THE QUANTUM TIMES

AMERICAN PHYSICAL SOCIETY ◆ TOPICAL GROUP ON QUANTUM INFORMATION

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A National Initiative in Quantum Information Science

An unprecedented and landmark meeting that could shape the future of quantum information science (QIS) funding in the US for years to come was recently held in Vienna, Virginia, just outside Washington, DC. The Workshop on Quantum Information Science, held April 23-25, 2009, gathered prominent scientists and representatives of US agencies to discuss national strategies for supporting QIS research in the US.

The Subcommittee on Quantum Information Science (SQIS) of the US National Science and Technology Council (NSTC) within the Office of Science and Technology Policy (OSTP) quickly organized this workshop in response to a recently released report, "A Federal Vision for Quantum Information Science." The report identifies three major QIS research challenges: assessing the power of quantum computation, assessing the limits of quantum control, and assessing the properties of collective quantum phenomena. A major discussion point of the workshop was whether this list was sufficiently broad and whether instead it should cover quantum communication, quantum computation, and quantum metrology. The members of the SQIS who authored the report were not identified.

Underscoring the importance of this workshop was the attendance of two Nobel Laureates (Bill Phillips and Tony Leggett) and a Fields Medalist (Mike Freedman) as well as representatives of numerous US federal research agencies, including the National Security Agency (NSA), the Intelligence Advanced Research Projects Activity (IARPA), the Defense Advanced Research Projects Agency (DARPA), the National Science Foundation (NSF), the National Institute of Standards and Technology (NIST), the Department of Energy (DOE), the Army Research Laboratory (ARL), the Air Force Research Laboratory (AFRL), and the Naval Research Laboratory (NRL). The meeting was open to anyone who wanted to register, but was organized on short notice, with many people first becoming aware of the workshop's existence via April 6 and April 7 posts to the blogs of Dave Bacon and Scott Aaronson.

Carl Williams of NIST and the OSTP kicked off the workshop by stating that the goals of the workshop were to identify the important science questions, the systemic problems in the field hindering progress, the obstacles to the health and vitality of the field, and ideas for assisting federal agencies to better advocate for QIS. In his words, this workshop was "our time to influence the future budget" of U.S. QIS funding. Reinforcing this, he noted that the OSTP is part of the executive branch, which sends proposed federal budgets to Congress and that the OSTP is able to lobby congressional staffers, unlike most other government employees who are banned from such activities. Williams stated that he was under orders not to mention any specific numbers for the budget. He also apologized for the short notice for the workshop, stating that it needed to be organized hastily in order to influence the 2011 federal budget. He stated that waiting any longer would have delayed influencing the federal budget until 2012. Williams further added that the SQIS-written document was a "vision document," not an "investment policy," because of the change in

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Inside...

We are entering a time of great opportunity for quantum information science (QIS) and the majority of this issue is devoted to a discussion of a major national initiative in QIS. In our lead article, Mark Wilde and Andrew Landahl give a detailed report from the recent workshop convened to discuss just such an initiative. Please note that the article includes a number of working **hyperlinks**. As such, in order to use these we recommend reading the issue in a standard PDF reader.

I also would like to reiterate the need for further communication from you, our readers. The APS *strongly encourages* unit newsletters include a 'Letters to the Editor' section. In order to do so, however, I need to actually receive such letters. Now, perhaps more than ever, we are in need of a robust dialogue within our community. As was suggested by at least two people recently, I will make my e-mail address even easier to find and use by including it here in this box. Please be sure to include a reference to GQI in your subject line just in case your e-mail is caught in my spam filter. I look forward to hearing from you!

ITD

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presidential administrations. He stated that a similar vision document on nanotechnology spanned the Clinton to Bush transition, which eventually led to the National Nanotechnology Initiative. President Obama's recent call for the doubling of the NSF budget and Dmitry Maslov's recent call for NSF quantum information proposals at the QIP 2009 conference in Santa Fe, New Mexico, both suggest that the current administration may support growth in QIS funding, at least within the NSF.

John Preskill of the Institute for Quantum Information (IQI) at the California Institute of Technology (Caltech) organized the technical program. The workshop featured open discussions and technical talks from many of the leading researchers in QIS. The quality of the technical talks was exceptional, and many of the speakers and participants spoke openly about their concerns for our field.

Issues

A number of issues were raised by members in attendance. The following are a list of some of these. Summaries of some of the technical talks follow this review of the issues. A complete list of talks, some of which hit upon these issues, can be found at the workshop website.

STABLE FUNDING

Several attendees mentioned that stable funding is a major concern for their programs. Charlie Marcus of Harvard said, "When funding is lean and people are mean, cooperation goes down, and cooperation is essential to the advancement of the field." Bill Phillips of NIST mentioned in an open discussion presentation that "jerking researchers around" from one project to the next will decrease productivity in the long run for the field. Phillips further argued that stable funding needs to be a long-term commitment, not a short-term commitment like the Manhattan Project.

COORDINATION

While QIS scientists routinely meet together, QIS funding agency representatives routinely meet together, and QIS funding agency representatives routinely meet with the QIS scientists whom they fund; apparently a meeting in which all such parties appear in a single meeting has yet to happen until this workshop. Jon Dowling of Louisiana State University suggested such meetings should recur periodically as a healthy way to keep our field on course.

While many participants were supportive of having some kind of national initiative on QIS, no concrete decisions were made. In particular, it was still unresolved as to how to best coordinate agencies that fund QIS research. Bill Phillips suggested that maintaining a diversity of funding styles as currently exists is a good thing; however, coordination ends up being affected, because some funding styles favor "mavericks" while others favor "yeomen," and the field needs both kinds of researchers to make progress.

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The Role of Liberal Arts Colleges in a National QIS Initiative

The United States is unique in that it has a large number of primarily undergraduate institutions, usually (though not always) referred to collectively as 'liberal arts colleges' or just simply 'colleges.' This is generally different to that term's usage in Canada or the UK. Many well-known QIS researchers actually work at these institutions, e.g. Bill Wootters (Williams College), Ben Schumacher (Kenyon College), Michael Horne (Stonehill College), Alex Wilce (Susquehanna University), and Peter Love (Haverford College). These institutions are generally small and do not necessarily benefit from the presence of multi-million dollar research facilities. They nonetheless play an important role in educating future physicists. Consider the following statistics from the American Institute of Physics from 2007:

Institution type	Number	BS/BAs awarded
Graduate	188	2981
Undergraduate	511	2416

Note that this data excludes institutions that award a Master's but no PhD.

