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Towards an Account of Complementarities and Context-Dependence

Hong Joo Ryoo
Department of Philosophy
University of California, Berkeley
lyuhongju1@berkeley.edu

ABSTRACT. Discussions in the philosophy of explanation involving scientific explanations often include a form of logical entailment, causal history, unification, and more. Strevens([10],[11]) constructs the Kairetic account in an attempt to unify the entailment structure, causal relations, and the notion of difference-making in a manner that also offers high-level explanations. When dealing with quantum mechanics, Strevens then points toward the Deductive-Nomological account of probabilities, known as the DNP account. In this paper, I will introduce the preliminary accounts (D-N, causal, Unificationism) and the Kairetic and DNP accounts and offer an extension of the Kairetic/DNP account to accommodate the view of complementarities. This will be done through a scheme that I call context-dependent mapping. This will be illustrated in a couple of example cases.

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

1. Introduction to the Preliminary Accounts

There are various notions of explanation in metaphysics and the philosophy of science. In particular, I will focus on the following notion: when a set of propositions explains some other proposition. Logical entailment is utilized in the form of premises and a conclusion that soundly/logically follows. Hempel and Oppenheim[4] offer such an account involved with this scheme called the deductive-nomological (D-N) account, which utilizes a set of laws in its premises. What is entailed is the occurrence we want to explain: this is referred to as the explanandum. The Kairetic account aims to utilize the entailment structure of the D-N account without necessarily including physical laws but with a focus on causation.

In contrast, accounts of causation such as that described by Lewis[7] involve examining the causal history, i.e., what occurred in the trajectory of a system in space-time, what was present, what resulted, etc. These do not necessarily involve established scientific laws. Ultimately, Strevens aims to construct a causal account. Furthermore, Kitcher[6] offers an account called Unificationism, which deals with explanations of the greatest unification prowess. Namely, what is evaluated is the number and similarity of patterns, stringency/cohesion of the patterns, and derivational power. In the unification approach, an event is explained by showing how its occurrence can be deduced from a theory that brings together a wide array of distinct phenomena. This demonstrates that the event is an instance of a highly general and potentially all-encompassing pattern of events throughout the universe. The best explanation, then, is the explanation that unifies the most number of phenomena. Unificationism determines which factors are explanatorily relevant by evaluating how well they contribute to a unified understanding; the more unified, the more relevant the factors are. Furthermore, difference-making involves identifying specific factors/conditions that critically influence the occurrence of an event. In scientific explanations, a difference-maker is any variable that, when altered, significantly changes the outcome. In Unificationism, as Strevens[10] puts it:

> [The] explanatorily relevant parts of any causal network are the elements that made a difference to whether or not the explanandum occurred. It is important to note the whether or not. To be explanatorily relevant, a causal factor must not merely make a difference to how the explanandum occurred; it must make a difference large enough to bear on whether or not it occurred at all.

This affirms that the most general, unified explanation's relevant factors are indeed relevant if they are difference-makers. As will be discussed in the later sections, Strevens utilizes a process he refers to as "abstraction" as a method to receive generalized explanations and, with enough abstraction, explanations with difference-makers. This, paired with causal entailments, serves to compose the roots of the Kairetic account.

2. The Kairetic Account

Strevens[10] refers to the Kairetic approach as "fully causal" — meaning that the framework underpinning each explanation is firmly rooted in causal relationships. Unlike other models that may incorporate non-causal or correlative elements, the Kairetic account exclusively relies on causation to delineate how various factors contribute to phenomena, thereby ensuring a solid causal basis for scientific explanations. This implies that while there are structures in place that are borrowed from unification (that which is used to conclude certain difference-making factors), the Kairetic account concerns the notion of causation and the assembly of causal explanation through means of incorporating all relevant causal influences. Accordingly, Strevens affirms that this causal account will utilize unificationism's methods of determining which factors are explanatorily relevant and how such is done. He introduces the notion of a causal model for an explanandum, which is intended to describe how some causal factors (situations, relevant laws, background conditions) entail the explanandum. This is the entailment structure. The Kairetic account aims to utilize this notion and its corresponding causal influences as potential difference-makers for the sake of constructing a "unified" account of explanation.

