Introduction to Topological Quantum Computing

Steven H. Simon

Alcatel-Lucent

But First: A longwinded introduction on the history of this field

Reference:

Non-Abelian Anyons and Topological Quantum Computation
S. DasSarma, M. Freedman, C. Nayak, S.H. Simon, A. Stern
arXiv:0707.1889, Rev Mod Phys upcoming

The original string theorist (~1867)

=?

Lord Kelvin
Knot Invariant:

Picture of a Knot

Rules

Such that topologically equivalent pictures give the same output

Some Mathematical Quantity

Theory of Knots

Jones Polynomial (V. Jones, 1985)

\[ t + t^3 - t^4 \]
(Most) Knot Invariants Are “Exponentially Hard” to Calculate

(Jaeger et al 1990)

What about this knot?

Seemingly Unrelated: Topological Quantum Field Theory

- TQFT = QFT where amplitudes depend only on the topology of the process. (Witten, Moore, Seiberg, Froelich, ... 1980s)

\[ Z = \int \mathcal{D}\{ \text{configs} \} e^{iS(\text{config})} \]

- For Chern-Simons TQFT, amplitude of a process is given by the Jones Polynomial of the knot. Integrating out Chern-Simons field leaves “topological interaction”. (Witten, 1989).
Proposed TQFT Computer

- If you had a TQFT in your lab, by measuring amplitudes, you could figure out the Jones Polynomial (M. Freedman, 1990s)

Solves a "hard" problem in polynomial time

Flashback to Prehistory of Quantum Computing

Simulating a quantum system (say the Hubbard model) on a classical computer is exponentially hard.

But if you had the physical quantum system in your lab, it could simulate itself easily.

Yuri Manin (1980)

1. What else could you do besides simulate yourself?
2. What would errors do?
Proposed TQFT Computer

- If you had a TQFT in your lab, by measuring amplitudes, you could figure out the Jones Polynomial (M. Freedman, 1990s)

1. What else could you do besides simulate yourself?
2. What would errors do?
3. Can we build a TQFT?

What we now believe:
1. You can do universal quantum computation with certain TQFTs
2. Errors are suppressed in a very nice way
3. Such systems exist (FQHE; more might exist if we look for them)

The Sweetest Route To Quantum Computing

1. What else could you do besides simulate yourself?
2. What would errors do?
3. Can we build a TQFT?

A. Kitaev M. Freedman
From: Bonesteel, Hormozi, Simon, Zikos, PRL05

Search and Discovery

Devices Based on the Fractional Quantum Hall Effect May Fulfill the Promise of Quantum Computing

In the 1980s, Princeton University physicist Alexei Tsvelicky and coworkers proposed the fractional quantum Hall effect. Since then, researchers have been working to control this phenomenon, which involves quantum particles with fractional quantum numbers. Now, a team of researchers has developed a new approach to creating fractional quantum Hall devices.

The new approach uses a technique called quantum Hall effect (QHE), which involves quantum particles with fractional quantum numbers. The researchers used this technique to create a new type of quantum Hall device that can be used to perform quantum computing.

Quantum computing is a rapidly growing field that has the potential to revolutionize computing technology. Quantum computers use quantum bits, or qubits, to perform calculations that are impossible for classical computers. This has led to the development of new approaches to quantum computing, including the use of quantum Hall devices.

The new approach uses a technique called quantum Hall effect (QHE), which involves quantum particles with fractional quantum numbers. The researchers used this technique to create a new type of quantum Hall device that can be used to perform quantum computing.

Quantum computing is a rapidly growing field that has the potential to revolutionize computing technology. Quantum computers use quantum bits, or qubits, to perform calculations that are impossible for classical computers. This has led to the development of new approaches to quantum computing, including the use of quantum Hall devices.

Quantum computing is a rapidly growing field that has the potential to revolutionize computing technology. Quantum computers use quantum bits, or qubits, to perform calculations that are impossible for classical computers. This has led to the development of new approaches to quantum computing, including the use of quantum Hall devices.

Quantum computing is a rapidly growing field that has the potential to revolutionize computing technology. Quantum computers use quantum bits, or qubits, to perform calculations that are impossible for classical computers. This has led to the development of new approaches to quantum computing, including the use of quantum Hall devices.

Quantum computing is a rapidly growing field that has the potential to revolutionize computing technology. Quantum computers use quantum bits, or qubits, to perform calculations that are impossible for classical computers. This has led to the development of new approaches to quantum computing, including the use of quantum Hall devices.

