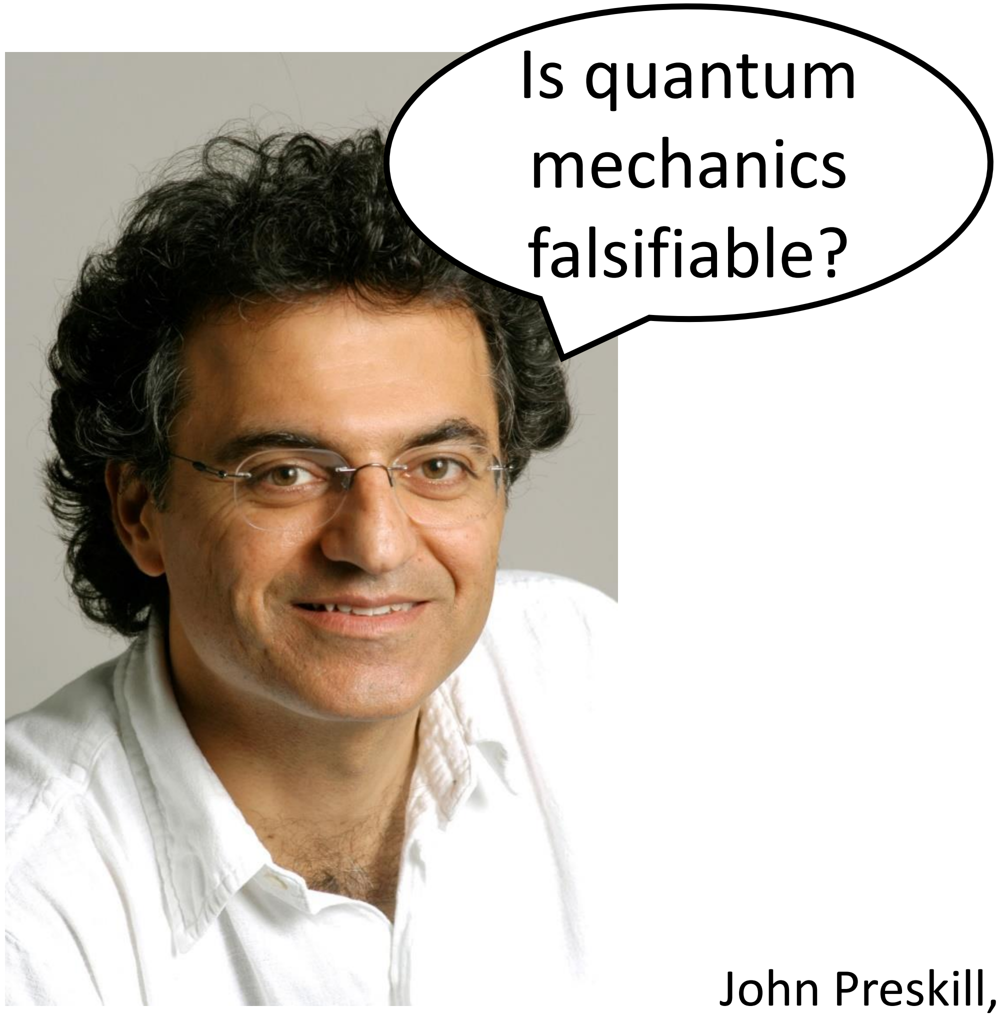
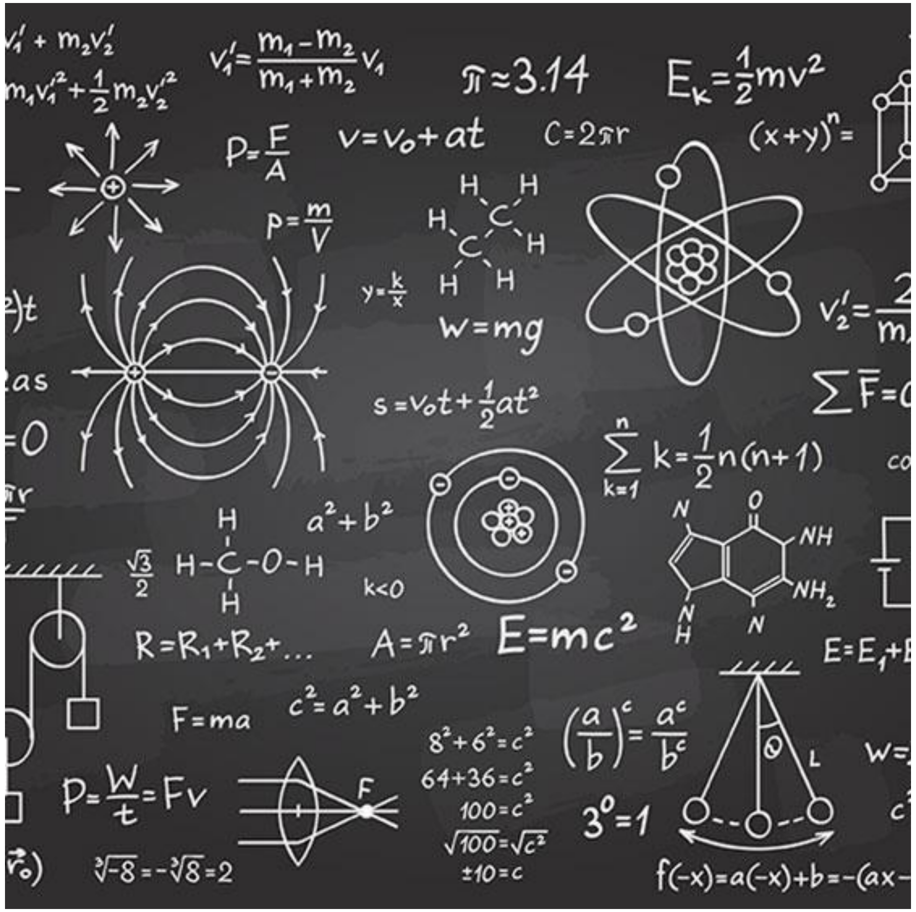
Umesh Vazirani, Physicist