In determining difference-makers, Strevens[10] proposes the following process: a causal model M for explanandum E can undergo abstraction to produce a new causal model M*, which is also entailed by the original causal model M.

In essence, abstraction maps an initial causal model M to another model M* that is entailed by M in a manner that preserves the explanandum E. As an example, consider the following set that explains the falling and breaking of a cup: gravitational force greater than the frictional force of the hands, momentum buildup from gravitational acceleration minus air resistance forces, energy conversion to the individual molecules of the cup, breaking of bonds within the compound that constitute the cup, etc. about the physics and background, if these conditions are met, then we have a breaking of the cup. This set is an example of a set which can be abstracted to be the following: the cup was dropped, the ground was made of hard material, the cup was made of glass, the room contained nothing notable that would've prevented the cup from breaking otherwise, etc. about the background, if these conditions are met, then we have the effect of the cup breaking. The latter model is entailed by the first in that it summarizes the crucial elements that are necessary and sufficient for the event (the cup breaking) to occur. This involves stripping away less relevant details and focusing on the causal elements that, when altered, would significantly change the phenomena. Through this process of abstraction, Strevens[10] finds it possible to find what the difference-makers are in an event. He proposes an abstraction kernel, which is a maximally abstract causal model for explanandum E. This means that the kernel for some model M is entailed by every model that is entailed by M. For example, let M entail M1, which entails M2, and so forth until a final index N, where MN can't be abstracted further. MN is entailed by all previous models M, M1, M2, ..., MN-1. The kernel of M can be said to be MN, and the elements of this explanatory kernel are said to be "difference-makers." Ultimately, this process of abstraction relates to Unificationism as they both aim to simplify/generalize explanations and identify fundamental causes.

3. The Disjunction Problem

Furthermore, Strevens[10] introduces a problem to the Kairetic account that involves disjunctions. Simply stated, explanations can be made increasingly abstract through the incorporation of various disjunctive conditions. For instance, the statement that the cup broke because either a cat bumped into it or a human mixed a chemical into it serves to introduce the disjunction of a cat's collision of the cup. This is maximally abstract as there is no other entailment to be had from this statement—it is just that either a cat collided or a human mixed something into the cup. This can also be generalized to an arbitrary number of disjunctions, such as the addition of an electrician shocking the cup. In order to prevent a maximally abstracted model with irrelevant difference-makers, Strevens suggests "forbidding" this type of abstraction, which is done by examining how cohesive the model is. Cohesion describes the extent to which a model is realized by a singular causal process. Strevens[10] claims that cohesion is a "measure of the degree to which the same kinds of difference-makers are active" in every system that the model describes; this, however, does not mean that maximal cohesion is a requirement but a desideratum for the evaluator. As Strevens[11] claims, when considering a "similarity space" that rates the physical processes of each potential causal model based on the degree of similarity, cohesiveness refers to a contiguous set (or a set containing elements similar enough with respect to the laws of physics) within this space: this contiguity will serve to establish a "causally contiguous" requirement to each disjunction. This set in similarity space has its basis in the underlying physics; it is the deciding factor of whether higher-level properties with different realizers are sufficiently similar to satisfy the cohesion requirement.

Relating it to our discussion of the cup, in the model of the electrician, the cat, or the human, the factors of the electrician or cat may not be seen as cohesive in the sense of similarity space and the underlying physics. This is because these factors of the model as a whole can be split into three subsets (for each being), and the process of the causal breaking of the cup will only lie within one of these subsets with minimal influence (if any) from the other two subsets. The mechanisms are radically different, and the examples of the cat and electrician are not cohesive enough to make for plausible disjunctions. Hence, the proposed solution to the disjunction problem is to examine the similarity space and allow for the disjunctions that are contiguous enough, neglecting the disjuncts that do not align. To further elaborate on the concept of cohesion in the Kairetic account, cohesion serves as a fundamental criterion for determining the explanatory relevance of factors within a causal model.

