August 10, 2006

Reality is Strange But Real

Alice: “Does a bird really sing in the forest when no one is there to hear it?”
Friar Tuck: “That is a matter of philosophy, my child.”
Heisenberg: “No it’s not, you babies. I have conclusively proven that the notion of an objective reality is untenable, and in contradiction with experiment…”
Einstein: “Not so fast… let’s look a little more closely and try to understand what is really going on here, in reality… perhaps time is just another dimension, like space, and perhaps we could learn to do new things that we hardly imagined in the past..”

Back to Reality: Summary of a New Synthesis

This summary will try to be as simple as possible, but will build up to the most recent mathematical technicalities, and a new insight which – curiously enough – came to me on the day 6/6/6, on a flight home from China. (Do things like 6/6/6 or objective reality really worry you? Are you afraid of what you might see if you turned on the light in the darkness? If so, I recommend Arthur Clarke’s book Childhood’s End, or, if you have more time, www.werbos.com.) Towards the end, I will have to get into very precise technicalities, without which none of this is truly real.

Decades ago, Albert Einstein defied emerging conventional wisdom by claiming that objective reality still does exist, despite the mystical belief by Heisenberg that this world is only a passing illusion, and despite the great success of new computational tools started by Heisenberg which seem to support Heisenberg’s beliefs. Einstein proposed that the complicated wave functions and density matrices used in modern quantum mechanics are really just statistical tools for calculating the average, emergent dynamics of a universe governed by “Classical Field Theory” (CFT). In Einstein’s version of Classical Field Theory, everything in the universe is made up of smooth, continuous fields (“force fields”) that are governed by a specific kind of beautiful, simple local dynamical law called “Lagrange-Euler equations.” He once said: “God does not throw dice with the universe.”

Einstein also claimed that there is nothing magical or metaphysical about the act of measurement; the statistics of measurement can all be *derived*, in principle, by working out the physics of how objects like human brains and computers interact with other parts of a physical experiment. He disagreed with Heisenberg’s theory of quantum measurement, in which the wave function of the entire universe is instantly changed whenever a qualified metaphysical “observer” simply looks at it… (The weirdness of Heisenberg’s idea was explained clearly by Schrodinger; anyone who has not yet heard of Schrodinger’s Cat should Google on it or glance at any decent popular book on physics.)

My claim in this paper is that Einstein was right after all, despite decades and decades of work which assumed the opposite and seemed to prove what was assumed.

There are three legitimate reasons why most well-informed physicists turned away from Einstein's position. Those who want to get straight to the new idea may jump to the equations in section (3b), or to the more complete specification of the new assumptions posted at http://arxiv.org/abs/quant-ph/0607096.

(1) Classical intuitive arguments used against Einstein

First, many physicists needed to find a simple, concise, motivating way to introduce quantum mechanics in first-year courses. Thus, for example, they explained how "classical mechanics is just the limit of quantum mechanics as Planck's constant, h, goes to zero." But in fact, that limit is not at all the same as what Einstein proposed. As h goes to zero, quantum mechanics becomes the same as the *older* classical physics of Lorentz, a physics of perfect point particles of radius zero, as hard and as indivisible as the "atoms" of the ancient Greeks.

Einstein proposed that everything in the universe is ultimately made of "waves" or "vibrations." Ironically, the only elementary experiment which seems to contradict this idea is the photoelectric effect, the subject of Einstein's own famous PhD thesis! That experiment can be explained from a wave-like point of view by thinking about how it looks in *reverse time*, which I will talk about in section (2). There are many fuzzy, casual conventional wisdoms about quantum theory which can be traced back to simplifications made in introductory textbooks, and to a lack of feedback from recent empirical work to those textbooks.

Many people, including Louis De Broglie and myself, have written at great length about the proliferation of casual arguments against Einstein. For example, see what I have posed at the "quantum" section of www.werbos.com, or at arxiv.org.

By the way, people who write textbooks this way should consider the side effects of what they are doing. A few years ago, after a diligent search, my wife found a magnificent dentist, possibly the best dentist in the whole Washington D.C. area. As he cleaned my teeth one day, he said: "I did not really think I would grow up to be a dentist. Back when I was younger, I was the number one student in my entire class in chemistry at Princeton. I thought I would have such a bright future. But then I took the course on quantum mechanics, which was of course the foundation of everything. It destroyed my life and my spirit. I worked so hard to really understand it, to really make sense of it. Almost all the other students said they had no troubles understanding it. It made perfect sense to them. But not to me. I could not really understand it. So I gave up, and here I am."

I replied: "Really? But you should not have given up. Your teachers should have given you more support and better direction. If you thought you did not understand it, that proves you really were the best student in the class. It proves that you were more in touch with it than those students who mistakenly thought they understood." He smiled and thought I was just being tactful… but as I explained more, he started to realize that I was dead serious. How much has physics (and chemistry) lost by discouraging such people?

But not all physicists have shirked these issues. Today's Financial Times (6/11/66. p. W7) quotes Richard Feynman: "I think I can safely say that no one understands quantum mechanics." But perhaps today we can start to change that.

(2) Modern rational arguments related to "Bell's Theorems" etc.

(2a) The beginning of this literature: von Neumann

Second, there is a huge literature on "Bell's Theorem experiments." This really dates back to solid, rigorous work by John Von Neumann, who was a good friend of Albert Einstein at Princeton, and sympathized with Einstein's viewpoint. Von Neumann asked himself: "Could it be that we really can explain the equations of quantum mechanics as a kind of statistical tool for describing the evolution of objective reality over time? Since I know this kind of mathematics better than Einstein, can I find it? To begin with… as a kind of reductio ad absurdum argument… can we deduce whether such an explanation could be possible?"

Von Neumann's book, Mathematical Foundations of Quantum Mechanics, is one of the classics in this field.

A key part of Von Neumann's book was an impossibility theorem – a proof that the exact predictions made by quantum mechanics cannot possibly fit *any* theory belonging to a very large class of possible theories about objective reality. The theories he ruled out even *included* theories in which "God plays dice with the universe." Many people then reacted by saying that Von Neumann had ruled out the possibility of objective reality. But that isn't how Von Neumann viewed his own work. As a good mathematician (some say, the greatest of the twentieth century), he knew that the best way to do something hard is often to prove that the goal is impossible *subject to* certain assumptions; the next stage is to examine the key assumptions very carefully, and figure out how to get around them. In his book, he concluded by saying that quantum mechanics violates our intuitive concepts about *causality*; that is what is really going on here, which we need to re-examine.

