Submittee: Robert Raussendorf
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Title: Quantum Information and Foundations of Quantum Mechanics
Event Type: Conference-Workshop

Location:
Ike Chuang Learning Centre and Hennings (Physics Bldg); University of British Columbia, Vancouver, BC

Dates:
July 2 - 5, 2013

Topic:
Quantum Information /// Foundations of Quantum Mechanics (Bell inequalities etc)

Methodology:
Talks (invited + contributed) /// Poster Session

Objectives Achieved:
It is becoming increasingly clear that the two fields addressed in this workshop have overlapped and could benefit from each other. The purpose of this workshop was to identify key directions of research in which this overlap is particularly strong, and bring together researchers who might pursue them jointly.

Scientific Highlights:
This is a matter of personal taste. Personally, I found the talks by Heunen, Bartlett and Emerson particularly enlightening. The questionaire may provide a wider angle on this.

Organizers:
Dan Browne, University College London, London, UK, Physics /// Robert Raussendorf, UBC, Physics

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Speakers:
Invited talks: (1) Samson Abramsky (Oxford, UK, Computer Science): The Logic and Geometry of Non-locality and Contextuality // Abstract: We shall show how quantum non-locality and contextually are naturally described and unified in the language of sheaf theory. This leads to several concrete developments in quantum information and foundations: a) a novel classification of multipartite entangled states in terms of their degree of non-locality; b) a topological analysis of