John Preskill, Caltech
UmeshFest
Simons Institute, 28 April 2024

I (almost) never miss a flight …

upper bounds…

lower bounds…

How can the lens of (quantum) computer science enrich our understanding of the physical universe?

As I recall, the first time I heard Umesh speak was at a 1997 conference in London. He explained the lower bound on quantum search. Bennett, Bernstein, Brassard, and Vazirani had proved that Grover's algorithm is optimal before Grover's algorithm was discovered! (I talked about topological quantum computing with anyons.)

Quantum Information Science

An Emerging Field of Interdisciplinary Research and Education in Science and Engineering

Report of the NSF Workshop
October 28-29, 1999
Arlington, Virginia

Steering Committee

C. H. Bennett	IBM
D. P. DiVincenzo	IBM
N. Gershenfeld	MIT
H. M. Gibbs	University of Arizona
H. J. Kimble	Caltech
J. Preskill	Caltech
U. V. Vazirani	UC/Berkeley
D. J. Wineland	NIST
C. Yao	Princeton University

AGENDA

NSF Workshop on Quantum Information Science

Arlington Hilton, Gallery I

Day 1, October 28, 1999

<u>Morning Session</u>

8:30 – 9:00 NSF Welcome, Introduction

<u>Overview talks</u>

A. Ekert, Chair

9:00 – 9:35 C. Bennett, Overview of Quantum Information
9:35 – 10:10 U. Vazirani, Quantum and Classical Complexity
10:10 – 10:45 G. Brassard, Quantum Communication and Cryptography
10:45 – 11:00 Coffee break
11:00 – 11:35 J. Preskill, Future Directions of Quantum Information Science
11:35 – 12:10 J. Kimble, Physical Implementations of Quantum Logic

Email to Bennett and Vazirani, 1 Nov 1999:

Charlie and Umesh: I would like for you each to write about 3-4 pages for Sections (1) and (2), making the points that you think are important. Recall section (1) is about the general themes of the field and the accomplishments to date, while (2) is about the outstanding open problems and issues. You don't need to coordinate with one another; I'll take what you give me and try to integrate it into a draft. I'm assuming that Charlie will emphasize quantum information theory and cryptography, while Umesh will emphasize algorithms, bounds, communication complexity, but it doesn't matter if what you say overlaps.

I would like to have this no later than two weeks from today, Monday November 15. Sooner if possible.

Umesh sent his stuff on November 23. Charlie had already provided a draft summary and outline on October 31.

[QIS] is already providing a wholly new language for describing how Nature works, and new ways of thinking about a wide variety of scientific and technical questions. As with any revolutionary scientific insight, the long-term implications cannot be clearly anticipated, but we are confident that they will be profound.

