

Structure and Interpretation of Quantum Mechanics — a Functional Framework

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ABSTRACT

We present a framework for representing quantum entities in Haskell. States and operators are functional objects, and their semantics is defined — as far as possible — independently of the base in the Hilbert space. We construct effectively the tensor states for composed systems, and we present a toy model of quantum circuit tool-box. We conclude that functional languages are *right tools* for formal computations in quantum physics. The paper focuses mainly on the representation, not on computational problems.

Categories and Subject Descriptors

D.1.1 [Programming techniques]: Functional Programming

General Terms

Theory

Keywords

Haskell, Quantum physics, Vector spaces, Dual bases, Operators, Tensor products, Quantum gates, Multi-parametric classes.

1. INTRODUCTION TO QUANTIZATION

1.1 How to model quantum objects?

Computer scientists became interested in quantum computing mainly because of the possibility to accelerate the solution of algorithmically hard problems, see e.g. [1, 2, 3], also [4] and many others. But — as Feynman [5] remarked in 1982, — perhaps the most promising direction of evolution of programmable quantum systems is not the “algorithmics”, but the simulation of *other* quantum structures. This is also advocated by Preskill [6], and worked upon by others [7, 8, 9, 10].

It is thus legitimate to ask how to represent properties of general quantum structures in a computer. As noted in [11], and elsewhere, we need a thorough abstraction layer upon physical details, in order to work on circuits and algorithms. There are attempts to introduce specific programming structures for the design of typical (imperative) languages [13, 14], making it easier to code the

transformations acting upon the quantum registers. Bird and Mu [11] discovered the applicability of functional languages for writing such codes in a particularly compact and elegant way, and propose to use functional compositions and monadic chains to deal gracefully with the (nondeterministic) measures. Asse Sahry [12] goes further, and develops in Haskell a more complete functional framework for the simulation of quantum processing units and the observation of results. He also points out some difficulties arising from the application of typical programming languages to a non-classical domain. For a review of other attempts to simulate quantum structures, mainly collections of qubits manipulated imperatively see [15].

Typical representations of quantum entities are algebraic, in the classical sense. A quantum state is a vector belonging to a space, whose dimension is the number of discernible measurement results, e.g., a qubit which classically can be “up” or “down” can be represented as a linear superposition of $(\begin{smallmatrix} 1 \\ 0 \end{smallmatrix})$ and $(\begin{smallmatrix} 0 \\ 1 \end{smallmatrix})$. A multi-qubit is a Kronecker (tensorial) product of such matrices and needs composed data structures. For a harmonic oscillator it is known that a measurement can yield its excitation level — an integer between 0 and ∞ . Here we see that lazy data structures might be useful. For the analysis of quantum algorithms qubits usually suffice, but some papers, e.g. [16], show that in order to assemble a physical multi-bit quantum gate, it is useful to couple the elements with quantum oscillators, objects beyond the qubit layer. In 1996 E. Knill observed [17] that a future quantum computer will certainly be a hybrid, with a classical part actively engaged in *preparing and interfacing* the quantum part (hardly a surprise for physicists performing experiments on quantum systems, but needing screwdrivers as well...). These meta-operations will transcend the elementary qubit abstraction layer.

Thus, our ambition is to propose a *general*, not restricted to qubits, implementable, functional abstraction layer for quantum entities, which would be effective even in the (observable sectors of an) infinite-dimensional Hilbert space, and which would correspond formally and intuitively to the formalism used in classical texts devoted to quantum physics, e.g., [18, 19]. Quantum states will be *functions*, and we shall use Haskell to code them. The title of the paper has been inspired by the book [20], whose authors underline the methodological usefulness of generic, functional structures for the computational representation of physical entities.¹

Our framework achieves the following.

- We have a unified programming paradigm for different quantum systems.

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¹But the similarity to the title of the book of R.E.G. Hughes, *Structure and Interpretation of Quantum Mechanics*, Harvard University Press, is a pure coincidence. This book might be quite interesting for philosophical-oriented readers.

Structure And Interpretation Of Quantum Mechanics

Lars-Göran Johansson



Structure And Interpretation Of Quantum Mechanics:

The Structure and Interpretation of Quantum Mechanics R. I. G. Hughes, 1989 *The Structure and Interpretation of Quantum Mechanics* R. I. G. Hughes, 1989 R I G Hughes offers the first detailed and accessible analysis of the Hilbert space models used in quantum theory and explains why they are so successful He goes on to show how the very suitability of Hilbert spaces for modeling the quantum world gives rise to deep problems of interpretation and makes suggestions about how they can be overcome

Interpreting Quantum Mechanics Lars-Göran Johansson, 2016-12-05 Presenting a realistic interpretation of quantum mechanics and in particular a realistic view of quantum waves this book defends with one exception Schrodinger's views on quantum mechanics Johansson goes on to defend the view that the collapse of a wave function during a measurement is a real physical collapse of a wave and argues that the collapse is a consequence of quantisation of interaction Lastly Johansson argues for a revised principle of individuation in the quantum domain and that this principle enables a sort of explanation of non local phenomena