4. Connecting the Kernels: The Standalone Explanation

The complete and self-contained explanation that provides a causal understanding of the causal relations of event E is referred to as the standalone explanation. Strevens[11] offers the following thought: a ”standalone explanation” is defined as a causal model specifically tailored for an event (E) and is composed exclusively of elements that directly influence the occurrence of E (recall that these are known as difference-makers). This model is constructed from a series of ”explanatory kernels,” which are simpler, abstracted causal models that progressively build upon one another. Each kernel in the sequence incorporates and satisfies the causal requirements of the preceding model, ensuring that every successive model adheres strictly to the causal architecture established by its predecessors. The final kernel in this chain is directly correlated to the event E, capturing all and only the essential causal factors that explain E. This ensures that the explanation is both precise and comprehensive, focusing solely on the components necessary for the occurrence of E without any extraneous details. It is evident that the process so far is as follows: one would consider a causal model, abstract it such that there are only difference makers in the final result, and then construct a standalone explanation with a chain of kernels for each element of the previous models. Strevens[11] considers what properties of a standalone explanation make that explanation preferable. In particular, he identifies three such parameters: length, intensity, and generality. An explanation with sufficient length to include all relevant causal factors, without it being so long to the point where it has numerous irrelevant factors, is preferred. Events in the distant past are generally considered less relevant unless they directly influence the explanandum in a significant way. In addition, the “more general, more abstract” the standalone explanation, the better it is. This relates back to the dropping of the cup; the explanation regarding macro-level events is more general and better than the one involving several microstates. A standalone explanation of the phenomena would involve the narrative of each factor involved in the breaking of the cup. The explanation’s kernels would pinpoint the direct influences of each factor involved in each model. The standalone explanation candidates can also be evaluated on their cohesiveness, the extent to which gaps are filled, and how exhaustive the explanation is. Furthermore, the intensity of an explanation, or how detailed the causal mechanisms are, may be adjusted/abstracted based on the audience so that the explanation does not become overly technical or inaccessible. While Strevens' primary interest lies in what objectively makes an explanation good, he does not ignore the practical aspects of explanation. More intensive/detailed explanations may provide a greater understanding, yet explanations that are too technical will make them less accessible. Overall, the Kairetic account mirrors the approach of Unificationism, preferring the general, more encompassing explanation that can potentially capture diverse occurrences under some unified theory.

5. The Multiple Realizability Objection

There is an objection (called the multiple realizability objection) made about the ability to explain high-level phenomena with multiple possible factors at play. Consider the phenomena of stress reduction. This explanandum can be achieved through physical exercise, meditation, therapy, medication, etc. These factors can yield reduced stress but operate under vastly different physical mechanisms. This is different from the disjunction problem: the multiple realizations problem deals with the diversity of mechanisms underlying a single phenomenon, while the disjunction problem deals with the complexity introduced by overly abstract or disjunctive explanations. The thought is that since there are various factors that can contribute to the explanandum (of stress reduction), it must be difficult to use one explanatory model (with one central factor such as exercise) to explain it. In assessing multiple realizations, two options are discussed: smooth and discrete. These are judged on the basis of distance in similarity space: if the realizers are similar in this similarity space, then it is considered smooth (and contiguous) and does not pose a problem, but if the realizers are sufficiently far apart in similarity space, then there is going to be a discrete set of possible realizers. These discrete realizers form the central problem. Contrastingly to the cohesion case, the difference in similarity space allows for these realizers to exist not as disjunctions but as two separate explanatory avenues. Strevens[11] identifies reasons for multiple realizability: the presence of black boxes (causal models that specify outputs based on inputs without detailing the internal workings), functional analysis (which breaks down systems into components identified by their function without specifying underlying causal mechanisms), and the citation of functional properties (defining kinds or properties by their causal abilities). Black boxes and functional analysis simplify complex systems into components defined by their roles or outputs, often without detailed causal explanations. In addition, functional properties consider roles and effects. In particular, they are the attributes of systems or components that are not defined by their intrinsic physical features but solely by the roles they perform and the effects they cause. Strevens addresses this objection through the notion of an explanatory framework. This framework serves to hold fixed certain background conditions. For instance, in some psychological studies, a subject's behavior can be explained through the fixed condition that the examined mental states behave like desires and beliefs. In economics, it can be held fixed that consumers and sellers behave like somewhat rational autonomous agents. In engineering, the details of transistors and their microelectronic properties can be frameworked. In the previous example of stress reduction, we can framework the roles of meditation, therapy, and other environmental contexts. This serves to embrace the black boxes and allows for the explanation to be much less taxing to perform. It is important to note that the elements that are frameworked must have some sense of cohesion with respect to fundamental physics; if the elements are of similar physical processes, then the frameworking is "cohesive." This allows for explanation to set aside the physically distinct elements in a principled manner. In the next section, I aim to explore this objection in the context of the fundamental physics of small scales. Specifically, Quantum Mechanical phenomena involve multiple realizations that may be difficult to navigate around.

