



**What Have I Learned From
Computer Scientists
and What Else Would I Like
to Learn from Them?**

Dave Bacon

**WHAT DAVE HAS
LEARNED FROM
COMPUTER
SCIENTISTS**

NP doesn't stand for “Not Polynomial”

Why do physicists have so much trouble with NP?
Because it's not something they'd ever come up with!

Scott's proposal: C is a *physicist complexity class* iff

- (i) C has complete promise problems and
- (ii) $C^C = C$.

Examples: L, P, BPP, BQP, PSPACE

Complexity theory of physicist-classes waiting to be developed...

Computer scientists have been studying Bell inequalities



Closet computer scientist?



compute: $f(x,y)$
 quantify: bits
 communicated

thinking for
 complexity

y")

$$\hat{a} \sim \frac{1}{\sqrt{2}} (|01\rangle - |10\rangle) \sim \hat{b}$$

It's the representation, stupid

Data structures are a big deal! 2^n is not always 2^n

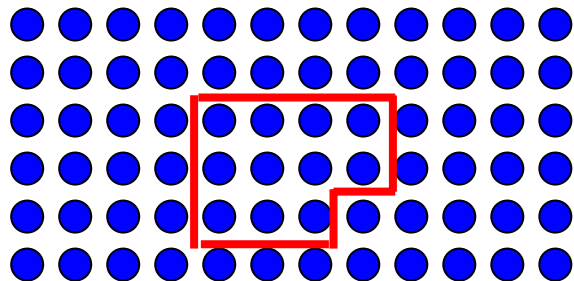
$$|\psi_1\rangle \otimes |\psi_2\rangle \otimes \cdots \otimes |\psi_n\rangle$$

2^n complex numbers vs. $2n$ complex numbers

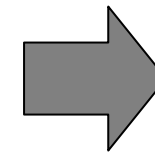
Consequences for the everyday physicist:

Efficient simulation of quantum systems

Verstraete, Vidal, Osborne, etc.



“entanglement”
proportional to
perimeter



Efficient
classical
simulation

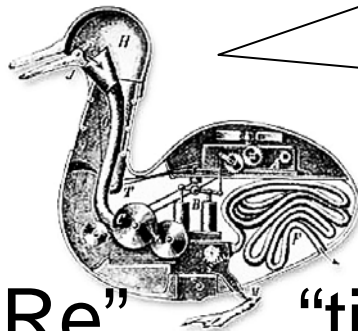
Defeat

Computer scientists have taught me how to know when I am defeated.



QMA-complete problem: Determine whether a given 2-local Hamiltonian has maximum eigenvalue at least $c+\epsilon$ or at most $c-\epsilon$, promised that one of these is the case

The power of “reduction”-ism



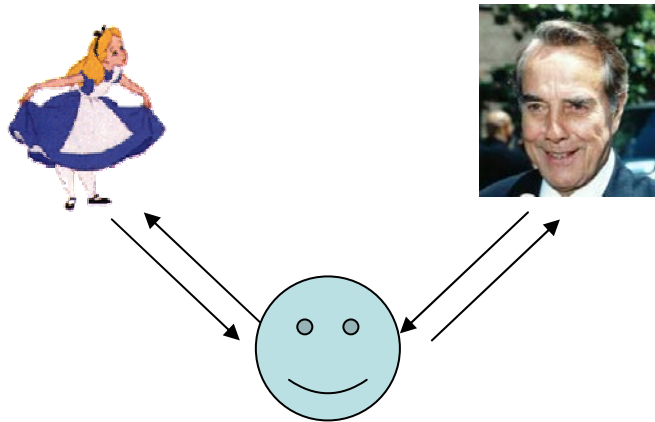
“Re” “tion”

Reduction: $A \Rightarrow B$
B is hard
Solving A is hard

Hardness of approximation

WHAT SCOTT HAS LEARNED FROM PHYSICISTS

Physicists have been studying the Parallel Repetition Theorem and didn't know it



Play such a game n times in parallel. Does the probability of winning all n games decrease exponentially in n ?

Asked by physicists in the case of the CHSH game

Parallel Repetition Theorem: Yes.

For the CHSH game, best known result comes from Feige-Lovasz semidefinite programming relaxation...

Alice and Bob can win n parallel CHSH games with probability at most 0.854^n .

A Hamiltonian is not a type of sandwich

There actually **are** some interesting questions about continuous-time quantum computing...