Quantum computing is a rapidly growing field that has the potential to revolutionize computing technology. Quantum computers use quantum bits, or qubits, to perform calculations that are impossible for classical computers. This has led to the development of new approaches to quantum computing, including the use of quantum Hall devices.

Quantum computing is a rapidly growing field that has the potential to revolutionize computing technology. Quantum computers use quantum bits, or qubits, to perform calculations that are impossible for classical computers. This has led to the development of new approaches to quantum computing, including the use of quantum Hall devices.

Quantum computing is a rapidly growing field that has the potential to revolutionize computing technology. Quantum computers use quantum bits, or qubits, to perform calculations that are impossible for classical computers. This has led to the development of new approaches to quantum computing, including the use of quantum Hall devices.

Quantum computing is a rapidly growing field that has the potential to revolutionize computing technology. Quantum computers use quantum bits, or qubits, to perform calculations that are impossible for classical computers. This has led to the development of new approaches to quantum computing, including the use of quantum Hall devices.

Quantum computing is a rapidly growing field that has the potential to revolutionize computing technology. Quantum computers use quantum bits, or qubits, to perform calculations that are impossible for classical computers. This has led to the development of new approaches to quantum computing, including the use of quantum Hall devices.

Quantum computing is a rapidly growing field that has the potential to revolutionize computing technology. Quantum computers use quantum bits, or qubits, to perform calculations that are impossible for classical computers. This has led to the development of new approaches to quantum computing, including the use of quantum Hall devices.

Quantum computing is a rapidly growing field that has the potential to revolutionize computing technology. Quantum computers use quantum bits, or qubits, to perform calculations that are impossible for classical computers. This has led to the development of new approaches to quantum computing, including the use of quantum Hall devices.

Quantum computing is a rapidly growing field that has the potential to revolutionize computing technology. Quantum computers use quantum bits, or qubits, to perform calculations that are impossible for classical computers. This has led to the development of new approaches to quantum computing, including the use of quantum Hall devices.

Quantum computing is a rapidly growing field that has the potential to revolutionize computing technology. Quantum computers use quantum bits, or qubits, to perform calculations that are impossible for classical computers. This has led to the development of new approaches to quantum computing, including the use of quantum Hall devices.

Quantum computing is a rapidly growing field that has the potential to revolutionize computing technology. Quantum computers use quantum bits, or qubits, to perform calculations that are impossible for classical computers. This has led to the development of new approaches to quantum computing, including the use of quantum Hall devices.

Quantum computing is a rapidly growing field that has the potential to revolutionize computing technology. Quantum computers use quantum bits, or qubits, to perform calculations that are impossible for classical computers. This has led to the development of new approaches to quantum computing, including the use of quantum Hall devices.

Quantum computing is a rapidly growing field that has the potential to revolutionize computing technology. Quantum computers use quantum bits, or qubits, to perform calculations that are impossible for classical computers. This has led to the development of new approaches to quantum computing, including the use of quantum Hall devices.

Quantum computing is a rapidly growing field that has the potential to revolutionize computing technology. Quantum computers use quantum bits, or qubits, to perform calculations that are impossible for classical computers. This has led to the development of new approaches to quantum computing, including the use of quantum Hall devices.

Quantum computing is a rapidly growing field that has the potential to revolutionize computing technology. Quantum computers use quantum bits, or qubits, to perform calculations that are impossible for classical computers. This has led to the development of new approaches to quantum computing, including the use of quantum Hall devices.

Quantum computing is a rapidly growing field that has the potential to revolutionize computing technology. Quantum computers use quantum bits, or qubits, to perform calculations that are impossible for classical computers. This has led to the development of new approaches to quantum computing, including the use of quantum Hall devices.

Quantum computing is a rapidly growing field that has the potential to revolutionize computing technology. Quantum computers use quantum bits, or qubits, to perform calculations that are impossible for classical computers. This has led to the development of new approaches to quantum computing, including the use of quantum Hall devices.

Quantum computing is a rapidly growing field that has the potential to revolutionize computing technology. Quantum computers use quantum bits, or qubits, to perform calculations that are impossible for classical computers. This has led to the development of new approaches to quantum computing, including the use of quantum Hall devices.

Quantum computing is a rapidly growing field that has the potential to revolutionize computing technology. Quantum computers use quantum bits, or qubits, to perform calculations that are impossible for classical computers. This has led to the development of new approaches to quantum computing, including the use of quantum Hall devices.

