

Classical Simulation of Short-Time Quantum Dynamics

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 (Received 2 November 2022; accepted 25 April 2023; published 12 June 2023)

Recent progress in the development of quantum technologies has enabled the direct investigation of the dynamics of increasingly complex quantum many-body systems. This motivates the study of the complexity of classical algorithms for this problem in order to benchmark quantum simulators and to delineate the regime of quantum advantage. Here, we present classical algorithms for approximating the dynamics of local observables and nonlocal quantities such as the Loschmidt echo, where the evolution is governed by a local Hamiltonian. For short times, their computational cost scales polynomially with the system size and the inverse of the approximation error. In the case of local observables, the proposed algorithm has a better dependence on the approximation error than algorithms based on the Lieb-Robinson bound. Our results use cluster-expansion techniques adapted to the dynamical setting, for which we give a novel proof of their convergence. This has important physical consequences besides our efficient algorithms. In particular, we establish a novel quantum speed limit, a bound on dynamical phase transitions, and a concentration bound for product states evolved for short times.

DOI: 10.1103/PRXQuantum.4.020340

I. INTRODUCTION

The study of the dynamics of quantum many-body models is a highly active area of research in quantum information science, both from the perspective of physics and of computation. Probing dynamics provides access to a wealth of physical phenomena and can enable the solution of hard computational problems. Existing quantum simulators are already allowing us to explore quantum dynamics of high complexity. To assess the potential for quantum speed-up, it is important to understand the reach of classical methods for these tasks. Unless all quantum computations can be classically simulated, i.e., $BPP = BQP$, classical algorithms will be unable to approximate quantum dynamics in an arbitrary setting. Nevertheless, there exist restricted regimes in which efficient classical simulation is possible. An important special case is evolution for short times, during which the quantum information will not spread much. Tensor-network methods illustrate this point, as they provide provably efficient means of simulating

unitary dynamics in one spatial dimension for short times [1,2].

In this work, we characterize the computational complexity of short-time dynamics under a local Hamiltonian more generally. Locality in this context means that the Hamiltonian can be written as a sum of operators supported on small subsystems. We do not require geometric locality and we do not restrict the Hamiltonian to a finite-dimensional lattice. Instead, we only impose that every term in the Hamiltonian overlaps with a constant number of other terms. These conditions are satisfied by a wide class of physically relevant Hamiltonians, including parent Hamiltonians of quantum low-density parity-check (LDPC) error-correcting codes [3]. Dynamics governed by Hamiltonians of this type are amenable to *cluster expansions*, which have long been used in both classical and quantum statistical mechanics of lattice models [4–8], leading to results such as the uniqueness of Gibbs states [9,10], efficient approximation schemes for partition functions [11,12], the decay of correlations [13–15], and concentration bounds [16,17]. Despite their long history, cluster expansions have typically been applied to equilibrium properties, while dynamics have been rarely considered.

The paper is structured as follows. In the remainder of this section, we summarize the main results and give an overview of their implications for the complexity of quantum dynamics. In Sec. II, we define the cluster notation

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Stochastics Algebra And Analysis In Classical And Quantum Dynamics

Mike Jess



Stochastics Algebra And Analysis In Classical And Quantum Dynamics:

Stochastics, Algebra and Analysis in Classical and Quantum Dynamics Sergio Albeverio, Philip Blanchard, D. Testard, 2012-12-06 Et moi f si j avait su comment en revenir One service mathematics has rendered the je n y serais point aile human race It has put common sense back Jules Verne where it belongs 011 the topmost shelf next to the dusty canister labelled discarded non The series is divergent therefore we may be able to do something with it Eric T Bell o Heaviside Mathematics is a tool for thought A highly necessary tool in a world where both feedback and non linearities abound Similarly all kinds of parts of mathematics serve as tools for other parts and for other sciences Applying a simple rewriting rule to the quote on the right above one finds such statements as One service topology has rendered mathematical physics One service logic has rendered computer science One service category theory has rendered mathematics All arguably true And all statements obtainable this way form part of the raison d etre of this series_ This series Mathematics and Its Applications started in 1977 Now that over one hundred volumes have appeared it seems opportune to reexamine its scope At the time I wrote Growing specialization and diversification have brought a host of monographs and textbooks on increasingly specialized topics However the tree of knowledge of mathematics and related fields does not grow only by putting forth new branches *Stochastic Processes and Operator Calculus on Quantum Groups* U. Franz, René Schott, 2013-03-14 This book aims to present several new developments on stochastic processes and operator calculus on quantum groups Topics which are treated include operator calculus dual representations stochastic processes and diffusions Appell polynomials and systems in connection with evolution equations Audience This volume contains introductory material for graduate students who are new to the field as well as more advanced material for specialists in probability theory algebraic structures representation theory mathematical physics and theoretical physics **Quantum Information Iv, Proceedings Of The Fourth International Conference** Takeyuki Hida, Kimiaki Saito, 2002-05-30 **Stochastic Point Processes** S. Kidambi Srinivasan, A. Vijayakumar, 2003 Stochastic Point Processes are interesting from many points of view From and abstract point of view point process is a simple version of random measure these processes have acquired importance mainly due their viability in modeling a variety of phenomena spanning physical biological economic and engineering sciences This volume with contributions from leading probabilists contains besides surveys on the state of art of the theory papers dealing with problems of queues inventory reliability and population evolution There are also papers dealing with practical aspects like statistical inference and nonlinear filtering The book will be of interest to a wide spectrum of people including those working in the area of operations research signal processing electrical communications control and neural network **Mathematical Methods in Queuing Theory** Vladimir V. Kalashnikov, 1993-12-31 The material of this book is based on several courses which have been delivered for a long time at the Moscow Institute for Physics and Technology Some parts have formed the subject of lectures given at various universities throughout the world Freie