- Suppose a Hamiltonian H has the form $\sum_i H_i$, where each H_i acts on two neighboring vertices of a graph. Can we approximate e^{iH} by a unitary whose only nonzero entries are between neighboring vertices? What about vice versa?
- Robustness of adiabatic quantum computing

Infinite-dimensional Hilbert spaces are more trouble than they're worth

Exhibit A: Quantum Logic

- Throw out probability structure of QM
- Only look at lattice of subspaces of Hilbert space

Key insight of quantum computing: You don't need to go to infinite-dimensional Hilbert space to get interesting questions

**WHAT DAVE WOULD
LIKE TO LEARN
FROM COMPUTER
SCIENTISTS**

What is the power of the unstoppable-gate model?

Computer scientists are used to mucking around with reality (AWPP, $\text{Mod}_k L$, NEEE)

Physicists are really bad at mucking around with reality (But we can muck around with Hamiltonians!)

Can computer science contribute to conceptual revolutions in physics?

Preparation Gates Measurement

Modify: Gates are unstoppable
Measurement time: uncertain

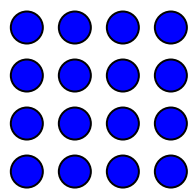
PostBQP=PP. (Another crazy thing we thought we'd put on this slide)

What else can we modular-exponentiate?

(Besides group elements?)

Is there anything that we can modular exponentiate in polynomial time but not logarithmic depth?

Related to Jozsa's question: Is $BQP = BPP^{BQNC}$?



Modular exponentiate

Hamiltonians?

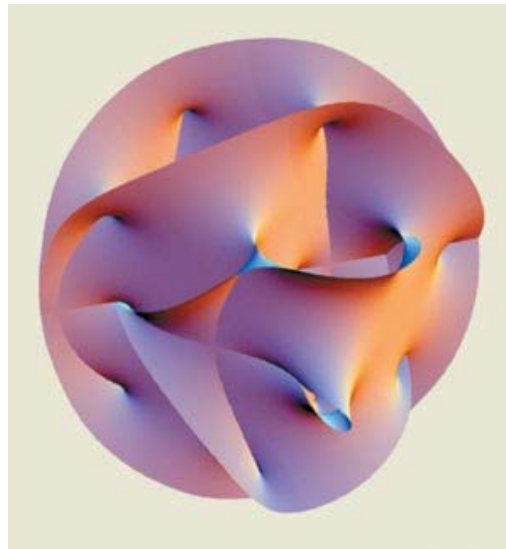
$$\exp\left(\frac{iHk}{2^n}\right)$$



Should we worry about 4-manifold isomorphism being undecidable?

Scott's answer: No.

Dave's answer:



**WHAT SCOTT
WOULD LIKE TO
LEARN FROM
PHYSICISTS**

Who ordered mass?

Mass is weird (compared to charge, spin, etc.):

- Bends spacetime
- Interconvertible with energy
- Masses of undiscovered particles seem hard to predict
- Not clear if it comes in discrete units

CompuQuestion: Can we come up with an abstract computational model where an analogue of mass pops out?

Can ask about anything (spacetime, particles, speed of light, 2nd law, black holes, ...)

What's with the holographic principle?

Holographic entropy bound: Any region of space can store at most 1.4×10^{69} bits per square meter of surface area (*not* volume)

CompuQuestion

Holographic principle: “Physics of the bulk has an isomorphic description on the boundary”

I wave my arm. How does the boundary of the solar system know about that?

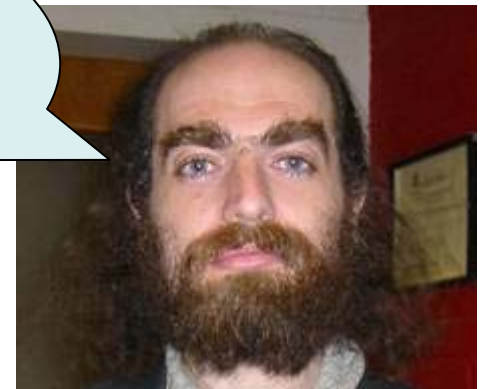
What's with the dimensionality of spacetime?

According to the physicists:

- If space had 2 dimensions, we'd already have a theory of quantum gravity
- If space had 4 or more dimensions, we'd already have fault-tolerant quantum computers

3 dimensions suck!

uoc'ge
telliig me!



One thing physicists and computer scientists can agree on

A question is only meaningful if it's phrased in terms of procedures (experiments, computations) that could in principle be performed

In other words:

The real enemy is mathematicians