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The Quantum Times

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Building more intelligent machines: can 'co-design' help?

Suzanne Gildert

There are many challenges that we face as we consider the future of computer architectures, and as the type of problems that people require such architectures to solve changes in scale and complexity. A recent article written for HPCwire [1] on 'co-design' highlights some of these issues, and demonstrates that the High Performance Computing (HPC) community is very interested in new visions of breakthrough system architectures. Simply scaling up the number of cores of current technologies seems to be getting more difficult, more expensive, and more energy-hungry. One might imagine that in the face of such diminishing returns, there could be innovations in architectures that are vastly different from anything currently in existence. It seems clear that people are becoming more open to the idea that something revolutionary in this area may be required to make the leap to 'exascale' machines and beyond. The desire for larger and more powerful machines is driving people to try to create more 'clever' ways of solving problems (via algorithms and software development), rather than just increasing the speed and sheer number of transistors doing the processing. Co-design is one example of a buzzword that is sneakily spreading these memes that hint at 'clever' computing into the HPC community.

Generalization and specialization

I will explain the idea of co-design by using a colorful biological analogy. Imagine trying to design a general purpose animal: Our beast can fly, run, swim, dig tunnels and climb trees. It can survive in many different environments. However, anyone trying to design such an animal would soon discover that the large wings required for it to fly also prevent it from digging tunnels effectively and that the thick fur coat needed to survive the extreme cold is not helpful in achieving a streamlined, fast swimmer. Any animal that was even slightly more specialized in one of these areas would quickly out-compete our general design. Indeed, for this very reason, natural selection causes specialization and therefore great diversity amongst the species that we see around us. Particular species are very good at surviving in particular environments.

The problems that processors are designed to solve today are by and large all very similar. One can view this as being a bit like the 'environmental landscape' that our general purpose creatures live in. If the problems that they encounter around their environment on a day-to-day basis are of the same type, then there is no reason to diversify. Similarly, a large proportion of all computing resources today address some very similar problems, which can be solved quite well using general purpose architectures such as Intel Centrino chips. These tasks include the calculations that underlie familiar everyday tasks such as word-processing, and displaying web pages. But there do exist problems that have been previously thought to be very difficult for computers to solve, problems that seem out

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of reach of conventional computing. Examples of such problems are face-recognition, realistic speech synthesis, the discovery of patterns in large amounts of data, and the extraction of 'meaning' from poetry or prose. These problems are like the trees and cliffs and oceans of our evolutionary landscape. The general purpose animals simply cannot exploit these features, they cannot solve these problems, so the problems are typically ignored or deemed 'too hard' for current computing platforms.

But there are companies and industries that do care about these problems. They require computing power to be harnessed for some very specific tasks. A few examples include extracting information from genetic data by biotechnology companies, improving patient diagnosis and medical knowledge of expert systems in the healthcare sector, improving computer graphics for gaming experiences in the entertainment industry, and developing intelligent military tools for the defense industry. These fields all require the searching and sorting of data in parallel, and the manipulation of data on a much more abstract level for it to be efficient and worthwhile. This parallel operation and abstraction is something that general purpose processors are not very good at. They can attempt such a feat, but it takes the power of a supercomputer-sized machine to tackle even very small instances of these specialized problems, using speed and brute force to overwhelm the difficulty. The result is very expensive, very inefficient, and does not scale well to larger problems of the same type.

It is this incorporation of variety and structure, the addition of trees, cliffs and oceans, into our computational problems that causes our general-purpose processors to be very inefficient at these tasks. So why not allow the processors to specialize and diversify, just as natural selection does in order to better deal with the environment(s) defined by our biological needs?

Following nature's example

Co-design attempts to address this problem. It tries to design solutions around the structure of the problem type, resulting in an ability to solve that one problem very well. In practice this is done by meticulous crafting of both software and hardware in synchrony. This allows software that complements the hardware and utilizes subtleties in the construction of the processor to help speed things up, rather than software that runs on a general architecture and incurs a much larger overhead. The result is a blindingly fast and efficient special purpose architecture and algorithm that is extremely good at tackling a particular problem. Though the resulting processor may not be very good at certain tasks we take for granted using general-purpose processors, solving specialized problems instead can be just as valuable, and perhaps will be even more valuable in the future.