The development of QIS faces special problems because of its long time horizon and its intrinsically interdisciplinary nature. Researchers in the field work at the margins of the traditional disciplines, and therefore sometimes find it difficult to attain funding or to advance their careers. The very best students are attracted by the excitement generated by QIS, but are uncertain how to pursue that interest within a conventional academic department. Most worrisome, the excellent young scientists who receive advanced degrees doing QIS research are often forced to leave the field because of a lack of stable funding to support their work …

Workshop on the Computational Worldview and the Sciences
Caltech, 15 March 2007

Thursday March 15, 2007

8:05
Shuttle from the Sheraton to Caltech
8:15-8:45
Registration and continental breakfast
8:45
Welcoming remarks: Richard Karp (Berkeley), Michael Foster (NSF) slides (Foster), cyber-enabled discovery and innovation (Foster), video (Karp and Foster)
9:00-9:40
Jon Kleinberg (Cornell): *Algorithmic models for social network phenomena* slides, video
10:00-10:30
Coffee
10:30-11:10
John Preskill (Caltech): *Quantum information and the future of physics* slides, video
11:30-12:10
Umesh Vazirani (Berkeley): *Computational constraints on scientific theories: insights from quantum computing* slides, video

12:30-2:00
Lunch
2:00-2:40
Richard Murray (Caltech): *Control in an information-rich world* slides, video
3:00-3:40
Ali Jadbabaie (U Penn): *Distributed motion coordination in multi-agent systems: From flocking and synchronization to coverage verification in sensor networks* slides, video
4:00-4:30
Coffee
4:30-5:10
Andrei Broder (Yahoo! Research): *Technical challenges in web advertising* slides, video
6:30
Workshop dinner
8:15
Shuttle from Caltech (driveway behind Guggenheim) to the Sheraton

Friday March 16, 2007

8:20
Shuttle from the Sheraton to Caltech
8:30-9:00
Continental breakfast
9:00-9:40
Andrew Connolly (Pittsburgh): *Streaming the sky: The challenge for astronomy in the era of petabyte surveys* video
10:00-10:30
Coffee
10:30-11:10
Andrea Montanari (Stanford): *Phase transitions in large graphical models: from physics to information theory and computer science* slides, video
11:30-12:10
Gavin Crooks (Berkeley and LBL): *Importance sampling of trajectories in complex systems* slides, video

12:30-2:00
Lunch
2:00-2:05 (late addition)
Andrew Odlyzko (U Minnesota): *Board of Mathematical Sciences and their Applications (BMSA) of the National Research Council (NRC)* video
2:00-2:40
Andrew Postlewaite (U Penn): *Decision-making in economics* slides, video
3:00-3:40
Ehud Kalai (Northwestern): *Modelling large games* slides, video
4:00-4:30
Coffee
4:30-5:10
Colin Camerer and Antonio Rangel (Caltech): *Computational models of economic valuation and strategy choice* slides, video
6:30
Organizing committee dinner

Computational Constraints on Scientific Theories:
Insights from Quantum Computation

Umesh Vazirani
U.C. Berkeley

Is Quantum Physics Falsifiable?

- Single particle quantum physics has been verified to exquisite accuracy.
- Multi-particle quantum systems – exponentially hard to compute what the theory predicts.
- What about predictions using mean field approximations/perturbation theory?
- Can any theory that requires exponential resources possibly be refuted?

11 Is Quantum Mechanics Falsifiable? A Computational Perspective on the Foundations of Quantum Mechanics

Dorit Aharonov and Umesh V. Vazirani

Saying that quantum mechanics (QM) is paradoxical is an understatement: Feynman once said, "I think I can safely say that no one understands quantum mechanics" (1964). Quantum mechanics has been a great source of fundamental issues and paradoxes in the philosophy of science, ranging from its statistical nature and stretching of causality to the measurement problem. A totally new kind of philosophical problem arises once we focus on computational aspects of QM.

(2013)


Federal Vision Quantum Information Science Workshop, Vienna VA, April 25, 2009

Home Program/Presentations Photos/Participants/Report

In January 2009, the United States National Science and Technology Council **issue a report on** A Federal Vision for Quantum Information Science**.** The report proposes that:

> "The United States ... create a scientific foundation for controlling, manipulating, and exploiting the behavior of quantum matter, and for identifying the physical, mathematical, and computational capabilities and limitations of quantum information processing systems in order to build a knowledge base for this 21st century technology."

