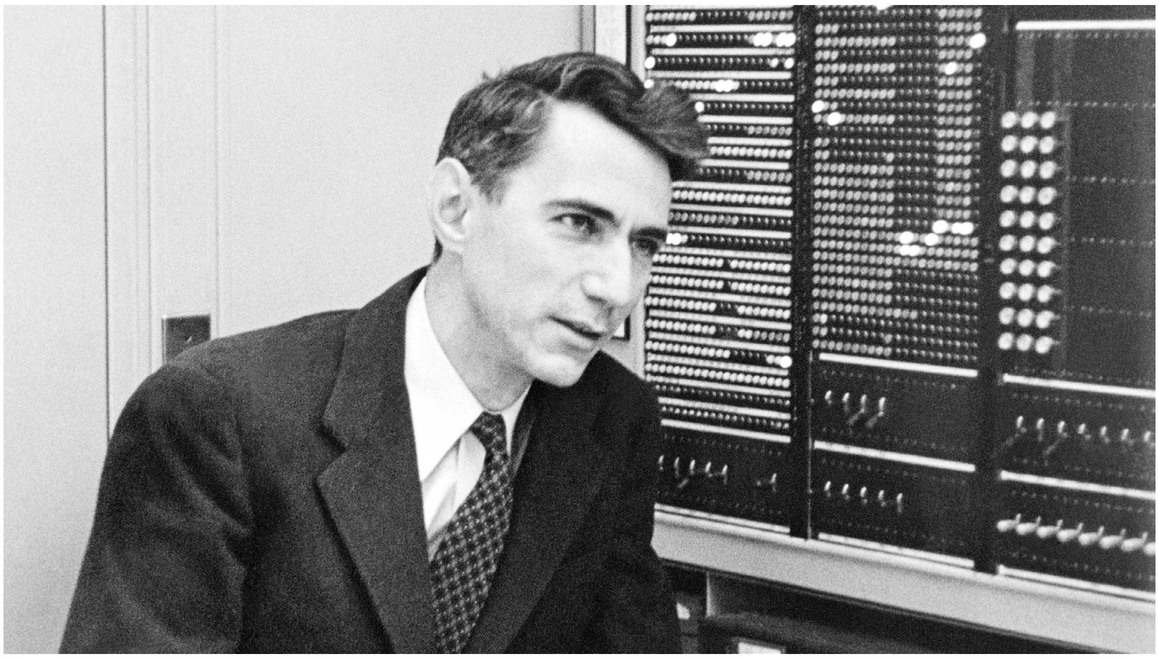
The Epistemological Circularity of the “No Information Transfer” Defense: How Shannon Came to the Rescue of Special Relativity

Joseph Wayne Smith and N. Stocks



Claude Shannon 1916-2001 (Tse, 2020)

1. Introduction

The standard defense against quantum mechanics’ apparent violation of special relativity—that entanglement involves “no information transfer”—relies on a derivative mathematical framework (Shannon, 1948) to resolve conflicts between foundational physical theories (Einstein, 1905; Einstein et al., 1935). In this essay, we argue that such appeals constitute epistemological circularity: information theory, as a later engineering construct built atop quantum and relativistic physics, cannot legitimately adjudicate conflicts between its theoretical foundations. The “no information transfer” response reveals not coherence but conceptual confusion, representing defensive theorizing rather than a genuine resolution of the tension between quantum nonlocality and relativistic causality.

2. The Problem of Quantum Nonlocality

Quantum entanglement presents a profound challenge to the causal structure of special relativity. When two particles are prepared in an entangled state and subsequently separated, measurement of one particle's quantum state instantaneously determines the state of the other, regardless of the spatial distance between them (Einstein, et al., 1935; Bell, 1964; Aspect et al., 1982). This correlation appears to violate the relativistic prohibition against faster-than-light causal influence, suggesting a fundamental incompatibility between quantum mechanics and special relativity.

