October 27, Tuesday

Session [IV] Quantum Computing

Chair M. Genovese

14:05 **Computability, complexity, machines and physics** *M. Rasetti* [key-speaker]

Abstract

Complexity Science bears naturally on fundamental aspects of Data Science. Crucial question of data science is "data mining", whose main endeavor is to extract information from data. In this context, recent projects in the natural sciences (Genome, Hubble, Brain Activity Map, etc.), connected with the serious issue of "Big Data", gave a central role to the notions of computability – or rather of incomputability – that Gandy's criteria allow to establish without performing any calculation. All these questions recently found a unified approach in the so-called Topological Data Field Theory, a novel theoretical construct, which succeeds in efficiently discovering patterns of hidden information in large data sets. The theory is formulated along a conceptual scheme in some way similar to the approach by Regge calculus to gravity. Here it is argued that quantization of TDFT would allow us to tackle undecidable problems, going "beyond Turing" – i.e., succeed in computing non-recursive functions. The idea is that while quantum computers are Turing machines; while incomputability requires infinitely many interacting Turing machines, due to its non-linearity a quantum topological data field theory would be able to incorporate these two features in natural way overcoming the barriers they singularly raise.

14:50 **Quantum information at the time-reversal symmetry edge of quantum chaos**

E. Prati [invited]

Abstract

Quantum information processing is conceived to be implemented on quantum computers behaving either as Von-Neumann machines based on quantum logic ports to solve quantum algorithms [1], or as quantum annealing systems made of adiabatically driven sets of interacting qubits, to solve optimization problems [2]. On the contrary, quantum biology [3] shows quantum information processes and optimization by exploiting the edge of quantum chaos in disordered and noisy environments [4], at the transition point between time-reversal symmetry and the broken symmetry conditions respectively. I discuss the disordered based quantum information processing and its possible physical implementation, the impact of time reversal symmetry on the long range coherence which allows quantum information to be processed up to room temperature in macroscopic objects and on the quantum information processing in general [5,6.7].

[1] Koh TS et al 2013, High fidelity gates in quantum dot spin qubits, PNAS 110, 49
[2] Boixo S 2014 Evidence for quantum annealing with more than one hundred qubits. Nature Physics, 10 3 218-224
[3] Panitchayangkoona G et al 2010 Long-lived quantum coherence in photosynthetic complexes at physiological temperature, PNAS 107 29 12766-12770

[4] Vattay G, Kauffman S and Niiranen S 2014 Quantum biology on the edge of quantum chaos. PloS One, 9 3 e89017

[5] Prati E et al 2012 Anderson–Mott transition in arrays of a few dopant atoms in a silicon transistor, Nature Nanotechnology 7 443–447.

[6] Prati E 2015 Towards room temperature solid state quantum devices at the edge of quantum chaos for long-living quantum states, in press, IOP Conference Proceedings

[7] Mucciolo ER, Capaz RB, Altshuler BL and Joannopoulos JD 1994 Manifestation of quantum chaos in electronic band structures Phys. Rev. B 50 12 8245-8251

15:20 **An exact relation between number of oracle queries required to solve an oracle problem quantally and quantum retrocausality** *G. Castagnoli*

Abstract

We extend the usual representation of quantum algorithms, limited to the process of solving the problem, to the process of setting the problem. This originates two time-symmetric and relational representations, one with respect to the problem setter, the other with respect to the problem solver, to whom the setting of the problem must be hidden inside a black box. We show that one is free to ascribe to the final measurement, required to read the solution of the problem, any part of the selection of the random outcome of the initial measurement, required to prepare the computer register with the desired setting of the problem. This projects the input state with respect to the problem solver, of complete ignorance of the problem setting, on a state of lower entropy where she knows part of the problem setting in advance, before performing any computation. The quantum algorithm turns out to be a sum over classical histories in each of which the problem solver, knowing in advance part of the problem setting, performs the computations steps (oracle queries) still required to identify the solution. Given an oracle problem and the fraction of the information (R) that specifies the random outcome of the initial measurement whose selection is ascribed to the final measurement, this retrocausality model provides the number of computation steps required to solve the problem quantally. Conversely, given a known quantum algorithm, it yields the value of R that explains its speed up. We compare the retrocausality model with a sample of quantum algorithms. R is steadily 1/2 or, in one case, slightly above it. Conversely, R = 1/2 always corresponds to an existing quantum algorithm and provides the order of magnitude of the number of computation steps required by the optimal one. If this held in general, it would solve the open problem of quantum query complexity. This work is an exploration.

