NASA’s Rupak Biswas Sees Usable Quantum Computing before End of Decade

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Quantum computing is a technology that promises to revolutionize the IT industry. Thus far, though, it has been unable to shake its perception as a sort of permanent “technology of the future.” But, with the availability of quantum annealing computers from D-Wave, that perception might be changing. One of the first D-Wave systems has been deployed at NASA Ames Research Center, where researchers have been busy putting the machine through its paces.

To get a sense of where quantum computing stands today, we asked Dr. Rupak Biswas, Deputy Director of Exploration Technology at NASA Ames, to describe some of the early experiences the space agency has had with the D-Wave machine and about the field of quantum computing more generally. We also quizzed Biswas on NASA’s plans for exascale computing and asked him to share his thoughts on US supercomputing leadership.

Quantum computing is one of a handful of technologies promising to be the "next big thing." What do you think are the most important capabilities it offers compared to conventional digital computers?

Rupak Biswas: The very fact that quantum computing uses qubits that can be in two states at the same time is extremely powerful. Thus, a system with two qubits can be in four states, while one with three qubits can be in eight states simultaneously. This principle of superposition enables a quantum computer to search or explore numerous possibilities in true parallel fashion, thereby providing a tremendous advantage over conventional computers.

Another important capability is tunneling: a quantum mechanical phenomenon where a particle goes through a barrier that it could not traverse classically. It is usually best explained using the wave-particle duality of matter and Heisenberg’s uncertainty principle. In a quantum computer, multiple qubits are able to penetrate the barriers in a concerted fashion.

Finally, there is the concept of quantum entanglement, where the quantum state of each qubit in a group of qubits cannot be described independently. Instead, the quantum state must be given for the system as a whole. This introduces the concept of long-range correlations between the measurement outcomes of remote qubits that have no known means of communicating directly with each other.

Where do you think quantum computing stands today, and when do you expect it to be mainstream?

Biswas: Quantum computing has matured tremendously over the past five years. There are numerous activities around the world where researchers are exploring how to create robust qubits, automatically correct errors, have them entangled, and increase coherence time. The challenge still is to build a system with large numbers of qubits that can be harnessed effectively to solve real problems. At the same time, other groups are working on quantum algorithms and software infrastructures to make these systems usable. I think we will start seeing the impact of quantum computing in the next five years, even though it might be a decade or so before it is considered mainstream.

The NASA Advanced Supercomputing (NAS) Divsion has installed a D-Wave quantum computing system at the Ames Research Center. What kind of work has been performed on the machine?

Biswas: We have been learning how to efficiently program practical applications on the machine. Currently, we are focused on those related to planning and scheduling, data mining, fault diagnostics and Bayesian networks for anomaly prediction. For the D-Wave system, any problem that we wish to solve must first be mapped to a QUBO [Quadratic Unconstrained Bindary Optimization] form. Thereafter, it has to be embedded into the machine architecture that requires developing graph theoretical methods and tools.

Both these steps involve setting numerous problem-dependent parameters that require careful tuning because the system has inherent control noise — the operating precision is 4 bits. For a quantum annealing system like D-WAVE, massive spin co-tunneling plays a key role and is affected by the connectivity patterns on the architecture. We expect that our research will provide a better understanding of the practical limitations of the system and, therefore, lead to future improvements.

Turning back to more conventional systems, what are NASA's plans for exascale computing? When is NASA planning to deploy its first exascale supercomputer?

Biswas: NASA’s supercomputing plans are driven by mission needs rather than achieving a certain peak performance number. NASA utilizes supercomputing modeling and simulation extensively to support numerous programs in aeronautics, Earth and space science, space exploration, and technology development. We need to provide our scientists and engineers a reliable end-to-end production supercomputing environment where they can most efficiently and effectively do their work while we continuously enhance the capability with minimal disruption. Over the past decade, NASA's computing capability has increased by three orders of magnitude. Extrapolating this trend, one can expect us to deploy our first exascale supercomputer in the early part of the next decade.

What types of applications that the agency uses will be able to take advantage of such a machine?

Biswas: Some NASA applications could effectively use an exascale system today, and many more applications will be exascale-ready within the next 10 years. Any application that must simulate phenomena at vastly different length and time scales could use an exascale or larger system. For instance, in Earth system modeling, length scales vary from global to regional, while time scales lie between centuries and hours. Similarly, astrophysical processes range in scale from a quantum singularity to the entire universe and from Planck time to billions of years.

In the field of computational fluid dynamics, the most accurate models, such as those using large eddy simulation and direct Navier Stokes methods, involve orders of magnitude ranges in length and time scales. In addition, the need to solve multi-phase, multi-physics problems for NASA missions can use up significantly more computational power than currently available. And engineering design cycles for launch and exploration vehicles using accurate high-fidelity simulations can be dramatically accelerated with an exascale system.

The FLOPS-centric model of supercomputing has been undergoing an increasing amount of scrutiny. By the time exascale machines arrive, will such a designation even be worthwhile? Do you believe most supercomputing users, NASA included, will be using other performance metrics as their main criteria?

Biswas: We at NASA already use other metrics as the main criteria to measure the performance of supercomputers, such as when making purchases and in managing daily operations. For many years, our primary metric has been how quickly and at what cost a system is able to run a workload of representative NASA applications. While FLOPS may provide an upper bound for supercomputer performance, it is not effective in predicting broad application performance, and the distinction becomes more apparent as we move towards exascale. For NASA, it is all about the impact that supercomputers are having and can have to accelerate our agency missions.

Are you worried that the US is in danger of losing it technological lead in supercomputing, especially as it pertains to these leading-edge systems?

Biswas: No, I am not worried. In fact, I am confident that that US has the wherewithal to maintain its supercomputing leadership. While many other countries are vying, this is a significantly more difficult challenge than just fielding a supercomputer with the most FLOPS. The supercomputing ecosystem is much more than a leading-edge hardware platform. It also includes robust and scalable systems and application software, associated infrastructure — such as storage and networking — an industry that thrives on competition and innovation, and a diverse community that collaborates and competes in the advancement of all of these areas. The US has the leadership in all of these areas and with a strategic vision and appropriate resources, will continue to maintain that status in the coming decade and beyond.

Dr. Biswas will talk about NASA's foray into quantum computing at the International Supercomputing Conference [1] *(ISC'14) in Leipzig Germany. The session* [2] *will take place on Wednesday, June 25, and will also feature Google's Harmut Neven and Frederico Spedalieri, from University of Southern California.*

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