A selection of processors that are starting to specialize are discussed in the HPCwire article. These include MDGRAPE-3, which calculates inter-atomic forces, and Anton, a system specifically designed to model the behavior of molecules and proteins. More common names in the processor world are also beginning to explore possible specializations. Nvidia's GPU based architectures are gaining in popularity, and FPGA and ASIC alternatives are now often considered for inclusion in HPC systems, such as some of Xilinx's products. As better software and more special purpose algorithms are written to exploit these new architectures, they become cheaper and smaller than the brute-force general purpose alternatives. The size of the market for these products increases accordingly.

The quantum processors built by D-Wave Systems [2] are a perfect example of specialized animals, and give an insightful look into some of the ideas behind co-design. The D-Wave machines don't look much like regular computers. They require complex refrigeration equipment and magnetic shielding. They use superconducting electronics rather than semiconducting transistors. They are, at first inspection, very unusual indeed. But they are carefully designed and built in a way that allows an intimate match between the hardware and the software algorithm that they run. As such they are very specialized, but this property allows them to tackle very well a particular class of problems known as discrete optimization problems,. This class of problems may appear highly mathematical, but looks can be deceiving. It turns out that once you start looking, examples of these problems are found in many interesting areas of industry and research. Most importantly, optimization forms the basis of many of the problems mentioned earlier, such as pattern recognition, machine learning, and meaning analysis. These are exactly the problems that are deemed 'too hard' for most computer processors, and yet could be of incredible market value. In short, there are many, many trees, cliffs and oceans in our problem landscape, and a wealth of opportunity for specialized processors to exploit this wonderful evolutionary niche!

Co-design is an important idea in computing, and hopefully it will open people's minds to the potential of new types of architecture that they may never have imagined before. I believe it will grow ever more important in the future, as we expect a larger and more complex variety of problems to be solved by our machines. The first time one sees footage of a tropical rainforest, one can but stare in awe at the wonders of never-before-seen species, each perfectly engineered to efficiently solve a particular biological problem. I hope that in the future, we will open our

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eyes to the possibility of an eco-sphere of computer architectures, populated by similarly diverse, beautiful and unusual creatures.

[1] http://www.hpcwire.com/features/Compilers-and-More-Hardware-Software-Codesign-106554093.html
[2] http://www.dwavesys.com/

__Suzanne Gildert__ is an experimental physicist and applications developer at D-Wave Systems. Her work uses quantum algorithms implemented with superconducting circuits to solve real world problems in machine learning and optimization. She runs a popular blog entitled 'Hack the Multiverse' which is a grassroots effort to encourage people to get involved in quantum computing through programming. She is also well-known in the blogosphere for her popular blog Physics and Cake. Suzanne obtained her PhD and MSci degree from The University of Birmingham UK, focusing on the areas of experimental quantum device physics and superconductivity. Outside of physics, Suzanne has a wide range of interests including artwork, machine learning, sci-fi, and entrepreneurship.

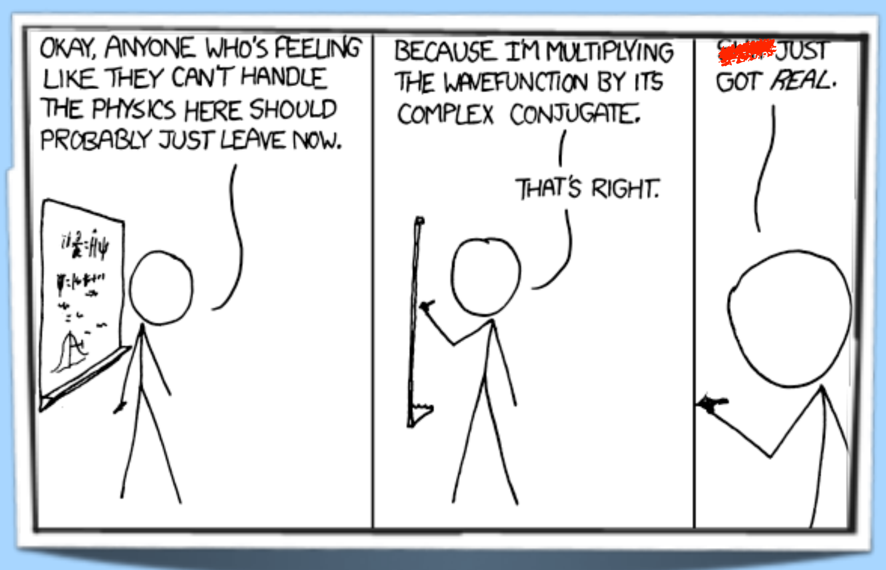
Seeking news items!!!