Given these data, how much effort should be expended by any national initiative on students and faculty at these institutions? It's a tough question. AIP data *does* indicate that students receiving their bachelor's from the larger universities are more likely to attend graduate school, but AIP is also quick to point out that the reason for this is not understood. In other words, the reason could be the type of student the smaller institutions attract *or* it could be that, by not being exposed to the graduate school experience, students at these institutions are simply less likely to consider it an option.

So just how much have institutions such as these done for the QIS community aside from the contributions of a handful of faculty active in the field? While this is difficult to judge, it may help to identify a few QIS researchers who attended such schools. Of the aforementioned faculty, Alex Wilce holds a BS from Oberlin College in Ohio and Ben Schumacher holds a BS from Hendrix College in Arkansas. Others possibly familiar to our readers include Ken Brown (Georgia Tech) whose PhD advisor was Birgitta Whaley, and who received his BS from the University of Puget Sound, and Chad Orzel who attended Williams and now teaches at Union College in Schenectady, New York.

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Scope of the Federal QIS Vision

Ivan Deutsch of the University of New Mexico gave a presentation in one of the open sessions in which he described QIS as residing in "three pillars," namely quantum communication, quantum computation, and quantum metrology, resting on a platform of quantum foundations. He noted that the scope of the existing federal QIS vision document misses many of these. Andrew Landahl of the University of New Mexico agreed with the pillars, but cautioned against establishing hard funding boundaries along these lines, as many interesting research questions span these, such as quantum imaging (metrology/communication) and quantum error correction (computation/communication). Several funding agents agreed, noting that earlier attempts to corral QIS research in this way failed. Richard Hughes of Los Alamos National Laboratory made the case for including quantum communication particularly compelling, citing many success stories for quantum communication research including his own quantum key distribution research at Los Alamos.

Tenure-Track Positions

Many participants, including organizer Carl Williams, commented on the dearth of tenure-track QIS hires in the US, particularly for theorists. Jonathan Dowling made the point in a compelling way by examining the career paths of theorists trained at the NSF-funded Institute for Quantum Information at Caltech. He counted that 20 of the last 25 Ph.D. students and postdoctoral fellows from Caltech do not have tenure-track positions in US universities. Without growth in the ranks of QIS educators in the US, students will be forced to go abroad to receive a QIS education and may potentially stay abroad afterward. To underscore the demand for QIS educators, Ivan Deutsch reported that 50 percent of the incoming graduate students to the University of New Mexico's Physics and Astronomy Department want to do research in QIS and that roughly 50 percent of the members of the APS Topical Group on Quantum Information are students.

Ray Laflamme, Director of the Institute for Quantum Computing (IQC) at the University of Waterloo in Canada made it clear that the IQC is taking advantage of the lack of tenure-track hiring in U.S. universities by grabbing talent early. With a stated goal of 30 faculty hires, 50 post-doc hires, and 125 students, and routine financial support at the $50M50 million level since 2005, Laflamme reported being nearly 50 percent towards that goal, with 18 faculty, 21 post-docs, and 64 students already on board. Many of the existing IQC faculty hires are theoretical and he stated that the future plans are to focus on experimental hires.

One idea discussed to stimulate the hiring of QIS tenure-track faculty at US universities was to have funding agencies support the full salaries for new QIS tenure-track faculty for a fixed number of years. The idea would be to "seed" the field and inspire other universities to hire in this area. Indeed, one university dean in attendance noted that

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It is not simply top-tier schools such as Williams or Oberlin that nurture talent, however. My own institution, Saint Anselm College in Manchester, New Hampshire, is generally not in the same category as the aforementioned schools, though we are a very rigorous school (our nickname is 'Saint C's'). Yet some of our former students are in PhD programs at Yale and Boston College for physics and Dartmouth for mechanical engineering, with several others in 3-2 cooperative engineering or Master's programs at Notre Dame, Rensselaer Polytechnic Institute (RPI), and Worcester Polytechnic Institute (WPI), among others.

What can a liberal-arts educated student offer that is different? My answer would be the ability to think outside the box since these students have very broad backgrounds in fields outside the sciences. Liberal-arts colleges excel at interdisciplinary education. In addition, many liberal-arts colleges have more stringent foreign-language requirements which is important, particularly for QIS which is such an international, not to mention interdisciplinary, field.

So what does this mean for a national initiative in QIS? If we want talented, young students from American schools to enter this field, it is imperative that we reach them as well as faculty at these schools. Here are some suggestions:

- More QIS REU programs (my student headed to Yale was inspired by his REU experience last summer).
- More QIS ROA programs (these are NSF programs *designed* to bring faculty from liberal-arts colleges to larger universities on research visits).
- Help support conferences that bring faculty and students from liberal-arts colleges in contact with researchers at larger institutions.
- Help support travel grants for faculty and students at these schools to attend major QIS meetings.
- Help support the newly founded Anacapa Society whose goal is to serve theorists at undergraduate institutions.

It is my hope that this column will spur action on this issue and I welcome any additional suggestions, comments, or offers of assistance.

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Op-ed *Mark Wilde*

I highlight two main points in this opinion piece: the brain drain of QIS researchers and ways for theorists to get their foot in the door of traditional engineering departments.

Brain Drain

Many researchers view Canada as the country leading the effort to build a quantum computer. Consider some of the commentary at the recent Third Annual QuantumWorks Annual General Meeting. Ned Allen of Lockheed Martin began his talk there by stating, "For many years, we've known that Canada has led the world in quantum information science, and so, it's an honor to be here among so many whose work I so admire." Eric Holdrinet of the Consulate General of Canada mentioned that Canada is specifically interested in a "Canada-California" partnership for the field of quantum information science, but there was little mention of a more general U.S.-Canada partnership. Mike Lazaridis, president and co-CEO of Research in Motion (maker of the BlackBerry®), one of the major supporters of quantum computing in Canada, showed his commitment to the long term in Canadian QIS research when he stated, "The investment Canada makes today in quantum computing will set the foundation for Canada's global commercial success in this important new technology in the 21st century."

