THE QUANTUM TIMES

NEWSLETTER OF THE APS TOPICAL GROUP ON QUANTUM INFORMATION, COMPUTATION, AND CONCEPTS

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Introducing *The Quantum Times*

I'd like to take a moment to introduce *The Quantum Times*, the new newsletter of the American Physical Society's Topical Group on Quantum Information, Computation, and Concepts (GQI for short). As of the March meeting, we had eclipsed 600 members and were continuing to grow. *The Times* will, very simply, serve as our newsletter! We hope to include regular reports from our chair, who is currently Charlie Bennett of IBM. You can find his first report to the right. In addition, we plan to include a few articles we think might be of interest to our readers. This first issue includes a report on the sessions we sponsored or co-sponsored at the March meeting in Baltimore contributed by Matt Leifer of the Perimeter Institute and Jon Dowling of LSU. In addition we have included short reports from our first-ever award winners and an essay by Dave Bacon of the University of Washington. I also would like to occasionally include a little something on the lighter side (pun absolutely intended) of quantum mechanics.

My goal is to provide a regular bit of news, mostly regarding GQI specifically, but occasionally involving ancillary news in quantum mechanics-related fields. In addition, my goal is to be mercifully *brief*. A lengthy newsletter that sits on someone's desk or in their inbox is not doing much good. But a newsletter that helps direct readers to further sources of information while also catching them up on the machinations of the group should prove more useful to a wider audience.

Expanding on that, we will also be further developing the website (http://www.aps.org/units/gqi) as a primary resource gateway for anyone interested in quantum mechanics, quantum information, and related fields. Specifically, we'll be expanding the links section, adding information on conferences that may be of interest to members, and connecting people to blogs, journals, and other sources of quantum-related news.

And finally, if you have anything that you think should be included in the newsletter or on the website, please let me know. The best way to reach me is via e-mail (idurham@anselm.edu), but feel free to give me a call or send me snail mail if you like. My contact information is included on the back of this newsletter. I would love to hear from you!

-Ian T. Durham
Saint Anselm College

Report from the Chair

The American Physical Society Topical Group on Quantum Information, Concepts, and Computation (GQI for short) co-sponsored, with DCOMP and/or DAMOP, thirteen sessions during the March Meeting in Baltimore, including focus sessions on quantum foundations, practical quantum computing, cold atoms in optical lattices, and linear optics quantum computing. In addition our group presented awards for two best student papers, one theoretical and one experimental, and held a brief business meeting, where secretary Barry Sanders reported that our group has been growing rapidly over the last year and as of the March meeting had over 600 members. We look forward to an active year including nominations for APS Fellowship, an updated website, and more sessions at next year's March meeting.

-Charles H. Bennett
IBM Corporation

March Meeting Roundup

This was the first year that the Topical Group in Quantum Information, Concepts and Computation has organized sessions at the APS March Meeting, and the level of participation was impressive. Overall, the TGQI organized or cosponsored twelve sessions, each of which was around three hours long, containing a total of 148 talks. Because of the sheer quantity of talks, this article concentrates on those sessions that were organized by TGQI alone. There is not even enough space to mention every single talk in those sessions, so the emphasis represents my own interests rather than being an indicator of quality. The interested reader can find the full program online at http://meetings.aps.org/Meeting/MAR06/Content/391 by clicking on the GQI and TGQI links.

Monday, March 13th was the busiest day for the group, beginning with a session on Quantum Entanglement in the morning, followed by two sessions on the foundations of quantum mechanics in the mid-morning and afternoon. The entanglement session featured many talks about the use of entanglement measures to characterize interesting properties of physical systems, such as critical points and phase transitions. The systems studied included spin networks, solid state systems, strongly correlated electrons and quantum chaotic systems. There were also some talks about more abstract entanglement theory, including talks on multi-party entanglement monotones and witnesses, correlation measures and simulating stabilizer state correlations with local hidden variable theories supplemented with classical communication.