Don't see your work mentioned in "Bits, Bytes, and Qubits?" Think we've forgotten about you? Send us **a one-to-three paragraph summary of your recent research** and we will include it in our news items. This is a great way to get your work noticed not just by others in the field, but also by some outside the field. At least once (possibly more) an item in *The Quantum Times* has directly led to an item appearing in *Physics Today*!

Unfortunately, the editor only has a finite amount of time he can dedicate to the actual writing process. As such, it would be *immensely helpful* if short submissions similar to what appears in "Bits, Bytes, and Qubits" were submitted for inclusion.

Submissions should be e-mailed in LaTeX, Word, Pages (iWork), RTF, PDF, or plain text to the editor, Ian Durham, at idurham@anselm.edu.

the lighter side from xkcd.com by Randall Monroe



Bits, BYTES, *and Qubits*

QUANTUM NEWS & NOTES

Quantum Shannon Theory Explained

Mark M. Wilde of McGill University has completed a new 642-page textbook entitled *From Classical to Quantum Shannon Theory*. The text is a significant update to the "information" part of Nielsen and Chuang's *Quantum Computation and Quantum Information* and covers many of the post-millenium breakthroughs in the field of quantum Shannon theory. It begins with a review of classical information theory and quantum mechanics and progresses to a detailed study of teleportation, super-dense coding, and entanglement distribution. The middle part of the book covers essential tools such as distance measures, classical and quantum entropy, and classical and quantum typicality. The culmination of the text is in the final two parts of the book where many important protocols are covered, including quantum compression, entanglement concentration, classical communication, entanglement-assisted classical communication, private classical communication, quantum communication, and trade-off coding. In these chapters, Wilde also overviews many of the recent surprises such as superadditivity of the Holevo quantity and superactivation of the quantum capacity. The book's final chapter features a terse summary of all of the aforementioned protocols phrased in the language of resource inequalities. The text is available under a Creative Commons Attribution-NonCommercial-ShareAlike license, meaning that you can modify and redistribute the book as you wish, as long as you credit Wilde and don't use it for commercial purposes. Such a license should allow course instructors to adapt the text for their own needs and include new discoveries as they are made. You can find the text online at the arXiv: http://arxiv.org/abs/1106.1445.

-Mark M. Wilde

'Lazy' states

Quantum decoherence, as it is traditionally explained, leads to an entropy change of the system as it gets correlated to its environment. In a recent report published in *Physical Review Letters* (**106**, 050403 (2011)), César A. Rodríguez-Rosario and Alán Aspuru-Guzik from Harvard University, in collaboration with Gen Kimura and Hideki Imai from Chuo University, have determined that the quantumness of these correlations plays a crucial dynamical role. Usually, when studying the properties of open quantum systems, specific assumptions of the dynamics of the system are made, like some particular couplings to the environment, that the environment is in thermal equilibrium, or the Markov approximation. By avoiding these approximations, and considering the total system-environment state, they found a simple exact expression for the time derivative of the entropy, or the entropy rate as it is known in non-equilibrium thermodynamics. From here, a class of system-environment states was found to lead to a zero entropy rate independent of the particulars of the coupling to the environment. This class of states, which they named 'lazy' states, have properties that make them a generalization of classically correlated states, as defined by quantum discord. At the same time, the amount of quantum correlations between the system and its environment provide a bound on the magnitude of the entropy rate. Thus, a new important connection between quantum information theory and non-equilibrium thermodynamics has been established: the evolution of quantum correlations between the system and its environment are essential for non-equilibrium thermodynamics.