As a result of these Canadian initiatives, the U.S. is experiencing a major "brain drain" of QIS researchers to Canada. A quick perusal of the faculty of the Institute for Quantum Computing at the University of Waterloo reveals that seven of 18 obtained their doctoral degrees at U.S. institutions. Each of these faculty members are major players in their respective fields of study. Raymond Laflamme discussed the IQC's aggressive future plans to grow to 30 faculty members, 50 postdocs, and 125 students and to build a world fabrication and metrology facility. He also said that "every time someone buys a BlackBerry, that person is donating to QIS research," well, to Canadian QIS research.

Singapore is also attracting many high-quality researchers, benefiting from a large donation from their government. Most of the faculty at the Centre for Quantum Technologies of the National University of Singapore obtained their doctoral degrees from European universities, have affiliations with European universities, and

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one of the things a dean looks for when hiring in a new area is whether competitor universities are hiring in that area. Another thing he noted was that having a source of stable funding for the new hire was also an important consideration.

IS IT SCIENCE OR IS IT ENGINEERING?

Many participants acknowledged that at least some of the issues facing QIS technologies are entering the realm of engineering, not science. Bill Phillips warned that it is still too soon to discount any platforms for quantum computing, and that he predicted that there will continue to be a close marriage of science and engineering for some time. Mark Kasevich noted that as some QIS technologies mature, small businesses will develop and that part of the federal vision for QIS funding should incorporate Small Business Innovation Research (SBIR) grants.

FEELING THE (INTERDISCIPLINARY) LOVE

A number of researchers made an effort to highlight connections between physics and computer science in their technical talks. Charlie Bennett of IBM went so far as to say that what is great about QIS is the combination of the discipline of computer science and the insight of physics. Later, in one of the open discussion sessions, a representative from the NSF said that she thought the talks at the workshop appeared to her to be either about computer science or about physics, but not both. She said that QIS researchers need to do a better job of showing how these two fields relate.

Dorit Aharonov of Hebrew University (Israel) then stood up and rebutted that her technical talk about constraint satisfaction problems and Hamiltonian ground states focused entirely on this point. Other researchers then stood up in turn and expressed the ways in which their research had this feature as well.

After these pointed responses, John Preskill quipped that he was "feeling the love in the room." He then gave an impassioned speech about how many of the seminal results in QIS have come from individuals with training in seemingly disparate disciplines. He cited Alexei Kitaev of Caltech whose deep knowledge of both physics and computer science enabled him to connect any theory to quantum error-correction. He cited Eddie Farhi of MIT who, with collaborators, leveraged knowledge of scattering theory to develop a new quantum algorithm for Boolean formulas. He cited Guifre Vidal of the University of Queensland who used the theory of entanglement to develop improved classical algorithms for simulating quantum systems. Preskill continued with many other examples, finally crediting part of his own ability for keeping productive in QIS research as deriving from inspirational discussions he has had with the bright individuals with diverse talents who have passed through the IQI.

THE CRACK PROBLEM

Alan Aspuru-Guzik of Harvard pointed out that applying for chemistry funding in the NSF requires finding the right heading under which to submit a proposal as determined by an elaborate "flow chart." He noted that QIS was not

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actively maintain these affiliations by traveling between Singapore and Europe. The Centre for Quantum Technologies also has an aggressive recruiting strategy, sponsoring visits for the new theory and experimental talent that is emerging from quantum information training programs in the U.S. and in the world.

Many "new wave" quantum information theorists have limited opportunities in the U.S. for contributing to this exciting field. We might naturally expect that theorists trained at the top-notch Institute for Quantum Information at Caltech would be training the next generation of quantum information theory and experimental students. But this is far from reality. Jonathan Dowling counted that 20 of the last 25 Ph.D. students and postdoctoral fellows from Caltech do not have tenure-track positions in U.S. universities. Dowling mentioned that the prime example is Dave Bacon at the University of Washington. The irreverently self-titled "Quantum Pontiff" has produced seminal contributions to the field in both quantum error correction and quantum algorithms. The so-called "Bacon-Shor" quantum code has had a profound impact on the theory of fault-tolerant quantum computation by reducing the overhead that is necessary to build a practical quantum computer. But he remains as a research professor there, currently looking for a permanent position.

Ivan Deutsch of the University of New Mexico mentioned that 50 percent of the incoming students there desire to conduct QIS research. With the limited number of positions in the U.S., the influx of interested students will have difficulty finding positions in the U.S. if the current funding situation does not change. Many companies in industry do not yet see the value for their bottom line if they were to invest in QIS research. Nevertheless, there is a growing industrial effort in this field, and hopefully, this effort will continue to grow.

Breaking down the doors to Engineering Departments

An often-mentioned concern is that it is currently difficult for QIS Ph.D.s to obtain a position in traditional engineering, physics, or computer science departments in U.S. universities. Such departments often reject a QIS candidate, claiming that person does not belong to their respective field.

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represented in this flow chart, making his work on quantum chemistry simulations using quantum computing nearly impossible to propose. NSF funding representatives acknowledged that this is something that needs to be fixed. Aspuru-Guzik's comments pointed to a larger issue, raised by several other participants in one of the open sessions, which is that QIS needs to be recognized as a field unto itself, not something that just "falls between the cracks" of several other fields.

GET THE MESSAGE OUT

Malcolm Carroll of Sandia National Laboratories noted that part of the onus is on researchers in the field to write or continue writing popular articles on QIS to inform the lay public of the importance of QIS. He noted that most people have heard of astronomy (even senators!), but many have not heard of QIS. Williams reinforced this comment by saying that popular articles go a long way toward sending a clear message about why a field is important.

Carl Williams ended the final night of open discussions by asserting that we really need to "get our stories straight" to convince Washington to begin a national initiative in QIS. He stated that the argument that "theorists do not have jobs" is not sufficient to convince Washington to support a national initiative. He offered a more convincing argument that we should send to Washington: *a quantum computer is a device that will help people*. He suggested that quantum computers can help secure the future information infrastructure of the US and (possibly) improve our ability to simulate chemical reactions, which in turn could improve the health of people through pharmaceutical discoveries.