Von Neumann is also well-known in the world of quantum foundations and philosophy. He is known for the "Von Neumann-Wigner" interpretation of measurement in quantum mechanics. Von Neumann admitted that you can get some accuracy in predicting experiments by pretending that a human eyeball or a robot observer (like a light polarizer hooked up to a digital camera with memory) is a Heisenberg-style "metaphysical observer" outside of the ordinary flux which changes wave functions over time. (Note: the wave functions of quantum mechanics are not defined over ordinary space-time. Neither Einstein nor Heisenberg would claim that the wave functions themselves represent objective reality – but there is a large third school of physics, the "many worlds school," which claims that they do.) But Von Neumann went on to argue that you would get better predictions by treating the robot observer or the brain as just another physical object, and applying the "observer" formulas to an imaginary second observer looking down on the whole scene. Better and better predictions come from pushing off the magic observation idea further and further away… until there is no metaphysical observation going at all within billions of years and billions of light years from earth!

Some have even proposed that Heisenberg's theory of quantum observation is correct, but that "God is the only observer." More seriously, people doing solid, experimental work with real quantum computing devices and optical computing have discovered that the Von Neumann approach really does make a big difference in real experiments. Mandel, for example, reported long ago how he gets "quantum measurement" effects when the only observer is a kind of mindless robot connected to a computer. But the faster the experiment, the more important it becomes to represent the physics of the observer more completely, by using some of the modern models described most clearly in the book *Quantum Optics* by Walls and Milburn. (Mandel and Wolf have a textbook, *Optical Coherence and Quantum Optics*, which is used much more widely, and agrees more with my viewpoint and Einstein's. However, they don't get around to discussing some of the key mathematics and challenges of quantum field theory in optics until page 522; thus Walls and Milburn is more essential to the most advanced work in areas like quantum computing with quantum optics. A similar but harder and more rigorous book by Howard Carmichael is also famous in quantum computing.) The Heisenberg observer theory is now well-known to be just a crude approximation to this well-worked out mathematics. Even Durer, Heisenberg's old boss at the Max Planck Institute, told me that the usual observer theory was never supposed to be so overly worshipped and enshrined as it has been by many teachers of quantum mechanics. (Durer told me this when I found myself sitting next to him, by accident, on a Washington subway train heading in the direction of the zoo.)

By the way, modern experimental physics has now disproven the old idea that "the wave function encodes our *information* about a physical system." When people try to predict the state of real, solid physical systems, it turns out that the wave function is not enough. When people tried to do quantum computing based on theoretical ideas about wave functions, they simply didn't work. I can imagine a many-worlds philosopher saying: "Aha! I told you so. The wave function describes the state of the greater multiverse of which this 'universe' is just one tiny strand. You need a probability distribution over possible STATES of the wave function in order to describe your knowledge!" But no, it doesn't work that way either; it's not that bad. To encode our knowledge, in the best practical experiments today, we use something called a "density matrix." Crudely – if the wave function is seen as a kind of "vector" in a mathematical space of infinite dimension, then a "density matrix" is a kind of matrix over that same space. It is scary how many "well-educated" physicists were never taught this basic empirical fact of life! But people who design nanochips do have to learn this; it's part of the chip simulation code distributed by the government-funded nanotechnology hub.

In any case, some of the people who read about Von Neumann's impossibility theorem immediately noticed a key loophole: Von Neumann proved that certain "classical" theories about reality could not agree with *all* of the predictions of quantum mechanics. But science on earth has not yet *tested all* of the predictions of quantum mechanics. It would actually be more exciting to find a classical theory which agrees with everything that quantum mechanics has predicted successfully so far, but makes different predictions for new experiments that we could perform! Could we find a *decisive* specific experiment where quantum mechanics and all theories about objective reality disagree? That question led up to the great next wave of research in this area.

(2b) Bells' Book, Clauser's Theorem and the Backwards Time Interpretation of Quantum Mechanics

The next major breakthrough here came from the work of Clauser, Holt, Shimony and Horne, whose famous theorem is commonly called a "Bell's Theorem," in recognition of prior work on mathematical inequalities by Bell. Most physicists have learned about this work from the classic more popularized book by Bell himself. (J.S.Bell, *The Speakable and Unspeakable in Quantum Mechanics*, Cambridge U. Press, 1987.)

I was lucky enough to be a graduate student at Harvard at the same time as Richard Holt – a more senior graduate student – was doing this work. Even more, I was lucky to have a chance to talk to him at length about his work and his experiments in the Harvard graduate cafeteria Harkness Commons, and at odd moments in the physics and engineering buildings. He gave me his own version of the original theorem, and a brief reprint which was more concise and precise than the usual longer discourses.

He and his collaborators had developed a *specific* design for an experiment, where quantum mechanics and "most" classical theories of physics were expected to disagree. More precisely: if the measured outcomes were in a certain large region of possibilities, the experiment would rule out all possible "local, causal hidden-variable theories of physics." Quantum mechanics predicted an outcome in that region.

The funny thing is that Holt's own experiment contradicted *both* quantum mechanics *and* local, causal hidden-variables." The result was in the expected region, but not the expected value. This remained true even after two very elaborate efforts to "clean up" the experiment. I have to confess that the treatment of this outcome by the establishment led me to excessive cynicism for a few years, and led me to take too many shortcuts myself at one point in the late 1970's. At least I learned from my mistake and did not repeat it – unlike the folks who cling to their most recent ideas forever, and refuse to re-examine their assumptions. But Holt's result was enough, in any case, to outlaw "local causal hidden variable theories." A host of other more precise experiments have been done since then which agreed with quantum mechanics very precisely, and more firmly ruled out "local causal hidden variable theories." (I still wonder sometimes whether the original experiment, using a different kind of apparatus, might have something to teach us – but I haven't had time to study the issue.)

But what is a "local, causal hidden-variable theory," and what does it have to do with Einstein's vision? What are we really ruling out here?

