, I argue that context-dependent mapping preserves both factors, as it accommodates the complementarity principle and avoids contradictory laws within a causal model. It elucidates difference-making (at least in the context of predictability and visibility relations) and becomes a mechanism within the DNP/Kairetic accounts. Consider the detailed standalone explanation in Figure 2. There are laws assigned to each relevant particle, representing the complementarity principle, which suggests that one feature manifests itself for every quantum entity. In addition, since the mapping assigns a particular law within a consistent similarity subspace to each particle, there are no apparent contradictions within any of the kernels.

5. Conclusion

This paper builds upon an account of explanation regarding the complementarity view within Strevens' Kairetic account using context-dependent mappings. By assigning specific laws to particles based on their experimental context, this approach ensures logical consistency and aligns with observed phenomena. My first claim was that the mapping involves itself within a kernel of a standalone explanation on a particle basis, meaning that every entity involved in the system undergoes this mapping: this aligns with the generality of the wave-particle complementarity.

Addressing the uncertainty objection, I argue that context-dependent mapping is essential for linking observed features with relevant physical laws despite quantum mechanics' probabilistic nature. This method enhances scientific understanding by accurately representing quantum duality and mitigating contradictions within explanatory accounts, providing a robust foundation for coherent and comprehensive scientific explanations.

Concerning understanding, I claim that the context-dependent mapping mechanism facilitates the notion of understanding as established by Strevens. Further avenues of thought include the potential application of context-dependent mapping in other established accounts of explanation in the philosophy of science and the specifics of what constitutes a context as an element of a context subset.

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