A Tale of Two Memories

by Gregory Crosswhite and Dave Bacon

Prologue--the Nature of Information

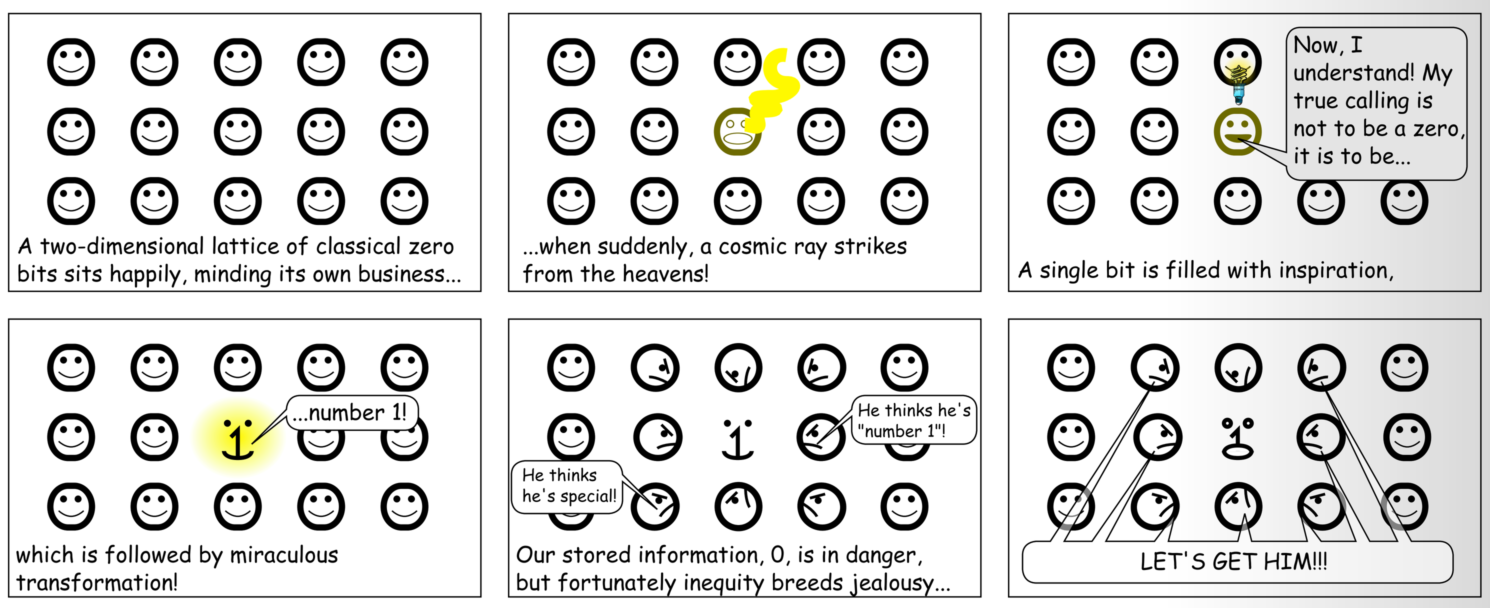
We have nature to thank for the myriad of electronic gadgets made possible by the relative ease of storing classical information. Were it not for the existence of physical systems that naturally protect encoded classical information, the miniaturization and commoditization of computing machinery which hailed the information age might never have happened!

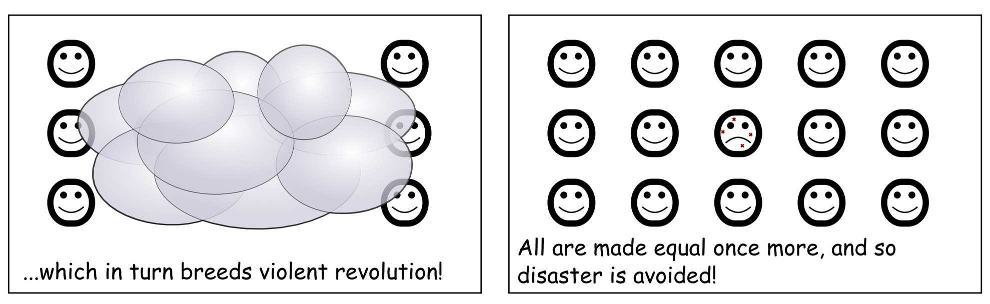
The goal of our group is to duplicate this success in the world of quantum information. We are seeking physical systems that robustly store quantum information just as well as their classical counterparts.

In this poster, we review the key idea of "peer pressure" (a result of magnetic couplings) that makes classical memories possible in two or more dimensions, and then we discuss what is known about quantum memories, and what unknowns we are now investigating.