Holt's reprint gave a very precise definition of each of the key words here: (1) "local";

(2) “causal;” and (3) “hidden-variable.” At times, erudite people have asked me: “Why should we care about *his* definition? I can think of a better definition. Why should I be bound by *his* ugly words and definitions?” But *his* definitions are the one’s used in the theorem, the theorem which tells us what we really learn from the experiment. To learn what we can from experimental reality, we have to look closely at *his* definitions.

Holt defined “local” to mean “no action at a distance.” In other words, event A at one point in space time can only influence events at another point B in space-time by causing a chain of events which physically moves from A to B. For example, in Einstein’s theory of gravity (still the only well-tested successful theory of gravity!), the earth attracts the moon by gravity only because a gravitational field propagates outward from the earth to the moon. Einstein’s vision does call for a theory of the universe which is *local*.

“Hidden variable” means a theory of physics which assumes that objective reality exists. J.S. Bell calls this “realism,” and he explains “local” and “realistic” at great length in his book. Einstein’s vision also requires realism. Based on Bell’s book, many people make the error of thinking that Einstein’s vision has been ruled out forever by the Bell’s Theorem Experiments.

But what about the third condition, “causality”? Remember – that’s the one that Von Neumann warned us to look at most closely. It turns out that Holt’s definition of “causality” really means “time-forwards statistical causality in the macroscopic world.” (In technical terms, it assumes that our window of observations into the universe form a time-forwards Markhov Process. Good systems engineers know very well that a vector of observations into a Markhov Process is not itself a Markhov Process, in the general case.) For people who believe that “future and “past”’ and “up and down” are God-given invariants in the entire universe, this assumption is so obvious that it’s not even worth mentioning. They assume that the statistical causal arrow of time, and the direction “down,” are universal invariants, always pointing exactly in the same direction. But the universe is not flat, and Einstein’s vision *does* allow for the possibility that time is just another dimension. Humans *can* conceive of and understand a universe in which “down” is a different direction on different sides of the earth, and we *can* understand a universe in which some statistical causality or connection can run backwards in time. We can develop a way of doing mathematics and predictions which uses Einstein’s viewpoint but does *not* do calculations by throwing in the hoary assumption that everything always goes from past to future.

In conclusion – we can resurrect Einstein’s vision by simply giving up the old assumption of universal *time-forwards* statistical flows of causality, and making predictions based on the Lagrange-Euler equations *by themselves*, without throwing in that assumption.

I originated this “third major interpretation” of quantum mechanics back in 1973, in a paper published in Nuovo Cimento. I call it the Backwards Time Interpretation (BTI) of Quantum Mechanics. (The first major interpretation is the popular version of the “Copenhagen School,” which denies the assumption of objective reality. The second major interpretation is the nonlocal or many-worlds school, which has taken many forms.) Many others – such as Cramer, Huw Price and Leggett – have echoed this idea in various forms in more recent years. Price has been especially eloquent in describing how we need to change our style of thinking about the world in order to accommodate this new way of thinking. My web page contains more details and pointers.

In addition, my recent published papers describe how we can improve even the many-worlds theory of physics by throwing out the "metaphysical observer," and using the Backwards Time Interpretation to explain how observation works. In other words, the *combination* of the many-worlds theory plus BTI results in a more conventional kind of theory of physics, which gets rid of the nasty observer stuff and makes more sense than anything else in the orthodox world. But I still prefer the Einstein vision, for many reasons. By the way – all of the nasty paradoxes like the "Bell's theorem experiments" are based on the asymmetry in time of the usual observer formalism; when we revise our understanding of measurement, all of that goes away automatically, *if* we can find a classical CFT which matches the quantum laws of evolution of the density matrix. (Next section.)

In the end, the Backwards Time Interpretation (BTI) tells us that Einstein's vision is still "legal." (It also addresses what is proven by similar experiments discussed by philosophers.) It tells us that an Einstein-style theory of the universe is still possible *in principle*. But it's a long way from proving that something may be *possible* (to the best of our present knowledge) to showing *how to do it*. BTI does not give us a complete concrete picture by itself of what is *actually* happening, in objective reality, in an experiment like Holt's. So far as I know, I am the only person on earth as yet who has written about the Bell's Theorem challenge who has gone on to address the real challenge before us: how do we make the Einstein option *real* , by constructing a concrete Lagrange-Euler theory that can actually reproduce the predictions of quantum theory? How can we do what Von Neumann tried to do, now that we have new mathematical tools and physical insights to support this effort?

With all due respect to Heisenberg and Durer – as I come from a mystically inclined Rhineland family myself, I fully sympathize with his ultimate motivations here, and I recognize that physics may someday advance to a vision more "mind-like" than Einstein's vision. But we aren't there yet. Physics today does not have the kind of data (or model) yet to justify that type of alternative model. We will never be able to appreciate the greater weirdness which is really out there until we first get rid of the false weirdness which has resulted from incomplete mathematical understanding of what we have already seen in the laboratory. We must become better at crawling and walking before we can safely fly through astral planes and all that.

(3) Making Reality Real: Towards a Specific Lagrange-Euler Theory of Everything

Now let's get into concrete details. Those who aren't ready to instantly accept what I say in section (3a) on faith may want to scan (3b) first, to see how some of my more startling claims are verified by related mathematical findings widely used in quantum optics and electronics.

(3a) Review of our earlier published work on dynamical equivalence

According to Einstein's vision, the state of the universe at any time t is really the same thing as the state of some "fields" over all space at time t. For a traditional mathematical paper, I would say that there is a certain number N of fields, in any Einstein-style theory. (Of course, different theories could pick a different value for N.) The state of the universe at time t is defined as the value of N functions, $\varphi_1(\underline{x}, t)$ and $\varphi_2(\underline{x}, t)$ through $\varphi_N(\underline{x}, t)$, across all points in space $\underline{x}$ at time t. (Einstein would even add some information about properties of these functions, but I won't do that here. It isn't necessary yet.) But I will try to go as light as possible in this paper. For now – please remember that I will write "S(t)" to signify the state of the entire state of the universe at time t, in Einstein's view. "S(t)" will signify the state of all the fields in the universe across all of space at time t, in an Einstein-style Classical Field Theory (CFT).