Technical Talks

We summarize the first two days of talks at the workshop. The first day began with Charlie Bennett summarizing the progress in quantum Shannon theory. He had several memorable quotes including "quantum information is like the information in a dream. You know that it was there, but you don't know what it was until you tell someone about it" and "classical computation is quantum computation handicapped by having an eavesdropper on all its wires. You can't really get anything done if someone is always looking over your back." He mentioned several of the past year's big results, including the disproving of the additivity conjecture by Matt Hastings and the demonstration of quantum communication with two zero-capacity quantum channels by Graeme Smith and Jon Yard (both highlighted in the *winter issue of the Quantum Times*).

Charlie Marcus highlighted recent progress for quantum computing with semiconductor systems. Before turning to gate-defined structures, he mentioned that work in optically addressed exciton-state qubits has made impressive progress lately, highlighting recent work from David Awshalom's group at UCSB and Yoshi Yamamoto's group at Stanford. He discussed progress initialization, control and readout of logical qubits comprising quantum dot pairs and showed device designs for coupled double-dots. Marcus praised the open nature of QIS research—a fast charge sensing RFSET (radio frequency single electron transistor) technique from

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There are a few ways to begin tackling the problems with engineering departments. I specifically highlight the case of electrical engineering departments.

If you are trying to become a member of an engineering department, consider that many chairs of engineering departments across the U.S. have likely not even read (some not even heard of!) the journals *Nature*, *Science*, or *Physical Review Letters*. Electrical engineering departments, in particular, are looking for candidates that actively publish in the Institute of Electrical and Electronics Engineers (IEEE) journals. Possibilities for theoretical contributions in QIS include the *IEEE Transactions on Information Theory*, the *IEEE Transactions on Computers*, and the *IEEE Transactions on Communications*. Possibilities for experimental contributions include the *IEEE Transactions on Quantum Electronics*, the *IEEE Photonics Technology Letters*, and the *IEEE Transactions on Applied Superconductivity*. With QIS becoming more applied as we progress from the laboratory to practice, increasing the flow of submissions to these journals will increase the exposure of QIS to engineering departments and will help in encouraging them to build expertise in QIS.

For editors of these journals, consider that the field will profit from the quick dissemination of research results. The arXiv is a useful means of distributing original, timely research results to the community, but many traditional researchers prefer to see the peer review "stamp of approval" before they consider citing or recommending an article (though, see Michael Nielsen's comments on flaws in the peer review system). Additionally, many hiring committees consider only journal publications, not necessarily arXiv preprints.

For those reviewing articles in these journals, consider the engineering and practical impact of the results that are being submitted. If an article has an extensive review of some of the literature in quantum information, this is not a negative aspect of the article, but is instead a benefit for the future quantum scientists and engineers. Again, timely responses here are of utmost importance for the progression of QIS.

Additionally, consider that engineering departments are looking for candidates that have a success pattern in researching new engineering areas and teaching traditional engineering courses. I highlight a specific

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Schoelkopf's superconducting group is useful for readout of his semiconductor qubits — and said that much of the effort in the first five years since the DiVincenzo-Loss proposal for semiconductor quantum computing was focused on simply setting up these systems. In the last five years, several teams around the globe are now achieving single electron control.

Umesh Vazirani posed an interesting question: "What if there was a classical cryptosystem unbreakable by a quantum computer?" The result is that everyone would want such a system today, and a quantum computer would then have had a huge impact without ever being built! He stated that it is difficult to solve a set of noisy linear equations and such a task is just as difficult as approximating the shortest vector in a lattice. A classical cryptosystem based on this idea may be one that would be unbreakable by a quantum computer, but unfortunately, this system is not efficient – not even close to the efficiency of the RSA cryptosystem. He ended by stating that solving an exponential-resource problem would be another great way to verify the quantum theory.

Robert Schoelkopf discussed recent progress in superconducting quantum systems. The group at the University of California, Santa Barbara, conducted a "tour de force" in quantum optics by showing how to explore the full Wigner function of an oscillator with a superconducting system. Schoelkopf's group conducted the first known version of Grover's algorithm with a two-qubit superconducting system.

There were many stellar talks after Schoelkopf, and Ike Chuang finished off Thursday with a talk discussing quantum computer architecture. He claimed that he has learned much about quantum computer architectures over the past 10 years simply by having many conversations with computer architecture experts at MIT. He stated that the main issue for quantum computing is quantum error correction and fault-tolerant quantum computation — 99 percent of the overhead in a quantum computer will go to quantum error correction routines for fault-tolerant quantum computation. Reducing this overhead will be crucial in building a scalable quantum computer. Any little way that can help reduce this overhead will be beneficial. The main areas where theorists can poke are in finding good quantum codes and architectures that will have a small overhead with a high threshold for noise.

On Friday, Bill Phillips discussed progress in quantum computing with ultra-cold neutral atoms and a few key experiments that have demonstrated many of the processes needed for quantum computing and quantum simulation. He mentioned that optical tweezers aid in implementing a so-called quantum shift register.

Barbara Terhal reviewed classes of states with an efficient classical description, such as matrix product states. QIS has explored these classes of states, and the result has been an explosion of techniques for simulating quantum systems on a classical computer. She also discussed area laws in QIS. An area law applies to the following scenario: We begin with a product state and encode with local unitaries. The amount of entanglement of the resulting encoded state scales with the boundary of the local unitaries, not with the area. Such area laws have been of recent interest in QIS in fundamental studies of entanglement.

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The Department of Electrical Engineering at the University of Southern California hired Igor Devetak as a quantum communication theorist for two main reasons: (1) he gave a rigorous proof of the quantum capacity theorem (the "fully quantum" equivalent Shannon's channel capacity theorem) that appeared in the *IEEE Transactions on Information Theory*, and (2) he had a significant amount of experience teaching electrical engineers when he was at Cornell University. Unfortunately, Igor left the field to pursue a career in finance, but he had a lasting impact on QIS by training several Ph.D. quantum information theorists.

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.

Paul Kwiat presented some of the engineering achievements for QIS with photonic systems, including the recent demonstration of quantum key distribution over 144 kilometers between two Canary Islands and progress in measurement-based quantum computation with linear optics. He suggested that hyperentangled states might be a road to achieving fault tolerance in linear optical systems.

Alan Aspuru-Guzik overviewed the progress in simulation of quantum systems. He also highlighted the growing interest in the field of quantum biology, a field exploring the existence of quantum effects in biological systems. A recent article in *Science Magazine* on the role of quantum coherence boosting the efficiency of photosynthesis has sparked this field of study. The Centre for Quantum Technologies held a workshop in January and DARPA held a workshop in September 2008 for its upcoming Quantum Effects in Biological Environments (QuBE) program. The Workshop on Quantum Effects in Biological Systems will be in July in Lisbon, Portugal.