Understanding Quantum Raffles Michael Janas, Michael E. Cuffaro, Michel Janssen, 2021-12-03 This book offers a thorough technical elaboration and philosophical defense of an objectivist informational interpretation of quantum mechanics according to which its novel content is located in its kinematical framework that is in how the theory describes systems independently of the specifics of their dynamics It will be of interest to researchers and students in the philosophy of physics and in theoretical physics with an interest in the foundations of quantum mechanics Additionally parts of the book may be used as the basis for courses introducing non physics majors to quantum mechanics or for self study by those outside of the university with an interest in quantum mechanics With a Foreword by Jeffrey Bub *Understanding Quantum Raffles* is a wonderful book for both the specialists and those with curious minds The elegance and the simplicity with which the three Mikes explain some of the deepest aspects of quantum mechanics on the basis of probabilities and correlations are dazzling and delightful The same elegance and simplicity also make the book ideal for any engaged reader who ever wondered what is so special about quantum mechanics In our age of new quantum technologies this is something anyone should read Guido Bacciagaluppi author of *Quantum Theory at the Crossroads* This book makes a sustained argument for an informational interpretation of quantum theory blending an elegant mathematical characterisation of quantum correlations with incisive historical and philosophical analysis A must read for those interested in quantum foundations and also a fertile source of teaching inspiration for quantum theory Leah Henderson Department of Theoretical Philosophy University of Groningen This is one of the most fascinating and accessible presentations of the informational approach to quantum mechanics What has so far been mostly restricted to the theoretical physics community is here masterfully explained for a broader audience even without a physics background Scholars students and laypeople alike will appreciate the clear vivid and yet deep discussion of what raffle tickets and correlation ellipsoes can tell us about the physics and philosophy of the quantum world Markus Müller Institute for Quantum

Optics and Quantum Information Vienna *The Blackwell Guide to the Philosophy of Science* Peter Machamer, Michael Silberstein, 2008-04-15 This volume presents a definitive introduction to the core areas of philosophy of science **Samson Abramsky on Logic and Structure in Computer Science and Beyond** Alessandra Palmigiano, Mehrnoosh Sadrzadeh, 2023-08-01 Samson Abramsky's wide ranging contributions to logical and structural aspects of Computer Science have had a major influence on the field This book is a rich collection of papers inspired by and extending Abramsky's work It contains both survey material and new results organised around six major themes domains and duality game semantics contextuality and quantum computation comonads and descriptive complexity categorical and logical semantics and probabilistic computation These relate to different stages and aspects of Abramsky's work reflecting its exceptionally broad scope and his ability to illuminate and unify diverse topics Chapters in the volume include a review of his entire body of work spanning from philosophical aspects to logic programming language theory quantum theory economics and psychology and relating it to a theory of unification of sciences using dual adjunctions The section on game semantics shows how Abramsky's work has led to a powerful new paradigm for the semantics of computation The work on contextuality and categorical quantum mechanics has been highly influential and provides the foundation for increasingly widely used methods in quantum computing The work on comonads and descriptive complexity is building bridges between currently disjoint research areas in computer science relating Structure to Power The volume also includes a scientific autobiography and an overview of the contributions The outstanding set of contributors to this volume including both senior and early career academics serve as testament to Samson Abramsky's enduring influence It will provide an invaluable and unique resource for both students and established researchers Brazilian Studies in Philosophy and History of Science Décio Krause, Antonio Videira, 2011-01-27 This volume The Brazilian Studies in the Philosophy and History of Science is the first attempt to present to a general audience works from Brazil on this subject The included papers are original covering a remarkable number of relevant topics of philosophy of science logic and on the history of science The Brazilian community has increased in the last years in quantity and in quality of the works most of them being published in respectable international journals on the subject The chapters of this volume are forwarded by a general introduction which aims to sketch not only the contents of the chapters but it is conceived as a historical and conceptual guide to the development of the field in Brazil The introduction intends to be useful to the reader and not only to the specialist helping them to evaluate the increase in production of this country within the international context **Probing The Meaning Of Quantum Mechanics: Information, Contextuality, Relationalism And Entanglement - Proceedings Of The Ii International Workshop On Quantum Mechanics And Quantum Information. Physical, Philosophical And Logical Approaches** Diederik Aerts, Maria Luisa Dalla Chiara, Christian De Ronde, Decio Krause, 2018-11-15 This book provides an interdisciplinary perspective on one of the most fascinating and important open questions in science What is quantum mechanics talking about Quantum theory is perhaps

our best confirmed physical theory. However, despite its great empirical effectiveness and the subsequent technological developments that it gave rise to in the 20th century from the interpretation of the periodic table of elements to CD players, holograms and quantum state teleportation, it stands even today without a universally accepted interpretation. The novelty of the book comes from the multiple viewpoints and subjects investigated by a group of researchers from Europe and North and South America.

Interpreting quantum mechanics: a historical approach Favio, Vitery Cala, Édgar Gustavo, Eslava Castañeda, 2016-03-02. This book condenses some of the critical features of the discussion about the interpretative problems of quantum mechanics, pointing out some possible ways out of the conundrum. In order to set the road for these matters, chapter one introduces a conceptual history of the theory and its alternative interpretations. Chapter two profiles a taxonomy of the interpretative problems and some possible solutions focused in the so-called measurement problem. Chapter three questions the thesis of quantum mechanics becoming what it is due to historical contingency. Finally, in chapter four, an argument is advanced to consider one particular interpretation, the causal account, as an alternative view that may help with the solution of the interpretative knot.

The Conceptions of Reality in the Interpretations of Quantum Mechanics Gerd Christian Krizek, 2024-09-15. This book explores the different conceptions of reality in the various interpretations of Quantum Mechanics, demonstrating the intimate connection to philosophy of physics. With interest in the foundations of Quantum Mechanics having revived in recent decades, a number of interpretations have been formulated or rediscovered, and these remain in strong competition with one another for acceptance by the scientific community. At the same time, they imply quite different notions of reality. The author provides an overview of these conceptions of reality and their embedding in physical theories, interpretations of Quantum Mechanics, and related philosophical frameworks. Starting with Aristotle's principles, the deep, fruitful connection between philosophy and physics guides this journey through the foundations of Quantum Mechanics.

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