EFFECT PROPAGATION PROCESS: A PHILOSOPHICAL FRAMEWORK FOR POST-QUANTUM CAUSALITY

Marvin Hansen
Emet-Labs.com
marvin.hansen@gmail.com

ABSTRACT

The concept of causality, central to our understanding of why things exist, change, and come into being, has evolved from multi-factor ancient views and Seneca's spatiotemporal prerequisite—a notion debated philosophically by relationalists like Leibniz and critiqued scientifically by Russell. However, quantum gravity, suggesting spacetime may be emergent from a deeper reality and causal structures can be indefinite, fundamentally challenges this traditional background-dependent notion. In response, this paper proposes the "Effect Propagation Process" framework for post-quantum causality. This framework re-envisions causality not as discrete links between events within a fixed spacetime, but as the fundamental continuous transfer of influence originating from a deeper quantum structure. By providing a unified philosophical perspective compatible with classical causality in the emergent limit and aligning with leading quantum gravity theories, the Effect Propagation Process offers a novel lens on the nature of causal reality, with significant implications for ontology and epistemology.

***K*eywords** Causality · Post-Quantum Causality · Philosophy of Causality · Causal Structures, · Effect Propagation Process, · Epistemology · Ontology

1 Introduction

The concept of causality, fundamental to our understanding of the world, has evolved from ancient philosophical inquiries identifying multiple necessary factors for a cause to be true. This classical view required a spatiotemporal background, as argued by Seneca. However, this notion faced philosophical debate from relationalists like Leibniz and later critiques from Bertrand Russell regarding its status in physics.

The advent of quantum gravity, however, suggesting spacetime may be emergent from a deeper reality and causal structures can be indefinite, poses a profound challenge to traditional causality which relies on a defined background spacetime.

In response, the author proposes the "Effect Propagation Process" as a philosophical framework for post-quantum causality. In this framework, causality is viewed not as discrete links between events in a fixed spacetime, but as the fundamental continuous transfer of influence from within a deeper quantum structure. The "Effect Propagation Process" framework attempts to provide a unified perspective for post-quantum causality that remains compatible with classical causality and aligns with leading theories in quantum gravity.

1.1 History of Causality

In Timaeus (c 360 BC), one of the first known attempts to understand why things come into being, Plato explores the cause (*aitia*) and “contributing causes” (*sunaitiai*). Plato stipulates that multiple indispensable factors, the model, the maker (Demiurge), the material, and the space (receptacle), explain how the physical world with all the things in it are made [1].

Aristotle (c 350 BC) formalized the notion of causality in his Metaphysics [2] which serves as the foundation of the classical framework of the "Four Causes” [3]. These are:

1. The material cause or that which is given in reply to the question “What is it made out of?”
2. The formal cause or that which is given in reply to the question "What is it?”. What is singled out in the answer is the essence of the what-it-is-to-be something.
3. The efficient cause or that which is given in reply to the question: “Where does change (or motion) come from?”. What is singled out in the answer is the whence of change (or motion).
4. The final cause, the end purpose, is given in reply to the question: “What is its good?”. What is singled out in the answer is that for the sake of which something is done or takes place.

Aristotle moved beyond simplistic notions of causality to identify multiple, distinct factors necessary for explaining how things come into being and change.

Seneca (c 56 AD) argues in letter 65 [4] that cause and effect operate within a stage (space) and follow an order (time). Remove the stage or the order, and the conventional understanding of ’making something’ or ’causing something’ breaks down. His argument highlights time and place as indispensable conditions for ’making something’, identifying the need for a spatiotemporal context as a prerequisite for classical causality. This focus on space and time as necessary conditions served as a precursor to later physical concepts treating spacetime as a background for causal processes.

The idea of space and time as an independent background did not go unchallenged in philosophy, even before the advent of modern physics. Gottfried Wilhelm Leibniz (1646-1716), in his famous debate with Isaac Newton’s representative, rejected the concept of absolute space and absolute time as independent, fundamental containers. Instead, Leibniz proposed [5] a relational view, arguing that space is merely the order of coexisting things (simultaneity), and time is merely the order of successive things. For Leibniz, space and time were not substances or backgrounds that existed on their own, but systems of relations between the objects and events that constitute reality. He arrived at this conclusion through rigorous philosophical reasoning, arguing from fundamental metaphysical principles, such as the Principle of Sufficient Reason, that the concept of absolute space and time was logically untenable. This relational perspective offered a significant historical philosophical alternative to the pre-eminent Newtonian worldview of his time.