This Workshop on Quantum Information Science (QIS) has been organized in response to the NSTC report. It brings together leading theorists and experimenters drawn from physical science, computer science, mathematics, and engineering who will assess recent progress in QIS and identify major goals and challenges for future research.

The workshop will include open evening sessions so that all participants can express their views concerning the priorities for a national QIS initiative. The workshop will be followed b a report that will be submitted to the federal agencies that sponsor or perform QIS researcl

Presentations now available!

Invited Speakers

Scott Aaronson
Dorit Aharonov
Andris Ambainis
Alán Aspuru-Guzik
Charles Bennett
Anne Broadbent
Isaac Chuang
Michael Freedman
Mark Kasevich
Jeff Kimble
Paul Kwiat
Raymond Laflamme
Anthony Leggett
Mikhail Lukin
Norbert Lütkenhaus
Charles Marcus
William Phillips
John Preskill
Robert Schoelkopf
Keith Schwab
Leonard Schulman
Barbara Terhal
Umesh Vazirani
John Watrous
Birgitta Whaley
Carl Williams
David Wineland
Peter Zoller

Some open questions in quantum information science

Here we list some open questions, mostly drawn from the workshop presentations, that are being addressed by current research. The questions listed are merely representative examples; they are not necessarily more interesting or more important than questions that are omitted. For further context, see the Research Snapshots and the online workshop presentations.

The questions range from more theoretical questions toward the beginning of the list to questions relating more to experiment and technology toward the end. We have divided the list into a few broad categories, but the boundaries between categories are fuzzy, and some of the questions might easily have been classified differently.

58 open questions in 8 categories: algorithms, complexity, cryptography/communication, simulation, physics foundations, systems, implementation/hardware, implications.

[*Complexity*] How powerful are multi-prover quantum interactive proof systems?

[*Complexity*] The classical Probabilistically-Checkable-Proof (PCP) theorem indicates that it is hard for classical computers to find approximate solutions to classical constraint satisfaction problems. Is there a quantum version of the PCP theorem, and if so what are its implications?

[*Cryptography*] Are there general protocols that allow a classical verifier to check that a quantum computer is operating correctly?

[*Cryptography*] Can we prove the security of practical quantum key distribution against side-channel attacks based on device-independent assumptions?

At the White House
18 October 2016

Bernstein and Vazirani
(1993)

"The study of the computational power of quantum Turing Machines gives a method of demonstrating, in a quantifiable way, the inherent difference between the model proposed by quantum physics and *any* classical model.

Molecular Scale Heat Engines and Scalable Quantum Computation

Leonard J. Schulman* Umesh V. Vazirani†

Abstract

We describe a quantum mechanical heat engine. Like its classical counterpart introduced by Carnot, this engine carries out a reversible process in which an input of energy to the system results in a separation of cold and hot regions. The method begins with a reinterpretation in thermodynamic terms of a simple step introduced by von Neumann to extract fair coin flips from sequences of biased coin flips.

Some of the experimental set-ups proposed for implementation of quantum computers, begin with the quantum bits of the computer initially in a mixed state. Each qubit is ϵ polarized — in the state $|0\rangle$ with probability $\frac{1+\epsilon}{2}$, and in the state $|1\rangle$ with probability $\frac{1-\epsilon}{2}$, independently (or nearly so) of all other bits. The heat engine may be used to transform this initial collection of n qubits into a state in which a near-optimal $m = n[\frac{1+\epsilon}{2}\lg(1+\epsilon) + \frac{1-\epsilon}{2}\lg(1-\epsilon) - o(1)]$ qubits are in the joint state $|0^m\rangle$. These qubits can then be used as the registers for a quantum computation.

The heat engine is described at the level of an algorithm implementable in any quantum system capable of massive coherent states. A particular implementation is also described for a system of nuclear spins arranged in a chain. The temperature the cold qubits reach is inverse polynomial in n.