Book the First--Classical Bits

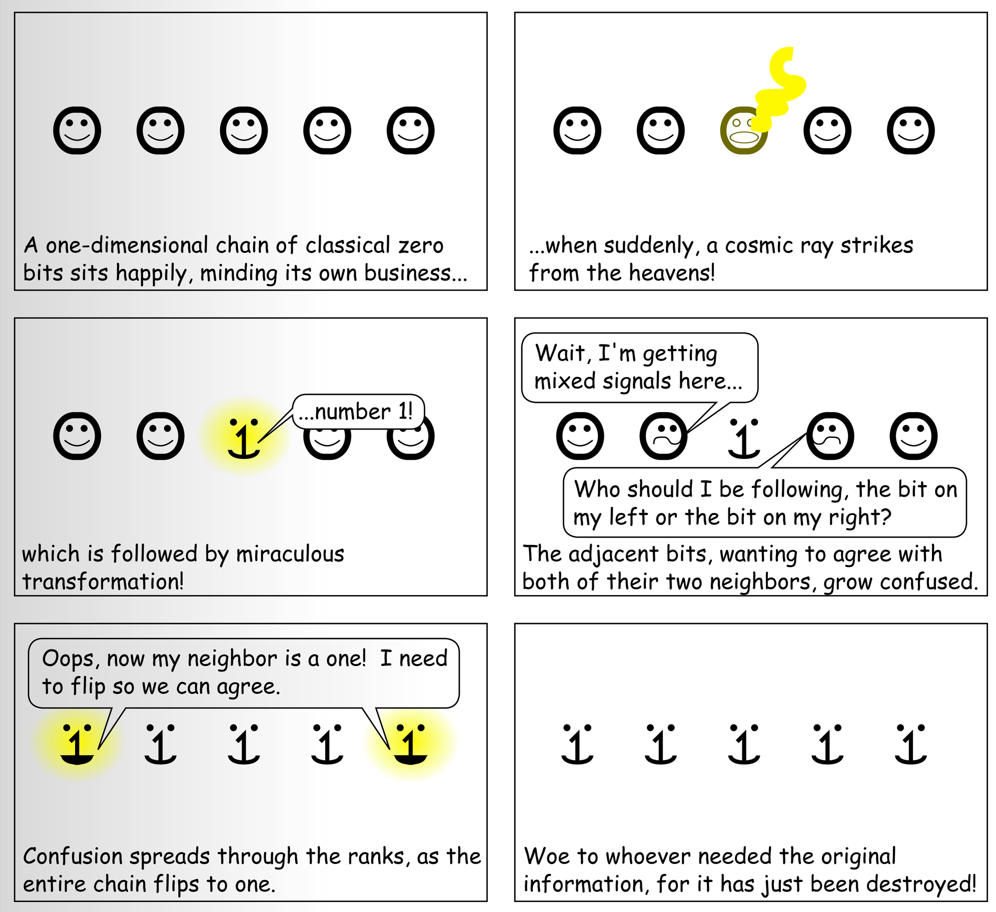
It was the best of memories,

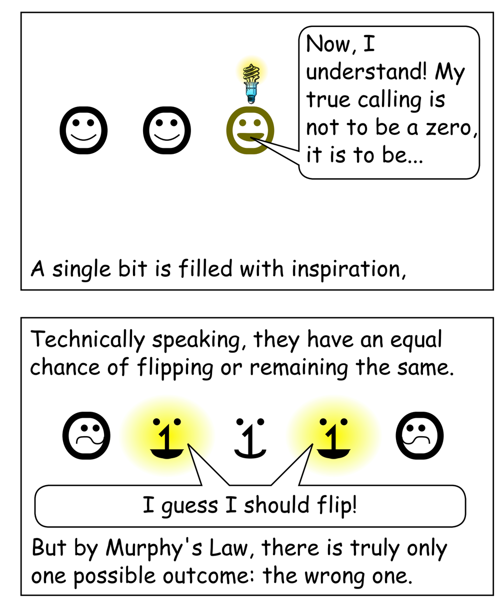




This strip shows how we are able to build physical systems that protect stored information, thanks to magnetic couplings between the particles that act as "peer-pressure". However, not all systems with such couplings act as a robust memory, as the next strip will illustrate.

it was the worst of memories.





Unlike the system on the previous page, this system is unable to store classical information, because it does not have enough dimensions; particles do not have enough neighbors to be able to tell the wrong bits from the right bits. Thus, classical memories need at least two dimensions.

