Quantum and Post-Moore's Law Computing

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This special issue of Internet Computing includes four articles that target the technical challenges and discuss the vast opportunities of quantum computing. The first article discusses mitigating the decoherence error in quantum data transformation algorithms and could potentially benefit big data analysis. The second article reviews a wide range of emerging applications that quantum computing could help. The third and fourth articles discuss the quantum cloud, providing software system design guidelines and characterizing hardware errors, both of which have the potential to improve today's cloud-based quantum computing infrastructure and benefit many users of the quantum cloud service.

As a new computing paradigm, quantum computing has promised unprecedented computational ability to tackle classically intractable problems, ranging from encryption and cybersecurity systems, to the simulation of quantum systems, to combinatorial optimization and machine learning. Quantum hardware also progressed considerably in the last few years. Several multiqubit quantum devices, utilizing a variety of underlying technologies, have been devised. These include both publicly available and private systems with over 50 qubits. However, movement towards the ultimate goal of a fault-tolerant universal quantum computer will require innovation and refinement from both software and hardware research and engineering in order to harness these noisy intermediate-scale quantum devices. The various noises in quantum devices, the counter-intuitive quantum applications, and the quantum software/hardware system infrastructure at scale, introduce grant challenges that must be addressed with innovations from all technology stacks.

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The four articles in this Special Issue on Quantum and Post-Moore's Law Computing address different flavors of these technical challenges and new opportunities. The first article discusses mitigating the decoherence error in quantum data transformation algorithms and could potentially benefit big data analysis. The second article reviews a wide range of emerging applications that quantum computing could help. The last two articles discuss the quantum cloud, providing software system design guidelines and characterizing hardware errors, both of which have the potential to improve today's cloud-based quantum computing infrastructure and benefit many users of the quantum cloud service.

The first article is "Quantum Information Science," by Swan *et al.* Quantum algorithms are counter-intuitive and their development methodology is quite different from that of the classical counterparts. The authors discuss several emerging applications in quantum computing, including quantum cryptography, quantum machine learning, quantum finance, quantum neuroscience, quantum networks, and quantum error correction. These applications are formulated in different mathematical backgrounds related to different properties of quantum systems. The authors provide several intuitive design insights of these applications, making them more accessible to a general audience. This could potentially motivate more people to get into the field of quantum computing.

Data transformation is one important potential application domain of quantum computing due to its intrinsic quantum parallelism. However, the corresponding quantum algorithm needs to be carefully optimized to fully leverage the potential of quantum computing. The second article, "Decoherence-Optimized Circuits for Multidimensional and Multilevel-Decomposable Quantum Wavelet Transform," by Mahmud *et al.*, proposes novel Quantum Wavelet Transform (QWT) circuits in which the permutations are optimized in terms of circuit depth, to account for the effects of decoherence. The optimized QWT circuits result in high fidelity and efficient implementation on quantum processors, and are

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expected to benefit dimension reduction in big data analysis.

The third article, “Measurement Crosstalk Errors in Cloud-Based Quantum Computing” by Seo and Bae, is related to the architecture of a quantum cloud. Contrary to classical computers, quantum computers are unlikely to be miniaturized and directly accessible to consumers, due to the complex laboratory equipment required for cooling and control. It is, thus, critical to design a cloud infrastructure that accommodates the growing use of quantum computers worldwide.

Operation errors remain a key roadblock in scalable quantum computation and measurement errors present some of the highest of such errors. The fourth article, “Quantum Software as a Service Through a Quantum API Gateway” by Garcia-Alonso *et al.*, examines these errors in detail on two cloud accessible quantum computers, focusing specifically on crosstalk when measurements occur in parallel rather than in sequence. Understanding these errors provide critical tools for improving them via better calibration or better compilation.

The articles in this issue are far from reflecting the entire upcoming quantum computing era. There are many other topics and upcoming innovations related to quantum computing, acrossing device, architecture, compiler, programming language, algorithm, etc. We expect to see related themes covered by *Internet Computing* in the near future—and continuing progress towards large-scale quantum computing that can demonstrate its advantage over classical computing.

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