The first foundations session contained several talks that might be described as advocating more radical approaches to the subject. There were talks questioning the usual assumptions behind the derivation of Bell inequalities and the measurement problem, and two radical alternatives to quantum theory were proposed. Ian Durham also presented some interesting ideas on how to handle correlations and entanglement in field theories.

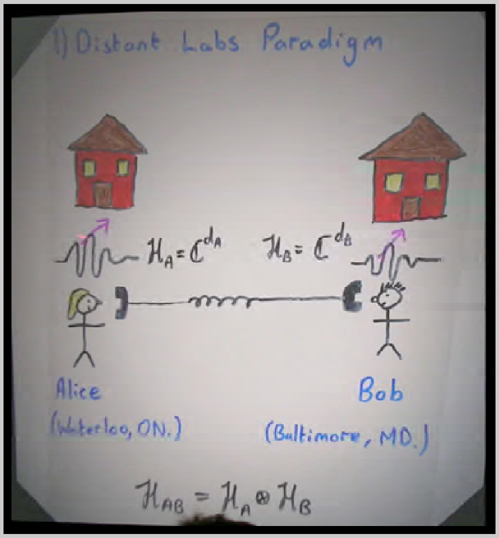
The second session was a focus session on foundations of quantum theory, which contained many interesting talks. First up, invited speaker Lucien Hardy outlined his Causaloid framework for general probabilistic theories without a fixed background causal structure. It is hoped that this might lead to a new path for developing a theory of quantum gravity. Secondly, Chris Fuchs gave a shortened version of his Bayesian manifesto, focussing on the role of symmetric informationally complete POVMs in his approach to quantum foundations. Next, Terry Rudolph presented an extension of Rob Spekkens' toy theory for dealing with continuous variables. This has lots of features in common with QM, but has a natural hidden variable interpretation, being a restricted version of Liouville mechanics. Rob Spekkens showed how two seemingly different notions of "nonclassicallity", namely negativity of pseudo-probability distributions and the impossibility of a non-contextual hidden variable theory, are actually the same within the new approach to contextuality that he has developed. Nicholas Harrigan outlined an approach to quantifying contextuality that he has been developing with Terry Rudolph. Joseph Altepeter, from Paul Kwiat's group, gave an interesting presentation on their current state of the art photonic Bell inequality experiments.

Later in the session, there was a talk about decoherence from Diego Dalvit, a collaborator of Wojciech Zurek. Ruth Kastner, who was due to deconstruct the now famous Ashfar experiment, was unfortunately unable to attend due to illness, but Ashfar was there to give his side of the story instead. The experiment is interesting at least because it has made quite a few physicists think about complimentarity and foundations in general a bit more deeply. In the final two talks, Jeff Tollaksen outlined a new way of measuring the "weak values" introduced by Aharonov and collaborators and Caslav Brukner outlined his work with Zeilinger on an "information based" approach to quantum foundations.

Tuesday March 14th featured the invited session of the group, where some leaders in the

(*continued*)

How many quantum physicists does it take to operate an overhead projector? Well, apparently the answer to that question is: at least four. Danny Greenberger (back, left) instructs Terry Rudolph (left), Rob Spekkens (center), and Chris Fuchs (right) on the finer points of modern technology. (Photo: Barry Sanders).



Lucien Hardy's Distant Labs Paradigm. No word on just what Alice and Bob were talking about. Check out the retro handsets on that phone. (Photo: Barry Sanders).

