Quantum Computing in Plato's Cave

Paolo Facchi,[1,2,*] Daniel Burgarth,[3] Vittorio Giovannetti,[4] Hiromichi Nakazato,[5] Saverio Pascazio,[1,2] and Kazuya Yuasa[5]

[1]*Dipartimento di Fisica and MECENAS, Università di Bari, I-70126 Bari, Italy*
[2]*INFN, Sezione di Bari, I-70126 Bari, Italy*
[3]*Department of Mathematics, Aberystwyth University, SY23 3BZ Aberystwyth, United Kingdom*
[4]*NEST, Scuola Normale Superiore and Istituto Nanoscienze-CNR, I-56126 Pisa, Italy*
[5]*Department of Physics, Waseda University, Tokyo 169-8555, Japan*

We show that the mere observation of a quantum system can turn its dynamics from a very simple one into a universal quantum computation. This effect, which occurs if the system is regularly observed at short time intervals, can be rephrased as a modern version of Plato's Cave allegory. More precisely, in the original version of the myth, the reality perceived within the Cave is described by the projected shadows of some more fundamental dynamics (the Ideals) which is intrinsically more simple (intelligible). We found that in the quantum world the "projected" reality perceived through sequences of measurements is even more complex than in a classical world. After discussing examples we go on to show that this effect is generally to be expected: almost any quantum dynamics will become universal once "observed" as outlined above. Conversely, we show that any complex quantum dynamics can be "purified" into a simpler one in larger dimensions.

In the last 30 years the possibility of using quantum effects to develop an alternative approach to engineering has emerged as a realistic way to improve the efficiency of computation, communication and metrology [1–5]. At the very core of this revolutionary idea, the possibility of designing arbitrary dynamics of quantum systems without spoiling the rather fragile correlations characterizing them is crucial. What experimentalists typically do is to apply sequences of control pulses (e.g., by sequentially switching on and off different electromagnetic fields) to steer quantum systems. In the quantum world, however, there is another option associated with the fact that the measurement process itself can induce a transformation on a quantum system. In this context an intriguing possibility is offered by the quantum Zeno effect [6, 7]. It forces the system to evolve in a given subspace of the total Hilbert space by performing frequent projective measurements (Zeno dynamics) [8–10], without the need of monitoring their outcomes (*non-adaptive* feedback strategy). Several attempts have already been discussed to exploit such effects for quantum computation, see e.g., [11–17].

In this talk we show that the constraint imposed via a Zeno projection can in fact *enrich* the dynamics induced by a series of control pulses, allowing the system of interest to explore an algebra that is *exponentially larger* than the original one [18]. In particular this effect can be used to turn a small set of quantum gates into a universal set. Thanks to the non-adaptive character of the scheme, this Zeno enhancement can also be implemented by a non-cooperative party, e.g., by noisy environment. Furthermore, we show that any complex quantum dynamics can be viewed as the projected dynamics of a simpler one in larger dimensions [19].

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* paolo.facchi@ba.infn.it

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