Quantum computing is a rapidly growing field that has the potential to revolutionize computing technology. Quantum computers use quantum bits, or qubits, to perform calculations that are impossible for classical computers. This has led to the development of new approaches to quantum computing, including the use of quantum Hall devices.

Quantum computing is a rapidly growing field that has the potential to revolutionize computing technology. Quantum computers use quantum bits, or qubits, to perform calculations that are impossible for classical computers. This has led to the development of new approaches to quantum computing, including the use of quantum Hall devices.

Quantum computing is a rapidly growing field that has the potential to revolutionize computing technology. Quantum computers use quantum bits, or qubits, to perform calculations that are impossible for classical computers. This has led to the development of new approaches to quantum computing, including the use of quantum Hall devices.
Outline:

• Long-winded introduction ✓
• Dummy’s Guide to Topological Quantum Computing

 Dummy’s Guide To Topological Quantum Computing

• Uses 2 Dimensional Systems which are realizations of TQFTs, i.e., have quasiparticles with NonAbelian Statistics.

• Quantum Information is encoded in nonlocal topological degrees of freedom that do not couple to any local quantity.

• States can be manipulated by dragging (braiding) quasiparticles around each other.

• The operations (gates) performed on the qubits depends only on the topology of the braids.
Statistics in Brief:

**Statistics:**
What happens to a many-particle wavefunction under “exchange” of identical particles.

**Dogma:**
Exchanging twice should be identity

- Bosons \( \mathcal{O}(r_1, r_2) = \mathcal{O}(r_2, r_1) \)
- Fermions \( \mathcal{O}(r_1, r_2) = -\mathcal{O}(r_2, r_1) \)

**In 2+1 Dimensions:**
Two Exchanges ≠ Identity

**In 3+1 Dimensions:**
Two Exchanges = Identity
No Knots in World Lines in 3+1 D!
Statistics:

In 3+1 D:
- No Knots in World Lines
- Topologically Different Paths = Different Permutations
- Statistics are Rep of the Permutation Group
- Bosons or Fermions

In 2+1 D:
- Knots in World Lines
- Topologically Different Paths = Different Braids
- Statistics are a Rep of the Braid Group
- More Possibilities (Anyons + Non-Abelions)

What is NonAbelian Statistics?

Suppose 2 Degenerate Orthogonal States $\psi_1, \psi_2$

$$\Theta_1 = a_1\psi_1 + a_2\psi_2 = \begin{pmatrix} a_1 \\ a_2 \end{pmatrix}$$

Matrix Representation Of The Braid Group
Froelich, Moore, Read, Witten, …

Unitary Matrix Represents (Topological) Braid Operation
Braid Group is "Non-Abelian" = Non-Commutative

Statistics Are Matrix Representation of Braid Group:
+ Matrices are Non-Abelian \[\text{NonAbelian Statistics}\]

**Non-Abelian Statistics (Summary):**

• Vector Represents State Within a Degenerate Space

\[ |\psi_1\rangle , |\psi_2\rangle \]

\[ \Theta_i = a_1|\psi_1\rangle + a_2|\psi_2\rangle = \begin{pmatrix} a_1 \\ a_2 \end{pmatrix} \]

• Dimension of degenerate space increases exponentially with number of quasiparticles.

• Unitary (Berry’s) Matrix Represents an Adiabatic Braiding Operation

\[ \Theta_f = U \Theta_i \]

Unitary Matrix Depends Only on The Topology of the Braid = TQFT
Dummy’s Guide To Topological Quantum Computing

• Uses 2 Dimensional Systems With “Non-Abelian” Statistics. (Also known as TQFTs).

Yes! FQHE

Is this for real?

And maybe someday in cold trapped atoms, spin systems, chiral p-wave superconductors, rotating BECs, JJ arrays, etc…

FQHE Experiments:

Horst Stormer  Dan Tsui

Bob Laughlin
**Nonabelian Statistics Really Exist In Quantum Hall States**
(We Think)

Numerical work by Rezayi, Haldane, Morf, and others *strongly* suggests that…

Many experiments under way to try to prove this!

**Dummy’s Guide To Topological Quantum Computing**

- Uses 2 Dimensional Systems With “Non-Abelian” Statistics.
  (Also known as TQFTs).

Yes! FQHE

Is this for real?

And maybe someday in spin systems, cold trapped atoms, chiral p-wave superconductors, rotating BECs, JJ arrays, etc…
**Dummy’s Guide To Topological Quantum Computing**

- Uses 2 Dimensional Systems with "Non-Abelian" Statistics. (Also known as TQFTs).