research field gave more in depth talks. The first two talks focussed on experimental implementations of quantum computing, with Rainer Blatt giving an overview of ion trap quantum computing and Yoshihisa Yamamoto talking about quantum optics and solid state implementations. Such talks are particularly appreciated by theorists such as myself, who often forget the difficulties facing practical implementations of quantum computing. Next, Mark Raizen spoke about the direct observation of atomic number squeezing in a degenerate Bose gas. The session ended with two more theoretical talks. Valerio Scarani, substituting for Nicholas Gisin, spoke about general properties of nonsignalling theories. This was within the framework of nonlocal, or Popescu-Rohrlich boxes, which are hypothetical entities that violate Bell inequalities more than is allowed by quantum mechanics, whilst still forbidding instantaneous signaling between subsystems. These have attracted a lot of interest recently, as a tool for studying how the structure of quantum correlations gives rise to the information processing power of quantum theory. Finally, Birgitta Whaley gave an overview of the results of her group on using ideas from quantum control theory to protect quantum information from errors.

Finally, on Thursday March 16th, there was a focus session on linear optics quantum computation. The Thursday Focus Session on Linear Optics Quantum Computation (LOQC) was sponsored by the APS Topical Group on Quantum Information (TGQI). The invited talk for the session by Terry Rudolph of Imperial College highlighted the recent theoretical progress in cluster-state or "one-way" approaches to LOQC, which have lowered the overhead for building a scalable system by several orders of magnitude since the inception of the scheme by Knill, Laflamme, and Milburn in 2000. Another talk by Federico Spedalieri of JPL pointed towards new polarization encoding schemes for a fault tolerant approach. A number of talks focused on the building blocks of LOQC including single robust and efficient single or few-photon sources, switches, memories, and detectors – where much of the experimental effort has been in the past few years. James Franson from APL advocated a new approach to entanglement using photon holes that could prove to be robust against noise and photon loss.

Overall, the APS March meeting was interesting and enjoyable for quantum types this year. I highly recommend attending, because it is one of the principal ways that we can convey the excitement and interest of our unique field to the rest of the physics community in North America. It is also a great opportunity to catch up with other quantum people, meet researchers from other fields and find out the latest about what is going on in the rest of physics. We hope to see you there next year.

-Matt Leifer
Perimeter Institute
-Jon Dowling
Louisiana State University

2005 Student Paper Awards

This year marked the first in which awards were given for the best student papers. The awards were generously sponsored by the Perimeter Institute (theory award) and the Institute for Quantum Computing (experiment award), both in Waterloo, Ontario. Both awards included a $500 cash prize. Summaries of the papers are given here by their respective authors.

Stochastic One-Way Quantum Computing with Ultracold Atoms in Optical Lattices

One-way quantum computing (1WQC) boasts the advantage over the standard quantum circuit approach of allowing all entanglement to be prepared in a single initial step, prior to any logical operations, by generating the so-called "cluster state". While various experimental implementations for 1WQC have been proposed, the use of neutral atoms in optical lattices is particularly advantageous, due to the relative efficiency with which cluster states can be generated therein. However, systematic phase errors are expected, resulting in imperfect cluster states built from controlled-phase operators which generate non-maximal entanglement between neighboring atomic qubits. For cluster states of practical size, such phase errors have been shown to result in unacceptable fidelity losses. Although standard fault tolerance schemes can be applied to one-way quantum computing, such approaches fail to address this unique type of correlated error.

We have developed a protocol for 1WQC which is robust against these systematic phase errors. The protocol uses a stochastic identity to teleport quantum states between adjacent qubits in an imperfect cluster state with perfect fidelity. This identity is non-determinisitic, but it is known in advance from measurement outcomes whether or not it will succeed. One can therefore be used to distill an algorithm-specific cluster state of arbitrarily high fidelity from an imperfect cluster state. The stochastic protocol thus represents a major step toward practical 1WQC with neutral atoms in optical lattices.

-Michael Garrett
University of Calgary

The original paper was coauthored with David Feder, Assistant Professor at the University of Calgary.

