From Computability to Simulation, Optimization, and back

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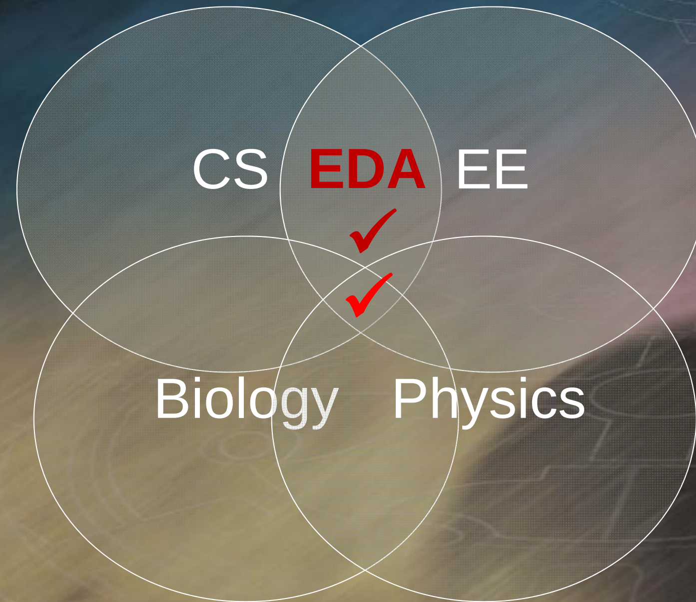
EDA among Sci & Eng fields



What can be Computed ?

- Casting practical problems in formal terms
  - AI, EDA: *simulation, layout, verification…*
- Computability in principle (e.g., *decidability*)
- Efficient computation at large scale
  - *NP, PSPACE…*
- Optimization algorithms & heuristics
  - *Approximation schemes, ILP…*
- Practical software (*empirical algorithmics, SWE*)
- Cross-pollination between EDA & other CS

"Computation is Physical"

- Non-traditional physics & technolgies <u>may</u> offer additional computational powers (or not)
  - S. Aaronson, J. Watrous: "Closed Timelike Curves Make Quantum & Classical Computing Equivalent," 2008
- Key questions from last slide apply, suggest comparisons: classical vs non-classical comp
  - Full spectrum from theoretical to practical
- Can non-traditional computing be faster ?
  - Most answers will be negative – that's OK
  - How does one arrive at a negative answer ?

Simulation as a Tool of Scientific Discovery

- Basic idea
  - Develop a simulator of a new physical effect or technology on conventional computers
  - The more efficient the simulation, the less helpful the new effect / technology (otherwise, simulation can be useful in the lab)
- Many types of simulation possible
  - Monte-Carlo simulation of Probabilistic CMOS
  - Numerical solution of Schrodinger's equation
  - Symbolic simulation of quantum states
  - Logic simulation of memristors

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Efficient classical simulation of the approximate quantum Fourier transform

Abstract | References (11) | Citing Articles

Download: PDF (108 kB) or Buy this Article (US$25) (Use Article Pack)

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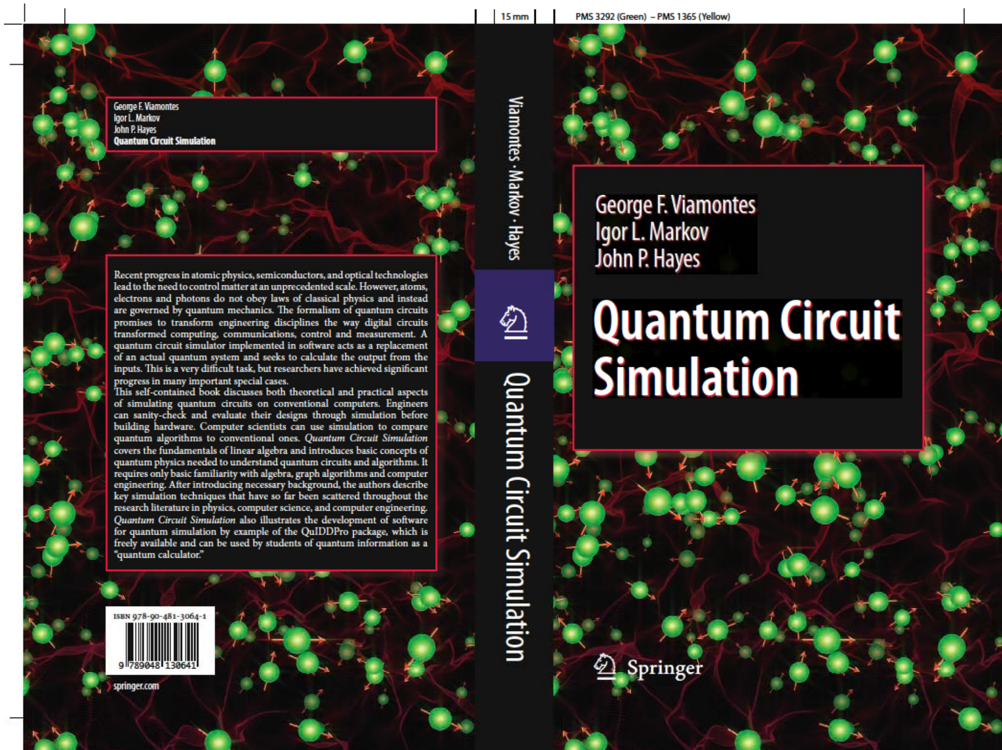
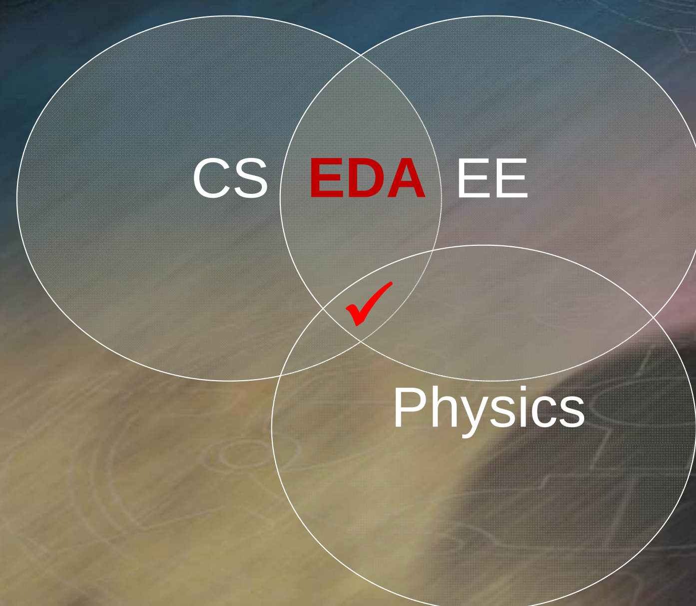
We present a method for classically simulating quantum circuits based on the tensor contraction model of Markov and Shi (e-print arXiv:quant-ph/0511069). Using this method we are able to classically simulate the approximate quantum Fourier transform in polynomial time. Moreover, our approach allow us to formulate a condition for the composability of simulable quantum circuits. We use this condition to show that any circuit composed of a constant number of approximate quantum Fourier transform circuits and log depth circuits with limited interaction range can also be efficiently simulated.