6. Groundwork: Quantum Mechanical Phenomena and Probabilistic Explanation

Modern quantum mechanics has a myriad of phenomena that have probabilistic conjunction and disjunction-like properties, such that each conjunct phenomenon is different in its physical behaviors and interactions. Among those, this paper will explicitly attempt to address wave-particle duality and black hole complementarity. This section will introduce the wave-particle duality and the DNP account. In discussing probabilities and the Kairetic account, Strevens points towards Railton's DNP account, suggesting one utilize it instead for simple probabilities. He then offers a thought about the potential implementation of a notion of causation in the DNP account.

In wave-particle duality, a 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, it is deterministic in that the experimental apparatus used unequivocally influences the nature of the observed phenomena: depending on the experiment, there seems to be a set of physical laws corresponding to waves or particles. I will be discussing how to capture this observational quality as an extension in the Kairetic account. In the current model of micro-scale physics, Strevens[11] suggests that quantum mechanics is probabilistic: "probabilistic explanations are the only possible explanations," as in this above case. This probability is genuinely irreducible to our current knowledge, deemed simple probabilities, and Strevens[11] declares the Kairetic account does not have "much that is novel to say" about it. Ultimately, Strevens[11] directs the audience to Railton's Deductive-Nomological-Probabilistic (DNP) account, which is simply the D-N account with probabilistic laws. As Strevens puts it:

> [The Kairetic account for simple probabilities] follows the broad outlines of the DNP and similar accounts.

Railton[9] proposes two features of this account: the size of the probability associated with the explanandum is irrelevant to the force of the explanation and denies that an explanation that is probabilistic instead of deterministic is a causal account. By pointing towards the DNP account and away from the Kairetic account, Strevens[11] leaves the topic of simple probabilities open for further development within the context of the Kairetic account.

Accordingly, Strevens[11] suggests an initial (not complete or exhaustive) framework for integrating these simple probabilities into causal explanations. Without denying the notion of causation in simple probabilities (like the DNP account), he aims to introduce potential avenues for incorporating causation. He first expands on the concept of causal entailment within the context of simple probabilistic explanations. In particular, he introduces the idea that factors can entail a physical or inductive probability for an event without directly causing it, similar to how a report in a newspaper might suggest a high chance of an event without causing it. This leads to the distinction between causal influences and mere entailers in explanations that involve probabilities. He outlines two ways a factor might causally influence a probabilistically produced event: either as part of the event's supervenience basis (as one of the event's determining physical properties) or by influencing these determinant properties indirectly. In the direct case, a factor may be considered part of what establishes the physical probability of an event, like the size of a potential barrier influencing particle behavior in quantum mechanics. In the indirect case, a factor affects the event by altering other factors that directly establish the event's probability. Furthermore, Strevens[11] suggests that probabilistic causal entailment mirrors the "dependence relationship" between an event and its causal factors. This relationship is defined by the laws of nature, which specify how the simple probability of an event depends on these factors. For a probabilistic model to adequately represent this causal influence, its derivation must explicitly follow the laws and conditions that establish this dependency, using straightforward logical derivation. The crux of Strevens's argument is that the causal relationship between an event and its influencing factors hinges on how the laws of nature link the event's probability to these factors. This establishes a framework for understanding probabilistic causal entailment as a reflection of the underlying dependence of events on their causal influences, applicable to both physical and inductive probabilities. Nonetheless, as mentioned before, Strevens senses that the Kairetic account for simple probabilities would take a form similar to that of the DNP account, with some notion of causation. If one were to attempt to create a standalone explanation, especially involving quantum mechanics, then it is fitting for one to use a structure similar to that of the DNP account to construct the kernels that arise from quantum mechanics. Strevens[11] depicts such an explanation in Figure 1:

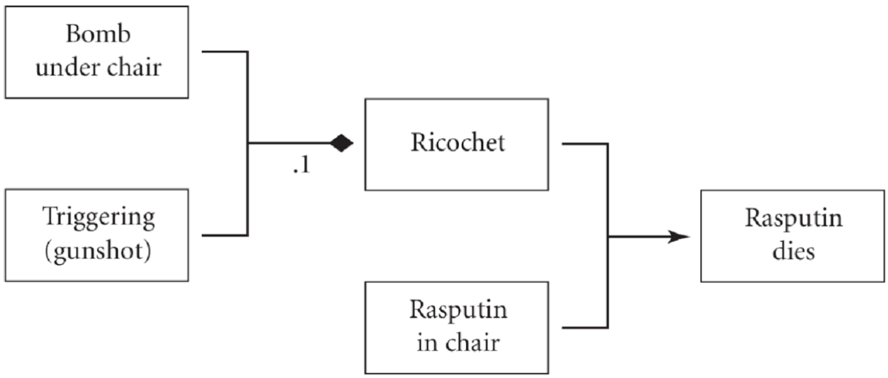

FIG. 1: *A Sample Standalone Explanation*

In this sample standalone explanation, Strevens offers a (simple) probabilistic explanation of Rasputin's death. The event involves a Bomb under Rasputin's chair and a gunshot that is intended to trigger the bomb. With a small probability, represented by 0.1, the bullet does not trigger the bomb and instead causes a ricochet into Rasputin. The thought is that using the DNP or similar models, one can construct a model for the simple probabilistic element of the ricochet. Accordingly, Strevens[11] affirms that:

> A deep standalone explanation must spell out the properties of the fundamental-level laws in virtue of which the explanandum has the physical probability it does.

He suggests that the quantum mechanical aspects of the phenomena are grounded in fundamental laws through deductive structure. Whether through the DNP account or a similar account, Strevens nevertheless points towards the necessity of fundamental laws to form initial causal models for simple probabilities. These can then be involved in a larger standalone explanation involving other deterministic events, such as Rasputin's death.

Strevens' thought regarding the DNP account is that it serves to explain a simple probability kernel, which can be a part of a standalone explanation in the Kairetic account. The entailment structure of the DNP account allows for one to construct a standalone explanation like the one in Figure 1. It is imperative to consider the connection between the similarity space of the Kairetic account and the DNP account within this standalone explanation; in particular, the DNP account consists only of physical laws of the similarity space. This aligns with Strevens' thoughts that the Kairetic account (and, in this case, the standalone explanation) must tie into physical laws. I will be considering both the DNP account and the larger standalone explanation of the Kairetic account when attempting to accommodate the complementarity view; more will be discussed in the following sections.

7. Introduction to Complementarities in Quantum Mechanics and General Relativity

While Strevens asserts the probabilistic nature of quantum mechanics as simple probabilities, some may advocate for a view of complementarities that isn't completely probabilistic but unequivocally dependent on the apparatus (reference frame, experimental instruments, and other entities in a system) used in observation. The complementarity principle posits that entities/systems can display apparently contradictory properties depending on the way they're observed or measured. These manifested properties are mutually exclusive yet equally necessary for a consistent description of the entity/system with our physical laws. This section will depict the paradoxes that may arise from considering quantum mechanics and general relativity and will introduce the complementarities that aim to reconcile them. I aim to provide more context as to the view of complementarities and express caution when dealing with complementarity features simultaneously. The wave-particle duality, for instance, requires the apparatus to be the sole determinant of the manifested features. In wave-particle duality, a 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 (de Broglie 1923, Young 1804). 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. I will be discussing how to capture this observational quality as an extension in the Kairetic account. Beyond this complementarity, there are plenty of paradoxes and complementarities that arise from our physical theories.