High fidelity quantum information processing with ions

Quantum computers, if built, offer the ability to efficiently solve certain computational problems which have no known efficient algorithm on classical computers. Of these problems, most notably is factoring having implications in the field of cryptography and hence national security. In recent years, multiple groups have experimentally demonstrated all of the DiVincenzo criteria for quantum computation and some simple algorithms in ion-trap systems. However, many roadblocks exist on the journey to build a practical large-scale device. In any large-scale quantum computer, error correcting codes will play a large role, and for these codes to work, the error rates in the processor must be suppressed to very low levels. The focus of my thesis work, along with others in the Ion Storage group at NIST in Boulder, has been to characterize the errors in our ion-trap system and reduce them to levels where fault tolerance may be achieved. Two areas were of primary focus: memory errors and errors due to the presence of laser light.

A dominant source of memory error is decoherence induced by fluctuating ambient magnetic fields. We addressed this problem and created long-lived qubit memories using a first-order magnetic-field-independent hyperfine transition. Our results with 9Be+ qubits showed a coherence time of approximately 15 seconds, an improvement of over five orders of magnitude from previous experiments. Using pessimistic models for memory decoherence over time, the memory error during the measurement interval (the longest timescale in our system) is on the order of 10^{-5}, below known fault-tolerance thresholds.

Errors during quantum gate operations must also be maintained to low levels to enable efficient error correction. In many atomic-ion based quantum information processing architectures, off-resonant laser light is used to perform quantum gate operations. In such schemes, spontaneous photon scattering is a fundamental source of decoherence. We experimentally studied decoherence of coherent superpositions of hyperfine states of 9Be+ in the presence of off-resonant laser light. Our results indicated that decoherence is dominated by inelastic Raman photon scattering which, for sufficient detunings from the excited states, occurs at a rate much smaller than the elastic Rayleigh scattering rate. For certain detunings, the measured decoherence rate is a factor of 19 below the calculated total scattering rate indicating that qubit coherence is maintained in the presence of photon scattering. Using the measured decoherence rate and experimental parameters from this experiment, the calculated error due to spontaneous scattering during a 2-qubit gate is also below known fault-tolerance thresholds.

-Chris Langer
National Institute of Standards and Technology

The original paper, based on Langer's thesis work at the University of Colorado, was coauthored by R. Ozeri, J. D. Jost, B. DeMarco, A. Ben-Kish, R. B. Blakestad, J. Britton, J. Chiaverini, R. Epstein, D. B. Hume, W. M. Itano, D. Leibfried, R. Reichle, T. Rosenband, P. Schmidt, S. Seidelin, J. Wesenberg, and D. J. Wineland

Free to Decide

Over at Michael Nielsen's blog (http://www.qinfo.org/people/nielsen/blog/), Michael has a post telling us that he won't be posting again until August. Personally Michael's lack of posting scares the bejebus out of me: if he's not posting, he must be working on some grand research which will make everything I do look even more trivial than before. Michael, you're scaring me!

Anyway, along with the post Michael posts a comment by UW's John Sidles trying to stir up some debate by asking about a paper by Conway and Kochen, "The Free Will Theorem", (http://arxiv.org/abs/quant-ph/0604079). Actually I had heard about this paper a while ago, via some non-arxiv channel (where I can't remember, exactly) and had basically guessed from the brief description I had heard what the paper was about. This is how you know that you are getting old and curmudgeonly when you can hear a title to a paper and a description of the results and can guess the way in which those contents were prove (There are rumors, which I myself have never verified, that at a certain well known quantum computing research group, the days starts as follows. A little before lunch, the researchers wander in, check their email and look at the day's postings on the arxiv. Now they don't do anything more than read the titles. The research group then proceeds to go to lunch. At the lunch they discuss, with great debate, the most interesting papers posted that day. Having never ever even read the papers! There is a similar story about a certain researcher in quantum computing, who, if you tell that researcher a new result, (s)he will, within a day, almost always be able to rederive the result for you. Of course, my personal nickname for this person is "The Oracle" and it is tempting to tell "The Oracle" that a certain open problem has been solved, when it has not been solved, and see if (s)he can come up with the answer!)