According to the best, experimentally-based version of quantum field theory (QFT) today, the state of our knowledge about the state of the universe at time t is given by an object called a density matrix, ρ. I will write "ρ(t)" to represent the state of the density matrix at time t. Density matrices in QFT are required (by QFT) to have certain properties. The sum of their diagonal elements must equal one, and they must be nonnegative matrices. They must also be a kind of symmetric matrix which mathematicians call "Hermitian."

In CFT, we do not really know the state of the universe at any time t. At best, we know what the *probability* is for all *possible* states S(t). Thus the state of our knowledge is usually represented by a *probability distribution function* (pdf) for possible states S(t). More precisely, our state of knowledge at time t is a function Pr(S, t) which gives the probability at time t of any possible state S. pdfs also have to obey certain rules, in order to make sense; above all, the probability Pr(S, t) should never be less than zero, for any state S, and the sum of probabilities over all possible states should equal one.

Einstein proposed that we can explain QFT as a kind of *statistical* calculating tool for calculating how Pr(S, t) varies with time t.

To make Einstein's proposal real, we first need to explain how a density matrix ρ(t) could represent our statistical knowledge about time t – Pr(S, t). More precisely, we need to find a way to specify what the value of ρ(t) should be, for any function Pr(S, t) which meets the rules for being a legitimate pdf.. At least, this is the natural way to start. (It doesn't work exactly that way, as I will explain.) We need to defining a mapping or higher-level function which tells us what ρ(t) is, for any acceptable Pr(S, t). And then, more important, we can try to prove that the laws of *change* of ρ(t) used by quantum mechanics actually fit the laws of change for Pr(S, t) *as predicted by* some sort of Lagrange-Euler theory about S(t). If we do this much, we prove that Einstein is right, and we prove that the Lagrange-Euler theory actually predicts everything we have predicted using today's models of how ρ(t) changes with time.

The previous paragraph is overly simple. The real connections are a bit trickier, as I will describe. But it's very important to understand this initial strategy very clearly, in order to understand the more refined version which actually works.

For many years, I struggled to find the mapping from Pr(S, t) to ρ(t) which would make this work. And I asked for advice or ideas from many people. My best efforts from earlier times are partly posted at my web site (the quantum part of www.werbos.com) and at arXiv.org. Finally, in the year 2002, I figured out a mapping which had some very exciting properties, which I published in the International Journal of Bifurcation and Chaos (IJBC), and later posted.

The mapping which I specified could translate *any* acceptable Pr(S, t) into an ρ(t) which fits the rules of QFT. But there were certain tricky points:

(1) The resulting density matrices were all what physicists call "bosonic." (Some physicists would jump to the conclusion: "See, if it's classical everything must commute. You can't get to real QFT." That's false. Bosonic theories are real QFTs, and we still get nonzero commutators in the calculations where bosonic QFT does.) But quantum electrodynamics (QED) – the specific QFT we use to predict electricity and magnetism and the motion of electronics when we design lasers and nanochips – is partly bosonic and partly "fermionic." Thus I could not go directly from a CFT to QED or anything like it – directly. But I have found a way to overcome this key problem, which I will discuss.

(2) If we allow *any* initial pdf, Pr(S, t) in the CFT would undergo a dissipation or thermodynamic drift towards equilibrium states. Thus when we (my wife and I) calculated the dynamics of ρ(t) *in the general case*, it had some extra terms, different from the usual equations of QFT for fields propagating in free space. We called this new dynamical principle "the free space master equation," and published the result in English and in Russian. (See quant-ph/0309087 at arXiv.org.) Our interpretation was that QFT – like the statistical laws chemists usually use – represents the behavior of partially converged equilibrium states of nature. Thus we decided to *give up* trying to match the dynamical laws for *all possible* pdfs Pr(S, t); instead, we focused on trying to match the predictions ("spectra") of QFT for stable states and for "scattering states." All of the tested predictions of QFT so far can be reduced to predictions for scattering or for spectra; thus it is good enough to show that kind of statistical equivalence. We were delighted to find that the mapping which I proposed in IJBC 2002 fits QFT exactly, in the following sense:

$Tr(A_n \rho)$ = Expected value (A(S) for Pr(S, t))

In other words, for any function A of the state of the universe at time t, the fundamental formula used in QFT to give the expected value of the quantity A is exactly the same as the classical expectation value of A. Equilibrium states are typically calculated *both* in QFT and in CFT by finding the states which minimize energy; if energy is the same function in both cases, we would get the exact same equilibrium and spectra. It sounds like a complete proof of equivalence, at least for bosonic field theories.

(3) The only well-tested quantum theories of physics today (QED and its big brother "the standard model of physics") assume that "fermions" are Greek-like perfect point particles. According to QED, the electron is an exact point, with zero radius. Because it repels itself through electric charge, and all the charge is concentrated at one point, the energy of its self-repulsion is infinite. Of course, that's crazy. QED only "works" because of a kind of ad hoc procedure, called "renormalization/regularization," which basically assumes that God descends from heaven and inserts infinite self-love just exactly at the central point, just enough to cancel out the infinite self-hate and insert (ad hoc) the observed physical mass/energy of the electron. (Of course, mass is the same thing as energy in Einstein's relativity, which we all adhere to here.) People like Lorentz did something similar long ago in classical physics, but Einstein calls for us to *explain* why particles exist and why they have the masses they do, by modeling them as whirlpools of force in smooth whirling, energetic fields. Many Lagrange-Euler field theories have been developed which *do* predict these kinds of stable whirlpools of force; physicists call these whirlpools "solitons." Bosonic QFTs have also been developed which generate solitons; there are important classic books by Rajaraman, by Chodos, and by Makhankov, Rybakov and Sanyuk which discuss this important subject, both in CFT and in QFT.

To match QED (and the standard model of physics), I proposed that we develop not *one* Lagrange-Euler theory, but a whole family of them. For example, we can assume (for now, for simplicity) that all massive elementary particles are actually whirlpools of force with some radius, r, too small for us to measure yet. *For each possible value of r* ($r>0$), we can develop a CFT which is equivalent to a bosonic QFT containing solitons of "radius r". The claim is that QED and the standard model represent the *limit* as r goes to zero of such a family of models. The challenge, then, is to specify that family of models. This would do more than just restore Einstein's vision. It would also provide a basis for explaining why particles exist, and for getting rid of renormalization/regularization as part of the "theory of everything." (Of course, we can still use it in practical applications, just as we use dirty paper towels, but we don't have to assume that "God uses dirty paper towels to hold the universe together.") And it would provide a basis for unifying Einstein's general relativity directly and neatly with the new classical version of the standard model of physics.