  If you could design any Hamiltonian, you could choose one that gives Nonabelian Statistics.

  None of these Hamiltonians are particularly simple. None have (yet!) been found in nature.

  - Kitaev, Freedman, Levin, Wen, Nayak, Shtengel, Fendley, Fradkin, …

  And maybe someday in spin systems, cold trapped atoms, chiral p-wave superconductors, rotating BECs, JJ arrays, etc…

---

**Dummy’s Guide To Topological Quantum Computing**

- Uses 2 Dimensional Systems with "Non-Abelian" Statistics. (Also known as TQFTs).

  If you could design any Hamiltonian, you could choose one that gives Nonabelian Statistics.

  In cold atom lattices you can design your Hamiltonian

  … but … (T, t)

  - Zoller et al; Troyer, Whaley, …

  And maybe someday in spin systems, cold trapped atoms, chiral p-wave superconductors, rotating BECs, JJ arrays, etc…
Dummy’s Guide To Topological Quantum Computing

- Uses 2 Dimensional Systems With “Non-Abelian” Statistics. (Also known as TQFTs).

Quantum Information is encoded in nonlocal topological degrees of freedom that do not couple to any local quantity.

States are (usually) manipulated by dragging (braiding) quasiparticles around each other.

The operations (gates) performed on the qubits depends only on the topology of the braids.

And maybe someday in spin systems, cold trapped atoms, chiral p-wave superconductors, rotating BECs, JJ arrays, etc.

1) Real Superconductors: SrRuO4?

(2) Chiral p-wave pairing of cold atoms? Radzihovsky, Gurarie, et al … but … (T,t)

Rotating BEC = Quantum Hall Effect in Disguise
Coriolis Force = Lorentz Force

Ratio of (Rotation Rate / Density) needs to be increased 1-2 orders of magnitude still … and (T, t)

Cooper, Gunn, Wilken, Read, Rezayi, …
**Dummy’s Guide To Topological Quantum Computing**

- Uses 2 Dimensional Systems With “Non-Abelian” Statistics.
  (Also known as TQFTs.)

  JJ Arrays …
  Still a long way to go…
  … ask Lev…

And maybe someday in spin systems, cold trapped atoms, chiral p-wave superconductors, rotating BECs, JJ arrays, etc…

---

**Dummy’s Guide To Topological Quantum Computing**

- Uses 2 Dimensional Systems With “Non-Abelian” Statistics.
  (Also known as TQFTs.)

  Yes! FQHE

  In FQHE we believe we have *already* created phases of matter where nonabelian statistics exists.
Re:Theoretical Evidence

- Observation of FQHE
- $H = \text{Interacting 2D Electrons in B}$
- Low Energy (Chern-Simons) TQFT
- Symmetry Emergence – not symmetry breaking!

Re:Theoretical Comment

- Symmetry Emergence – not symmetry breaking!
**Dummy’s Guide To Topological Quantum Computing**

- Uses 2 Dimensional Systems which are realizations of TQFTs, i.e., have quasiparticles with **NonAbelian Statistics**.

- Quantum Information is encoded in **nonlocal topological degrees of freedom** that do not couple to *any* local quantity.

- States can be manipulated by dragging (**braiding**) quasiparticles around each other.

- The operations (gates) performed on the qubits depends only on the topology of the braids.

---

**Quasiparticles in Fractional QHE**

- Quasiparticles are topological defects
- Charge lives in the core
- **topological degrees of freedom live in the “vorticity”** (sort of)

The topological degree of freedom can be thought of as the configuration class of the emergent Chern-Simons gauge field.

Energy is independent of this topological degree of freedom.
**Topological Quantum Numbers:**

• (Usually) An individual quasiparticle exists only in a single state

---

**Topological Quantum Numbers:**

• Two (or more) quasiparticles can exist in more than one state… described by a quantum number, ex 0 or 1

You cannot determine the quantum number by only measuring one of the quasiparticles
Topological Quantum Numbers:

- Groups of particles similarly have quantum numbers

These quantum numbers can be thought of as describing the global topology of the effective Chern-Simons gauge field

Dummy’s Guide To Topological Quantum Computing

- Uses 2 Dimensional Systems which are realizations of TQFTs, i.e., have quasiparticles with NonAbelian Statistics.

- Quantum Information is encoded in nonlocal topological degrees of freedom that do not couple to any local quantity.