STOC 1999: Algorithmic cooling for NMR quantum computation

An area law and sub-exponential algorithm for 1D systems

Itai Arad[1], Alexei Kitaev[2], Zeph Landau[3], Umesh Vazirani[4]

Abstract

We give a new proof for the area law for general 1D gapped systems, which exponentially improves Hastings' famous result [1]. Specifically, we show that for a chain of d-dimensional spins, governed by a 1D local Hamiltonian with a spectral gap $\epsilon > 0$, the entanglement entropy of the ground state with respect to any cut in the chain is upper bounded by $\mathcal{O}(\frac{\log^3 d}{\epsilon})$. Our approach uses the framework of Refs. [2, 3] to construct a Chebyshev-based AGSP (Approximate Ground Space Projection) with favorable factors. However, our construction uses the Hamiltonian directly, instead of using the Detectability lemma, which allows us to work with general (frustrated) Hamiltonians, as well as slightly improving the $1/\epsilon$ dependence of the bound in Ref. [3]. To achieve that, we establish a new, "random-walk like", bound on the entanglement rank of an arbitrary power of a 1D Hamiltonian, which might be of independent interest: $\mathrm{ER}(H^\ell) \le (\ell d)^{\mathcal{O}(\sqrt{\ell})}$. Finally, treating d as a constant, our AGSP shows that the ground state is well approximated by a matrix product state with a sublinear bond dimension $B = e^{\tilde{\mathcal{O}}(\log^{3/4} n/\epsilon^{1/4})}$. Using this in conjunction with known dynamical programing algorithms, yields an algorithm for a $1/\mathrm{poly}(n)$ approximation of the ground energy with a subexponential running time $T \le \exp\left(e^{\tilde{\mathcal{O}}(\log^{3/4} n/\epsilon^{1/4})}\right)$.

ARTICLES
PUBLISHED ONLINE: 1 JUNE 2015 | DOI: 10.1038/NPHYS3345

nature physics

A polynomial time algorithm for the ground state of one-dimensional gapped local Hamiltonians

Zeph Landau[1], Umesh Vazirani[1] and Thomas Vidick[2]*

The density matrix renormalization group method has been extensively used to study the ground state of 1D many-body systems since its introduction two decades ago. In spite of its wide use, this heuristic method is known to fail in certain cases and no certifiably correct implementation is known, leaving researchers faced with an ever-growing toolbox of heuristics, none of which is guaranteed to succeed. Here we develop a polynomial time algorithm that provably finds the ground state of any 1D quantum system described by a gapped local Hamiltonian with constant ground-state energy. The algorithm is based on a framework that combines recently discovered structural features of gapped 1D systems with an efficient construction of a class of operators called approximate ground-state projections (AGSPs). The combination of these tools yields a method that is guaranteed to succeed in all 1D gapped systems. An AGSP-centric approach may help guide the search for algorithms for more general quantum systems, including for the central challenge of 2D systems, where even heuristic methods have had more limited success.

Rigorous RG Algorithms and Area Laws for Low Energy Eigenstates in 1D

Itai Arad[1], Zeph Landau[2], Umesh Vazirani[2], Thomas Vidick[3]

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Received: 4 June 2016 / Accepted: 10 June 2017
Published online: 2 August 2017 –

Abstract: One of the central challenges in the study of quantum many-body systems is the complexity of simulating them on a classical computer. A recent advance (Landau et al. in Nat Phys, 2015) gave a polynomial time algorithm to compute a succinct classical description for unique ground states of gapped 1D quantum systems. Despite this progress many questions remained unsolved, including whether there exist efficient algorithms when the ground space is degenerate (and of polynomial dimension in the system size), or for the polynomially many lowest energy states, or even whether such states admit succinct classical descriptions or area laws. In this paper we give a new algorithm, based on a rigorously justified RG type transformation, for finding low energy states for 1D Hamiltonians acting on a chain of n particles. In the process we resolve some of the aforementioned open questions, including giving a polynomial time algorithm for poly(n) degenerate ground spaces and an $n^{O(\log n)}$ algorithm for the poly(n) lowest energy states (under a mild density condition). For these classes of systems the existence of a succinct classical description and area laws were not rigorously proved before this work. The algorithms are natural and efficient, and for the case of finding unique ground states for frustration-free Hamiltonians the running time is $\tilde{O}(nM(n))$, where $M(n)$ is the time required to multiply two $n \times n$ matrices.