The Workshop on Quantum Information Science featured an outstanding lineup of world-class QIS researchers, many of whom are not highlighted here. On a personal note, it was a pleasure to listen to these dynamic speakers present their research and advocate for the future of QIS research in the U.S. We hope that there will be another workshop of its kind some time in the future to further promote a U.S. national initiative in QIS research.

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Bits, Bytes, and Qubits

QUANTUM NEWS AND NOTES

$|0\rangle$ **Quantum Lighting** You knew it was only a matter of time before something like this happened, especially when you started noticing LED's being used in stoplights. What's "this?" Watertown, Massachusetts-based QD Vision in collaboration with Nexxus Lighting of Charlotte, North Carolina, has developed an LED-based lamp with an added piece of optics. The piece in question is a cover coated with quantum dots. The LEDs act as a light source that excites the quantum dots. The dots then radiate light at wavelengths that depend on the size of the dot. For instance, a two-nanometer dot gives off blue light while four-nanometer dot gives off green light and a six-nanometer dot gives off red light, providing what amounts to a set of RGB "pixels." The dots can thus be mixed in various ratios on the surface to provide a desired color. Amazingly, these new lights *fit a standard recessed ceiling socket*. Since the lights are LEDs they're more efficient than both incandescent and compact fluorescents. The addition of the quantum dots to the existing LED technology boosts the color rendering index value of the lights, i.e. makes it look more like natural light. In other words, you don't have to sacrifice your naturally healthy complexion for efficiency! Oh, but there is a downside: they're projected to cost about $100 each, though the companies claim you'll make that cost up in energy efficiency.

$\langle 1|0\rangle$ **Long-distance, entangled communication** Anton Zeilinger's Vienna-based research group has successfully transmitted an entangled pair of

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photons 144 km (89.5 miles to Yanks and Brits and 77.8 nautical miles to pirates) between telescopes on the Canary Islands. If that distance sounds familiar, that is because the same setup was used in 2007 to test the feasibility of quantum key distribution (which does not necessarily require an entangled pair of photons). Maintaining entanglement over such long distances in the atmosphere is notable since one might expect the atmosphere to degrade the entanglement by interacting with the photons. In essence this is the "ultimate" open quantum system with the atmosphere acting as the environment. The distance of 144 km marks the longest distance over which two photons have maintained their entanglement in air.

$\langle 1|0\rangle$ **Extending the life of a qubit state** Speaking of extending lifetimes, researchers at the National Institute of Standards and Technology (NIST) have found a way to extend the lifetime of a given qubit state. Since realistic quantum information processing usually involves the presence of some sort of environment, qubits, particularly the non-optical type, have trouble staying in a particular state for very long due to interactions with the environment. This is known as decoherence. The NIST researchers applied specially times magnetic pulses to beryllium ions and in the process were able to extend the average lifetime from roughly one millisecond to hundreds of milliseconds. In addition to its use in quantum information, the new technique may prove useful in improving the accuracy of atomic clocks just in case, you know, your employer takes to monitoring your work by the millisecond. Don't laugh; it could happen.

$\langle 1|0\rangle$ **Spin manipulation for quantum computing** A team of researchers from the universities of Bochum (Ruhr), Dortmund, St. Petersburg, and Washington has succeeded in manipulating electron spin. While it is common when presenting ideas about quantum information to the lay-person or to undergraduates to use the spin of an electron as an example, it's tremendously difficult to manipulate electron spin. In the original Stern-Gerlach experiment, in fact, they used a gas of silver atoms. While, in practice, manipulating an electron *beam* is feasible (think CRT), it has little that lends itself to quantum computing. In addition, using a single electron as a qubit requires highly sensitive - and very expensive - equipment. Now, the Bochum-led group has confined electrons to an ensemble of one-million indium-arsenic quantum dots. Measurements are made on the ensemble and the effects of the individual qubits are totaled in order to get the overall result. As such, the resultant signal is six times as strong.

$\langle 1|0\rangle$ **Quantum dots on your roof** Speaking of quantum dots, a team of researchers led by Pavlos Lagoudakis of the University of Southampton in the UK has found a way to use quantum dots to improve the efficiency of solar cells. The idea is pretty simple, actually. A single solar cell consists of a single p-n junction semiconductor that comes saddled with a 31% theoretical and 18% actual efficiency. But these cells consist of large sheets of semiconductor material. What happens each cell *were* a quantum dot? Quantum dots have their own limitations in that charge carriers in them are not as mobile as they are in larger sheets of semiconducting material. This makes sense simply considering the size of most quantum dots. Lagoudakis' group combined the two ideas by etching lines on the traditional semiconductor sheet and then embedding cadmium-selenium quantum dots on the structure. The idea is to combine non-radiative energy transfer with the ability to multiply the charge carriers. The expected result should exceed the 31% theoretical limit known to exist for traditional semiconductors.

$\langle 1|0\rangle$ **New method for quantum simulation** Researchers at the Max-Planck-Institut für Quantenoptik, led by Gerhard Rempe, have developed a new method for performing simulations with atomic gases. The researchers have been able to modify the properties of the atomic gas by simultaneously applying laser pulses and magnetic fields. The gas is a Bose-Einstein condensate (BEC) of rubidium atoms. BECs have been successfully manipulated before using each method - laser pulses and magnetic fields - separately, but this is the first time the two have been combined. The advantage is that losses by one method are mitigated by the presence of the other since losses occur for different reasons in the two methods.

