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Introduction to special issue: Physics and computer science – quantum computation and other approaches

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Computer science and computer engineering are disciplines that have very definitely permeated and transformed every aspect of modern society. In these fields, cutting-edge research is about new models of computation, new materials and techniques for building computer hardware and novel methods for speeding-up algorithms. But it is also about building bridges between computer science and various other scientific fields, bridges that allow scientists to both think of natural phenomena as computational procedures and to employ novel models of computation to simulate natural processes (for example, quantum walks have been used to model energy transport in photosynthetic light harvesting complexes (Hoyer *et al.* 2010; Caruso *et al.* 2010)). A convergence of scientific, technological, economic and epistemological demands is driving and integrating this research.

Moreover, the theory of computation, in its canonical form, has a severe drawback: it does not take account of the physical properties of the devices used for performing computational or information processing tasks. Recent research approaches have therefore concentrated on thinking of computation in a physical context. The rationale behind this approach is that it must be possible to build the notions of information and computation upon physical principles because the behaviour of any device used for computation or information processing must ultimately be predicted by the laws of physics. Quantum mechanics stands in first place amongst the physical theories that could be used for this purpose.

Quantum mechanics and the theory of computation are two of the most important intellectual achievements of the 20th century. These two branches of science have not only inspired several generations of scientists and thinkers, they have also had a significant impact on the daily life of Mankind, from war to literature. In fact, there has been abundant cross-fertilisation between physics and computation due to the fact that many ideas, concepts and technological developments in each field have been used to advance knowledge in the other.

Quantum computation is one of the most recent joint ventures between physics and computer science and can be defined as the scientific field whose purpose is to solve problems with algorithms that exploit the quantum mechanical properties of those physical systems used to implement them. Among the theoretical discoveries and promising conjectures that have positioned quantum computation as a key element in modern science, we find:

(1) the development of novel and powerful methods of computation that may allow us to significantly increase our processing power for solving certain problems (Nielsen and Chuang 00; Gruzka 2000; Kitaev *et al.* 2002; Lanzagorta and Ullman 2009; Childs and van Dam 2010; Jordan 2005); and
(2) the simulation of complex physical systems (Feynman 1982; Harris and Kendon 2010; Brown *et al.* 2010).

A detailed summary of scientific and technological applications of quantum computers can be found in QIST (2004) and ERA-Pilot QIST (2007).

As for the physical realisation of quantum computers, several experimental platforms have been developed or customised over the last two decades. Indeed, although it is too early to predict the winning technologies for the implementation of quantum computers, encouraging advances have been made over recent years in fields like quantum optics (Joo *et al.* 2006; Lanyon *et al.* 2007; Prevedel *et al.* 2007; Branderhost *et al.* 2008), ion traps (Porras *et al.* 2006; Benhelm *et al.* 2008) and diamond-based technology (Weber *et al.* 2010). Moreover, according to the quantum computation roadmaps produced in the United States of America in 2004 (QIST 2004) and the European Union in 2007 (ERA-Pilot QIST 2007), it is reasonable to expect there will be quantum hardware with enough qubits and fault tolerant error correction to run quantum simulation and some quantum algorithms some time in the period 2012–2017.

In addition to the development of quantum algorithms, there are other approaches to building algorithms inspired by (classical) physical theories. Both quantum and classical approaches are immensely valuable to computer scientists as they provide us with new insights into what a computer can ultimately do and how we can reach that goal.

Thus, in the tradition of cross-fertilisation between physics and computation, this special issue of *Mathematical Structures in Computer Science* on quantum algorithms and other physics-inspired algorithms is intended as a contribution towards our understanding of what Nature has to say about our capacity to build automatic procedures for problem solving.

In conclusion, I would like to express my warm thanks to the Editor-in-Chief of *Mathematical Structures in Computer Science*, Professor Giuseppe Longo, for giving me the opportunity to edit this special volume as well as for his never-ending patience and support. I am also most grateful to the authors of the papers included in this special issue for their hard work and outstanding scientific contributions. I am deeply honoured to have been given the opportunity to work with you all.

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