Communications in Mathematical Physics (2017)

Computational pseudorandomness, the wormhole growth paradox, and constraints on the AdS/CFT duality

Adam Bouland[1], Bill Fefferman[2], and Umesh Vazirani[1]

[1]Dept. of Electrical Engineering & Computer Sciences, University of California, Berkeley
[2]Dept. of Computer Science, University of Chicago

Abstract

A fundamental issue in the AdS/CFT correspondence is the wormhole growth paradox. Susskind's conjectured resolution of the paradox was to equate the volume of the wormhole with the circuit complexity of its dual quantum state in the CFT. We study the ramifications of this conjecture from a complexity-theoretic perspective. Specifically we give evidence for the existence of computationally pseudorandom states in the CFT, and argue that wormhole volume is measureable in a non-physical but computational sense, by amalgamating the experiences of multiple observers in the wormhole. In other words the conjecture equates a quantity which is difficult to compute with one which is easy to compute. The pseudorandomness argument further implies that this is a necessary feature of any resolution of the wormhole growth paradox, not just of Susskind's Complexity=Volume conjecture. As a corollary we conclude that either the AdS/CFT dictionary map must be exponentially complex, or the quantum Extended Church-Turing thesis must be false in quantum gravity.

A Polynomial-Time Classical Algorithm for Noisy Random Circuit Sampling

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STOC 2023

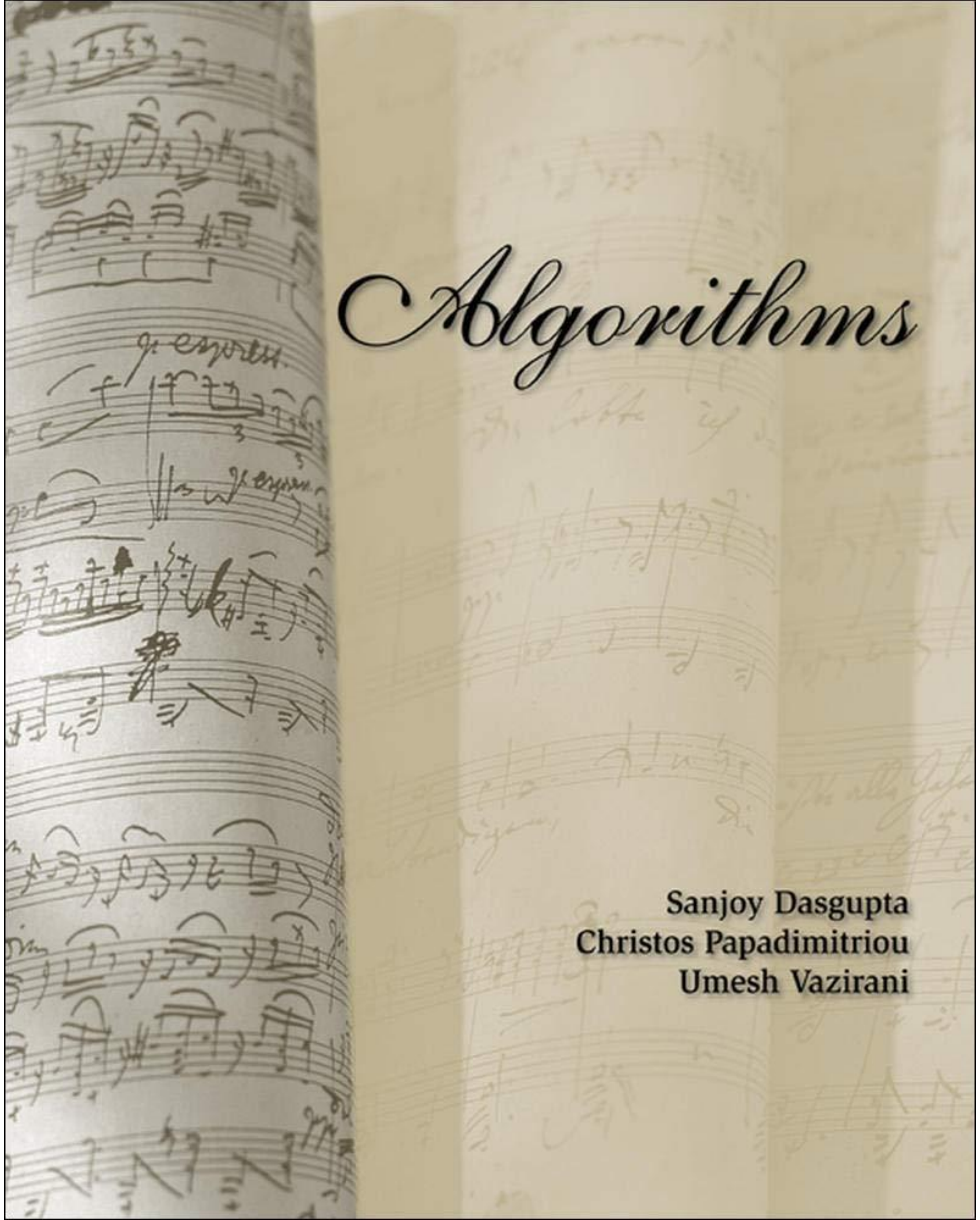
Some quantumists mentored by Umesh

Students

Ashwin Nayak 1999
Sean Hallgren 2000
Andris Ambainis 2001
Scott Aaronson 2004
Iordanis Kerenidis 2004
Ben Reichardt 2006
Thomas Vidick 2011
Urmila Mahadev 2018
Chinmay Nirkhe 2022