Some physicists might say: "But you are assuming an unobserved nonzero radius for the electron, too small to measure yet." That's true. But superstring theory does the same thing too, along with assuming lots of extra unobserved dimensions of space that we don't need in this approach. One of the underlying reasons why superstring theory does not need renormalization, in principle, is that it assumes a nonzero tiny radius for the electron; that gets rid of the infinite self-repulsion built into QED.

But there is still a hitch here. Using the mapping from Pr(S, t) to ρ(t) which we published in Werbos (2002), we later found (and published) some "discrepancy terms" that seemed to suggest a lack of exact match between CFT and QFT even in equilibrium. We weren't sure whether these discrepancy terms really signified anything; they appeared very small, in some ways, and we didn't know what to make of them. Again, we published and posted those details. We also posted some thoughts related to the more orthodox "bosonic standard model" proposed by Vachaspati, which would be enough by itself to eliminate our remaining problem with matching QED and the standard model of physics.

(3b) The Q Hypothesis: making Einstein's vision work for all data now explained in physics, and more…

The first step in getting beyond this earlier situation was to face up to problems which were bigger than we thought with the earlier work. Prof. Rajeev of Rochester pointed me towards a section of Rajaraman's book, which I checked against some papers of Coleman, showing very clearly that the mass-energy of a simple soliton in QFT is quite different from the mass-energy of the same soliton in the "corresponding CFT." The "quantum corrections" result in a quantum soliton with less mass-energy than the classical soliton. This is what happened when Coleman used exactly the same quantum operator H_n that I had worked with, in my Pr(S,t)-to-ρ(t) mapping!!! Clearly the discrepancy terms were very serious.

How could the equation above be valid (I had proved it in the general case)… and yet a discrepancy exist like this?

Furthermore, the equation which I displayed above is almost identical to equation 11.6-15 of Mandel and Wolf. I derived it from lemmas which reduce to the equations in section 6.2.2 of Walls and Milburn, for the case of light. (Probably I would have saved a lot of time if anyone had noticed the similarities here years ago and told me where to look; however, instead of generalizing what I later saw in Walls and Milburn, I derived the equation the hard way, from first principles independently.) There is no question that the equation is right. So how could there be a discrepancy in the energy predictions?

The paradox is explained as follows.

In the classical case, we try to find that classical state S which minimizes H(S), the energy of that state, out of the universe of possible states S. Of course, the probability distributions Pr(S, t) which minimize H(S(t)) are precisely those distributions which have zero probability except for those specific states S which minimize H(S). They provide the minimum possible energy out of *all* allowed pdfs.

By the way, an observant mathematician might ask: "Isn't the energy minimizing state just the vacuum state, in which the fields are all zero?" That's an important topic in the more complete, rigorous version of all this, but it's not a basic obstacle any more in the study of soliton models. I am tempted to say more… but it's not really necessary here and now, because many others have written about this technical point in the past.

When we map these energy-minimizing pdf into the corresponding ρ, we get the exact same energy prediction, as the formula says. When we map any other acceptable pdf into ρ, we also get the same energy prediction for them. So how could the predicted energy minimum be different, if we are minimizing the same values for energy over the same set of possible choices?

The explanation is that it's not the same set of choices after all. There are many density matrices ρ which are admissible in QFT, which are *not* available by mapping an acceptable pdf into the corresponding ρ! QFT is minimizing energy over a larger set of options. And, in fact, it finds the energy minima in states are *not* directly available from our mapping. One might hope for yet another more complex and indirect sort of equivalence, but the immediate result appears extremely discouraging, at first, for the Werbos/Einstein approach to the "theory of everything."

But there is a way out, which is unconventional and startling but ultimately very beautiful and satisfying – an even perhaps more testable than the previous approach.

The equations which I referred to in Mandel and Wolf and in Walls and Milburn were actually taken from earlier work by Glauber, who recently won the Nobel Prize for it. (How I wish I had taken one of *his* courses back at Harvard! My friends building lasers gave the impression that it was all ad hoc hands-on stuff with no real fundamental implications; how I wish I had known otherwise! In part this is what happens when people pursue heresies in a discrete or concealed way, embedded in empirical work. Of course the best theoreticians do their best to understand the experiments even when they don't do them themselves.) Both books explain how *three* mappings or representations – "P", "Q" and "W" – are of enormous practical value in quantum optics. P and Q come from Glauber, for use in studying light, and W from Wigner, initially from studying electrons.

I would guess that Glauber, like Wigner, Von Neumann's friend from Hungary, was trying to address the concerns of realism in a different way, similar to me, but backwards. Wigner's classic paper basically asked: "How can we understand what the wave function of an electron, $\psi(\underline{x})$, really tells us about the pdf of the actual state of an electron? Bohr tells us that $|\psi(\underline{x})|^2$ tells us the probability that an electron is actually at point $\underline{x}$, but the wave function has more information than that, and the electron has more than just position; it has momentum. I hereby define a new mapping from the wave function $\psi(\underline{x})$ to the probability $p(\underline{x}, \underline{\pi})$ that an electron will be at point $\underline{x}$ with momentum $\underline{\pi}$."
This mapping from quantum wave functions to classical pdfs has turned out to be extremely useful in understanding and designing complex systems like resonant tunneling diodes, as well as quantum optics. It has been generalized to go from density matrices ρ to pdfs Pr(S) for the state of the electromagnetic field. In a similar way, Glauber's Q

mapping goes from ρ to classical pdfs. Glauber's P mapping is essentially just a backwards special case of the exact same mapping I used in the IJBC paper. (I defined a few other mappings in earlier papers, but that is not relevant here.)

Here is the point. My problem with discrepancies is based on the fact that some density matrices ρ allowed by QFT do not map into acceptable classical pdfs. In optics, it is now well known that some "observed" (or inferred) states ρ map into "pseudo-probability" distributions, which look like pdfs, but are unacceptable, because they show negative probabilities for some states. (I could have argued that this was an artifact of backwards time effects and quantum measurement, if it were only an issue with optics, but the problem of soliton masses and spectra is more serious.) The same problem occurs with the Wigner mapping, though not as bad, and with a little more hope of resolution.

