Int J Theor Phys (2008) 47: 2130–2132
DOI 10.1007/s10773-007-9570-4

Conventional and Unconventional Quantum Physics

David P. DiVincenzo

Received: 5 December 2006 / Accepted: 14 September 2007 / Published online: 4 October 2007
© Springer Science+Business Media, LLC 2007

Abstract A tribute to Giuseppe Castagnoli, without whom the historic first workshops on quantum computation in the early 1990s would not have been possible.

Keywords Quantum computing · Quantum information · Institute for Scientific Interchange

I expect that I will always remember the years around 1994 as the most exciting of my professional career, and among the highest peaks of those years were my visits to the Villa Gualino. Those visits were largely made possible by the generosity of Giuseppe Castagnoli, for which I am most grateful.

I will record a few personal recollections here about my first couple of visits to the Institute for Scientific Interchange at the Villa Gualino, and offer some thoughts about what might (and might not) have been pleasing to Mr. Castagnoli about the meetings that took place then.

I was not involved in the first meeting on quantum computation that took place in 1993 (in the first half of the year, I believe), with the prompting, backing, and encouragement of Castagnoli. The group picture of that meeting is well known to me and to many readers, and shows a formidable group of assembled talent, among whom were many who became leaders in the burgeoning field of quantum information science. All of the authors of the first paper on quantum teleportation were present, and it is clear that work was stimulating a lot of new discussion about how concepts of information theory bore on the foundations of quantum theory; this represented, I think, the principal interest of many of the other assembled scientists there, Castagnoli among them.

But there were also, in 1993, hints of some promising practical directions for quantum computing: among that group, Deutsch, Jozsa, Vazirani, and Brassard saw hope in some new algorithms that they had recently developed to use the hypothetical quantum engine. The

D.P. DiVincenzo (✉)
IBM Research Division, T.J. Watson Research Center, P.O. Box 218, Yorktown Heights, NY 10598, USA
e-mail: divince@watson.ibm.com

quantum Fourier transform was very much in the air, although no one had such a good use for it then. And, there were tentative efforts by a few of this group to match quantum computing ideas to practice: Bennett and Brassard were constructing a prototype apparatus for quantum cryptography, and Mahler was discussing, although at the time only theoretically, what a solid state device, working at the single-quantum level, might look like.

I only got interested in quantum computing myself some months later; I was looking for a new area of research to get into, and I was fascinated by the work connecting quantum physics and information science that my colleagues Charlie Bennett and Rolf Landauer at IBM had been doing for many years. I collected a set of papers from them, and set off, entirely coincidentally, to the Villa Gualino, to be a participant in a program on mesoscopic physics. That program was, I have to admit, pretty sleepy, and I had plenty of time to read and think about quantum computing.

The Villa Gualino was, at that time, a very special kind of place to go to for thinking about science. It was not the kind of swanky place that is more and more the only type of location chosen for meetings. Torino is a nice city, but not a *very* nice city, so there are few compelling distractions in the surroundings; and the Villa is a bit cut off from the city by being on a steep hillside far above the Po. More special was the literally half-ruined state of the Villa itself. Its being under renovation, at an Italian pace, did not hinder one from getting lost in odd forgotten spots here and there around its extensive grounds. But in the midst of all this, there were three squares a day, a spare sleeping room, and plenty of places to hang about and work on your physics. Its dreamy and hermetic quality is, I think, one that I will not encounter again.

The next coincidence was that, in the midst of my monastic term at Villa Gualino in the fall of 1993, there arrived a small group for a follow-on gathering to the quantum information meeting of earlier in the year. This was a great chance for me, and I spoke with and got to know all of those who had come: Andreas Albrecht, Wojciech Zurek, Guenther Mahler, Seth Lloyd, and Artur Ekert. This was all of them, I think—there is no record that I know of, photographic or otherwise, of this gathering. But it was a very important coincidence for me, it made it certain that quantum computing would become my full time occupation. I still remember hiking to the top of the hill where the Villa sits with Albrecht and Lloyd, having it explained to me that the dipole structure of the cosmic background microwave radiation can be thought of as the collapse of a Schroedinger cat—it was very addictive stuff. I was also already pretty sure that I could improve upon the work that Lloyd had done, following the earlier ideas of Mahler, on using spin chains for quantum information processing. But that only came to fruition years later.

