Knot, knot. Who's there?

Gregory Hamilton

Follow this and additional works at: http://scholarship.richmond.edu/forum

Part of the Civic and Community Engagement Commons, Community-Based Learning Commons, Journalism Studies Commons, Nonfiction Commons, Other Arts and Humanities Commons, Other Social and Behavioral Sciences Commons, Photography Commons, and the Publishing Commons

Recommended Citation

Available at: http://scholarship.richmond.edu/forum/vol2016/iss2/2

This Feature is brought to you for free and open access by UR Scholarship Repository. It has been accepted for inclusion in Forum Magazine by an authorized editor of UR Scholarship Repository. For more information, please contact scholarshiprepository@richmond.edu.
**Physics, b*tches.** If you’re like me, you spend more time with computers than people. Depressing, I know. To their credit, computers don’t make snide comments about my “social ineptness” or “that incident last Christmas” (looking at you, Aunt Janet). Computers also happen to be central to solving innumerable problems in physics, economics, climatology, chemistry – you get the picture. Thus, we need our computers and their components to be small, fast and powerful. Unfortunately, we’re close to hitting a wall. By Moore’s Law, the number of transistors – the primary component of computers – on an integrated circuit doubles roughly every two years, becoming smaller and smaller. But transistors can only get so small. At the length scale we’re working with, electronics will stop existing in the way we classically think of them. This implies we’ll have to take a quantum approach to computing.

“Why would we do that?” you ask. “Sounds hard.” You’re right on that point, but in principle, quantum computers won’t do anything that classical computers can’t. However, they will offer extraordinary speed-ups in computation. I’m talking thousands of times faster. They’ll allow us to simulate quantum many-body problems, model superconductivity and bring huge insights to long-standing problems in many disciplines of science. Quantum computing is the next step in expanding our knowledge – the next Internet, if you will.

So what is quantum computing? In a classical computer, a question or operation is framed in terms of 0s and 1s via electrical signals. You’d give the question to the computer, and it would use “logic gates,” or transistors to manipulate the information and give an answer to your question and perform your operation. For a quantum computer, we would do much the same thing. Our 0s and 1s would correspond to a particle’s state. As an example, every particle has a “spin,” which can be either “up” or “down.” If a particle is in state “up,” we can call that “1,” and if it’s in state “down,” call it “0.” For a large number of particles in some initial configuration of “ups” and “downs,” we’d again use logic gates (here called quantum operators) to manipulate the data and get an answer.

The difference is that, for quantum computing, particles aren’t just in the “0” or “1” state. They’re in both and everything in between. In quantum mechanics, the world gets fuzzy, and particle properties don’t assume...
discrete values until we measure them. That particle is in a superposition of states. Because of this superposition, a quantum computation is like millions of classical computers running the same calculation but with different initial configurations. This is what gives a quantum computer its power.

Working to build a quantum computer has made great progress in the past few decades, but we’ve hit some snags. For one, the world outside a quantum computer is hostile. The environment easily interferes with computations. And if our logic gates aren’t precisely tuned, then we don’t do the calculation we wanted. So what’s a scientist to do? Tie knots.

You heard me. Tie knots.

In the usual three-dimensional world you and I live in, there are really only two types of particles: bosons and fermions. Go down to two dimensions, and we find particles known as anyons. Quantum computers rely upon anyons for their operations, but these particles exhibit rather unique behavior. Take any two anyons and interchange them, moving one in a circle around the other. The direction in which they were interchanged matters! That is, there is a measurable difference between whether you interchanged them in a clockwise or counter-clockwise manner. The path anyons take through space-time is similar in fashion to a string. Strings can be braided together and form knots. The field of knot theory is wholly devoted to finding out how we tell the difference between knots. It turns out that if we set up certain types of anyons in an organized fashion – that is, we frame our “question” for the computer – and we braid them together by moving them in circles around one another, we can build a quantum knot in space-time. The braids that we make become logic gates along the way, and when we close the braid and form the knot, we measure it by computing the knot invariant (something that stays constant for a knot, no matter how you twist or fold it). Repeat that process enough times, and you’ve got your answer to the original question you framed.

But why tie knots? What’s the advantage? The beautiful thing about knots is that they’re robust. Tie your shoes, and then take the two lace ends and fuse them together. Ignoring the actual shoe for a moment, the shoelaces have formed a knot. So long as you don’t tear the knot, it will stay the same no matter how much you stretch, squeeze, bend or tighten the lace. The information in the knot is preserved. For a knot, it doesn’t matter how wiggly the string is, so long as you braided it correctly. In this kind of quantum computation (known as topological quantum computing), the knot is made not by individual strings, but by the whole particle ensemble. Thus, particles can jiggle, or the environment can interfere, and neither effect really matters so long as the knot has been made. That is, we’ve hardcoded substantial error correction into the system – a huge hurdle to overcome in quantum computing. Topological quantum computing is still just theory, but given the massive funding by organizations like Microsoft, Google and Big Brother, we’re hoping to see concrete results soon.

To tie it all together (Father, forgive me for the puns I’m about to commit), knots have become critical to our understanding and application of topological quantum computing. It’s a field that braids together multiple disciplines and offers a glimpse of the future of technology and information. So to conclude, ask knot what you can do for topological quantum computing, but what topological quantum computing can do for you.

Knot Theory in Action: These two anyon particles are sitting in a two dimensional space. Here, particle one (red) moves in a path around particle two (blue). Normally, when red gets back to its starting position, nothing’s changed. But in anyon statistics, the system is altered, and the alteration depends on whether red moved clockwise or counterclockwise around blue.