The obvious solution is to switch to the Q version of what I have been doing. In the Q mapping, <u>every</u> allowable quantum ρ maps into an allowable classical pdf Pr(S). Thus the energy minimizing states observed and computed in QFT will also exist as valid classical mixtures of states, with exactly the same energy level. The energy discrepancy disappears, because the "corresponding classical theory" here is *different* from what it was both in Coleman's work and in my earlier work. If we assume a different classical interpretation of what the density matrix is telling us, we end up with a different (but equally tractable and general) mapping between classical energy and quantum energy. They are still equivalent, but this time the equivalence is real.

Let me be more precise here. In a classical field theory, the state of the universe at time t is given as S(t)={$\boldsymbol{\varphi}(\underline{\mathbf{x}}, t)$, $\boldsymbol{\pi}(\underline{\mathbf{x}}, t)$}, the set of the field variables φ_i and π_i across all points $\underline{\mathbf{x}}$ in three-dimensional space at time t. In Werbos (2002), I defined a mapping from states S(t) to quantum wave functions, which I wrote as:

$$\underline{v}(S) = \exp\left(c\sum_{j=1}^{n} \int (\theta_j(\underline{p}) + i\tau_j(\underline{p}))a_j^+(\underline{p})d^d\underline{p} \right)|0\rangle \quad , \qquad (1)$$

where d is the number of spatial dimensions (i.e. $\underline{\mathbf{x}} \in R^d$) and:

$$\theta_j(\underline{p}) = \sqrt{w_j(\underline{p})} \int e^{-i\underline{p}\cdot\underline{y}} \varphi_j(\underline{y})d^d\underline{y} \qquad (2)$$

$$\tau_j(\underline{p}) = \frac{1}{\sqrt{w_j(\underline{p})}} \int e^{-i\underline{p}\cdot\underline{y}} \pi_j(\underline{y})d^d\underline{y} \qquad (3)$$

$$w_j(\underline{p}) = \sqrt{m_j^2 + |\underline{p}|^2} \qquad (4)$$

In order to map *from* a probability distribution Pr(S) to a density matrix ρ, one defines:

$$\rho = \int \frac{\underline{v}(S)\underline{v}^H(S)}{|\underline{v}(S)|^2} \Pr(S) d^\infty S ,$$

which turned out to be a generalization of Glauber's "P" representation. That is what I analyzed in Werbos (2002). However, as an alternative, one may interpret a density matrix ρ in QFT to signify the classical ensemble defined by:

$$\Pr(S) = \langle \underline{\mathbf{v}}(S) \mid \rho \mid \underline{\mathbf{v}}(S) \rangle \quad (5)$$

This is the generalization of Glauber's "Q" representation.

OK: so here is the new hypothesis: in the spirit of Wigner, I propose that the density matrix ρ in modern bosonic QFT may represent a statistical ensemble of classical field states as given in equation 5. There are real field states out there, in objective reality, and ρ is just a way of encoding their probabilities; the generalized Q mapping lets us decode the probabilities, and tells us what is really out there in objective reality. (Actually, they are conditional probabilities, conditional upon what we know and do, but this is the basic principle.) Equation 5 does not allow ρ to encode all possible classical ensembles; *however, because the universe is thermalized, we cannot actually reach all possible classical ensembles in our experiments.* I will now go back and try to explain this in more detail.

The new hypothesis neatly eliminates all the classical-quantum discrepancies with mass-energy and spectra. Or does it? It turns out that we are still minimizing energy over different sets of possible ensembles here. This time, there seems to be a problem in the opposite direction. Every density available on the quantum side corresponds to a pdf on the classical side. But now there are available classical states which are not available on the quantum side!

In effect, the Q mapping maps density matrices ρ into *fuzzy* versions of what the P mapping yields, in going from ρ to pdf. The probability distribution given by the Q mapping is the same as the P mapping, multiplied by something that looks exactly like a Gaussian probability distribution, a distribution over the canonical field variables of the field theory. (See Walls and Milburn, etc.) Classical pdf which are fuzzy enough to be "reached" by the Q mapping will have the same energy as ρ has in QFT, but specific definite states of minimum energy cannot be reached. The minimum energy in the classical theory will be lower than the minimum energy in QFT.

In summary… if we accept the theory that ρ actually represents the classical pdf that the Q mapping gives us, we end up with the conclusion that QFT is *not telling us* the minimum of energy over all possible classical ensembles. It only tells us the minimum energy over a certain *set* of possible classical statistical states.

If so, how could classical field theory possibly be the true underlying theory of how reality works?

There is a simple but startling answer. In our experiments, we do not actually have the power to *create* all possible field states that we might postulate as mathematical functions. We don't have that much control over the universe. The power of thermodynamics limits us every day, in everyday life and in normal laboratory experiments. The dynamic laws of QFT, used in the many-worlds theory, share a crucial property with CFT: they assume that the dynamics of the universe are exactly the same even when "the movie is played backwards." Thus it should be just as easy to put a ball on the floor, in such a way that it suddenly falls *upwards* without our doing anything – if we could control all the initial state of the universe exactly. We can't. And that's what seems to be happening here.

In summary – in order to make Einstein's vision real, it seems we must make two assumptions. First, the notion of time-forwards causality is not part of the underlying microscopic laws of physics. Second, in all the experiments available to us, "the universe is thermalized." The heavy free particles or molecules coming in and out of scattering experiments are actually thermodynamic ensembles, a statistical mixture of a classical ground state and certain small degree of excitation. The statistical distribution is (or is well approximated by) a Gaussian distribution over the canonical field variables, which happen to be defined directly in terms of the energy function. This "subquantal" temperature is presumably what gives us Planck's constant!