The standard response to this tension has become nearly canonical: while quantum correlations manifest instantaneously, they involve “no information transfer,” and therefore special relativity's prohibition on superluminal signaling remains intact (Peres and Terno, 2004; Gisin, 2014). Because no usable signal can be transmitted via entanglement—the correlations only become apparent through classical communication and comparison of results—defenders argue that no genuine violation of relativistic causality occurs.

In this essay, we contend that this defense commits a fundamental epistemological error: it invokes Shannon information theory (Shannon, 1948)—a mathematical framework developed decades after both special relativity and quantum mechanics, and built conceptually upon them—to resolve apparent contradictions between these foundational theories. This entails explanatory circularity: using a derivative framework to legitimize its own foundations. The argument reveals not theoretical coherence, but conceptual confusion about the proper ordering of physical explanation.

3. The Historical and Conceptual Priority Problem

Special relativity was formulated in 1905 (Einstein, 1905), quantum mechanics crystallized in the 1920s through the work of Heisenberg, Schrödinger, Born, and others (Heisenberg, 1925; Schrödinger, 1926), while Shannon information theory emerged only in 1948 as a mathematical framework for communication engineering (Shannon, 1948). The temporal sequence is clear: information theory is historically posterior to both theories whose conflict it is invoked to resolve.

More critically, information theory is conceptually derivative. Shannon's framework presupposes the physical substrate within which communication occurs—a substrate described by quantum mechanics and special relativity. Information theory does not provide an independent physical account of nature, but rather a mathematical abstraction over physical processes already governed by quantum and relativistic principles. As Timpson correctly notes, information-theoretic concepts in quantum mechanics often function as interpretative overlays rather than fundamental physical explanations (Timpson, 2013).

The proper direction of explanation runs from fundamental physical theory to derivative mathematical frameworks, not the reverse. When defending special relativity against apparent quantum violations by appeal to information theory, we reverse this explanatory order. We use a construct that assumes both theories' validity to adjudicate their apparent conflict—a logically circular maneuver.

4. What Does "Information" Mean in This Context?

The defense that entanglement involves "no information transfer" requires specifying what "information" means. In Shannon's original formulation, information is defined operationally through communication channels: it quantifies reduction in uncertainty about a message source, given channel transmission (Shannon, 1948). This framework assumes a classical communication scenario with sender, channel, receiver, and measurable signal transmission.

However, quantum entanglement does not fit neatly into this framework. The correlations between entangled particles are not transmitted through any identifiable channel, involve no sender encoding a message, and manifest independently obtained measurement results only through statistical comparison. To claim that "no information transfer" occurs is thus to apply a framework designed for classical communication to a phenomenon that violates the classical assumptions on which that framework rests.

Moreover, the criterion for "information" becomes suspiciously tailored: we define "information" such that entanglement doesn't transfer it, then conclude that special relativity isn't violated because no "information" travels superluminally. This is patently question-begging. We construct the definition to preserve the desired conclusion, then present the conclusion as vindication of the theories in question.

Bub and Timpson have examined the role of information-theoretic concepts in quantum foundations, noting that "information" often functions more as interpretive gloss than as rigorous physical explanation (Bub, 2007; Timpson, 2013). When information-theoretic language is invoked to dissolve apparent contradictions, we should scrutinize whether genuine physical insight is being provided or whether conceptual problems are merely being obscured through redefinition.

5. The Physical Mystery Remains

Even granting that no usable signal can be transmitted via entanglement, a profound physical mystery persists: how do spatially separated measurements produce perfectly correlated results instantaneously? The correlations are real, experimentally verified, and violate Bell inequalities in ways that exclude local hidden variable explanations (Bell, 1964; Aspect et al., 1982; Hensen et al., 2015). Something genuinely nonlocal occurs.

The "no information transfer" defense addresses only whether the nonlocality can be exploited for signaling, not whether nonlocality itself conflicts with relativistic causal structure. Special relativity theory's foundational claim is not merely that signals cannot propagate faster than light, but that causal influence respects the light cone structure of spacetime. If measurement outcomes at spacelike separation are instantaneously correlated in ways that cannot be explained by local causes, this violates at the very least the spirit, if not the letter, of relativistic causality (Maudlin, 2011).