(A note: throughout this article I will use the words "free will" to describe something which, you may or may not agree is related to "free will" as you imagine it. In particular if an object is said to not have free will if its future evolution can be predicted from information in the past lightcone of the object. If it cannot be so predicted with certainty it is then said to possess free will. In fact, I find this definition already interesting and troublesome: can we ever predict anything by only knowing information in our past light cone? How do we know that in the next instance of our evolution a light ray will hit us and burn us up? Certainly we cannot see such a light ray coming, can we? We can, of course, use physics to explain what happened: but can we use it to predict our future behavior? Of course for the electromagnetic field, we could shield ourselves from such radiation and reasonably assume that we can predict what is occurring. But what about gravity, which can't be shielded? For an account of this type of argument I recommend Wolfgang's comments: http://wbtsm.blogspot.com/2005/12/multiple-descriptions-3.html).

Okay, back to the story at hand. What is Conway and Kochen's free will theorem? The basic idea is quite simple. I will explain it in the context of Bell's theorem and the Kochen-Specker theorem, since the author's don't describe it in this manner. Bell's theorem, we known, tells us that there is no local hidden variable theory explaining what quantum theory predicts. The Kochen-Specker theorem is less well known (which leads, in my opinion, the proponents of this different result to suffer a severe inferiority complex in which they constantly try to argue that the KS theorem is more important than Bell's theorem.) What the Kochen-Specker theorem says is that if there is a hidden variable theory of quantum theory, it must be contextual, i.e. the Kochen-Specker theorem rules out non-contextual hidden variable theories. The way I like to think about the Kochen-Specker theorem is as follows: suppose that there are some hidden variables associated with some quantum system. Now if you make a measurement on this system you will get some outcomes with differing probabilities. Now sometimes you get outcomes with certainty. You'd like to say that when you perform this measurement, this outcome is actually associated with the value of some real hidden variable. But what the KS theorem tells you is that this is not possible: there is no way that those measurement outcomes are actually associated with the hidden variables in a nice one to one manner. What does this have to with contextuality/non-contextuality? Well the "context" here is what other measurement outcomes you are measuring when you measure along with the outcome associated with a particular hidden variable. In non-contextual hidden variable theories, what those other measurement results are doesn't matter: it is those types of theories that the KS theorem rules out.

(Note: From my personal perspective, I find the KS theorem fascinating, but not as disturbing at Bell's theorem: that "what you measure" determines "what you can learn" is a deep insight, and one that tells us something about the way reality can be described. However it is not that difficult to imagine the universe as a computer in which accessing the memory of the computer depends on the context of your input: i.e. to get a hold of memory location which holds the value 01001010, you need to query the machine and it seems perfectly reasonable to me that the machine is set up in a manner such that I can't get all of those bits, since my measurement will only get some of them and the context of the measurement will change some of the other bits. This was basically John Bell's reaction to the Kochen-Specker theorem. Interestingly there is a claim in this Conway and Kochen theorem that this loophole has been filled! I have a bit to say about this below. Of course no matter where you come out in this argument, there is no doubt that the KS is DEEP: it tells us that the universe is not a computer whose memory we can gain total access to. And if we can't gain access to this memory, then does the memory have any "reality"?!!)

Well I'm rambling on. Back to the subject at hand, the free will theorem. In the free will theorem, Conway and Kochen set up an experiment in which you take two spin-1 particles and perform measurement on these spins. (Now for those of you in the know you will already be suspicious that a spin-1 particle was used (the 3 dimensional irrep of SU(2)) as well as an entangled quantum state…sounds like both KS and Bell doesn't it?)) The free will theorem is then:

> If the choice of directions in which to perform spin 1 experiments is not a function of the information accessible to the experimenters, then the responses of the particles are equally not functions of the information accessible to them.

