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Report Title

Classical Simulations of Quantum Computations

ABSTRACT

The main development has been the invention of the holographic method for deriving polynomial time algorithms where none were known before. The method is heavily inspired by the quantum computational model, but the algorithms we have derived to date can all be executed on classical computers in polynomial time. The problems for which such polynomial time algorithms have been derived include versions a restricted monomer-dimerproblem from statistical physics, various coloring and embedding problems from graph theory, and finding maximal sets of planar linear equations that have a common solution. The holographic method is closely related to the matchgate approach the author derived earlier, which offers one of the few known methods for simulating significant subclasses of quantum computations classically in polynomial time.

List of papers submitted or published that acknowledge ARO support during this reporting period. List the papers, including journal references, in the following categories:

(a) Papers published in peer-reviewed journals (N/A for none)

L. G. Valiant Quantum circuits that can be simulated classically in polynomial time, SIAM J. on Computing, 31:4 (2002) 1229-1254.

L. G. Valiant Expressiveness of matchgates, Theoretical Computer Science, 289:1 (2002) 457-471 (and 299 (2003) 795.)

Number of Papers published in peer-reviewed journals: 0.00

(b) Papers published in non-peer-reviewed journals or in conference proceedings (N/A for none)

ALL PEER-REVIEWED CONFERENCE PROCEEDINGS:

L. G. Valiant "Holographic Algorithms - Extended Abstract". Proc 45th IEEE Symposium on Foundations of Computer Science, Rome, Italy, October 17-19, (2004) 306-315.

A. Klivans and A. Shpilka, Learning arithmetic circuits via partial derivatives, Proc. 16th Annual Conference on Learning Theory, Lecture Notes in Artificial Intelligence, Vol 2777,Springer-Verlag,(2003) pp.463-476.

L. Babai, A. Shpilka and D. Stefanovic, Locally testable cyclic codes,
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E. Mossel, A. Shpilka, and L. Trevisan, On epsilon-generators in NC0, Proc. 44th Annual Symposium on Foundations of Computer Science, IEEE Press,(2003),136-145.

R Raz ans A. Shpilka, Deterministic polynomial identity testing in noncommutative models, Proceedings of 19th IEEE Conference on Computational Complexity, Amherst, MA, June 21-24, 2004, pp 215-222.

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R. Spalek and M. Szegedy, All quantum adversary methods are equivalent,Proc. 32nd International Colloquium on Automata, Languages and Programming, July 11-15, Lisbon, Portugal, LNCS, Vol. 3580,(2005), Springer-Verlag,1299-1311.

M. Szegedy, Quantum speed-up of Markov chain based algorithms, Proc 45th IEEE Symposium on Foundations of Computer Science, Rome, Italy, October 17-19, (2004) 32-41.

L. G. Valiant, Holographic circuits, Proc. 32nd International Colloquium on Automata, Languages and Programming, July 11-15, Lisbon, Portugal, LNCS, Vol. 3580, (2005), Springer-Verlag, 1-15.

Number of Papers published in non peer-reviewed journals: 9.00

(c) Papers presented at meetings, but not published in conference proceedings (N/A for none)

Number of Papers not Published: 0.00

(d) Manuscripts

L. G. Valiant Holographic algorithms, ECCC Report, TR05-099, (2005)

M. Szegedy, Spectra of quantum walks and a root-delta-epsilon-rule, arxiv.org/PS_cache/quant-ph/pdf/0401/0401053.pdf

Number of Manuscripts: 2.00

Number of Inventions:

Graduate Students

Number of Graduate Students supported: 0.00

Total number of FTE graduate students: 0.00

Names of Post Doctorates

Amir Shpilka

Number of Post Docs supported: 1.00

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List of faculty supported by the grant that are National Academy Members

Leslie G. Valiant

Names of Faculty Supported

Leslie G. Valiant

Number of Faculty: 1.00

Names of Under Graduate students supported

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Names of Personnel receiving masters degrees

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Names of personnel receiving PHDs

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Names of other research staff

Mario Szegedy (was a short term visitor from Rutgers University)

Sub Contractors (DD882)

Inventions (DD882)

1. Problem Studied

(A): The initial problem we studied was whether quantum computations could be simulated in polynomial time using classical computers.

(B): The new problem area we discovered on the way was whether ideas from quantum mechanics could be used to derive polynomial time algorithms for classical computers independent of quantum computation.

2. Results

(A): We discovered and explored a significant subclass of quantum computations that can be simulated classically in polynomial time [1, 2]. The methodology used was that of matchgates which was apparently novel. The subclass identified as so simulatable stands as one of the few such examples known. A subclass of our subclass was identified to have a correlate in physics [3].

(B): The above work led to the discovery that the matchgate methodology was not restricted to simulating quantum computations but could be applied also to more general counting classes. Exponentially many combinations of linear superpositions, in the general style of quantum physics, could be simulated in polynomial time classically under certain conditions, sometimes with good effect. We called these holographic algorithms, and our work then developed in two directions:

First, we developed polynomial time classical algorithms for a series of combinatorial problems for which no such algorithms had been known before [4]. An archetypal such problem is a restricted version of the general matching problem, known to physicists as the monomer-dimer problem. In the theory each basis allows different primitive operations, and the task, given a combinatorial problem, is to find a basis on which the needed primitives of the problem at hand can be realized consistently.

Second, we developed a complexity theory based on such algorithms [5]. In particular we showed which sets of primitives needed to be realized in some common basis for certain complexity classes (e.g #P) to collapse to the classical polynomial level.

There has also been some recent theoretical progress by others on understanding such holographic algorithms [6].

3 Bibliography

[1] L. G. Valiant, Quantum circuits that can be simulated classically in polynomial time, *SIAM J. on Computing*, 31:4 (2002) 1229-1254.

[2] L. G. Valiant, Expressiveness of matchgates, *Theoretical Computer Science*, 289:1 (2002) 457-471 (and 299 (2003) 795.)

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[4] L. G. Valiant, Holographic algorithms, *ECCC Report*, TR05-099, (2005) http://eccc.uni-trier.de/eccc-reports/2005/TR05-099/index.html

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[6] Jin-Yi Cai and Vinay Choudhary, Valiant's Holant Theorem and Matchgate Tensors. http://www.eccc.uni-trier.de/eccc-reports/2005/TR05-118/index.html