entanglement monogamy and macroscopic locality; c) a cohomological characterisation of contextuality; d) a unifying principle for Bell inequalities based on logical consistency conditions /// (2) Stephen Bartlett (Sydney, Australia, Physics): Quantum computational matter // Abstract: Low-temperature phases of strongly-interacting quantum many-body systems can exhibit a range of exotic quantum phenomena, from superconductivity to fractionalized particles. One exciting prospect is that the ground or low-temperature thermal state of an engineered quantum system can function as a quantum computer. For this idea to be sensible, the usefulness of a ground or low-temperature thermal state for quantum computation cannot be critically dependent on the details of the system's Hamiltonian; if so, engineering such systems would be difficult or even impossible. A much more powerful result would be the existence of a robust ordered phase which is characterised by its ability to perform quantum computation. I'll discuss some recent results on the existence of such a quantum computational phase of matter, working within the measurement-based (cluster state) model of quantum computation. I will show that the ability to perform certain logic gates such as the identity gate over long distances in the model corresponds precisely to the recently-proposed notion of 'symmetry-protected topological order' for an appropriate symmetry group. Using some techniques from fault-tolerance, we can then prove that any perturbation of the cluster state model will result in a ground state that remains universal for quantum computation, provided the perturbation is sufficiently small and respects a certain symmetry. (References: http://arxiv.org/abs/1201.4877 and http://arxiv.org/abs/1207.4805) /// (3) Roger Colbeck (ETH Zurich, Switzerland, Physics) : Is a system's wave function in one-to-one correspondence with its elements of reality? // Abstract: Although quantum mechanics is one of our most successful physical theories, there has been a long-standing debate about the interpretation of the wave function---the central object of the theory. Two prominent views are that (i) it corresponds to an element of reality, i.e. an objective attribute that exists before measurement, and (ii) it is a subjective state of knowledge about some underlying reality. A celebrated result by Pusey, Barrett and Rudolph has shown that a subjective interpretation would contradict certain physically plausible assumptions, in particular that multiple systems can be prepared such that their elements of reality are uncorrelated. In this talk, I will show that a subjective interpretation can be ruled out as a corollary of the result that no extension of quantum theory can give improved predictions about measurement outcomes. Thus, based on the assumption that measurement settings can be chosen freely (with respect to a natural chronological ordering), a system's wave function must be in one-to-one correspondence with its elements of reality. /// (4) Joseph Emerson (IQC Waterloo, Canada, Combinatorics & Optimization): Negative quasi-probability and contextuality are equivalent resources for quantum computation // Abstract: I will present results identifying necessary resources for universal quantum computation using qudit systems (power of odd prime). First, I show that negative quasi-probability in a distinguished representation is a necessary resource for universal quantum computation with stabilizer codes via magic-state distillation. This condition defines a natural boundary in the space of quantum states which includes the stabilizer polytope as a strict subset, and hence identifies a large class of "bound magic states". I then show that this negativity boundary coincides with a boundary for contextuality in the graph-theoretic framework recently proposed by Cabello, Severini and Winter. Time-permitting, I will discuss a resource-theory of magic and introduce the concept of "mana", which is a computable magicness monotone that can bound the overhead cost of magic-state distillation. Joint work with: Victor Veitch, Mark Howard, Chris Ferrie, Dan Gottesman, David Gross, and Ali Hamed. /// (5) Chris Heunen (University of Oxford, UK, Computer Science): Quantum systems allow active state spaces // Abstract: Much about a quantum system is captured by the collection of its classical subsystems, including logical, information-theoretic, and foundational aspects. I will survey this development in terms of algebras of observables. However, this data is not enough to determine a quantum system, nor are the unitaries. I will discuss how a combination of both does suffice, showing that a combination of kinematics and dynamics completely determines quantum systems through the classical information observers can obtain from them, leading to an "active" notion of state space for quantum systems. /// (6) Pawel Horodecki (University of Gdansk, Poland, Physics) : Relative entropy of contextuality // Abstract: The measure of quantum and post-quantum contextuality basing on relative entropy will be presented. We shall discuss its application to examples of contextuality based on XOR-type games. Recent application on the quantum orthogonality graphs in context of the state independent contextuality will be also provided. /// (7) Terry Rudolph (Imperial College, London, UK, Physics): The WAY theorem and quantum information // Abstract: Periodically one sees papers from people who got excited because some fundamental restriction on accessible states/operations (typically couched in the language of conservation laws/superselection rules) must have deep implications for our ability to build a quantum computer, or do some provably impossible communication protocol (such as bit commitment) etc. Understanding why this is not the case forms part of the theory of quantum reference frames, a field from which the study of asymmetry as a resource has evolved. Conversely, ideas from quantum information can be used to provide a new perspective on what is a fairly old field. In this talk I will consider some new quantum-information theoretic perspectives on the WAY theorem, a 50 year old theorem about how conservation laws affect our ability to perform projective measurements of non-conserved quantities. /// (8) Rob Spekkens (PI Waterloo, Canada, Physics): On causal explanations of quantum correlations // Abstract: If correlation doesn't imply causation, what does? Causal discovery algorithms take as their input facts about correlations among a set of observed variables, and they return as their output causal structures that can account for the correlations. We show that any causal explanation of Bell-inequality-violating correlations must contradict a core principle of these algorithms, namely, that an observed statistical independence between variables should not be explained by fine-tuning of the causal parameters. The fine-tuning criticism applies to all of the standard attempts at causal explanations of Bell correlations, such as superluminal causal influences, superdeterminism, and retrocausal influences that do not introduce causal cycles. This suggests a novel perspective on the assumptions underlying Bell's theorem: the nebulous assumption of realism can be replaced with the principle that all correlations ought to be explained causally and Bell's notion of locality can be replaced with the assumption of no fine-tuning. Finally, we discuss the possibility of salvaging a causal explanation of quantum correlations by casting quantum theory as an innovation to the theory of Bayesian inference. Based on arXiv:1208.4119. /// (9) Mordecai Waegell (Worcester Polytechnic, USA): New proofs of Quantum Contextuality // Abstract: This talk will survey the new proofs we have obtained of the Kochen-Specker theorem over the last several years. The proofs belong to two different families, one of which has its origins in the three exceptional four-dimensional regular polytopes (the 24-cell, the 600-cell and the 120-cell) and the other in the N-qubit Pauli group (for N >= 2). The proofs of the latter family come in two types: they can be based on sets of commuting observables of a special kind or they can be based on families of projectors derived from the former observable sets. An appealing feature of all our proofs, without exception, is that they can be displayed in the form of diagrams or tables from which they are obvious by inspection. The inspection merely takes the form of verifying that certain parity checks are satisfied, and for this reason our proofs can be referred to as "parity proofs". We survey the new results we have obtained, after first reviewing earlier work in the field. We discuss the relevance of our work for experimental tests of contextuality and nonlocality, and end by highlighting open questions and unresolved issues. /// (10) Simone Severini (University College London, UK, Mathematics): (Non-)Contextuality of physical theories as an axiom // Abstract: We show that there is of family of inequalities associated to each compatibility structure of a set of events (a graph), such that the bound for noncontextual theories is given by the independence number of the graph, and the maximum quantum violation is given by the Lovasz tetha-function of the graph, which was originally proposed as an upper bound on its Shannon capacity. Probabilistic theories beyond quantum mechanics may have an even larger violation, which is given by the fractional packing number. We discuss the sets of probability distributions attainable by noncontextual, quantum, and generalized models; the latter two are shown to have semidefinite and linear characterizations, respectively. The implications for Bell inequalities are discussed. In particular, we show that every Bell inequality can be recast as a noncontextual inequality within this family. For details and proofs see arXiv:1010.2163 [quant-ph].

Links:
http://www.qi.ubc.ca/QMFmain.html