

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 toolbox. 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 $\begin{pmatrix} 1 \\ 0 \end{pmatrix}$ and $\begin{pmatrix} 0 \\ 1 \end{pmatrix}$. 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 philosophicaly-oriented readers.

Structure And Interpretation Of Quantum Mechanics

R. I. G. Hughes



Structure And Interpretation Of Quantum Mechanics:

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 *An Introduction to the Mathematical Structure of Quantum Mechanics* F. Strocchi, 2008 Arising out of the need for Quantum Mechanics QM to be part of the common education of mathematics students this book formulates the mathematical structure of QM in terms of the C algebra of observables which is argued on the basis of the operational definition of measurements and the duality between states and observables *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 *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 ellipses can tell us about the physics and philosophy of the quantum world Markus Müller Institute for Quantum Optics and Quantum Information Vienna *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.

Theology and Modern Physics Peter E. Hodgson, 2017-09-08 The new discoveries in physics during the twentieth century have stimulated intense debate about their relevance to age old theological questions. Views range from those holding that modern physics provides a surer road to God than traditional religions to those who say that physics and theology are incommensurable and so do not relate. At the very least physics has stimulated renewed theological discussions. In this critical introduction to the science-theology debate Peter E. Hodgson draws on his experience as a physicist to present the results of modern physics and the theological implications. Written for those with little or no scientific background, Hodgson describes connections between physics, philosophy and theology and then explains Newtonian physics and Victorian physics, the

theories of relativity astronomy and quantum mechanics and distinguishes the actual results of modern physics from speculations The connections with theology are explored throughout The concluding section draws discussions together and makes an important new contribution to the debate

Liberating Sociology: From Newtonian Toward Quantum Imaginations: Volume 1: Unriddling the Quantum Enigma Mohammad H. Tamdgidi, 2020-01-20 In this major new study in the sociology of scientific knowledge social theorist Mohammad H Tamdgidi reports having unriddled the so called quantum enigma This book opens the lid of the Schrödinger's Cat box of the quantum enigma after decades and finds something both odd and familiar Not only the cat is both alive and dead it has morphed into an elephant in the room in whose interpretation Einstein Bohr Bohm and others were each both right and wrong because the enigma has acquired both localized and spread out features whose unriddling requires both physics and sociology amid both transdisciplinary and transcultural contexts The book offers in a transdisciplinary and transcultural sociology of self knowledge framework a relativistic interpretation to advance a liberating quantum sociology Deeper methodological grounding to further advance the sociological imagination requires investigating whether and how relativistic and quantum scientific revolutions can induce a liberating reinvention of sociology in favor of creative research and a just global society This however necessarily leads us to confront an elephant in the room the quantum enigma In Unriddling the Quantum Enigma the first volume of the series commonly titled Liberating Sociology From Newtonian toward Quantum Imaginations sociologist Mohammad H Tamdgidi argues that unriddling the quantum enigma depends on whether and how we succeed in dehabituating ourselves in favor of unified relativistic and quantum visions from the historically and ideologically inherited classical Newtonian modes of imagining reality that have subconsciously persisted in the ways we have gone about posing and interpreting or not the enigma itself for more than a century Once this veil is lifted and the enigma unriddled he argues it becomes possible to reinterpret the relativistic and quantum ways of imagining reality including social reality in terms of a unified nonreductive creative dialectic of part and whole that fosters quantum sociological imaginations methods theories and practices favoring liberating and just social outcomes The essays in this volume develop a set of relativistic interpretive solutions to the quantum enigma Following a survey of relevant studies and an introduction to the transdisciplinary and transcultural sociology of self knowledge framing the study overviews of Newtonianism relativity and quantum scientific revolutions the quantum enigma and its main interpretations to date are offered They are followed by a study of the notion of the wave particle duality of light and the various experiments associated with the quantum enigma in order to arrive at a relativistic interpretation of the enigma one that is shown to be capable of critically cohering other offered interpretations The book concludes with a heuristic presentation of the ontology epistemology and methodology of what Tamdgidi calls the creative dialectics of reality The volume essays involve critical comparative integrative reflections on the relevant works of founding and contemporary scientists and scholars in the field This study is the first in the monograph series Tayyeb Series in East

