# Journal Club, 8th October 2013, James Wootton

### When does a physical system compute?

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Computing is a high-level process of a physical system. Recent interest in non-standard computing systems, including quantum and biological computers, has brought this physical basis of computing to the forefront. There has been, however, no consensus on how to tell if a given physical system is acting as a computer or not; leading to confusion over novel computational devices, and even claims that every physical event is a computation. In this paper we introduce a formal framework that can be used to determine whether or not a physical system is performing a computation. We demonstrate how the abstract computational level interacts with the physical device level, drawing the comparison with the use of mathematical models to represent physical objects in experimental science. This powerful formulation allows a precise description of the similarities between experiments, computation, simulation, and technology. We give conditions that must be satisfied in order for computation to be occurring, and apply these to a range of non-standard computing scenarios. The framework also covers broader computing contexts, where there is no obvious human computer user. We define the critical notion of a 'computational entity', and show the role this plays in defining when computing is taking place in physical systems.

### Entanglement monotomes for non-Abelian anyonic systems

Robert N. C. Pfeifer, 1310.0373 [quant-ph]

Bipartite entanglement entropies, calculated from the reduced density matrix of a subsystem, provide a description of the resources available within a system for performing quantum information processing. However, these quantities are not uniquely defined on a system of non-Abelian anyons. This paper describes how reduced density matrices and bipartite entanglement entropies (such as the von Neumann and Renyi entropies) may be constructed for non-Abelian anyonic systems, in ways which reduce to the conventional definitions for systems with only local degrees of freedom.

### Optimal complexity correction of correlated errors in the surface code

Austin G. Fowler, 1310.0863 [quant-ph]

The surface code is designed to suppress errors in quantum computing hardware and currently offers the most believable pathway to large-scale quantum computation. The surface code requires a 2-D array of nearest-neighbor coupled qubits that are capable of implementing a universal set of gates with error rates below approximately 1%, requirements compatible with experimental reality. Consequently, a number of authors are attempting to squeeze additional performance out of the surface code. We describe an optimal complexity error suppression algorithm, parallelizable to $O(1)$ given constant computing resources per unit area, and provide evidence that this algorithm exploits correlations in the error models of each gate in an asymptotically optimal manner.

### An optimal dissipative encoder for the toric code

John Dengis, Robert Koenig, Fernando Pastawski, 1310.1036 [quant-ph] (see also 1310.1037)

We consider the problem of preparing specific encoded resource states for the toric code by local, time-independent interactions with a memoryless environment. We propose a construction of such a dissipative encoder which converts product states to topologically ordered ones while preserving logical information. The corresponding Liouvillian is made up of four-local Lindblad operators. For a qubit lattice of size $L \times L$, we show that this process prepares encoded states in time $O(L)$, which is optimal. This scaling compares favorably with known local unitary encoders for the toric code which take time of order $\Omega(L^2)$ and require active time-dependent control.

### A hierarchy of exactly solvable spin-1/2 chains with $so(N)_1$ critical points

Ville Lahtinen, Teresia Mansson, Eddy Ardonne, 1310.1876 [cond-mat.str-el]

We construct a hierarchy of exactly solvable spin-1/2 chains with $so(N)_1$ critical points. Our construction is based on the framework of condensate-induced transitions between topological phases. We employ this framework to construct a Hamiltonian term that couples N transverse field Ising chains such that the resulting theory is critical and described by the $so(N)_1$ conformal field theory. By employing spin duality transformations, we then cast these spin chains for arbitrary N into translationally invariant forms that all allow exact solution by the means of a Jordan-Wigner transformation. For odd N our models generalize the phase diagram of the transverse field Ising chain, the simplest model in our hierarchy. For even N the models can be viewed as longer ranger generalizations of the XY chain, the next model in the hierarchy. We also demonstrate that our method of constructing spin chains with given critical points goes beyond exactly solvable models. Applying the same strategy to the Blume-Capel model, a spin-1 generalization of the Ising chain in a generic magnetic field, we construct another critical spin-1 chain with the predicted CFT describing the criticality.