So it came to pass that in the following fall, when the quantum computing group gathered again, I was delighted to be among them. Of course, something revolutionary had happened in the meantime: Peter Shor had announced his prime-factorization quantum algorithm. The gathering then, in October 1994, was still small, but it was not to remain so: the meeting grew by leaps and bounds in the following few years. But the profile of the participants shifted significantly from the year earlier: a significant fraction of the group had expertise and interest in experimental implementations of quantum information processing.

Several events of that meeting stand out clearly in my mind:

Peter Shor had his first encounter with the quantum physics community at this event in 1994. He turned out to be very open to thinking and talking about a wide range of problems in physics, and this meeting opened a period of several years of fruitful collaboration between us. At that meeting a collective effort, involving many meetings of many participants at the Villa bar, settled a very important issue about quantum circuits: we discovered that the CNOT gate, assisted by one-qubit gates, constituted an efficient, universal gate set for quantum computation. We wrote a paper on this, which was written as the file “torgatxx.tex” (“torgat” short for “Torino-gates”, and “xx” indicating the many version numbers through which it went). We also referred to it as the “gang of nine” paper, indicating the number of authors, most of whom had been at the Villa Gualino workshop.

Peter Zoller and Ignacio Cirac joined the workshop, and presented a seminar, for the first time, I think, on the ion-trap scheme for quantum computation. This was an important turning point for me. I had been thinking and writing in the preceding year about ideas for solid-state implementations of quantum computers; but I could see that Cirac–Zoller scheme far exceeded anything that I had been able to do in concreteness and in direct contact with current experiment—my work on nuclear spins, for example, looked like Drexlerian nonsense beside theirs. Part of this was certainly due to the relative immaturity of precision quantum experiments in the condensed matter setting, relative to the atomic physics laboratory. But I also perceived that there was a methodological superiority in their work, which, if it could be exposed explicitly, would be a useful framework for many other proposals. It was in the next year or so that I had done this with my “five criteria”.

The year following this 1994 meeting would see a lot of work on quantum error correction, but I think that I wasn’t aware of it at that time: Ekert and Macchiavello probably were discussing error correction by symmetrization, and entanglement concentration and purification were soon to be hatched by Bennett and his colleagues. Shor, actually, already knew his nine-bit code then, but mentioned it only very obliquely; intellectual property concerns kept him gagged until his famous paper came out about a year later.

Castagnoli was observing many of these goings on very intently. He was active in discussions of “time-symmetric” quantum theory, which generated very heated discussions at that time, involving Vaidman, Peres, and others. It was at that time, or very shortly after, that Castagnoli delivered a lecture with his ideas for solving hard computations using quantum gates to implement constraints of an optimization problem, ideas which clearly flowed from his time-symmetrized point of view. I didn’t pick up very strongly on these ideas at that time, but perhaps I and others should have: it was only quite some years later that Kitaev, and then many others, began examining the quantum optimization problem (i.e., the problem of finding minimum energy states of a quantum Hamiltonian) from a complexity theory point of view. Kitaev’s conclusion has been, I think, at variance with what Castagnoli had hoped for—it now appears likely that many such quantum optimization problems are really intractable, in a way that very much parallels the intractability of NP-complete problems in classical computation.

I fear that, in the end, we did not please Castagnoli so much. Many of us who came to Torino in 1994 and future years were intent on stripping the mystery and philosophy from quantum mechanics, and making even its weirdest features servants to a new era of technology. But there were always some, and there will always be others ever and again, who, like Castagnoli, take physics as the springboard to the deepest speculations of the human intellect, and will continue to point its vectors in the direction of the most beautiful conceptual realms.