West Research and Translation of Human Architecture Journal of the Sociology of Self Knowledge XIII 2020 published by OKCIR Omar Khayyam Center for Integrative Research in Utopia Mysticism and Science Utopystics OKCIR is dedicated to exploring in a simultaneously world historical and self reflective framework the human search for a just global society It aims to develop new conceptual methodological theoretical historical practical pedagogical inspirational and disseminative structures of knowledge whereby the individual can radically understand and determine how world history and her his selves constitute one another Reviews Mohammad H Tamdgidi s Liberating Sociology From Newtonian Toward Quantum Imaginations Volume 1 Unriddling the Quantum Enigma hits the proverbial nail on the head of an ongoing problem not only in sociology but also much social science namely many practitioners allegiance consciously or otherwise to persisting conceptions of science that get in the way of scientific and other forms of theoretical advancement Newtonianism has achieved the status of an idol and its methodology a fetish the consequence of which is an ongoing failure to think through important problems of uncertainty indeterminacy multivariation multidisciplinary and false dilemmas of individual agency versus structure among many others Tamdgidi has done great service to social thought by bringing to the fore this problem of disciplinary decadence and offering in effect a call for its teleological suspension thinking beyond disciplinarity through drawing upon and communicating with the resources of quantum theory not as a fetish but instead as an opening for other possibilities of social including human understanding The implications are far reaching as they offer as the main title attests liberating sociology from persistent epistemic shackles and thus many disciplines and fields connected to things social This is exciting work A triumph The reader is left with enthusiasm for the second volume and theorists of many kinds with proverbial work to be done Professor Lewis R Gordon Honorary President of the Global Center for Advanced Studies and author of Disciplinary Decadence Living Thought in Trying Times Routledge Paradigm 2006 and Freedom Justice and Decolonization Routledge forthcoming 2020 Social sciences are still using metatheoretical models of science based on 19th century newtonian concepts of time and space Mohammad H Tamdgidi has produced a tour de force in social theory leaving behind the old newtonian worldview that still informs the social sciences towards a 21st century non dualistic non reductionist transcultural transdisciplinary post Einsteinian quantum concept of TimeSpace Tamdgidi goes beyond previous efforts done by titans of social theory such as Immanuel Wallerstein and Kyriakos Kontopoulos This book is a quantum leap in the social sciences at large Tamdgidi decolonizes the social sciences away from its Eurocentric colonial foundations bringing it closer not only to contemporary natural sciences but also to its convergence with the old Eastern philosophical and mystical worldviews This book is a masterpiece in social theory for a 21st century decolonial social science A must read Professor Ramon Grosfoguel University of California at Berkeley Tamdgidi s Liberating Sociology succeeds in adding physical structures to the breadth of the world changing vision of C Wright Mills the man who mentored me at Columbia Relativity theory and quantum mechanics can help us to understand the human universe no less than the physical universe Just as my

Creating Life Before Death challenges bureaucracy's conformist orientation so does Liberating Sociology liberate the infinite possibilities inherent in us Given our isolation in the Coronavirus era we have time to follow Tamdgidi in his journey into the depth of inner space where few men have gone before It is there that we can gain emotional strength just as Churchill Roosevelt and Mandela empowered themselves That personal development was needed to address not only their own personal problems but also the mammoth problems of their societies We must learn to do the same Bernard Phillips Emeritus Sociology Professor Boston University *Religion and Science* W. Mark Richardson, Wesley J. Wildman, 2012-10-12

Emphasizing its historical methodological and constructive dimensions Religion and Science takes the pulse of pertinent current research as the interdisciplinary study of science and religion gains momentum **Probabilities, Laws, and Structures** Dennis Dieks, Wenceslao J. Gonzalez, Stephan Hartmann, Michael Stöltzner, Marcel Weber, 2012-02-02 This volume the third in this Springer series contains selected papers from the four workshops organized by the ESF Research Networking Programme The Philosophy of Science in a European Perspective PSE in 2010 Pluralism in the Foundations of Statistics Points of Contact between the Philosophy of Physics and the Philosophy of Biology The Debate on Mathematical Modeling in the Social Sciences Historical Debates about Logic Probability and Statistics The volume is accordingly divided in four sections each of them containing papers coming from the workshop focussing on one of these themes While the programme's core topic for the year 2010 was probability and statistics the organizers of the workshops embraced the opportunity of building bridges to more or less closely connected issues in general philosophy of science philosophy of physics and philosophy of the special sciences However papers that analyze the concept of probability for various philosophical purposes are clearly a major theme in this volume as it was in the previous volumes of the same series This reflects the impressive productivity of probabilistic approaches in the philosophy of science which form an important part of what has become known as formal epistemology although of course there are non probabilistic approaches in formal epistemology as well It is probably fair to say that Europe has been particularly strong in this area of philosophy in recent years **Symposium on the Foundations of Modern Physics 1994** Kalervo Vihtori Laurikainen, Claus Montonen, K. Sunnarborg, 1994 *Philosophy of Chemistry* Eric Scerri, Lee McIntyre, 2014-11-11 This volume follows the successful book which has helped to introduce and spread the Philosophy of Chemistry to a wider audience of philosophers historians science educators as well as chemists physicists and biologists The introduction summarizes the way in which the field has developed in the ten years since the previous volume was conceived and introduces several new authors who did not contribute to the first edition The editors are well placed to assemble this book as they are the editor in chief and deputy editors of the leading academic journal in the field Foundations of Chemistry The philosophy of chemistry remains a somewhat neglected field unlike the philosophy of physics and the philosophy of biology Why there has been little philosophical attention to the central discipline of chemistry among the three natural sciences is a theme that is explored by several of the contributors This

volume will do a great deal to redress this imbalance Among the themes covered is the question of reduction of chemistry to physics the reduction of biology to chemistry whether true chemical laws exist and causality in chemistry In addition more general questions of the nature of organic chemistry biochemistry and chemical synthesis are examined by specialist in these areas