URL: http://link.aps.org/doi/10.1103/PhysRevA.76.042321
DOI: 10.1103/PhysRevA.76.042321
PACS: 03.67.Lx, 89.70.+c
KEYWORDS: Fourier transforms, quantum computing



EDA + Physics = Synergies

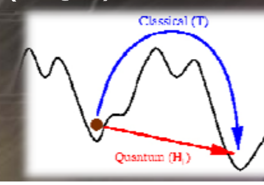


Principle of Energy Min'zation

- Physical systems naturally find *least-energy states*
- S. Kirkpatrick, C. D. Gelatt, M. P. Vecchi
  "**Optimization by Simulated Annealing**"
  Science, May 1983
  - Applied to VLSI placement with great success (interconnect length ~ total energy)
- Modern placement algorithms also use other physics metaphors
  - *Force-directed modeling; electrostatic repulsion*
- In many cases, simulation is optimization
- Vice versa: adapt EDA algos to physics & CS

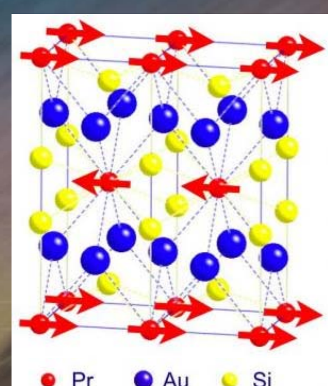
Principle of Energy Min'zation

- Idea: exploit natural energy-minimization to solve hard combinatorial problems
  - Encode problem instance into sys. configuration
  - Launch the system, let it settle into ground state
  - Read out the answers
- Energy minimization + quantum tunneling
  - *e.g., adiabatic quantum computing* (AQC)
- Sample app: number-factoring
  minimize $f(x,y)=(N-xy)^2$
  (zero out leading bits of x and y)



Ising Model

- Captures atomic interactions in physical systems using binary variables
- Represents total energy in terms of spin configurations
- Fundamental analysis tool
  - Magnetism
  - Phase transitions



$PrAu_2Si_2$
[ScienceNewsDaily.com, 4/09]

Ising Model

$G_{\text{ising}} = (V, E)$

V = set of spins (vertices): $S_0, \ldots, S_n$

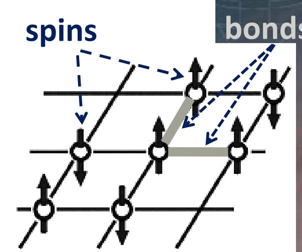
E = set of bonds (edges): (i, j)

$$S_i = \begin{cases} +1, & \text{spin is} \uparrow \\ -1, & \text{spin is} \downarrow \end{cases}$$

$J_{i,j}$ = bond weight: i.i.d (Gaussian or ± 1 bimodal)

h_i = magnetization: i.i.d (Gaussian)

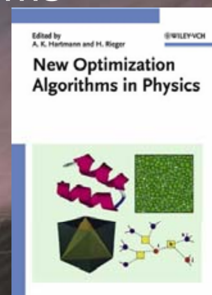
σ = spin configuration



$$Energy(\sigma) = -\sum_{(i,j)\in E} J_{i,j} S_i S_j - \sum_i h_i S_i$$

Finding Ground States

- Idea: observe computational similarities with hypergraph partitioning algorithms
  - Binary variables
  - Edge-based total cost function
  - Sparse connectivity



- Develop move-based algorithms for finding ground states in Ising spin-glasses
  - Empirical results: outperform state of the art in physics literature

From Computability to Simulation, Optimization, and back

- EDA research offers many answers as to what is computable
- EDA adapted key concepts from Physics
  - simulation ~ optimization
- EDA provided several key computational techniques to Physics, can do more
- When exploring new comp. technologies, expect many negative answers
- Use (new types of) simulation for scientific discovery, and also in engineering tools