Proceeding Paper
About the Nature of Quantum Information †

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Abstract: Although the interpretation of the concept of information is not clear, even in the classical framework, new interpretive problems have arisen with the advent of the so-called quantum information, which combine the difficulties in understanding the concept of information with the well-known foundational puzzles derived from quantum mechanics itself. The aim of this paper is to consider some arguments traditionally put forward to support the idea that quantum information is qualitatively different from classical information. The final conclusion is that there are no reasons to admit the existence of quantum information as qualitatively different from classical information: there is only one kind of information, physically neutral, which can be encoded by means of classical or quantum states.

Keywords: Shannon information; quantum information; information source; coding theorems; Shannon entropy; von Neumann entropy; transposition of signals; communications of messages; fidelity of transposition; effectiveness of communication

1. Introduction

The word 'information' refers to a concept associated with very different phenomena [1]. So, the first distinction to be introduced is that between a *semantic view*, according to which information carries semantic content and, thus, is related to notions as reference and meaning [2], and a *statistical view*, concerned with the statistical properties of a system and/or the correlations between the states of two systems. In turn, within the domain of statistical information, at least two different contexts can be distinguished. In the traditional *communicational context*, whose classical *locus* is Claude Shannon's formalism [3,4], information is primarily something that has to be transmitted for communication purposes. In the *computational context*, by contrast, information is something that has to be computed and stored in an efficient way [5–7]. In this work, I will deal exclusively with the concept of information within the communicational context, in which the problems of interpretation do not disappear, not even if attention is restricted to a single formal concept [8].

During the last few decades, new interpretive problems have arisen with the advent of so-called quantum information; these problems combine the difficulties in the understanding of the concept of information with the well-known foundational puzzles derived from quantum mechanics itself. Although there were many works on the matter before Benjamin Schumacher's article 'Quantum Coding' [9], this is usually considered the first precise formalization of the quantum information theory. In this context, the question 'What is quantum information?' is still far from having an answer that the whole quantum information community agrees with. In fact, the positions about the matter range from those who seem to deny the existence of quantum information [10], those who consider that it refers to information when it is encoded in quantum systems [11,12], and those who conceive it as a new kind of information absolutely different from classical information [13,14].

The aim of this paper is to consider some arguments traditionally put forward to support the idea that quantum information is qualitatively different from classical information.

2. Arguments and Counterarguments

Different arguments have been appealed to in order to explain the difference between classical information and quantum information. In this section, I will consider each one of them and will argue that they are not sufficiently strong.

2.1. Information and Its Sources

Information has been characterized as classical or quantum depending on the kind of source that generates it: classical/quantum information is what is produced by a classical/quantum information source [15,16].

However, when Schumacher's article is carefully read, one can see that this is not the case: the article defines the *message source A* that produces messages as a_M, and only in the stage of coding is the *quantum signal source* is introduced, which '*codes each message a_M from the source A into a signal state $|a_M\rangle$ of a quantum system M*.' [9] (p. 2738). In other words, there is no quantum source of quantum information that produces quantum states as messages: the quantum system *M* is part of the transmitter; the quantum state is not a message but a signal encoding the message (see [17]). This remark is in agreement with the very title of Schumacher's article: 'Quantum Coding' and not 'Quantum Information'.

2.2. Quantum Sources?

Somebody might insist: 'What prevents us from considering *M* a quantum source and defining quantum information as what is generated by a quantum source?'

Of course, definitions are conventional. Nevertheless, in this case, nothing would change in the discourse about quantum information if one replaced the term 'quantum information' with the term 'quantum state'. As Duwell [10] points out, the concept of quantum information would collapse with that of the quantum state.

2.3. Information and Coding Theorems

Another strategy is to link the very meaning of 'information' with the coding theorems: if Shannon's noiseless coding theorem and Schumacher's noiseless coding theorem are different, then the corresponding concepts of information are also different (see [15]).

However, since the coding theorems are proved for the case of very long messages (strictly speaking, for messages of length $N \to \infty$), they say nothing about the occurrence of a single state at the source and the resources needed to encode it. As a consequence, information would not be defined for single messages (see [17]). Moreover, it would not be possible to talk about information in situations that do not involve coding, as in traditional telephony, where the transmitter operates as a mere transducer. Furthermore, a source would generate different kinds of information with no change in its own nature, depending not on itself but on the fact of how messages will be encoded later. In other words, if the kind of coding to be used at the coding stage was not decided yet, the very nature—classical or quantum—of the information generated by the source would remain undetermined.

2.4. Shannon Entropy and von Neumann Entropy

It is usually supposed that just as the Shannon entropy $H(A)$ measures the classical information produced by a classical source, the von Neumann entropy $S(\rho)$ measures the quantum information produced by a quantum source.

However, since, as argued above, there are not quantum sources of information but sources of quantum signals (see [9]); the von Neumann entropy $S(\rho)$ is not a measure of the information produced by a source of information. What the von Neumann entropy measures are the optimal quantum resources needed to encode the information, that is, the number of quantum systems required, on average, to encode the messages produced at the source of information.

2.5. Information and Physical Carriers

It has also been argued that the difference between classical and quantum information relies on the fact that classical information requires a physical carrier that travels through space and needs a finite amount of time to travel, whereas, as the case of teleportation shows, quantum information does not need a physical carrier (see the discussion in [18]).

This view conflates the *transposition of signals* between the transmitter (the coding stage, which turns the message into a signal) and the receiver (the decoding stage, which turns the signal into a message) with *the communication of messages* between the source and the destination of the messages. This amounts to confusing the *fidelity* of signal transposition between the transmitter and receiver with the *effectiveness* of message communication between the source and destination (see [9]). In other words, teleportation is not a communication process; '*"quantum teleportation" is a rather exotic example of a transposition process*' [9] (p. 2741). As a consequence, the correct claim is that when information is encoded by quantum states, signals do not need a physical carrier to be transmitted.

2.6. Shannon Theory in Quantum Contexts

Brukner and Zeilinger [14] claim that Shannon's theory cannot be applied to quantum contexts since it assumes a classical notion of measurement, according to which measurement actually discovers pre-existing values of the system's properties.

In contrast to the authors' opinion, there is nothing in Shannon's theory that requires actual sequences of states in the source of information in order to define its entropy (see [19]). In fact, $H(A)$ only depends on the statistical features of the source and not on the nature of its states: '*the Shannon theory can be applied to any communication system regardless whether its parts are best described by classical mechanics, classical electrodynamics, quantum theory, or any other physical theory.*' [10] (p. 480).

3. Conclusions

On the basis of these arguments, we conclude that there are no reasons to admit the existence of quantum information as qualitatively different from classical information: there is only one kind of information, physically neutral, which can be encoded by means of classical or quantum states.

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