Again, this gives us an energy operator exactly the same as what we use in quantum mechanics -- though not as a normal form Hamiltonian, as I once argued for. The result is more like the canonical Hamiltonian which is a favorite of the people who talk about zero point fluctuations and the Casimir effect. I have explained before why I don't believe that vacuum fluctuations cause the Casimir effect – but this new theory does imply that some kind of real fluctuations have to be out there, if there is any kind of objective reality out there at all. Because the fluctuations are essentially just fluctuations in heavy particles in their own frame of reference, there are none of the problems with relativity or rigor that exist in traditional theories about vacuum fluctuation. But, because our "absolute zero" is not *precisely* a set of zero fluctuation, according to my Q theory, one might expect some fluctuation effects to continue even there, whereas QFT predicts nothing like that. In fact, experimenters working near absolute zero have discovered those kinds of effects, as I predict, in a host of experiments, which have been performed and checked and redone may times. For a recent review, see the paper by Mohanty in the references below, or just google on "zero temperature decoherence."

For the precise CFT theory to create a bosonic or classical standard model, there are many possibilities, as I discussed in a paper posted at arXiv.org. What intrigues me most now is the possibility of simply grabbing the model of a soliton "dyon" given by Hasenfratz and 'tHooft in their classic paper in Physical Review Letters, and using that as the modified "quark model" in the theory of Schwinger reported in *the later sections of* "A Magnetic Model of Matter" in Science in 1969. The Hasenfratz/'tHooft model is a bosonic field theory (easily mapped into the corresponding CFT, but again, we must use the Q mapping) with parameters that can be adjusted to change "r" without changing asymptotic quantities), but at distances far from the center, the bound particle looks exactly like a fermion, and fits what Schwinger proposes. As Schwinger suggests, this model promises to explain experiments in nuclear physics *better* that the strong part of today's standard model of physics. (A key technicality is that the modified gluons, bosonic solitons, need not have zero rest mass. Also, as with superstring theory, the validity of the theory must be established by "nonperturbative methods," which should be easy to do, exploiting the Q mapping to prove bounded energy and such. After all, we *know* that the statistics which emerge from appropriate well-defined CFTs are themselves well-posed! It is enough that the CFTs be well-posed for the this theory to be valid as a theory of nature.)

The availability of new mathematical analysis tools, borrowed from quantum optics, should make it possible to discover new degrees of freedom in manipulating nuclear fields which could not even be computed with the traditional tools used so far in quantum field theory. If we apply the tools so important to design and prediction in nanotechnology at the nuclear level, and even achieve coherent stimulation through devices like the new atomic lasers, could it be possible to create a kind of nuclear femtotechnology here?

By the way, this theory implies that the electron is actually a kind of tightly bound system, in which the (small) core is "dancing" or skittering in a chaotic way mirrored by the usual wave function. The wave function is not a "pilot wave," as De Broglie expects, but a kind of resonance effect, analogous to the audio-frequency envelopes you see in oscilloscope pictures of AM radio signals. These words are really just a translation of what is implied by the mathematics I have specified here.

The neutrino could be modeled, in principle, in a similar way – but with the limited data available now (including a lack of data on statistics), it may be simpler to take the heretical route of viewing it as a spin ½ boson which is not really a soliton, chaotic or otherwise. ("Mass terms" can arise from terms in the propagation of a wave or from interactions.) Likewise, in this view, light is not made up of solitons, but is quantized in energy because of how it interacts with charged particles both in its past and its future. It is curious how Einstein's work on the photoelectric effect sharply demonstrated the symmetries with respect to time, but did not draw the obvious conclusion – natural to Einstein's basic position as it evolved in later years – that the photon does not exist at all as a distinct soliton. Willis Lamb, who discovered the Lamb shift, did draw this conclusion after many years of leadership in this field – but the world of theory has lagged in catching up with the world of experiment.

As in past papers, I should thank Yanhua Shih for showing me many of his most elegant experiments, and explaining how the backwards-time ideas of Klyshko were crucial in designing the powerful forms of entanglement underlying these experiments. That aspect is described at length in some of the previous papers we have posted.

Summary

Though I have not displayed all the equations, I have completely specified a new "theory of everything" which fulfills and validates Einstein's vision of physics, which matches the tested predictions of conventional quantum field theory, and even successfully explains a few things which the standard model does not explain. Unlike superstring theory, it does not need to postulate unobserved additional dimensions of reality to achieve mathematical consistency.

The idea of backwards time effects and a thermalized universe may seem strange at first – but logic and Bell's Theorem give us only two choices: (1) to accept that objective reality is stranger than we thought, and that our human notions of "down" and "future" are not the universal invariants people assumed when they believed in an infinite flat earth; or (2) to hide our heads under a blanket like a baby and claim that objective reality cannot exist at all if it insists on being so frustrating and nonanthropocentric. (The many worlds theory is not really a third alternative, since even there one must choose between BTI and the Copenhagen view of measurement.)

If we get out from under the blanket, we will see that there are many new things we can do with these new toys. (Though I hope we will be wise enough to do some of the more dangerous initial experiments in space.) And perhaps we will even discover that our technology is not so limited as we thought, in exploring the universe, if only we understand better what is happening in objective reality, and open the door to a wide variety of competing testable realistic theories of everything.

References

J.S.Bell, *The Speakable and Unspeakable in Quantum Mechanics*, Cambridge U. Press, 1987

P. Bordone, M. Pascoli, R. Brunetti, A. Bertoni and C. Jacoboni, Quantum transport of electrons in open nanostructures with the Wigner-function formalism, *Phys Rev B*, Vol. 59, no. 4, p.3060-3069 (1999)

Howard J. Carmichael, *Statistical Methods in Quantum Optics1: Master Equations and Fokker-Planck Equations*. Berlin: Springer, 1999.

K.E. Cahill and R. J. Glauber, Ordered expansions in boson amplitude operators, *Phys Rev*, Vol. 177, No. 5, p.1857-1881 (25 January 1969)

K.E. Cahill and R.J. Glauber, Density operators and quasiprobability distributions, *Phys. Rev.*, Vol. 177,No.5, p.1882-1902 (25 January 1969)

A.Chodos, E.Hadjimichael and C.Tze, eds, *Solitons in Nuclear and Elementary Particle Physics*, World Scientific, 1984

J.F.Clauser, M.A.Horne, A.Shimony & R.A.Holt, Proposed experiment to test local hidden-variable theories. *Phys. Rev. Lett*, 1969, 23:880-884

Supriyo Datta, Nanoscale device modeling: the Green's function method, *Superlattices and Microstructures*, Vol. 28, No. 4, p.253-278 (2000)

Sidney Coleman, Quantum Sine-Gordon equation as the massive Thirring model, *Phys Rev D*, 1975, 11:2088

Louis DeBroglie, *Nonlinear Wave Mechanics: A Causal Interpretation* (A.Knodel & J.C.Miller, tr). Elsevier, 1960.