Yunchao Liu 2024

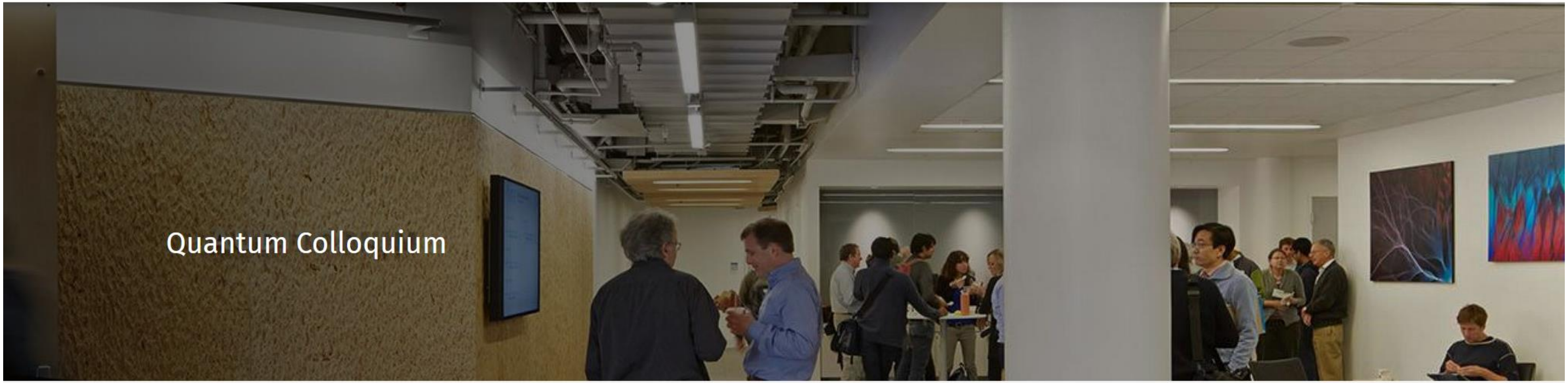
Postdocs

Leonard Schulman
Isaac Chuang
Amnon Ta-Shma
Dorit Aharonov
Wim van Dam
Daniel Gottesman
Ronald de Wolf
Zeph Landau
Julia Kempe
Oded Regev
Rahul Jain
Jeremie Roland
Itai Arad
Yi-Kai Liu
Sevag Gharibian
Or Sattath
Henry Yuen
Bill Fefferman
Adam Bouland



Algorithms

Sanjoy Dasgupta
Christos Papadimitriou
Umesh Vazirani



Quantum Colloquium

This colloquium series features talks by some of the foremost experts in quantum computation in the form of "an invitation to research in area X". With the explosion of interest in quantum computation, there is a dizzying flurry of results, as well as a diverse group of researchers who are drawn to this field. This colloquium series aims to target three audiences:

1. Experts in quantum computation: It is increasingly difficult for even experts to keep up with the results in adjacent areas. These colloquia will aim to identify the key results and techniques in the area, as well as the most important directions for further research.
2. Interested researchers in (classical) theoretical computer science: There are deep connections between ideas in quantum computation and classical complexity, algorithms, etc. These colloquia aim to make these connections more accessible to the broader TCS community.
3. Interested mathematical and physical science (MPS) researchers: These colloquia aim to enable MPS researchers to cut through the clutter to make connections to CS style results in quantum computation.

Series

Richard M. Karp Distinguished Lectures

Theoretically Speaking

Breakthroughs

Quantum Colloquium

All Public Lectures

How can the lens of (quantum) computer science enrich our understanding of the physical universe?

Physics + Computer Science = ?

Physics + Computer Science = Awesome