2 The impact of General Relativity on Causality

Einstein’s theory of General Relativity [6] maintained the requirement for a spatiotemporal context as a prerequisite for causality, echoing Seneca’s insight. However, GR fundamentally transformed this prerequisite from the static, absolute background of earlier physics into a dynamic spacetime manifold, warped and influenced by matter and energy. Unlike a passive stage, the spacetime of GR is an active participant in the causal processes unfolding within it.

Bertrand Russell (1872 - 1970) wrote in his 1912 essay "On the Notion of Cause" [7]:

> "The law of causality, I believe, like much that passes muster among philosophers, is a relic of a bygone age, surviving, like the monarchy, only because it is erroneously supposed to do no harm."

For Russell, the traditional idea of causality, a necessary, temporal asymmetrical link between distinct events, did not match the sophisticated, law-based descriptions used in successful physics. Russell’s argument is rooted in his observation that physics describes how the state of a system evolves. The focus is on the state of a system (e.g., position, velocity, field strength across space) and how that entire state changes continuously, rather than isolating specific, discrete events as "causes" and "effects."

Many fundamental physical laws are symmetrical in time or involve reciprocal relationships. If state S1 at time t1 is related to state S2 at time t2 by a law, it’s equally true that state S2 at time t2 is related to state S1 at time t1 by the same law. The relationship isn’t a one-way street from a necessary "cause" to a dependent "effect." Knowing the state at any time allows you (ideally, in a deterministic system) to calculate the state at any other time, past or future. Therefore, which one is the "cause" and which is the "effect" becomes arbitrary, and Russell demonstrated remarkable foresight with this assessment.

3 The impact of Quantum Gravity on Causality

The emergence of Quantum Gravity with its Dynamic Causal Structure [8] directly challenges the traditional separation of cause and effect, removes the spacetime frame of reference and introduces indefinite causal structures with time symmetry [9]. Therefore, the fundamental conceptualization of cause, effect, time, and space has been fundamentally challenged.

Seneca defines the necessary conditions for causality as space and time that provide location and ordering. In general relativity, the necessary conditions have been converged into a single spacetime manifold that serves as a frame of reference to determine location and order. However, Quantum Gravity requires a fundamental set of rules from which spatiotemporal relationships and causal order can emerge. Space and time are not necessary external conditions, but potential emergent properties of the necessary internal structure of reality itself. The problem isn't anymore whether spacetime is static or dynamic, but that spacetime itself may emerge from the quantum level and thus positions itself as a higher-order effect of a generative process.

> Instead of asking "Where and When does this cause operate?", quantum gravity asks "What is the underlying process from which the notions of 'where' and 'when', and thus causal order, emerge?"

Russell saw physics moving towards laws governing states, a view echoed in quantum gravity's search for fundamental rules or principles governing the structure from which spacetime and causal order emerge. At this stage, the understanding of causality evolved from a structure that required the existence of space and time as pre-given conditions for emergent causality. This emergent causality does not rely on a pre-existing spacetime, but is grounded in a more fundamental level of reality—a set of underlying rules or principles (i.e., conceptualized as a 'generating function') that determine the fundamental potential for existence, relation, and the eventual manifestation of spatiotemporal properties.

If this fundamental level (or its 'output' in terms of emergent properties) didn't include states that resemble classical spacetime, then the conditions Seneca deemed necessary for "making things" (definite causal links) wouldn't appear.

From the quantum perspective, 'space and time' that Seneca identified as necessary are not fundamental inputs to causality, but are outputs or emerging properties from a deeper quantum process grounded in this fundamental level.

The conceptualization of this fundamental level as a "generating function" captures the idea of a deeper source from which the necessary condition of classical causality's spatiotemporal structure arises. It's a shift from asking "What causes X given spacetime?" to "What process generates spacetime (and thus enables X to be caused)?".