Within modern physics, there is a large disagreement between the theories of general relativity and quantum mechanics. An important phenomenon to consider next is the phenomena of Hawking's[3] radiation: when an object enters a black hole (crosses a radius called the event horizon), then we expect to see the object emitted as radiation. The paradox goes as such: quantum mechanics predicts that the radiation will contain all of the relevant information of the object that entered the black hole, but general relativity suggests that this information will be destroyed in the sense of the information not being able to escape the event horizon[8]. The black hole complementarity is then a proposal to remove the frame-independence of this event[12]. Einstein's equivalence principle states that an object that crosses the event horizon will continue to experience falling toward the center of the black hole rather than just be emitted as radiation right away. This forms the crux of the complementarity: if we are in the reference frame of the falling object, we would continue to fall, but if we were on a reference frame outside of the event horizon, then we would see an object enter and then exit as radiation. In modern physics, complementarities are often proposed as solutions to disagreements between theoretical frameworks. Furthermore, the geometry of space-time and reference frames impact the observed quantum effect: the Unruh Effect[1], suggests that an observer in acceleration will perceive a warm bath of radiation, even if they are in what an inertial observer would describe as a perfect vacuum, void of quantum states. This effect is a manifestation of the observer-dependent nature of the vacuum state in quantum field theory; again, a complementarity is proposed for this paradox, referred to as the complementarity principle for the Rindler horizon (Hirayama, Kao, Kawamoto, Lin 2011). This principle suggests a relativity of observational knowledge for an accelerating observer in an analogous manner to the black hole complementarity principle. Just as in the wave-particle duality case, there seems to be a set of relevant physical laws corresponding to each complementarity feature. Accordingly, I will refer to the outcome that is unequivocally influenced by the experimental apparatus as a "context-dependent" outcome. The ultimate aim of this paper is to accommodate complementarities (and context-dependent explanandum) into the DNP and Kairetic accounts.

Thus far, I have aimed to establish the following points:

1. Strevens points towards the DNP account for simple probabilities within a standalone explanation of the Kairetic account.

2. There are paradoxes in our theories (wave-particle, information, Unruh effect, etc.).

3. Complementarities are proposed solutions to those paradoxes.

The thoughts developed in the following sections will consist of the following:

4. If one were to use frameworking in the manner described by Strevens, then the complementarity view is misrepresented.

5. If one were to use the DNP account, then contradictions may arise.

6. Using point 3, it is possible to construct a mapping such that the contradictory similarity spaces can be separated into two (or more) consistent similarity subspaces.

7. If one wishes to explore an account of explanation involving complementarities, then one can utilize the mapping in point 6. An example will be given involving the double slit experiment.

Let us begin with point 4.

8. In the Face of Complementarities

In this section, I will argue that frameworking in the Kairetic account misrepresents the complementarity view (point 4). As a first thought, if one were to try to work directly with a similarity space for accommodating complementarities, one may find it difficult to conceive in what manner the similarity space and frameworking work together in cases of complementarities and micro-scale physics. Strevens uses the similarity space as a space consisting of the physical processes of all potential causal models: explanations that invoke similar fundamental physics may be seen as cohesive, different ones may be denied for disjunction, etc. My concern surrounds the potential misrepresentation of quantum mechanics and relativity. If a similarity space is a basis for neglecting disjunctions and determining frameworked regions, then it appears that (for instance, in the case of wave-particle duality) dual phenomena that we typically assert exist as a form of conjunction, to begin with, are going to be two separate, arguably incohesive regions of this space. 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.

Moreover, it is possible to argue for point 5 by claiming that the laws themselves are contradictory. 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. Until a theory of unification reconciles quantum mechanics and general relativity, there may be inevitable contradictions within the entailment structure of the DNP account. If one desires to accommodate complementarities, this may be facilitated by a structure that isn't frameworking or the DNP account. The following section focuses on point 6 by introducing a mapping structure that intends to lift the burden of having contradicting premises by only using a subspace within a similarity space.

9. f_c: Context-dependence as a Representation of Complementarities

In order to achieve context dependence, some formalism may be necessary regarding the initial input of the observation. Consider the following approach to represent complementarities: 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. The double slit case, for instance, lets the light manifest as a wave. This physical setup involving the slit and light will be a part of a context subset c_{wave} alongside all other possible setups manifesting wave features of quantum entities. More examples of c_{wave} involve multiple slits, optical setups, etc. Setups involving accelerating reference frames producing the Unruh Effect will also be a part of a context subset c_{UA}, and all setups that can be treated as a black hole's matter system (the frame that enters the event horizon) will be an element of the subset c_{BHM}. These are all subsets of the context space C.