In other words if we have free will, then particles have free will! How does the theorem get proven? Well basically the proof uses the KS theorem as well as the perfect correlations arising from maximally entangle spin-1 systems. First recall that the KS theorem says that hidden variable theories must be contextual, i.e. if I give you just the measurement directions involved in a measurement, there is no way to map this onto yes/no outcomes in a manner consistent across a set of possible measurements. But suppose, however, that your map to yes/no outcomes (i.e. the particles response) also depends on a hidden variable representing information in the particles past light cone, i.e. that the particles have no free will (contrary hypothesis.) Now because we are dealing with a maximally entangled spin-1 system, two spacelike separated parties, A and B, will obtain the same outcomes for their measurement results for measurement directions for which they measure along the same direction. So for fixed values of the information in the past of both parties, the particle response should be identical and can only depend on local measurement direction. But this is not possible when one chooses an appropriate set of directions corresponding to the Kochen Specker proof. One can thus conclude that we cannot freely choose the measurements directions, i.e. that not all choices of measurements are possible: there must be hidden variables associated with the measurement choice as well. Thus we have shown that particles having dependence on information in the past light cone implies that the measurement choice must have dependence on information in the past light cone. Having shown the contrapositive, we have shown the free will theorem.

Now the interesting thing about the free will theorem is that doesn't tell us whether the universe allows us to have free will or not. It simply says that if we assume some form of free will, then the particles we describe will also have free will. Of course the "free will" we describe here is "independence of (classical) information in the past light cone," so some would object to this definition of "free will." In particular, by this definition, a system which is totally random has free will. But is seems to me that the interesting question about free will is not whether one can have such random systems, but whether one can have a mixture of determined and undetermined evolutions. I mean the fundamental paradox of free will seems to me to be that free will involves a lack of cause for an action, but we want this action to itself have causes. In this respect, the above theorem suffers a bit, in my opinion, for a simplistic version of free will which is too absolutist for my tastes. What I find fascinating is whether we can "quantify" different versions of free will and what such quantifications would tell us about our real world.

Well it seems that I've had the free will to ramble on quite a bit in this article. Hopefully you might decide that the subject is interesting enough to choose to read the paper on your own.

-Dave Bacon
University of Washington

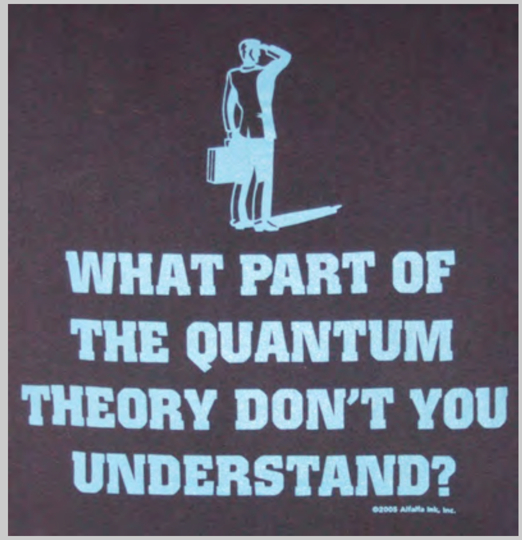
This is a slightly edited version of an essay Dave posted recently on his blog, The Quantum Pontiff *(http://dabacon.org/pontiff/). It is reprinted here with the express, written consent of the author.*

Newsletter information

Editor:
Ian T. Durham
Department of Physics
Saint Anselm College
100 Saint Anselm Drive, Box 1759
Manchester, NH 03102 USA
Phone: +1 603 222-4073
Fax: +1 603 222-4012
E-mail: idurham@anselm.edu

APS TGQI Executive Committee

THE LIGHTER SIDE



Charlie Bennett was seen wearing a sweatshirt with this on it at the March meeting. As it just so happens, the wife and children of your fearless newsletter editor bought a t-shirt version of this for yours truly back in February. Though we have no picture of Charlie in this, it is nonetheless worth noting what was on it. (Photo: Alyson Durham).