4 Causality as Effect Propagation Process

Logically, the understanding of causality evolves further towards an effect propagation process. Framing causality as an "effect propagation process" means:

1. Focus on the Transfer of Influence: It emphasizes the process by which a change, information, energy, or correlation at one point (in the fundamental structure) influences or leads to changes at another point. This is less about a discrete "cause A produces effect B" event linked by external space and time, and more about a continuous or discrete transfer through the underlying reality.
2. Detachment from Fixed Spacetime Paths: In quantum gravity, where spacetime geometry (and thus smooth paths) can be in a superposition or non-existent at the fundamental level, "propagation" isn't necessarily movement along a geodesic in a fixed manifold. It's the spreading of influence or correlation through the network, states, or elements defined by the fundamental structure.
3. Alignment with Emergence: When the fundamental structure gives rise to classical spacetime, this fundamental "effect propagation" would manifest as propagation through spacetime (e.g., waves, particles, forces traveling from one spatiotemporal point to another). Classical cause-and-effect becomes the macroscopic limit of this deeper process.
4. Handling Indefinite Causal Structures: In situations where the causal structure itself is indefinite (a superposition of different possible spacetimes or causal orders), "effect propagation" can be understood as the influence propagating through a superposition of possible pathways or relationships dictated by the fundamental structure. The "effect" isn't tied to a single, definite causal link but is a result of the propagation through all possible (weighted) connections.

Russell correctly pointed out that the asymmetric relation between a cause and its effect depends on the presence of a temporal order (i.e., the arrow of time). In the Effect Propagation Process framework, due to the detachment from a fixed spacetime, this fundamental temporal order is absent. Consequently, the entire classical concept of causality, where cause must happen before effect ('A happened before B'), cannot be fundamentally established. The distinction between a definitive 'Cause' and a definitive 'Effect' becomes untenable, just as Russell foresaw regarding the time-symmetry of fundamental laws. Instead of abandoning causality altogether in an indefinitive causal realm, the framework suggests merging the traditional notions of 'cause' and 'effect' into a single, fundamental entity: the effect propagation process itself. This conceptualization, where causality is defined in terms of this uniform influence transfer rather than an asymmetric sequential link, is consistent with operational frameworks in quantum foundations, such as that proposed by Hardy [8], which describe causal structure without presupposing a fixed spacetime background.

In this post-quantum context, the term "propagation" does not imply movement through a pre-existing space or over a defined time interval in the classical sense. Instead, it refers to the fundamental process by which influence, correlation, or causal efficacy is transferred or unfolds within the underlying structure of reality itself. This fundamental process is what gives rise to the appearance of propagation through spacetime in the classical, emergent limit. Furthermore, while classical causality relies on a definite temporal order and the apparent arrow of time (cause preceding effect), within the framework of the 'effect propagation process', this directedness is understood as an emergent property, arising from the fundamental process in the classical limit, rather than being a fundamental feature of the process itself.

While the 'effect propagation process' involves the transfer of influence or correlations within the fundamental structure, it is crucial to distinguish this from mere accidental correlation. The process reflects the fundamental way the underlying structure of reality mandates or constrains dependencies between its components, giving rise to the non-accidental relationships we recognize as causal connections in the emergent, classical world. This fundamental determination, rather than simple co-occurrence, is what the "effect propagation process" captures at the deepest level.

Replacing the notion of causality as requiring a pre-defined stage of space and time with the notion of causality being an effect propagation process then grounds post-quantum causality into a deeper quantum generative process. The notion of post-quantum causality as an effect propagation process remains agnostic of the exact quantum generative process.

Consequently, causality is understood as an effect propagation process that emerges from the fundamental structure or set of rules (akin to a generating function) from which spatiotemporal relationships emerge. Operating within this same fundamental structure, the process dictates how fundamental degrees of freedom relate and evolve.

The notion of the effect propagation process excludes the operational details of any particular physics theory and offers a coherent way of thinking about causality that aligns with the emergent nature of spacetime and the potential indefiniteness of causal order in the quantum realm. In doing so, it provides a unifying perspective for post-quantum causality by acknowledging the philosophical arguments for dynamic/relational reality which is rooted in process philosophy and relationalism.

