Quantum Information Theory and the Foundations of Quantum Mechanics

CHRISTOPHER G. TIMPSON Oxford, Oxford University Press, 2013 xiv + 293 pp., ISBN 9780199296460, £45.00, US$85.00 (hardback)

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Information is on everyone's lips. It seems that nowadays there is no philosophical or scientific inquiry that cannot benefit from a reformulation in terms of information theory (IT). Quantum theory (QT) is no exception. Indeed, one of the liveliest debates in the foundations of QT concerns the role that information may play in the solution of the well-known problems in the foundations of QT.

For instance, one of the hottest discussions concerns quantum non-locality. On the one hand, IT folks stress how, rather than approaching non-local entanglement as an 'embarrassment', IT invites us to see it as a resource for new information-processing protocols. On the other hand, it is unclear how this invitation can contribute to the solution of the problem of accounting for the apparent non-locality involved in quantum correlations.

Christopher G. Timpson's beautiful book is a welcome contribution to this dialectic. It provides an admirable mix of conceptual and technical analysis of the notion of information and critically analyses the most prominent proposals on the table in the debate over the role of IT in the foundations of QT.

Although the focus of Timpson's book is quantum information theory (QIT) and the foundations of QT, a considerable component of its basic precepts will be found extremely useful in any branch (be it more philosophical or more scientific) of applied IT. It is because of this additional value that in this review, sometimes to detriment of exhaustiveness, I prefer to concentrate on providing some samples of Timpson's main argumentative line. This should give a better idea of how this volume can represent valuable reading for both specialists in QIT and non-specialists.

First things first. In chapter 2, Timpson provides a sharp analysis of the concepts of information. The plural is due to the necessary distinction between information in the everyday sense and information in the technical sense (informationt). Both are abstract mass nouns, but while the former refers to a semantic and epistemic notion, informationt is a physically defined quantity, measured classically by Shannon information.

Informationt is usually described as an undefined notion. Contrary to this claim, at the roots of Timpson's analysis is a neat definition: 'Informationt is what is produced by an informationt source that is required to be reproducible at the destination if the transmission is to be counted a success' (22). Although avowedly deflationary, this definition provides a fertile background to dissipate much of the fog around the nature of informationt and its behaviour. It actually turns out that the majority of the results of this book pivots on this very simple definition.

Here is a straightforward example. According to the definition above, a successful transmission requires that the message be reproducible at destination. However, what it is said to be repeatable is not the token of a message, but the type. When we talk about something that is transmitted in communication protocols (the so-called pieces of information) we refer to types, i.e. abstracta, rather than to concrete objects.

The operation of conceptual cleansing continues when we pass from classical to quantum informationt (chapter 3). An especially noteworthy result is the rejection of the common view that quantum informationt is different in nature from classical informationt. Timpson's methodology allows instead to account for it as an extension of Shannon informationt. In fact, with the template of classical informationt at hand, Timpson reconstructs the notions of quantum informationt source, measure of quantum informationt and piece of quantum informationt, the latter being a sequence of Hilbert space states.

Chapters 2 and 3 are probably the most challenging parts of the book; however, they also constitute the part with the widest scope and that provides the reader with the basic do's and don'ts of informationt. I strongly recommend at least these two chapters to anyone who would like to use the notion of information as an analytical tool for the investigation of philosophical or scientific issues. The extensive treatment of non-locality that follows is instead more interesting to specialists of QT or QIT. Timpson provides a thorough analysis of teleportation, one of the traditionally most perplexing case studies in QIT (chapter 4). Teleportation is an entanglement-assisted communication protocol, where the explanation of the behaviour of quantum informationt has originated the most bizarre accounts. Roger Penrose, for instance, has argued that the protocol implies that quantum informationt travels backwards in time. Timpson's rejection of such accounts is almost disappointing in its simplicity. First of all, we must reflect on the abstract nature of pieces of informationt and on the fact that nothing concrete is actually transmitted in teleportation. Secondly, we must reflect on their technical features. Some abstract quantities, like energy, can be said to be properties of concrete objects with spatiotemporal location and in this sense can be said to flow around. The same cannot be said of informationt, which, for one thing, does not even obey a local conservation equation! Of course, it still remains to see what the processes underlying this protocol are, but this is a problem concerning the interpretation of QT: as a problem of transmission of informationt, the puzzle of teleportation is explained away.

In the next chapter, the critical analysis of the Deutsch–Hayden approach to non-locality further clarifies how QIT can contribute (spoiler alert: not much) to the explanation of non-local quantum correlations.

A main *leitmotiv* of the book is the scrutiny of the infamous slogan, 'information is physical', often regarded as the big discovery of QIT. One of the most influential interpretations of the claim is the view that Timpson calls 'information immaterialism' (section 3.7.1), an example of which is John A. Wheeler's 'it from bit'. Timpson argues that behind this view there is again a conflation between the epistemic sense of information and informationt. In any case, he concludes, this view is not supported by QIT.

The slogan 'information is physical' could also be interpreted against the background of quantum computation. In this context, this assertion might amount to claiming that the Church–Turing thesis is grounded on a physical principle or that it should be considered a constraint on physical laws. Timpson rejects both these options.

If only for the huge influence of this slogan over wide debates in philosophy of science and metaphysics, this thread of discussion makes this book worth reading.

Chapter 7 is titled 'Information and the Foundations of Quantum Mechanics: Preliminaries'. A weird title, given that a good part of the previous discussions was already about the foundations of QT. Anyway, this chapter significantly lowers the expectations of those hoping that it is sufficient to interpret the quantum state as information or knowledge, in order to solve the issues of QT. Part of Timpson's answer to this hope brushes up on John S. Bell's question, 'Information about what?'. If the answer is 'information about the result of experiments', then you get good old instrumentalism with fancy clothes. If the answer is 'information about how things are prior the measurement', you get hidden variables. In any case, according to Timpson the proposal does not contribute anything genuinely new in the foundations of QT.

Chapter 8 focuses on more ponderous strategies, which use IT to formulate an axiomatic reconstruction of QT, especially Anton Zeilinger's foundational principle and Robert Clifton, Jeffrey Bub, and Hans Halvorson's reconstruction of QT in terms of three information-theoretic principles. Although according to Timpson both reconstructions fail in their aim, this chapter concretely shows how IT can actually be useful to shed some light on key time-honoured questions in the foundations of QT of the kind: how does the quantum world differ from the classical one?

In chapter 9, Timpson defends quantum Bayesianism against three objections: solipsism, instrumentalism, and inadequacy in dealing with Wigner's friend scenarios. In chapter 10, he presents three more difficult new challenges. First, it is not clear what kind of ontology may underpin quantum Bayesianism; second, it seems that this interpretation deprives QT of much of its explanatory power; and third, it is not clear whether subjective probabilities are adequate within QT. I realize that, after reading this review, one could emerge with the impression that this is a depressing book, where virtually every considered proposal about QIT and the foundations of QT is found wrong or misleading (though with the exception of Bell's!). If I gave this impression, then I am genuinely sorry, because this is far from correct: in a context of general enthusiasm towards IT, Chris Timpson is not a killjoy. On the contrary, it is genuinely amazing to find out how graceful an essay can be, throughout 235 pages (appendix excluded) of '...and this is also wrong because . . . '. Most importantly, this volume is an exciting example of how good philosophy can be the antidote to the dangers of a general trend, where technology without Knowledge (capital K) is occupying all the spaces of scientific research.

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