$\langle 1|0\rangle$ **Martin J. Klein passes away** Physicist and historian of science Martin Klein passed away on March 28, 2009. He was just months shy of his 85th birthday. Klein was one of the pioneers of the history of quantum mechanics and was a leading authority on Einstein's work in the field, having served as senior editor of the Einstein Papers Project for ten years, from 1988 to 1998. He was also author of a biography of Paul Ehrenfest. In 2005 he was the first recipient of the APS' Forum on the History of Physics' (FHP) Abraham Pais Prize for the History of Physics,

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“for his pioneering studies in the history of 19th and 20th century physics, which embody the highest standards of scholarship and literary expression and have profoundly influenced generations of historians of physics." At the time of his death, Klein was the Eugene Higgins Professor Emeritus of the History of Physics as well as emeritus professor of physics. Several excellent obituaries have appeared, including in the *New York Times* (1 April). For more information, visit the website of the Yale Office of Public Affairs: http://opa.yale.edu/news/article.aspx?id=6582. ⟨1|

ITD

March Meeting Summary

This year’s March Meeting was held in Pittsburgh, Pennsylvania at the David L. Lawrence Convention Center along the banks of the Allegheny River. GQI once again had a full slate of sessions, several of which covered relatively new topics. In all, GQI sponsored or co-sponsored a total of 18 sessions.

On Monday, March 16 two simultaneous morning sessions were sponsored. One was a focus sessions on photons and quantum dots while the other was an invited session on interdisciplinary work in quantum information and many-body physics. Due to my busy schedule I was only able to catch snippets of the latter, in particular **Jens Eisert’s (Potsdam)** discussion of recent work in which he and his collaborators have shown that some systems may be *too* entangled to be useful for quantum computing purposes. In fact it seems that *most* quantum states suffer from this problem. Indeed, the fraction of useful pure states on n qubits is less than e^{-n^2}. This poses a distinct problem for measurement-based quantum computing since it is based on the notion of exploiting entanglement via measurement. For example, given a pair of entangled qubits, measurement on one provides information about the other. Thus the problem becomes clear if the states are too entangled to be useful. Budding quantum engineers need not worry, however. Eisert’s group has developed new methods by which to carry out measurement-based quantum computation. On a final not concerning Eisert’s talk, it was standing-room only!

The lunchtime session on Monday was a focus session on scalable quantum computing. I was able to catch a few of these talks. The first was by the group of **Mike Geller,** Emily Pritchett, Andrei Galiautdinov **(University of Georgia)**, and John Martinis (UCSB) who, took a unique approach to computational architecture by considering arbitrarily, weakly coupled two-level systems (i.e. qubits) to derive a fairly simple CNOT gate. This is in contrast to most other architectures considered for quantum computation that tend to be coupled by more complicated and less symmetric interactions. Following on the heels of Mike’s talk, **Lorenza Viola (Dartmouth College)** spoke about her work with Kaveh Khodjasteh (also at Dartmouth) on self-correcting quantum gates. The basic idea involves a procedure for designing unitary gates on an open quantum system without having to worry about encoding or measurement. In other words, you can bypass the need for measurement that comes with normal quantum error correction (QEC) procedures in favor of dynamically corrected gates (DCGs). The error correction strategy instead involves open-loop control, i.e. actively using the Hamiltonian to cancel out the errors. This method has the potential to greatly streamline the requirements for fault-tolerant quantum computing designs.

Monday afternoon again included two simultaneous sessions. A session devoted to spin qubits in quantum dots was held in the conjunction with the Division of Condensed Matter Physics (DCMP). At the same time, I chaired the annual focus session on quantum foundations. This year we were particularly fortunate to lead off with one of the 2008 **Leroy Apker Award** winners, **Byron Drury (Cambridge University/Haverford College)**. This marks the fourth year in a row that at least one of the

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Byron Drury (l) and **Peter Love** on the grass-covered roof of the convention center in Pittsburgh. Drury was a 2008 **Leroy Apker Award** winner from **Haverford College** where he worked under the supervision of Love. Drury is presently at **Cambridge University** in the UK completing Part III of the Mathematical Tripos. *Photo by author.*

awardees has been involved in quantum information-related research. Byron's work, performed while he was a senior at Haverford under the tutelage of **Peter Love**, involved using Cartan involutions to factor quantum logic gates. Since Peter gave a related talk later on in the same session, I will co-summarize the basic ideas. An involution on a semisimple Lie algebra, $\mathfrak{g}$, is an automorphism, θ, whose square is equal to the identity automorphism. If $B(\bullet,\bullet)$ is the Killing form (a type of symmetric bilinear form) of $\mathfrak{g}$, then the involution is known as a Cartan involution if $B_\theta(X,Y) = -B(X,\theta Y)$ is a positive definite bilinear form. A Cartan decomposition of $\mathfrak{g}$, is a decomposition $\mathfrak{g} = \mathfrak{m} \oplus \mathfrak{l}$ where $\mathfrak{m} = \mathfrak{l}^\perp$, for which $\mathfrak{l}$ and $\mathfrak{m}$ satisfy the commutation relations $[\mathfrak{l},\mathfrak{l}] \subset \mathfrak{l}$, $[\mathfrak{m},\mathfrak{m}] \subset \mathfrak{l}$, and $[\mathfrak{m},\mathfrak{l}] = \mathfrak{m}$. With these basic tools in place, one can, through a pair of such decompositions, construct the Quantum Shannon Decomposition of a given unitary matrix in terms of the corresponding Cartan involutions.

Other highlights from the foundations session included the legendary **Bob Griffiths (Carnegie Mellon)** who openly wondered what all the fuss was about regarding entanglement. Bob argues that the universe is inherently *quantum* as opposed to classical and we should, perhaps, view *classical* ideas as being weird. The equally insightful **Howard Brandt (Army Research Lab)** pondered the Riemannian geometry of quantum computation, something very likely relevant to many of the talks from last year's special session on gravity and quantum information. The always witty **Todd Brun (USC)** wasn't sure if he needed to present his paper on closed time-like curves (CTCs) because, if we're on a CTC he already would have presented it sometime in the past, but he figured he was there, so why not. His work was done in conjunction with Jim Harrington (LANL) and Mark Wilde (SAIC) and it involved a proof that CTCs allow for perfect state distinguishability. This ultimately means that an adversary with access to a CTC could break many of the QKD protocols such as BB84, BB92, or SARG04. **Urbasi Sinha (IQC/Waterloo)** presented the work of a collaboration of groups that tested Born's rule using a triple-slit experiment, **Looi Shiang Yong (Carnegie Mellon)** discussed the information stored in a subset of a certain number of qubits, **Matthew Grace (Sandia Labs)** presented collaborative work on the development of a general distance measure between unitary quantum operations of differing dimensions, and **Hanan al-Shargi (George Washington)** discussed the role of entanglement in the folding of prions (infectious agents composed of proteins and that cause "mad cow" disease and Creutzfeldt-Jakob disease).