Universitat of Berlin Chalmers University of Technology and the University of Goteborg University of California at Santa Barbara and others The subject of the book is the theory of queues This theory as a mathematical discipline begins with the work of A Erlang who examined a model of a telephone station and obtained the famous formula for the distribution of the number of busy lines which is named after him Queueing theory has been applied to the study of numerous models emergency aid road traffic computer systems etc Besides it has lead to several related disciplines such as reliability and inventory theories which deal with similar models Nevertheless many parts of the theory of queues were developed as a pure science with no practical applications The aim of this book is to give the reader an insight into the mathematical methods which can be used in queueing theory and to present examples of solving problems with the help of these methods Of course the choice of the methods is quite subjective Thus many prominent results have not even been mentioned Stochastic Processes in Epidemic Theory Jean-Pierre Gabriel, Claude Lefevre, Philippe Picard, 2014-03-11 This collection of papers gives a representative cross selectional view of recent developments in the field After a survey paper by C Lef vre 17 other research papers look at stochastic modeling of epidemics both from a theoretical and a statistical point of view Some look more specifically at a particular disease such as AIDS malaria schistosomiasis and diabetes Asymptotic Behaviour of Linearly Transformed Sums of Random Variables V.V. Buldygin, Serguei Solntsev, 2012-12-06 Limit theorems for random sequences may conventionally be divided into two large parts one of them dealing with convergence of distributions weak limit theorems and the other with almost sure convergence that is to say with asymptotic prop erties of almost all sample paths of the sequences involved strong limit theorems Although either of these directions is closely related to another one each of them has its own range of specific problems as well as the own methodology for solving the underlying problems This book is devoted to the second of the above mentioned lines which means that we study asymptotic behaviour of almost all sample paths of linearly transformed sums of independent random variables vectors and elements taking values in topological vector spaces In the classical works of P Levy A Ya Khintchine A N Kolmogorov P Hartman A Wintner W Feller Yu V Prokhorov and M Loeve the theory of almost sure asymptotic behaviour of increasing scalar normed sums of independent random vari ables was constructed This theory not only provides conditions of the almost sure convergence of series of independent random variables but also studies different ver sions of the strong law of large numbers and the law of the iterated logarithm One should point out that even in this traditional framework there are still problems which remain open while many definitive results have been obtained quite recently **Random Fields and Stochastic Partial Differential Equations** Y. Rozanov, 1998-03-31 This book considers some models described by means of partial dif ferential equations and boundary conditions with chaotic stochastic disturbance In a framework of stochastic Partial Differential Equa tions an approach is suggested to generalize solutions of stochastic Boundary Problems The main topic concerns probabilistic aspects with applications to well known Random Fields models which are representative for the corresponding stochastic Sobolev spaces

The term stochastic in general indicates involvement of appropriate random elements. It assumes certain knowledge in general Analysis and Probability. Hilbert space methods, Schwartz distributions, Fourier transform. A very general description of the main problems considered can be given as follows. Suppose we are considering a random field in a region $T \subset \mathbb{R}^d$ which is associated with a chaotic stochastic source by means of the differential equation in T . A typical chaotic source can be represented by an appropriate random field with independent values, i.e. generalized random function $\varphi(T)$ with independent random variables $\varphi(f)$ for any test functions φ with disjoint supports. The property of having independent values implies a certain roughness of the random field which can only be treated functionally as a very irregular Schwarz distribution. With the lack of a proper development of non linear analyses for generalized functions let us limit ourselves to the 1. For related material see for example J. L. Lions.

Probability Theory, Random Processes and Mathematical Statistics Y. Rozanov, 2012-12-06 Probability Theory, Theory of Random Processes and Mathematical Statistics are important areas of modern mathematics and its applications. They develop rigorous models for a proper treatment for various random phenomena which we encounter in the real world. They provide us with numerous tools for an analysis, prediction and ultimately control of random phenomena. Statistics itself helps with choice of a proper mathematical model, e.g. by estimation of unknown parameters on the basis of statistical data collected by observations. This volume is intended to be a concise textbook for a graduate level course with carefully selected topics representing the most important areas of modern Probability, Random Processes and Statistics. The first part, Ch. 1-3, can serve as a self contained elementary introduction to Probability, Random Processes and Statistics. It contains a number of relatively simple and typical examples of random phenomena which allow a natural introduction of general structures and methods. Only knowledge of elements of real complex analysis, linear algebra and ordinary differential equations is required here. The second part, Ch. 4-6, provides a foundation of Stochastic Analysis, gives information on basic models of random processes and tools to study them. Here a familiarity with elements of functional analysis is necessary. Our intention to make this course fast moving made it necessary to present important material in a form of examples.

Applications of Lie Algebras to Hyperbolic and Stochastic Differential Equations Constantin Vârsan, 2012-12-06 The main part of the book is based on a one semester graduate course for students in mathematics. I have attempted to develop the theory of hyperbolic systems of differential equations in a systematic way making as much use as possible of gradient systems and their algebraic representation. However, despite the strong similarities between the development of ideas here and that found in a Lie algebras course, this is not a book on Lie algebras. The order of presentation has been determined mainly by taking into account that algebraic representation and homomorphism correspondence with a full rank Lie algebra are the basic tools which require a detailed presentation. I am aware that the inclusion of the material on algebraic and homomorphism correspondence with a full rank Lie algebra is not standard in courses on the application of Lie algebras to hyperbolic equations. I think it should be. Moreover, the Lie algebraic structure

plays an important role in integral representation for solutions of nonlinear control systems and stochastic differential equations yielding results that look quite different in their original setting Finite dimensional nonlinear filters for stochastic differential equations and say decomposability of a nonlinear control system receive a common understanding in this framework

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