Topological Quantum Computing: Progress & Opportunities

Jason Alicea
Feynman 1982: quantum computing visionary
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~$300
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N/A
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$|00\rangle + |11\rangle$

$|00\rangle + e^{i\alpha}|11\rangle$

random phase
Quantum information tends to be **fragile**

\[ |00\rangle + |11\rangle \]

\[ |00\rangle + e^{i\alpha} |11\rangle \text{ (random phase)} \]

\[ |00\rangle \]
A (three) million dollar idea

Kitaev 1997: topological quantum computing pioneer

Encode & process qubits w/ (non-Abelian) anyons—hardware immune to environmental noise!
A (three) million dollar idea

2012 Fundamental physics prize recipient!

Kitaev 1997: topological quantum computing pioneer

Encode & process qubits w/ (non-Abelian) anyons—hardware immune to environmental noise!
Anyons
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1. Exponentially many quantum states with the same energy

\[ \sim 2^{\# \text{anyons}/2} \]
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Qubits \( |000\rangle, |001\rangle, \ldots \)
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Qubits \[ \langle 000 \rangle, \langle 001 \rangle, \ldots \]

2. “Braiding” transforms qubits
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   \[ |000\rangle \rightarrow U|000\rangle \]

Qubits
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3. Interesting "fusion" properties
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Qubits \[ |000\rangle, |001\rangle, \ldots \]
Billion $ question:
How do you build the hardware?
Serendipity
Serendipity  Engineering
Serendipity

Engineering

semiconducting wire +

Lutchyn, Sau, Das Sarma; Oreg, Refael, von Oppen (2010)
Serendipity Engineering

Lutchyn, Sau, Das Sarma; Oreg, Refael, von Oppen (2010)

semiconducting wire +

superconductor +
Serendipity Engineering

- Semiconducting wire + superconductor + magnetic field

Lutchyn, Sau, Das Sarma; Oreg, Refael, von Oppen (2010)
Serendipity is not Engineering

semiconducting wire + superconductor + magnetic field

Lutchyn, Sau, Das Sarma; Oreg, Refael, von Oppen (2010)
“Majorana modes” ~ half an electron state
Marcus group

Semi-conductor

Super-conductor

Materials science breakthrough...
Iron atoms

Superconductor
Compelling Majorana-mode evidence seen in these devices (and more)!

Lots of excitement…
Compelling Majorana-mode evidence seen in these devices (and more)!

Lots of excitement…

…sometimes too much

– SCIENCE

http://www.gizmag.com/majorana-fermions-detected/22241/

Majorana fermions – the answer to Life, the Universe, and Everything?

DARIO BORGHINO  APRIL 27, 2012
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Majorana fermions – the answer to Life, the Universe, and Everything?

-No!

DARIO BORGHINO   APRIL 27, 2012
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Synthesis & Characterization
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Synthesis & Characterization

Control

Aasen, Hell, Mishmash, Higginbotham, Danon, Leijnse, Jespersen, Folk, Marcus, Flensberg, JA, arXiv:1511.05153
Nontrivial fusion
Nontrivial fusion

Prototype topological qubit

\[ |0\rangle, |1\rangle \]
How quickly can anyons be braided? 
Or: How I learned to stop worrying about diabatic errors and love the anyon

Christina Knapp,1 Michael Zaletel,2 Dong E. Liu,2 Meng Cheng,2 Parsa Bonderson,2 and Chetan Nayak2,1

1Physics Department, University of California, Santa Barbara, California 93106, USA
2Station Q, Microsoft Research, Santa Barbara, California 93106-6105, USA

$|0\rangle \rightarrow |0\rangle + i|1\rangle$
Nontrivial fusion

Prototype topological qubit

Anyon braiding

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Together, these experiments reveal the essential “DNA” of anyons
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On horizon (?):

Verifying basic tenets of topological quantum computing...

...AND demonstrating new fundamental aspects of quantum mechanics