**Majorana fermions in superconducting wires: Effects of long-range hopping, broken time-reversal symmetry, and potential landscapes**
Wade DeGottardi, Manisha Thakurathi, Smitha Vishveshwara, and Diptiman Sen, Phys. Rev. B 88, 165111

We present a comprehensive study of two of the most experimentally relevant extensions of Kitaev's spinless model of a one-dimensional p-wave superconductor: those involving (i) longer-range hopping and superconductivity and (ii) inhomogeneous potentials. We commence with a pedagogical review of the spinless model and, as a means of characterizing topological phases exhibited by the systems studied here, we introduce bulk topological invariants as well as those derived from an explicit consideration of boundary modes. In time-reversal symmetric systems, we find that the longer range hopping leads to topological phases characterized by multiple Majorana modes. In particular, we investigate a spin model that respects a duality and maps to a fermionic model with multiple Majorana modes; we highlight the connection between these topological phases and the broken symmetry phases in the original spin model. In the presence of time-reversal symmetry breaking terms, we show that the topological phase diagram is characterized by an extended gapless regime. For the case of inhomogeneous potentials, we explore phase diagrams of periodic, quasiperiodic, and disordered systems. We present a detailed mapping between normal state localization properties of such systems and the topological phases of the corresponding superconducting systems. This powerful tool allows us to leverage the analyses of Hofstadter's butterfly and the vast literature on Anderson localization to the question of Majorana modes in superconducting quasiperiodic and disordered systems, respectively. We briefly touch upon the synergistic effects that can be expected in cases where long-range hopping and disorder are both present.

**Mechanism for controlling the exciton fine structure in quantum dots using electric fields: Manipulation of exciton orientation and exchange splitting at the atomic scale**
Garnett W. Bryant, Natalia Malkova, and James Sims, Phys. Rev. B 88, 161301(R)

Using atomistic tight-binding theory with a configuration interaction description of Coulomb and exchange effects, we describe excitons in symmetric quantum dots in a vertical electric field to explain how field-induced manipulation of exciton orientation and phase can eliminate the anisotropic exchange, leading to a drastic reduction of the fine-structure splitting and a 90 degree rotation of polarization, similar to experiment. This reorientation and rephasing of the exciton is done plane-by-plane inside the dot without significant squeezing of the exciton.

**Tunneling spectra simulation of interacting Majorana wires**
Ronny Thomale, Stephan Rachel, and Peter Schmitteckert, Phys. Rev. B 88, 161103(R)

Recent tunneling experiments on InSb hybrid superconductor-semiconductor devices have provided hope for a stabilization of Majorana edge modes in a spin-orbit quantum wire subject to a magnetic field and superconducting proximity effect. Connecting the experimental scenario with a microscopic description poses challenges of a different kind, such as accounting for the effect of interactions on the tunneling properties of the wire. We develop a density matrix renormalization group (DMRG) analysis of the tunneling spectra of interacting Majorana chains, which we explicate for the Kitaev chain model. Our DMRG approach allows us to calculate the spectral function down to zero frequency, where we analyze how the Majorana zero-bias peak is affected by interactions. For topological phase transitions between the topological and trivial superconducting phase in the Majorana wire, the bulk gap closure generically affects the proximity peaks and the Majorana peak.

**Simulation of the dynamics of many-body quantum spin systems using phase-space techniques**
Ray N, Erik S. Soerensen, Piotr Deuar , Phys. Rev. B 88, 144304

We reformulate the full quantum dynamics of spin systems using a phase-space representation based on $SU(2)$ coherent states which generates an exact mapping of the dynamics of any spin system onto a set of stochastic differential equations. This representation is superior in practice to an earlier phase-space approach based on Schwinger bosons, with the numerical effort scaling only linearly with system size. By also implementing extrapolation techniques from quasiclassical equations to the full quantum limit, we are able to extend useful simulation times severalfold. This approach is applicable in any dimension including cases where frustration is present in the spin system. The method is demonstrated by simulating quenches in the transverse-field Ising model in one and two dimensions.