The busy Monday session was followed by an almost equally busy Tuesday session beginning in the morning with a focus session on semi-conducting qubit approaches. There were two concurrent midday sessions. One was a focus session on superconducting phase qubits, that I did not make, while the second was on quantum entanglement. The talks from the latter that I was able to attend were generally very interesting (or as interesting as can be conveyed in ten minutes). **Kim Fook Lee (Michigan Technical)** presented work using coherent light fields to obtain nonlocal polarization correlations between distant observers based on Stapp's formulation. His scheme is useful in that it may be used to implement Ekert's QKD protocol. **Israel Klich (Virginia)** presented work performed in collaboration with Leonid Levitov (MIT) that gives a universal relation between the entanglement entropy for fermions and the statistics for current flowing through a quantum point contact. This provides an experimental means of measuring entanglement entropy as well as testing various conformal field theories for the existence of entanglement entropy from such fermions. A group led by **Shohini Gose (Wilfred Laurier)** presented work that essentially makes it possible to use the Svetlichny inequality in tripartite entanglement situations much in the manner we use Bell/CHSH-type inequalities in bipartite situations. The afternoon session focused on superconducting flux qubits and qubit amplifiers and readouts. Tuesday evening we held the GQI business meeting (see page 9 for minutes).

Wednesday was a lighter day that included only two sessions. It included the first of two sessions dedicated to semiconducting qubits and a focus session on materials in superconducting qubits. I was not able to attend either of these sessions.

Thursday was another busy day for GQI. The morning session covered superconducting transmons in circuit QED. The midday slot featured *three* concurrent GQI-sponsored sessions. The first was co-sponsored by DCMP and focused on recent progress regarding the nature of the 5/2 fractional quantum hall state. The second focused on recent progress in using quantum optics in circuit QED processes. The third, during which I presented my own research, focused on algorithms, simulation, and error correction in quantum information. Highlights from that session included work by **Frank Tabakin (Pittsburgh)** in collaboration with Bruno Julia Diaz (Barcelona) on the development of a parallel environment to simulate a quantum computer. Tabakin and Diaz are perhaps best known for their development of a very useful add-on to *Mathematica* for performing quantum computations using density matrices. This work is somewhat related, but was built from the ground up using - eek! - Fortran 90 (I didn't know anyone still used that!). One major advantage of this package is that it contains a feature that corresponds to solving a stochastic Schrödinger equation. This work was followed by **Mark Coffey (Colorado School of Mines)**, in collaboration with student Ron Deiotte, presenting a very interesting examination of the relation between the Schmidt

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numbers of two-qubit operators and CNOT complexity where the latter is up to local unitary operations. This also allows them to obtain exact decompositions of two-qubit operators in terms of CNOT gates. **Winton Brown (Dartmouth)**, working with Lorenza Viola (Dartmouth), discussed their approach to asymptotic convergence rates for low-order statistical moments of pseudorandom quantum circuits. Their method uses Markov matrices as a perturbation expansion in order to analyze the convergence rates of the Haar measure. Yours truly, **Ian Durham (Saint Anselm)**, presented ongoing research into the mathematical limitations placed on open quantum systems by certain conditions such as the so-called Deutsch consistency condition. This generalizes work begun originally to analyze quantum computations on closed time-like curves and is progressing toward a more general understanding of open quantum systems, particularly those for which the environment is somehow held fixed (static).

Thursday closed with the second semiconducting qubits session. I missed this in order to visit relatives and get a behind-the-scenes tour of the Carnegie Museum of Natural History where my cousin's son volunteers after school in the mollusk laboratory. All the Carnegie museums are apparently worth a visit and I certainly enjoyed the fantastic displays at the Natural History museum. APS organized a visit to the Science Museum at the same time.

I missed Friday's two sessions as I spent the day "airport hopping" enroute back to Maine and New Hampshire. I can report that the two sessions GQI sponsored that day included a focus session on quantum metrology and nanomechanics and a session on spin qubit coherence and control. All in all, it was a fairly good week with nice weather, good food, and interesting (though short) talks.

ITD

GQI Business Meeting
MINUTES, MARCH 17, 2009

Extra fees
Would increase of $1 or $2 affect membership? Concern over leveling off of member numbers.

March Meeting organization
Communication problems with Div. of Condensed Matter Physics, e.g. SQUID amplifiers

How to increase membership
Membership list? Follow up on lapsed membership? Strong arming missing peoples?

Student award
Generally considered a success this year.

DAMOP
Only few AMO sessions at March Meeting. Should GQI business meeting alternate with DAMOP? Establish liaison with DAMOP Program Committee. Look into possibility of invited sessions at DAMOP.

Ivan Deutsch, University of New Mexico

Conferences, Workshops, & Schools

QIP 2010

13th Workshop on Quantum Information Processing

18-22 January, 2010, Zürich, Switzerland

Hosted by:

ETH

Eldgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

http://www.qip2010.ethz.ch

II Quantum Information School and Workshop - Paraty 2009

1 - 11 September 2009 Paraty, Rio de Janeiro, Brazil

http://www.paratyquantum.info

This is a two-part event. The School (1-6 Sep) will feature short postgraduate courses on theoretical and experimental aspects of QI.

Lecturers and courses:

1 - Alain Aspect (Institut d'Optique, Orsay): tbc
2 - Adán Cabello (University of Sevilla): Quantum contextuality (and nonlocality): concepts and applications
3 - Jens Eisert (University of Potsdam): Quantum information meets many-body systems
4 - Raymond Laflamme (IQC, University of Waterloo): Quantum Information with Nuclear Magnetic Resonance
5 - Paulo Nussenzveig (University of São Paulo): Quantum information with entangled photon beams
6 - Werner Vogel (University of Rostock): Nonclassicality and Entanglement in continuous-variable systems

It will be followed by a Workshop (7-11 Sep) convening some of the world's experts on quantum information and related subjects. See the website for an updated list of participants.