- States can be manipulated by dragging (braiding) quasiparticles around each other.

- The operations (gates) performed on the qubits depends only on the topology of the braids.
Topological Quantum Numbers:

- Groups of particles similarly have quantum numbers

These quantum numbers can be thought of as describing the global topology of the effective Chern-Simons gauge field.

No local measurements can determine this quantum number! →
No local operator can couple to this quantum number →
Topological quantum numbers decoupled from "noise"

Comparison with Conventional Error Protection:

<table>
<thead>
<tr>
<th>Conventional Protection:</th>
<th>Topological Protection:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Many Physical Qubits Code One &quot;Logical&quot; or Computational Qubit</td>
<td>Global topology codes qubits</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Physical</th>
<th>Detailed Geometry</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\alpha</td>
<td>00000&gt; + \beta</td>
</tr>
<tr>
<td>$\alpha</td>
<td>0&gt; + \beta</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Topology</th>
<th>Redundancy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Software Error Correction</td>
<td>Hardware Error Protection</td>
</tr>
</tbody>
</table>

Midway: Bacon Codes etc
**Dummy’s Guide To Topological Quantum Computing**

- Uses 2 Dimensional Systems which are realizations of TQFTs, i.e., have quasiparticles with NonAbelian Statistics.

- Quantum Information is encoded in nonlocal topological degrees of freedom that do not couple to any local quantity.

---

**How to Measure?**

**How to Manipulate?**

---

**Topological Quantum Numbers:**

- To Measure the Quantum Number

(1) Move the particles microscopically close, and measure force
To Measure the Quantum Number

(1) Move the particles microscopically close, and measure force

OR

(2) Do an interference experiment surrounding both quasiparticles

 Dummy’s Guide To Topological Quantum Computing

• Uses 2 Dimensional Systems which are realizations of TQFTs, i.e., have quasiparticles with NonAbelian Statistics.

• Quantum Information is encoded in nonlocal topological degrees of freedom that do not couple to any local quantity.

• States can be manipulated by dragging (braiding) quasiparticles around each other.

• The operations (gates) performed on the qubits depends only on the topology of the braids.
Dragging (Braiding) Particles Adiabatically
Dragging (Braiding) Particles Adiabatically

Major Simplification !

Theorem (Simon, Bonesteel, Freedman… PRL05): In any topological quantum computer, all computations can be performed by moving only a single quasiparticle!

Reduced technological difficulty!
Simple Example: 5/2 state

\[ \Psi_i = |00\rangle \]
Simple Example: 5/2 state

\[ \Psi_i = |11\rangle \]

Not quite so simple example: 12/5 state

\[ \Psi_i = |00\rangle \]
Not quite so simple example: 12/5 state

\[ \Psi_f = A \left| 00 \right> + B \left| 11 \right> \]

\[ |B/A| = \text{golden mean} = \frac{1 + \sqrt{5}}{2} \]
**Dummy’s Guide To Topological Quantum Computing**

- Uses 2 Dimensional Systems which are realizations of TQFTs, i.e., have quasiparticles with **NonAbelian Statistics**.

- Quantum Information is encoded in **nonlocal topological degrees of freedom** that do not couple to *any* local quantity.

- States can be manipulated by dragging (braiding) quasiparticles around each other.

- The operations (gates) performed on the qubits depends **only** on the topology of the braids.

---

**Topological Robustness**

- 

- 

-
**Topological Robustness**

Quantum Information is Topologically Protected (Isolated) From Decoherence

*AND*

The Operations are Topologically Protected!

- The operations (gates) performed on the qubits depends *only* on the topology of the braids.
From an interview with Bill Gates in the May, 2004 online edition of Scientific American

SA: Well, some of the physical entities [non-Abelian anyons, a type of sub-atomic particle] need to actually be discovered before they can move ahead from theory to create the type of quantum computer that Michael Freedman is working on at Microsoft Research?