Declaring that "no information transfers" does not resolve this tension; it merely redefines the problem out of existence by stipulating that only signaling-capable nonlocality counts as genuine violation. This is defensive conceptual maneuvering rather than explanatory progress. The physical correlation exists, manifests instantaneously across arbitrary distances, and defies classical causal explanation—yet we are told there is no problem because the correlation cannot be used to send messages.

6. Circularity in Theoretical Justification

The fundamental circularity can be stated precisely: Shannon information theory presupposes the validity of quantum mechanics and special relativity as background physical theories. When apparent conflicts arise between quantum mechanics and special relativity, appealing to information theory amounts to using a framework that assumes both theories' validity to prove their mutual consistency. *This is circular reasoning*.

Consider the logical structure:

(1) Quantum mechanics and special relativity appear to conflict (entanglement seems nonlocal).

(2) Information theory, built upon quantum mechanics and special relativity, defines “information” in a way that excludes entanglement correlations.

(3) Therefore, no “information” transfers superluminally.

(4) Therefore, special relativity theory is not violated.

The problem lies in step (2): we cannot legitimately use information theory—which presupposes both quantum mechanics and special relativity—to resolve their apparent inconsistency. The framework whose coherence is in question cannot provide the criteria for its own vindication.

7. Implications for Philosophy of Physics

This circularity reveals a broader pattern in contemporary physics: when foundational theories encounter apparent contradictions, the response increasingly involves redefining terms, introducing auxiliary concepts, or appealing to derivative frameworks rather than confronting the conflict directly. The "no information transfer" defense exemplifies this pattern.

Maudlin has forcefully argued that quantum nonlocality represents genuine tension with relativistic locality, not merely an interpretive puzzle (Maudlin, 2011, 2014). The persistence of debates about quantum foundations and the proliferation of competing interpretations—each attempting to reconcile quantum mechanics with intuitions about locality and causality—suggests that the “no information transfer” response has not actually resolved the underlying conceptual problems.

From a Lakatosian perspective, the information-theoretic defense represents a protective belt of auxiliary hypotheses shielding the theoretical core from apparent falsification (Lakatos, 1978). Rather than revising quantum mechanics or special relativity theory in light of their apparent incompatibility, we introduce an additional conceptual layer that redefines the terms of conflict. This is characteristic of "degenerating research programmes": theoretical additions that accommodate anomalies post hoc rather than generating novel testable predictions.

The correct scientific response to apparent contradictions between foundational theories should be either: (i) demonstrate that the contradiction is illusory through derivation from more basic principles, or (ii) acknowledge genuine inconsistency and pursue theoretical revision. Appealing to derivative frameworks built upon the very theories in question achieves neither option. It obscures the problem rather than resolving it.

8. Conclusion

The "no information transfer" defense against quantum mechanics' apparent violation of special relativity commits epistemological circularity by invoking Shannon information theory—a framework conceptually posterior to and dependent upon both quantum mechanics and special relativity—to adjudicate their compatibility. Information theory cannot legitimately resolve conflicts between its own theoretical foundations.

This defense reveals not theoretical coherence but conceptual confusion about the proper ordering of physical explanation. Fundamental physical theories should be justified through more basic principles or empirical adequacy, not through appeal to derivative mathematical frameworks that presuppose their validity. When such appeals occur, they function as defensive theoretical maneuvering rather than genuine explanation.

The persistence of quantum nonlocality as a conceptual problem—despite decades of information-theoretic reframing—suggests that the underlying tension between quantum mechanics and special relativity remains unresolved. Genuine resolution would require either demonstrating their consistency through deeper physical principles or acknowledging fundamental revision of one or both theories. Appeals to information theory achieve neither, serving instead to postpone confronting the actual physical and conceptual difficulties.

The broader lesson extends beyond this specific case: when derivative frameworks are invoked to resolve apparent contradictions between foundational theories, we should scrutinize whether genuine physical insight is being provided or whether conceptual problems are merely being obscured through redefinition. Upon critical examination, the "no information transfer" defense exemplifies the latter.

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