Application deadlines: 07 June (School) / 30 June (Workshop)

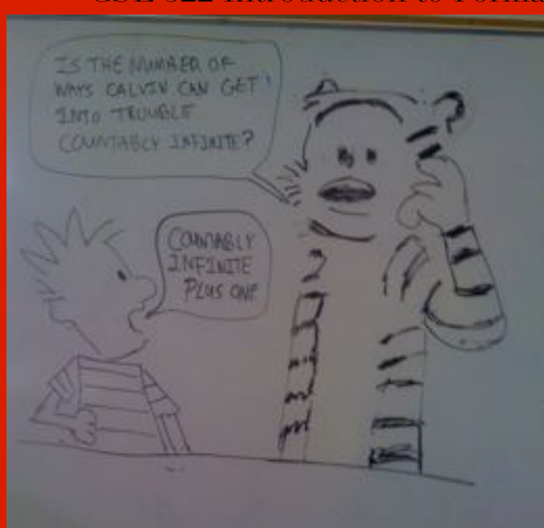
The Organizing Committee

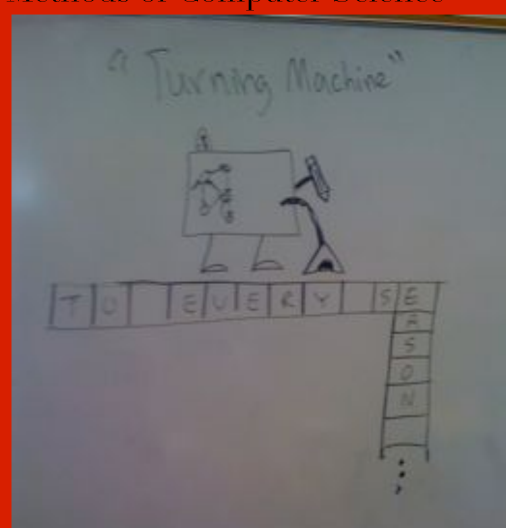
Daniel Jonathan - UFF, Niterói, Brazil
Marcelo França Santos - UFMG, Belo Horizonte, Brazil
Marcelo Terra Cunha - UFMG, Belo Horizonte, Brazil
Ruynet L. de Matos Filho - UFRJ, Rio de Janeiro, Brazil
Stephen Walborn - UFRJ, Rio de Janeiro, Brazil

THE LIGHTER SIDE

Scenes from Dave Bacon's course

CSE 322 Introduction to Formal Methods of Computer Science





Positions

FACULTY OF MATHEMATICS AND PHYSICAL SCIENCES

SCHOOL OF PHYSICS AND ASTRONOMY

CHAIR IN QUANTUM INFORMATION SCIENCE

Applications are invited for a chair in theoretical Quantum Information Science within the School of Physics and Astronomy. The existing Quantum Information group consists of a reader, two lecturers, a Royal Society URF and a professor in experimental Quantum Information. The topics covered by the group include physical realizations of quantum computation, communication and cryptography, entanglement and computational complexity, BECs and optical lattices, quantum optics, topological quantum computation, and foundations and applications of quantum information.

Based within the Quantum Information Group, you will be a scientist of international standing working in any aspect of quantum information science, including, but not restricted to: quantum computation, communication and cryptography; simulation of quantum systems; condensed matter and solid state implementations; quantum error correction and fault tolerance; foundations of quantum mechanics. You will have an established record of publications in internationally recognised research journals and have the ability to attract Research Council and/or industrial funding for research grants either on an individual basis or in collaboration with other members of the University.

The salary will be within the professorial range – minimum £58,624.

Informal enquiries may be made to Professor Bryan Hickey, tel +44 (0)113 343 3862, email headphys@leeds.ac.uk or Professor Tom Hartquist, tel +44 113 343 3885 email twh@ast.leeds.ac.uk.

To apply online please visit http://www.leeds.ac.uk and click on jobs.
Alternatively application packs can be obtained from Susan Alexander, Recruitment and Administrative Co-ordinator, Human Resources, tel +44 (0)113 343 3949, email s.alexander@adm.leeds.ac.uk.

Job ref: 335016 closing date: Friday 12 June 2009

Research Fellow in Foundations of Physics - Faculty of Science - Research Academic Level B - St Lucia

This position is to join the Perimeter Institute (PI) - Australia Foundations (PIAF) team of Professor Milburn and Dr Dowe at The University of Queensland. At UQ the philosophy group is exploring the philosophy of time in relation to current physics. In parallel the physics group studies time in the context of relativistic quantum information theory. The successful applicant will participate in collaborative research activities with other nodes of the PIAF collaboration at University of Sydney, Griffith University and the Perimeter Institute. Applicants will possess postgraduate qualifications (PhD level or equivalent) in theoretical physics and/or philosophy with specific emphasis on foundations of physics, especially quantum physics; have demonstrated expert knowledge in the area of foundations of physics and the possibility to make a unique contribution to the PIAF collaboration. It would be desirable if applicants were able to demonstrate an ability to supervise postgraduate students. The remuneration package will be in the range $70,969 - $84,275 p.a., plus employer superannuation contributions of 17% (total package will be in the range $80,034 - $98,602 p.a.). This is a full-time, fixed term appointment for two years at Research Academic level B. To discuss the role contact Professor Gerard Milburn via email milburn@physics.uq.edu.au . or Dr Phil Dowe via email p.dowe@uq.edu.au . Send applications to Ms Joanne Ryan, School of Mathematics and Physics, The University of Queensland, St Lucia, Qld 4072, or email j.ryan@uq.edu.au **Applications close 12 June 2009** Reference No 3020569 Professor Gerard J. Milburn Centre for Quantum Computer Technology 3.05 Parnell Bldg. The University of Queensland St Lucia QLD4072 Australia TEL 61(0)733656931 FAX 61(0)733461214 milburn@physics.uq.edu.au

Topical Group on Quantum Information

SEEKING CONTRIBUTIONS

The Quantum Times is seeking contributions from readers for all areas of the newsletter. In particular we are interested in articles, meeting summaries, and op-ed pieces. 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

The Quantum Times is published four times per year, usually in February, May, August, and November, though times can vary slightly. Submissions are accepted at any time.

All submissions 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 (*not* Word '08), RTF, PDF, and plain text.

Contact information:
Ian T. Durham, Editor, *The Quantum Times*
Department of Physics
Saint Anselm College
Manchester, New Hampshire
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Correction

In a note on entanglement sudden death (ESD), we incorrectly noted that ESD also stands for 'early-stage entanglement' (which would be ESE). We should have noted that it also stands for 'early-stage *dis*entanglement.' Our apologies as well as thanks to Joe Eberly regarding this point.