The next step is to identify a mapping f_c from a subset of C onto a particular region of similarity space S. These similarity subspaces will be sets of laws that are self-consistent—no laws in one subspace will contradict each other. Namely, there will be no major overlap of general relativity and quantum mechanics, no overlap of wave and particle features of quantum entities, etc. For instance, if the context involves a double slit, then the particle is to be considered in terms of wave formalism SWave, and if there is scattering, then it is to be considered in terms of particle formalism $S_{Particle}$. Through this map, it is possible to restrict similarity space to only the laws applicable to the complementarity feature that is manifested. This mapping onto a similarity space will serve as an initial physical basis from which the DNP and Kairetic account can yield some higher-level phenomena.

In essence, using our empirical information from past experiments and verified theories, we are able to prescribe the relevant laws to a physical system. The thought is to have the mapping be grounded in empirical data and theoretical frameworks that are accepted independently of the specific explanations being constructed. The mapping aims to, depending on the context/setup, utilize disjoint and non-contradictory laws for the entailment structure. Figure 2 depicts a sample mapping.

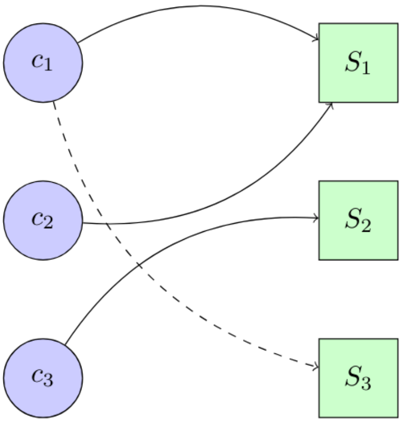

FIG. 2: *Visual Representation of f_c*

In this mapping, c_i represents the set of contexts (as a subset of the complementarity space C) that manifest one complementary feature: this may be the set of all accelerating frames in the Unruh effect or the set of all matter frames in the presence of a black hole. S_i represents the similarity subspaces of a similarity space S. This may be the equations governing quantum field theory, black hole relativity, wave physics in quantum mechanics, etc. The thought is that each S_i does not contain contradictions and instead has consistent physical laws. The mapping f_c is intended to be the representation of a context c_i unequivocally influencing the relevant set of laws S_i. If one desires to apply this mapping, in the case of dual phenomena, one can consider each mapping onto different similarity subspaces and use the corresponding physical principles to construct a DNP or similar account of scientific explanation.

10. Example of the Multi-slit mesh

In this section, I will aim to establish that an account of complementarities can be constructed through the f_c mapping. I will construct an example case to demonstrate how one could utilize context-dependent mapping. Consider an interference phenomenon arising from shining a light towards multiple slits in a mesh (with sufficient geometry such that diffraction occurs). From our knowl-

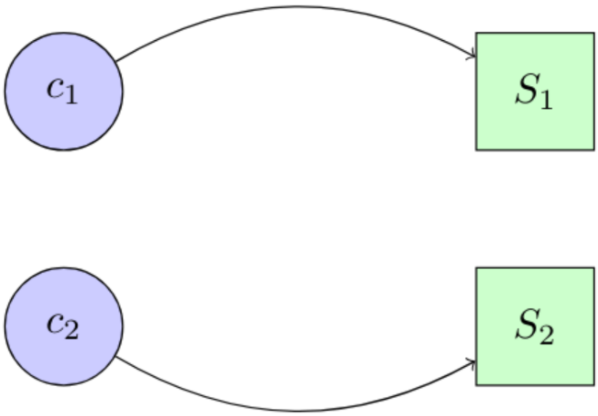

FIG. 3: *Complementarity of Wave-Particle Features*

edge of light, in this context, the physical laws that may apply are those involving wave-like manifestations of light. Figure 3 depicts the complementarity's relevant similarity subspaces and the sets of contexts to which each one corresponds.