-Alán Aspuru-Guzik

Complementarity and weak measurements

Niels Bohr's principle of complementarity assumes that light (and, in fact, all matter) is both a particle and a wave and yet these two 'complementary' aspects can never ben observed simultaneously. The most famous demonstration of this principle is a take on the two-hundred-year-old double slit experiment in which individual photons are passed through the slits. The interference pattern representing the wave nature of the light, appears after a large number of photons have passed through the slits. However, if one attempts to determine through which of the two slits a photon passes by placing a detector at a slit, the interference pattern is destroyed. Thus, in accordance with Bohr's principle, it appears we cannot observe both the particle and the wave nature of light. Researchers at the University of Toronto, however, appear to have done just that.

The group, led by Aephraim Steinberg, performed what are called 'weak measurements' on the photons' momentum and thereby circumvented Bohr's principle. The team accomplished this by having the photons pass through a thin sliver of calcite. This gave each photon a tiny 'nudge' with the amount of deviation from its path being directly linked to which slit it passed through. This was not enough to destroy the interference pattern. While it may appear that this violates the uncertainty principle, that is not actually the case since that principle applies to a single particle and the team's results were based on an averaging over all of the photons. It is nevertheless a triumph for weak measurements and promises to re-open a number of foundational questions. The work was published in the June 3 issue of *Science*.

-ITD

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News, continued

Bernstein cancer cured

Many of you may know the always effervescent Herb Bernstein of Hampshire College, a co-author of the first paper on concentrating entanglement. In addition to purely theoretical work, Herb has proposed several important *real* (not Gedanken) experiments, going back decades: measuring the fermion factor of -1 under 2π rotation; the first entanglement concentration ever done in a lab; and his latest, yet to be performed, "SuperDense Communication of Quantum Information by Semi-Teleportation." Herb has now been cured of myxofibrosarcoma --a small lump in his back muscle discovered in January-- by a combination of radiation therapy and his May 10th surgery. The operation was quite extensive. Herb would greatly appreciate hearing from friends and colleagues as he works his way back to better health. So as not to inundate him, for more information, including the URL of the Bernsteins' website that tracks Herb's progress please contact me (Ian Durham, Editor of *The Times*) at idurham@anselm.edu.

-ITD

APS

Topical Group on Quantum Information

The Quantum Times

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Contributions

Contributions from readers for any and all portions of the newsletter are welcome and encouraged. We are particularly keen to receive

- **op-ed pieces and letters** (the APS is *strongly* encouraging inclusion of such items in unit newsletters)
- **books reviews**
- **review articles**
- **articles describing individual research** that are aimed at a broad audience
- **humor** of a nature appropriate for this publication

Submissions are accepted at any time. They must be in electronic format and may be sent to the editor at idurham@anselm.edu. Acceptable forms for electronic files (other than images) include LaTeX, Word, Pages (iWork), RTF, PDF, and plain text.

Editorial policy

All opinions expressed in *The Quantum Times* are those of the individual authors and do not represent those of the Topical Group on Quantum Information or the American Physical Society in general.

Dear Colleagues,

A workshop entitled *AMO Theory: Recent Developments and a Vision for the Future* will be held at the National Science Foundation in Arlington, VA, on August 18-19, 2011, with the following objectives:

I. To bring together leading researchers in atomic, molecular, and optical physics to assess the state of theoretical research in the field and to formulate a vision for theoretical atomic, molecular, and optical physics (TAMOP) for the next decade.

II. To survey the current organizational and funding landscape in TAMOP, including the balance between individual investigators, groups of investigators, centers and institutes, and types of institutions, and to suggest general guidelines for the next decade.

This workshop will bring together leading scientists from the US and elsewhere, funding agents, AMO-related center directors, and other interested representatives in a highly interactive format. Panel and open-floor discussions will follow a number of scientific overview talks. Funding agents will report on the current funding situation. Involvement of the Office of Science and Technology Policy is also anticipated. The end product of this workshop will be a report prepared by the four co-organizers.