This philosophical concept of the effect propagation process finds support in various areas of philosophy and physics. For example, the effect propagation process finds support in physical theories that propose fundamental structures underlying spacetime such as Causal Set Theory, and generalizes the idea of influence transfer present in standard physics (i.e., Quantum Field Theory). Lastly, the notion of causality as an effect propagation process offers a philosophical interpretation for mathematical tools that describe non-classical causal behavior, such as Process Matrices and Operational Frameworks like Hardy's Causaloids[8].

4.1 The Teleology of the Effect Propagation Process:

Within the Effect Propagation Process framework, the traditional notion of a fundamental Final Cause or inherent purpose (like Aristotle's teleology, where things strive towards their inherent ends, or Plato's Demiurge acting for the Good in creating the cosmos) is not incorporated as a primary mechanism of causality at the deepest level. Classical teleology sought to explain why things exist or change by reference to their ultimate goals or functions. However, this type of explanation, while potentially useful and observable in complex emergent systems like biological organisms, does not appear to be a driving force in fundamental physics as currently understood or as envisioned by theories exploring the quantum gravitational realm.

The Effect Propagation Process framework focuses instead on describing the fundamental process of influence transfer and the rules of emergence from the underlying structure of reality. This process describes how one state of the fundamental structure relates to and influences subsequent states, leading to the manifestation of phenomena, including spacetime and classical objects. It does not, however, inherently explain why that process occurs or for what ultimate end the universe is unfolding at this fundamental level. Teleological descriptions, if applicable, would likely be viewed as emergent properties of highly organized, complex systems that arise from the fundamental Effect Propagation Process,

or as a distinct layer of explanation relevant to the organization and behavior of macroscopic entities and conscious agents, rather than a fundamental aspect of causality itself woven into the basic fabric of reality. The implications for teleology are thus a strong separation between fundamental causal dynamics (the "how") and questions of ultimate purpose or inherent ends (the "why"), suggesting that teleological explanations are likely emergent or anthropocentric rather than constitutive of the deepest level of causal reality.

4.2 The Ontology of the Effect Propagation Process:

The Effect Propagation Process framework fundamentally reconfigures our understanding of what is real at the deepest level—our ontology. Classical causality, whether Aristotelian, Newtonian, or even relativistic (as interpreted by Seneca), largely operates within an ontology where spacetime is a fundamental background or container, and individual objects and events exist in this spacetime. Causality is then understood as a relationship between these localized objects or events within this pre-given spatiotemporal arena. The being of a thing is intimately tied to its existence at a specific place and time.

The proposed framework shifts this ontology radically. It suggests that fundamental reality is not spacetime itself, but an underlying structure or set of rules (conceptualized as a 'generating function') that is potentially non-spatiotemporal or operates in a realm where spacetime as we know it has not yet fully emerged. This fundamental level is proposed as the truly real, determining the fundamental potential for existence, relation, and the eventual manifestation of spatiotemporal properties. The Effect Propagation Process is then understood not just as a process operating on this fundamental reality, but as the very dynamic essence of this ontology. It represents how influence propagates and how fundamental degrees of freedom relate and evolve within this underlying structure, thereby constituting the process of emergence itself. This implies that the very coming into being of the reality we observe, including spacetime and classical objects, is a consequence of this fundamental process. The implication for ontology is profound: our intuitive sense of "being" or "existing" (classically rooted in existence at a location in time) must be reconceived in terms of participation in or emergence from this fundamental, dynamic, and potentially non-spatiotemporal process of effect propagation. Reality is fundamentally relational and processual, with spacetime being a higher-level emergent phenomenon.

4.3 The Epistemology of the Effect Propagation Process:

The Effect Propagation Process framework is fundamentally an epistemological proposal, offering a new way to conceptually grasp and organize our understanding of causality in the post-quantum era. Classical epistemology of causality, influenced by thinkers like Hume and Kant, is largely concerned with how we gain knowledge about cause-effect relationships observed within the framework of space and time. Hume focused on the empirical observation of constant conjunctions and temporal priority, suggesting our belief in causality is based on habit. Kant argued that causality is a necessary cognitive category we apply to our sensory input to structure coherent experience in space and time. In both cases, knowledge of causality is tied to our interaction with and structuring of phenomena within a presupposed spatiotemporal order.