In this figure, the set of contexts c_1 contains the contexts that involve the manifestation of light as a wave, such as cases with double (or even multiple) slits with appropriate length(s). It is a set of all such contexts (of the energy of surrounding particles, the reference frames, and other physical background conditions) for which one may identify wave-like features of particles. Accordingly, c_2 involves the contexts for which light manifests itself as a particle - Compton scattering, photoelectric effect, etc. S_1 and S_2 are the similarity subspaces that involve the physics of a wave and the physics of a particle. In the case of the mesh, one with knowledge of physics would make these judgments:

- The set of contexts c_1 is appropriate to use.
- f_c maps c_1 onto S_1.
- Using the laws in S_1, we can construct an entailment structure.

The first judgment arises from the observation of the explanandum (of interference), and the second judgment comes from the physics background: having knowledge of the dual phenomena allows one to see that it is fitting to utilize wave-like laws of quantum mechanics. I will now continue to briefly construct a structure of the DNP account using S_1 laws. The model would look like this: the particles' wavefunction from the Schrodinger Equation, laws of constructive and destructive interference of waves, etc. and these would entail the explanandum: the interference pattern in the mesh.

11. Example of the Optical Telescope

Furthermore, I will offer an example in which the interference patterns of quantum mechanics are considered through the DNP account within a standalone explanation of the Kairetic account. Suppose one wants to explain the phenomena of a telescope (which uses a mesh similar to the previous example) showing a certain spectrum of light from a star. The explanandum, in this case, is the telescope reading, which takes the form of a spectrum shown on a screen. If one wishes to use the mapping, then one can adopt the one in the previous example: the light emitted from the star and the diffraction mesh geometry c_1 determine that the similarity subspace from which the laws are drawn would be the same S_1. Using the laws in S_1, one can use the DNP account to demonstrate that, in this case of the complementarity, we have wave-like features within the telescope and a certain interference pattern. Furthermore, one can go on to consider the Kairetic account. A causal model M can look like this: we have the aforementioned quantum interference pattern (explained by the DNP account), the other classical optical properties of the telescope, no medium that alters the transmission of light, a spectrometer that indicates calcium if the pattern corresponds to a certain family of other patterns, etc., if these previous elements are satisfied then we get the spectrum displayed in the telescope. The model would then continuously be abstracted so that the only remaining elements are difference makers. Figure 4 depicts the standalone explanation as a parallel to the diagram of Rasputin's death - the kernel of the Interference pattern is then explained by the first example (DNP structure) for which the mapping onto the wave (interference) laws has been performed.

Figure 4: Optical Telescope Reading Standalone Explanation

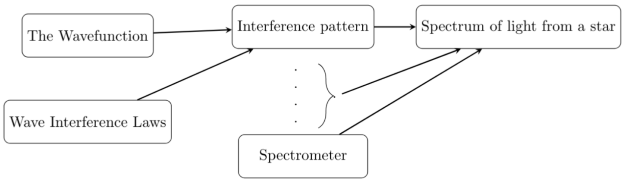

FIG. 4: *Optical Telescope Reading Standalone Explanation*

Using the DNP account and specifying the laws within it, it is possible to explain the quantum mechanical aspects of a telescope. The DNP account explains the probabilistic nature of photon interaction at the quantum level, while the Kairetic account is used to model how these interactions causally lead to reliable spectral readings under specific observational settings. This aligns with Strevens' thoughts about the DNP account being able to account for the simple probabilities. When constructing a standalone explanation, it may come to one's attention that the quantum interference pattern, which emerges within a model, would be the kernel of a DNP entailment analogous to the ricochet in Figure 1. The mapping, when used in the Kairetic account, may serve to give a causal model that does not sprout from a potentially contradictory set of laws but rather from a view of complementarity.

12. Conclusion

In this paper, I gave a preliminary framework for considering views of complementarities within the DNP and Kairetic accounts. The f_c mapping can be extended to the other complementarities. Suppose one wanted to explain the observation of a preservation of information around a black hole. The mapping scheme would look similar to Figure 3. The laws surrounding the equivalence principle (or the corresponding similarity subspace) will be selected if the frame of reference is the matter frame. The laws of quantum mechanics will be selected if the frame of reference is outside of the event horizon. Using this, one can construct a DNP model that utilizes the laws of either complementary principle. Further development of this thought may be particularly useful in cases of non-negligible quantum and relativity effects before an established unification.

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