Adrian Hutter **Journal Club** 17 June 2014

Cellular-automaton decoders for topological quantum memories
M. Herold, E. T. Campbell, J. Eisert, and M. J. Kastoryano
arXiv:1406.2338

We introduce a new framework for constructing topological quantum memories, by recasting error recovery as a dynamical process on a cellular automaton. We envisage quantum systems controlled by a classical hardware composed of small local memories, communicating with neighbors, and repeatedly performing identical simple update rules. This approach does not require any global operations or complex decoding algorithms. Our cellular automata draw inspiration from classical field theories, with a Coulomb-like potential naturally emerging from the local dynamics. For a 3D automaton coupled to a 2D toric code, we present evidence of an error correction threshold above 6.1% for uncorrelated noise. A 2D automaton equipped with a more complex update rule yields a threshold above 8.2%. Our framework provides decisive new tools in the quest for realizing a passive dissipative quantum memory.

Time-reversal-invariant topological superconductivity induced by repulsive interactions in quantum wires
Arbel Haim, Anna Keselman, Erez Berg, and Yuval Oreg
Phys. Rev. B **89**, 220504(R)

We consider a model for a one-dimensional quantum wire with Rashba spin-orbit coupling and repulsive interactions, proximity coupled to a conventional s-wave superconductor. Using a combination of Hartree-Fock and density matrix renormalization group calculations, we show that for sufficiently strong interactions in the wire, a time-reversal-invariant topological superconducting phase can be stabilized in the absence of an external magnetic field. This phase supports two zero-energy Majorana bound states at each end, which are protected by time-reversal symmetry. The mechanism for the formation of this phase is a reversal of the sign of the effective pair potential in the wire, due to the repulsive interactions. We calculate the differential conductance into the wire and its dependence on an applied magnetic field using the scattering-matrix formalism. The behavior of the zero-bias anomaly as a function of the field direction can serve as a distinct experimental signature of the topological phase.

Adiabatic topological quantum computing
Chris Cesare, Andrew J. Landahl, Dave Bacon, Steven T. Flammia, and Alice Neels
arXiv:1406.2690

Topological quantum computing promises error-resistant quantum computation without active error correction. However, there is a worry that during the process of executing quantum gates by braiding anyons around each other, extra anyonic excitations will be created that will disorder the encoded quantum information. Here we explore this question in detail by studying adiabatic code deformations on Hamiltonians based on topological codes, notably Kitaev's surface codes and the more recently discovered color codes. We develop protocols that enable universal quantum computing by adiabatic evolution in a way that keeps the energy gap of the system constant with respect to the computation size and introduces only simple local Hamiltonian interactions. This allows one to perform holonomic quantum computing with these topological quantum computing systems. The tools we develop allow one to go beyond numerical simulations and understand these processes analytically.

Novel Phase of Solid Oxygen Induced by Ultrahigh Magnetic Fields
T. Nomura, Y.H. Matsuda, S. Takeyama, A. Matsuo, K. Kindo, J.L. Her, and T.C. Kobayashi
Phys. Rev. Lett. **112**, 247201

Magnetization measurements and magnetotransmission spectroscopy of the solid oxygen α phase were performed in ultrahigh magnetic fields of up to 193 T. An abrupt increase in magnetization with large hysteresis was observed when pulsed magnetic fields greater than 120 T were applied. Moreover, the transmission of light significantly increased in the visible range. These experimental findings indicate that a first-order phase transition occurs in solid oxygen in ultrahigh magnetic fields, and that it is not just a magnetic transition. Considering the molecular rearrangement mechanism found in the $O_2 - O_2$ dimer system, we conclude that the observed field-induced transition is caused by the antiferromagnetic phase collapsing and a change in the crystal structure.

Single-Shot Readout and Relaxation of Singlet and Triplet States in Exchange-Coupled ^{31}P Electron Spins in Silicon
Juan P. Dehollain, Juha T. Muhonen, Kuan Y. Tan, Andre Saraiva, David N. Jamieson, Andrew S. Dzurak, and Andrea Morello
Phys. Rev. Lett. **112**, 236801

We present the experimental observation of a large exchange coupling J=300μeV between two P31 electron spin qubits in silicon. The singlet and triplet states of the coupled spins are monitored in real time by a single-electron transistor, which detects ionization from tunnel-rate-dependent processes in the coupled spin system, yielding single-shot readout fidelities above 95%. The triplet to singlet relaxation time T1=4ms at zero magnetic field agrees with the theoretical prediction for J-coupled P31 dimers in silicon. The time evolution of the two-electron state populations gives further insight into the valley-orbit eigenstates of the donor dimer, valley selection rules and relaxation rates, and the role of hyperfine interactions. These results pave the way to the realization of two-qubit quantum logic gates with spins in silicon and highlight the necessity to adopt gating schemes compatible with weak J-coupling strengths.

Generation of universal linear optics by any beam splitter
Adam Bouland and Scott Aaronson
Phys. Rev. A **89**, 062316

In 1994, Reck et al. showed how to realize any unitary transformation on a single photon using a product of beam splitters and phase shifters. Here we show that any single beam splitter that nontrivially mixes two modes also densely generates the set of unitary transformations (or orthogonal transformations, in the real case) on the single-photon subspace with $m \geq 4$ modes. (We prove the same result for any two-mode real optical gate, and for any two-mode optical gate combined with a generic phase shifter.) Experimentally, this means that one does not need tunable beam splitters or phase shifters for universality: any nontrivial beam splitter is universal for linear optics. Theoretically, it means that one cannot produce intermediate models of linear optical computation (analogous to the Clifford group for qubits) by restricting the allowed beam splitters and phase shifters: there is a dichotomy; one either gets a trivial set or else a universal set. No similar classification theorem for gates acting on qubits is currently known. We leave open the problem of classifying optical gates that act on three or more modes.

Emergence of charge density wave domain walls above the superconducting dome in 1T-TiSe2
Y. I. Joe, X. M. Chen, P. Ghaemi, K. D. Finkelstein, G. A. de la Pea, Y. Gan, J. C. T. Lee, S. Yuan, J. Geck, G. J. MacDougall, T. C. Chiang, S. L. Cooper, E. Fradkin, and P. Abbamonte
Nat. Phys. **10**, pp 421 - 425

When the charge density wave state in TiSe2 is suppressed by hydrostatic pressure or chemical doping, superconductivity appears. This suggests the presence of a quantum critical point. Yet a high pressure X-ray study unexpectedly finds that the quantum critical point is nowhere near the superconducting dome.

Possible Origin of Stagnation and Variability of Earths Biodiversity
Frank Stollmeier, Theo Geisel, and Jan Nagler
Phys. Rev. Lett. **112**, 228101

The magnitude and variability of Earths biodiversity have puzzled scientists ever since paleontologic fossil databases became available. We identify and study a model of interdependent species where both endogenous and exogenous impacts determine the nonstationary extinction dynamics. The framework provides an explanation for the qualitative difference of marine and continental biodiversity growth. In particular, the stagnation of marine biodiversity may result from a global transition from an imbalanced to a balanced state of the species dependency network. The predictions of our framework are in agreement with paleontologic databases.