15:40 COFFE BREAK

Session [II–C] Teleportation, entanglement and CTCs

Chair Joan Vaccaro

16:00 **Bizarre monogamy of entanglement in time** *M. Nowakowski*

Abstract

In this presentation we state a fundamental question about the structure of correlations in time and analyze temporal monogamy relations. We show that the nature of temporal correlations is inherently different from the spatial ones and prove new monogamy relations for temporal correlations. We perform this task applying entangled histories framework and show the difference between spatial and temporal correlations in case of Legget-Garg inequalities and entropic time inequalities. Finally, we point out that in a context of the tensor algebra used for linking states in different times further studies on mathematical structure of the state representing evolving systems are needed. These considerations are supported by introduction of necessary tools specific for the tensor algebra used for representation of spatial correlations.

16:20 **(Quantum?) Processes and Correlations with no definite causal order** *C. Branciard*

Abstract

The framework of process matrices introduced by Oreshkov et al. [Nat. Commun. 3, 1092 (2012)] allows for so-called causally non separable processes that are “locally compatible” with quantum theory, but are incompatible with a definite causal order. Such processes may (or may not) generate correlations that are themselves incompatible with a definite causal order, and violate so-called causal inequalities. I will clarify in this talk the link between the causal nonseparability of process matrices and their ability to violate causal inequalities, highlighting the rich analogy with entanglement and Bell nonlocality.

16:40 **Title T.B.A.** *S. Lloyd* *[key-speaker]* *Two types of Time Travel:"Harry Potter versus the time machine*

Abstract

T.B.A.

17:20 **Poster Session**

Time emerging from quantum correlations: an experimental illustration *E. Moreva*

Abstract

Page and Wootters' mechanism of "static" time is experimentally realized using a static, entangled state of the polarization of two photons, one of which serves as a clock to gauge the evolution of the second.

Testing Quantum Gravity by Quantum Light

I. Ruo Berchera, I. P. Degiovanni, S. Olivares, N. Samantaray, P. Traina, and M. Genovese

Several quantum gravity theories (string theories, holographic theory, heuristic arguments from black holes,…) predict or conjectured non commutativity of position variables along perpendicular directions at Planck scale. This would imply a sort of space-time uncertainty principle determining slight random wandering of transverse position, called "holographic noise" (HN).

Indeed, in Michelson interferometer the estimation of the phase shift among the arms can be seen as a simultaneous measurement of the positon of the beam splitter along perpendicular direction and therefore should be affected by HN, which will accumulates in a random walk-like behavior during a round trip of light propagation.

Albeit still too faint to be measured even with the most sensitive interferometers available nowadays, this effect could be measurable by correlating the output ports of two independent interferometers, provided they share the same space-time volume. In that case other sources of noise limiting the sensitivity (mainly shot noise) will vanish since they are independent, while HN, the same in both the devices, should emerge in the correlation measurement. In particular, this last idea led to the planning of a double 40 m interferometers at Fermilab, dabbed as "Holometer" [1].

We show how the use of quantum correlation and entanglement lead to a significant improvements of the sensitivity to the HN of the double interferometric scheme, up to a noise-free scenario for the ideal lossless case [2,3]. This finding prompts the possibility of testing QG in experimental conjuration affordable in a traditional quantum optics laboratory with current technology.

[1] https://holometer.fnal.gov/
[2] Quantum light in coupled interferometers for quantum gravity tests, IR Berchera, IP Degiovanni, S Olivares, M Genovese, Phys. Rev. Letters 110, 213601(2013).
[3] One- and two-mode squeezed light in correlated interferometry, I. Ruo Berchera, I. P. Degiovanni, S. Olivares, N. Samantaray, P. Traina, and M. Genovese, Phys.Rev. A, Accepted.

17:25 **END SESSIONs**