BG: There is an approach that doesn't involve an advance in physics; it involves a missing piece in terms of a physical phenomenon that we don't know about. The models are in terms of existing physical phenomena. Now, can you really build that. Does it scale up? It's hard to say.
Outline:

- Long-winded introduction ✓
- Dummy's Guide to Topological Quantum Computing ✓
- FAQ

Frequently Asked Questions

1. Is there ANY decoherence?
2. Why is topological so much better than nontopological q-computing?
3. Does it matter if you put the quasiparticles back where they started?
4. Can you quantum compute with the 5/2 state?
5. What other fractions are interesting?
6. How far apart should the particle be, and how fast should you move the particles around.
7. Can you show me a CNOT gate? how accurate is it?
8. How many braid operations does it take to do a useful computation
9. Do you really believe this?
Frequently Asked Questions

1. Is there ANY decoherence?
2. Why is topological so much better than nontopological q–computing?
3. Does it matter if you put the quasiparticles back where they started?
4. Can you quantum compute with the 5/2 state?
5. What other fractions are interesting?
6. How far apart should the particle be, and how fast should you move the particles around?
7. Can you show me a CNOT gate? how accurate is it?
8. How many braid operations does it take to do a useful computation
9. Do you really believe this?

Decoherence?

Topologically Nontrivial Processes Creates Decoherence

These process can be eliminated exponentially at low T!
Frequently Asked Questions

1. Is there ANY decoherence?
2. Why is topological so much better than nontopological q–computing?
3. Does it matter if you put the quasiparticles back where they started?
4. Can you quantum compute with the 5/2 state?
5. What other fractions are interesting?
6. How far apart should the particle be, and how fast should you move the particles around.
7. Can you show me a CNOT gate? how accurate is it?
8. How many braid operations does it take to do a useful computation
9. Do you really believe this?

Why is topological so good

- Topological Protection of Memory -
  - Decoherence is suppressed EXPONENTIALLY

- Operations are AUTOMATICALLY PRECISE (quantized)

“Beauty is truth, truth beauty,—that is all ye know on earth, and all ye need to know.” – Keats
**Frequently Asked Questions**

1. Is there ANY decoherence?
2. Why is topological so much better than nontopological q–computing?
3. Does it matter if you put the quasiparticles back where they started?
4. Can you quantum compute with the 5/2 state?
5. What other fractions are interesting?
6. How far apart should the particle be, and how fast should you move the particles around.
7. Can you show me a CNOT gate? how accurate is it?
8. How many braid operations does it take to do a useful computation
9. Do you really believe this?

---

**Not quite so simple example: 12/5 state**

\[ \Psi_i = \vert 00 \rangle \]
**Not quite so simple example: 12/5 state**

\[ \Psi = A |00\rangle + B |11\rangle \]

\[ |B/A| = \text{golden mean} = \frac{1 + \sqrt{5}}{2} \]

This is a very simple quantum computation.
**Frequently Asked Questions**

1. Is there ANY decoherence?
2. Why is topological so much better than nontopological q-computing?
3. Does it matter if you put the quasiparticles back where they started?
4. Can you quantum compute with the 5/2 state?
5. What other fractions are interesting?
6. How far apart should the particle be, and how fast should you move the particles around.
7. Can you show me a CNOT gate? how accurate is it?
8. How many braid operations does it take to do a useful computation?
9. Do you really believe this?

---

**Does 5/2 compute?**

Universal Q-Computation ⇔ Approximate any Unitary Transform

The Moore-Read Pfaffian Cannot Do This!

Braid Group Representation is not “Dense”

---

BUT…. Hybrid schemes might work!
Frequently Asked Questions

1. Is there ANY decoherence?
2. Why is topological so much better than nontopological q−computing?
3. Does it matter if you put the quasiparticles back where they started?
4. Can you quantum compute with the 5/2 state?
5. What other fractions are interesting?
6. How far apart should the particle be, and how fast should you move the particles around.
7. Can you show me a CNOT gate? how accurate is it?
8. How many braid operations does it take to do a useful computation
9. Do you really believe this?

Universal Set of Topologically Robust Gates
(Bonesteel, Hormozi, Simon, 2005, 2006)

Single qubit rotations: $|\psi\rangle \rightarrow U_{\phi} \rightarrow U_{\phi} |\psi\rangle$

Controlled NOT:
Solovay-Kitaev Improved CNOT

Frequently Asked Questions

1. Is there ANY decoherence?
2. Why is topological so much better than nontopological q-computing?
3. Does it matter if you put the quasiparticles back where they started?
4. Can you quantum compute with the 5/2 state?
5. What other fractions are interesting?
6. How far apart should the particle be, and how fast should you move the particles around.
7. Can you show me a CNOT gate? how accurate is it?
8. How many braid operations does it take to do a useful computation
9. Do you really believe this?
Frequently Asked Questions

Do you really believe this?

Introduction to
Topological Quantum Computing
Introduction to Topological Quantum Computing

Thanks for Listening!