The challenges posed by quantum gravity, where spacetime may be emergent and causal order indefinite, break down these classical epistemological assumptions. If the fundamental level of reality is not spacetime, how do we gain reliable knowledge about its causal structure? Our classical methods, relying on observing event sequences in a fixed background, are insufficient. The Effect Propagation Process framework provides a new conceptual lens for this post-classical epistemology. It suggests that knowledge about fundamental causality is about understanding the rules and dynamics of the underlying structure from which spacetime and classical causal order emerge. This involves re-framing the key questions of causal inquiry, shifting from asking where and when causes operate to probing the nature of the fundamental process from which spatiotemporal and causal notions arise. Epistemologically, this means developing new theoretical and potentially experimental approaches (like analyzing correlations in quantum systems or studying the mathematical structure of proposed quantum gravity models) to infer the properties of this underlying reality and how the fundamental process of influence transfer unfolds. The framework provides the philosophical grounding for interpreting what kind of knowledge is possible and meaningful in a potentially spacetime-independent reality, guiding the search for understanding in a regime that defies classical intuition.

5 Conclusion

The journey to understand causality reveals a profound evolution in philosophical and scientific thought. From ancient philosophical inquiries like Aristotle's identification of necessary factors for change and existence, to Seneca's crucial insight that causality operates within a spatiotemporal context, the classical view established spacetime as a fundamental prerequisite. This notion, however, faced philosophical debate from relationalists like Leibniz and later scientific critiques from Bertrand Russell, who questioned its status in physics by highlighting reliance on laws over discrete cause-effect events. Even General Relativity, while fundamentally transforming spacetime into a dynamic entity, maintained its requirement as the arena for causal processes. Yet, the advent of quantum gravity, suggesting spacetime may be emergent from a deeper reality and causal structures can be indefinite, poses the most profound challenge yet, fundamentally dismantling this traditional backdrop against which causality has been understood for millennia.

In response to this profound challenge, this paper has proposed the "Effect Propagation Process" as a philosophical framework for post-quantum causality. This framework fundamentally reconceives causality not as discrete relationships between events situated within a fixed spacetime, but as the fundamental, continuous transfer of influence originating from and operating within a deeper, potentially non-spatiotemporal, underlying structure of reality. We have detailed how this process navigates the challenges of detachment from fixed spacetime paths, aligns with the concept of emergence, and accommodates the description of indefinite causal structures, with the arrow of time and classical cause-effect sequences understood as emergent macroscopic phenomena.

This conceptual shift offers a unified perspective for post-quantum causality that aligns with intuitions drawn from various approaches in modern physics and quantum information, including Causal Set Theory's fundamental causal order, the generalized influence transfer seen in Quantum Field Theory, and the mathematical descriptions of non-classical causal behavior found in Process Matrices and operational frameworks like Hardy's Causaloids. Critically, the "Effect Propagation Process" remains compatible with classical causality, viewing it as a specific, emergent manifestation of the more fundamental process in the limit where spacetime and definite causal order become good approximations.

Furthermore, this reframing carries significant implications for fundamental philosophical questions. It reshapes our ontology, suggesting that the most fundamental reality is not spacetime but the underlying dynamic structure and the process of effect propagation itself, from which being and phenomena emerge. It redefines the scope and methods of epistemology, shifting the focus of causal knowledge from observing event sequences in spacetime to inferring the rules and dynamics of this deeper process. While leaving traditional teleology as likely an emergent property of complex systems rather than a fundamental causal principle, the framework provides a robust conceptual grounding for exploring the nature of causal influence in a universe that may fundamentally defy classical intuition.

Ultimately, by providing a coherent philosophical language for causality detached from the necessity of a pre-given spacetime, the Effect Propagation Process framework serves as a valuable tool for thought. It not only addresses a critical conceptual gap exposed by quantum gravity but also offers a flexible perspective potentially applicable to understanding complex systems beyond fundamental physics, such as in the analysis of networks, social phenomena, or artificial intelligence, where classical spatiotemporal notions of cause and effect are often inadequate. As we continue to probe the nature of emergent reality, frameworks like the Effect Propagation Process will be relevant for building intelligent systems that can reason effectively in the diverse and often non-classical geometries of complex real-world problems.

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[1] `https://deepcausality.com`

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