Participation is open to all interested attendees from the AMO community (subject to space constraints). We especially encourage attendance by young investigators, including new faculty members and senior postdocs, to help us identify future directions in TAMOP. In addition, the majority of the workshop sessions will be broadcast via EVO (see http://evo.caltech.edu/evoGate/ for installation details), thereby also allowing for remote participation in the discussion.

For further information see the workshop website http://panda.unm.edu/TAMOP. An online discussion will be conducted on this site in the weeks leading up to the workshop, so that the community can formulate a set of "big scientific questions" for the field and can address the programmatic issues of Objective II. Your input to this discussion is essential to guide the process.

Registration and the discussion forum for the workshop will be open on June 20, 2011 at http://panda.unm.edu/TAMOP.

Sincerely yours,
The Workshop Co-Organizers
Klaus Bartschat (klaus.bartschat@drake.edu)
Doerte Blume (doerte@wsu.edu)
Carlton Caves (caves@info.phys.unm.edu)
Ivan Deutsch (ideutsch@unm.edu)

Position Announcement

The Université de Sherbrooke invites applications for tenure-track position with a research profile in Condensed Matter Physics or in the Physics of Quantum Information.

Description

The new professor is expected to teach in French at the undergraduate or graduate level and his/her research program, either in Experimental or Theoretical Physics, will reinforce or broaden the research areas already in place in the department. The 13 faculty of the department conduct research in the following areas: Superconductivity, Strongly correlated electrons, Magnetism, Quantum information, Photonics and Mesoscopic Physics. Many are members of the following networks: RQMP (Regroupement Québécois sur les Matériaux de Pointe), INTRIQ (Institut teansdisciplinaire d'informatique quantique), CIFAR (Quantum Materials, Quantum Information Processing and Nanoelectronics programs). They have access to world-class computing resources via Compute Canada and to exceptional facilities in the fields of Quantum Materials and Nanotechnology.

How to apply

Résumés must be received by 5:00 p.m., November 30, 2011. Please use the convenient electronic system to submit your application to the coordinates listed below. With your résumé, also include a letter of interest containing a short description of your research program and a statement of vision on teaching.

In addition, please have three letters of recommendation supporting your application sent directly by the signatories to the coordinates listed below.

Monsieur le Doyen
Offre d'emploi no 1060
Faculté des sciences
Université de Sherbrooke
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Sherbrooke (Québec) J1K 2R1
Courriel : doyensci@USherbrooke.ca


International Workshop on
Theoretical Aspects of the
Discrete Time Quantum Walk
Date: November 7th-10th, 2011
Venue: Instituto de Física Corpuscular, Valencia, Spain
Abstract Deadline for Oral Presentation: Sep. 1st 2011
Aim
What are probability and stochastic processes in Quantum Mechanics? To study the foundations of stochastic processes in Quantum Mechanics, the discrete time quantum walk (DTQW), which is the quantum analogue of the classical random walk, may be useful. This has recently been a hot research field, especially in quantum information science, and has been experimentally realized. This workshop will bring the theoretical researchers in the DTQW. While this workshop is focused on the theoretical side, we also welcome experimentalists. The organizers strongly encourage young researchers to actively join us to this workshop.
Conference Scope
1. Proposals on Physical Realizations of the DTQW
2. Asymptotic Behavior of DTQW
3. Decoherence in the DTQW
4. Applications to Quantum Information Science
Invited Speakers
Frederick W. Strauch (Williams College, USA)
Takuya Kitagawa (Harvard University, USA)
Organizers
Armando Perez (Departamento de Fisica Teorica and IFIC, Universidad de Valencia/CSIC, Spain)
Yutaka Shikano (Tokyo Institute of Technology, Japan)
Eugenio Roldán (Departamento de Óptica, Universidad de Valencia, Spain)
Mari Carmen Bañuls (MPQ, Garching, Germany)
Scientific Secretary
M. Hinarejos (Departamento de Fisica Teorica and IFIC, Universidad de Valencia/CSIC, Spain)
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http://ific.uv.es/~perez/DTQW_Valencia.html