# Dream of quantum computing closer to reality as mathematicians chase key breakthrough

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The ability to exploit the extraordinary properties of quantum mechanics in novel applications, such as a new generation of super-fast computers, has come closer following recent progress with some of the remaining underlying mathematical problems. In particular, the operator theory used to describe interactions between particles at atomic scales or smaller where quantum mechanical properties are significant needs to be enhanced to deal with systems where digital information is processed or transmitted. In essence, the theory involves mathematical analysis based on Hilbert Spaces, which are extensions of the conventional three dimensional Euclidean geometry to cope with additional dimensions, as are required to describe quantum systems.

These challenges in mathematical analysis and prospects for imminent progress were discussed at a recent conference on operator theory and analysis organised by the European Science Foundation (ESF) in collaboration with the European Mathematical Society and the Mathematical Research and Conference Center in Bedlewo, Poland. The conference brought together some of the world's leading mathematical physicists and quantum mechanics specialists to tackle the key fields relating to spectral theory, according to the conference's co-chair Pavel Kurasov from the Lund Institute of Technology in Sweden. Among the participants were Uzy Smilansky, one of the leading authorities on quantum chaos, from the Weizmann Institute of Technology in Israel, and Vladimir Peller, specialist in pure mathematical analysis at Michigan

State University in the US.

As Kurasov pointed out, a big challenge lies in extending current operator theory to describe and analyse quantum transport in wires, as will be needed for a new generation of quantum computers. Such computers will allow some calculations to be executed much more quickly in parallel by exploiting quantum coherence, whereby a processing element can represent digital bits in multiple states at once. There is also the prospect of exploiting another quantum mechanical property, quantum entanglement, for quantum cryptography where encryption key information can be transmitted with the ability to detect any attempt at tampering or eavesdropping, facilitating totally secure communication. In fact quantum cryptography has already been demonstrated over real telecommunications links and will be one of the first commercial applications based exclusively on quantum mechanics.

The operator theory required for quantum information processing and transmission is already well developed for what are known as self-adjoint operators, which are used to describe the different quantum states of an ideal system, but cannot be used for systems like a communications network where dissipation occurs. "So far only self-adjoint models have been considered, but in order to describe systems with dissipation even non-self-adjoint operators should be used," said Kurasov. The aim set out at the ESF conference was to extend the theory to non self-adjoint operators, which can be used to analyse real systems. "These operators may be used to describe quantum transport in wires and waveguides and therefore will be used in design of the new generation of computers," said Kurasov."Physicists are doing experiments with such structures, but the theory is not developed yet. An important question here is fitting of the parameters so that models will describe effects that may be observed in experiments." This question was discussed during inspiring lecture by Boris Pavlov from Auckland University, New Zealand – world leading specialist in mathematical analysis who became interested in physical applications.

Intriguingly Kurasov hinted that a breakthrough was likely before the next ESF conference on the subject in two years time, on the problem of reconstructing the so called quantum graphs used to represent states and interactions of quantum systems from actual observations. This will play a vital role in constructing the intermediate components of a quantum computer needed to monitor its own state and provide output.

Kurasov noted that this ESF conference was one in a series on the operator analysis field organized every second year, with proceedings published regularly in a book series *Operator Theory: Advances and Applications*.

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