Path Integrals and Hamiltonians Belal E. Baaquie, 2014-03-27 Providing a pedagogical introduction to the essential principles of path integrals and Hamiltonians this book describes cutting edge quantum mathematical techniques applicable to a vast range of fields from quantum mechanics solid state physics statistical mechanics quantum field theory and superstring theory to financial modeling polymers biology chemistry and quantum finance Eschewing use of the Schrödinger equation the powerful and flexible combination of Hamiltonian operators and path integrals is used to study a range of different quantum and classical random systems succinctly demonstrating the interplay between a system's path integral state space and Hamiltonian With a practical emphasis on the methodological and mathematical aspects of each derivation this is a perfect introduction to these versatile mathematical methods suitable for researchers and graduate students in physics and engineering

The Oxford Handbook of the History of Quantum Interpretations Guido Bacciagaluppi, Olivier Darrigol, Thiago Hartz, Christian Joas, Alexei Kojevnikov, 2022 This Oxford Handbook provides a rigorous interdisciplinary review of the history of interpretations of quantum physics presenting the key controversies within the field as well as outlining its successes and its extraordinary potential across various scientific fields

Engineering Chemistry I (for BPUT) Patrizia Bocchetta, 2024

Information Dynamics Thomas Dittrich, 2022-11-23 This wide ranging book introduces information as a key concept not only in physics from quantum mechanics to thermodynamics but also in the neighboring sciences and in the humanities The central part analyzes dynamical processes as manifestations of information flows between microscopic and macroscopic scales and between systems and their environment Quantum mechanics is interpreted as a reconstruction of mechanics based on fundamental limitations of information processing on the smallest scales These become particularly manifest in quantum chaos and in quantum computing Covering subjects such as causality prediction undecidability chaos and quantum randomness the book also provides an information theoretical view of predictability More than 180 illustrations visualize the concepts and arguments The book takes inspiration from the author's graduate level topical lecture but is also well suited for undergraduate studies and is a valuable resource for researchers and professionals

Quantum Information Theory and the Foundations of Quantum Mechanics Christopher G. Timpson, 2013-04-25 Christopher G Timpson provides the first full length philosophical treatment of quantum information theory and the questions it raises for our understanding of the quantum world He argues for an ontologically deflationary account of the nature of quantum information which is grounded in a revisionary analysis of the concepts of information

4th Dimension and Human (Volume 3) Prof. Dr. Bilal Semih Bozdemir, 4th Dimension and Human What is the 4th dimension Time as the 4th dimension Relativity and the 4th dimension Spacetime and the 4th dimension Visualizing the 4th dimension The human

experience of time Perception of time Memory and the 4th dimension Aging and the 4th dimension Time travel and the 4th dimension Dreams and the 4th dimension Altered states and the 4th dimension Death and the 4th dimension Consciousness and the 4th dimension The limits of human perception Expanding human senses Technology and the 4th dimension Virtual reality and the 4th dimension Augmented reality and the 4th dimension Artificial intelligence and the 4th dimension The future of human experience Quantum mechanics and the 4th dimension Strings and the 4th dimension Parallel universes and the 4th dimension Spirituality and the 4th dimension Mysticism and the 4th dimension Mythology and the 4th dimension Literature and the 4th dimension Art and the 4th dimension Music and the 4th dimension Philosophy and the 4th dimension The ethics of manipulating time The societal impact of the 4th dimension The scientific pursuit of the 4th dimension Challenges and limitations in 4th dimension research Potential breakthroughs in 4th dimension exploration The 4th dimension and the human condition The 4th dimension and the meaning of life Embracing the 4th dimension Preparing for the future of the 4th dimension Conclusion The 4th dimension and the human experience **The Amazing World of Quantum Computing** Rajendra K. Bera, 2020-03-14 This book discusses the application of quantum mechanics to computing It explains the fundamental concepts of quantum mechanics and then goes on to discuss various elements of mathematics required for quantum computing Quantum cryptography waves and Fourier analysis measuring quantum systems comparison to classical mechanics quantum gates and important algorithms in quantum computing are among the topics covered The book offers a valuable resource for graduate and senior undergraduate students in STEM science technology engineering and mathematics fields with an interest in designing quantum algorithms Readers are expected to have a firm grasp of linear algebra and some familiarity with Fourier analysis **Subject Guide to Books in Print** ,1991

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