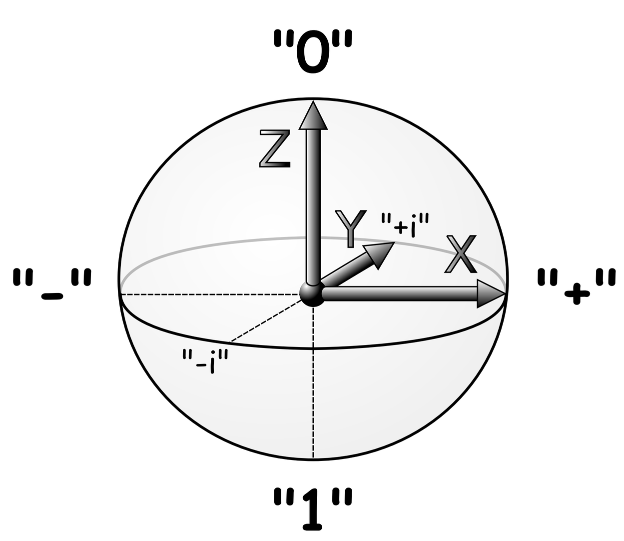
Ribbon of References

Eric Dennis, Alexei Kitaev, Andrew Landahl, and John Preskill, "Topological quantum memory," J. Math. Phys. 43, 4452-4505 (2002).

Dave Bacon, "Operator Quantum Error Correcting Subsystems for Self-Correcting Quantum Memories," Phys. Rev. A 73, 012340 (2006).

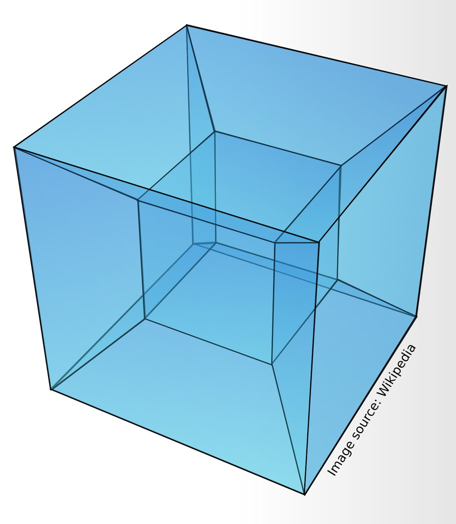
Book the Second--Quantum Bits

There was a surplus of dimensions,



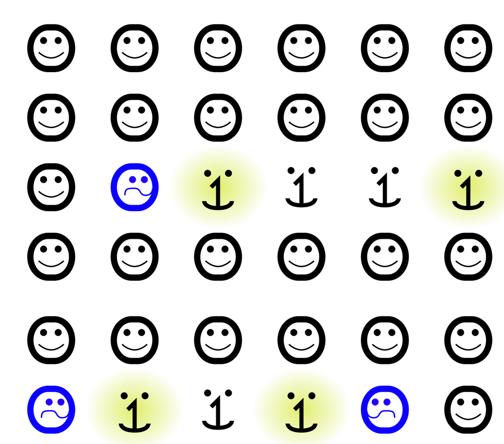
Quantum bits ("qubits"), unlike classical bits, have two continuous degrees of freedom. Values for the qubit can be visualized as points on a sphere. Some of these points have been given special names, in some cases hinting to a correspondance with values of a classical bit.

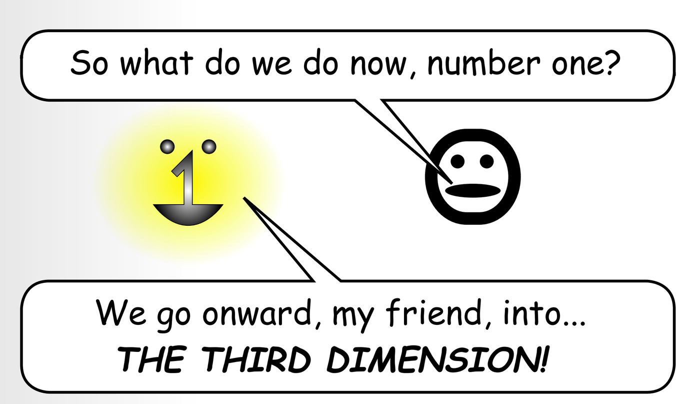
The only known robust quantum memory requires *four* dimensions. The intuition for why this is true lies in thinking in terms of a generalization of the successful two-dimensional classical memory with two dimensions used for *each* degree of freedom. Needless to say, four dimensions are one too many for this system to be built!



there was a shortage of dimensions.

But if four dimensions are too many, then two are too few! To understand why, think of the two degrees of freedom of the qubit as being split between the two dimensions of the system; as a result, each degree of freedom is effectively stored in only one dimension. As the diagram on the right shows, errors propagate in chains across the system, with particles at the endpoints as likely to add to the error chain as they are to pare it back.





So must we give up our quest for a robust quantum memory? Balderdash! We might not live in four dimensions, but we certainly have more than two! Is three dimensions enough to build a quantum memory? That is what our group is determined to find out!

Are we forever doomed to choose between the inconstructible and the ineffectual, or is there a third way? ***TO BE CONTINUED...***