B.S.DeWitt & N. Graham eds, *The Many Worlds Interpretation of Quantum Mechanics*, Princeton U. Press, 1973

P. Hasenfratz & G. 't Hooft, Fermion-boson puzzle in a gauge theory, *Phys Rev Lett*, Vol. 36, p. 1119-1122 (10 May, 1976)

Yoon-Ho Kim and Yanhua Shih, Experimental realization of Popper's experiment: violation of the uncertainty principle?, *Foundations of Physics,* forthcoming.

V.G.Makhankov, Yu.P.Rybakov and V.I.Sanyuk,*The Skyrme Model*, Springer-Verlag, 1994.

Leonard Mandel and Emil Wolf, *Optical Coherence and Quantum Optics*. Combridge University Press, 1995.

F. Mandl and G. Shaw, *Quantum Field Theory*, revised edition. Wiley, 1993.

P. Mohanty and R.A. Webb, Decoherence and Quantum Fluctuations, *Phys Rev B*, 55, R 13452–R13455 (1997)

P. Mohanty, Electron decoherence at zero temperature, in *Proceedings of the NATO Advanced Workshop on Size-Dependent Magnetic Scattering*, Kluwer, 2000.

] Z.Y.Ou & L.Mandel, Violation of Bell's inequality and classical probability in a two-photon correlation experiment. *Phys Rev Lett*, 1988, 61:50-53. See also Z.Y.Ou, X.Y.Zou, L.J.Wang & L.Mandel, Observation of nonlocal interference in separated photon channels. *Phys Rev Lett,* 1990, 65:321-324. See also Quantum philosophy, *Scientific American* June or July 1992

Huw Price, Cosmology, time's arrow, and that old double standard. In Savitt Steven F. Savitt (ed), *Time's Arrow Today:Recent Physical and Philosophical Work on the Arrow of Time*, Cambridge U. Press, 1997

R. Rajaraman, *Solitons and Instantons: An Introduction to Solitons and Instantons in Quantum Field Theory*. Elsevier, 2nd edition, 1989.

J. Schwinger, A Magnetic Model of Matter, *Science* 165, 757 (1969).

Raymond F. Streater and Arthur S. Wightman, *PCT, Soin and Statistics and All That*, Princeton University Press, 1964.

J. Von Neumann, Mathematical Foundations of Quantum Mechanics (Beyer – tr), Princeton University Press, 1955.

D.F.Walls and G.F. Milburn, Quantum Optics (Springer, New York, 1994

P.Werbos, An approach to the realistic explanation of quantum mechanics, *Nuovo Cimento Letters*, Vol.29B, Sept. 8,1973.Vol. 8, No.2, p.105-109.

P. Werbos, Classical ODE and PDE Which Obey Quantum Dynamics, *Int'l J. Bifurcation and Chaos*, Vol. 12, No. 10 (October 2002), p. 2031-2049. Slightly updated as quant-ph 0309031.

E.P. Wigner, Phys. Rev. 40, p. 749 (1932)

Y. Yamamoto, F. Tassone and H. Cao, *Semicondictor Cavity Quantum Electrodynamics*, Berlin: Springer, 2000.

Appendix: Additional Technical Connections

In this paper, I have tried to convey and specify the essential new ideas with a minimum of unnecessary detail. However, there are certain connections to other areas which are important, even at this general level of discussion.

First, in discussing Quantum Field Theory (QFT), I have glossed over the fact that there are actually four major mainstream versions of what a QFT actually is, mathematically (not counting issues of interpretation).

There is the original canonical version of QFT, described in the text by Mandel and Shaw. That is the point of departure for the usual many-worlds versions of QFT, for the vast bulk of the work using QFT in device design and condensed matter physics, and for the discussion above.

There is a second version more popular in theoretical physics, based on functional integration, which emerged from Feynman's work on path integrals and Schwinger's work on source theory. This is considered equivalent to the first version, for reasons discussed in many standard texts; however, these discussions remind me of a paper by Coleman (discussing a different pair of theories) where he says, in effect, "I have proven these two theories are equivalent, provided that they both exist, which no one begins to know how to prove." There are mathematical subtleties here which have yet to be nailed down.

There is a third version by Streater and Wightman, which appears far more elegant than the others at first. It is often cited as the gold standard for mathematical rigor in proving that a QFT is well-defined in an axiomatic sense. That is the formulation for which the "spin-statistics theorem has been proven." (Some would cite that theorem as a basis for dismissing my suggestion about the neutrino a bit too hastily – but the issue is not so simple, especially since no one has actually seen exchange statistics for neutrinos.)
But no one has actually shown that *any* specific QFT over three-dimensional space and time can actually fit that formulation, let alone the standard model. By contrast, if we propose that the universe is governed by CFT, it is enough to show that the CFT are well-enough defined; there is a huge literature on the existence of solutions to nonlinear PDE which can be used.

There is a fourth version based on Wick transformations, which I will not discuss here.

Within the canonical version of QFT, QFT is actually made up of two parts: (1) *quantum dynamics*, which, in the modern form, are expressed as the Von Neumann equation for the evolution of the density matrix; and (2) *quantum measurement*, which is usually calculated by the standard measurement operator "collapse of the wave function" procedure. This paper mainly deals with quantum dynamics.

The "Bell's Theorem" experiments, similar paradoxes, and much of today's quantum computing are based on quantum measurement more than quantum dynamics. For that reason, my papers at arxiv.org (and other previous published papers) focused very heavily on quantum measurement. (IJBC also discusses computing.) My personal web page (www.werbos.com)goes further, and discusses specific experiments related to quantum measurement, and links to the work of Yanhua Shih and Huw Price – perhaps the two other people who understand the realities here the best. But in the end, I argue that quantum measurement is *derived* from quantum dynamics; for that reason, in recent years, I have put more effort into nailing down the situation with dynamics.

Discussions with Richard Holt crystallized my understanding of the Backwards Time Interpretation, but they aren't where it started. For many years, I had believed – like most of the world – that we should keep working with the "Newtonian" view of physics as a kind of time-forwards progression. That view does seem natural to our brain, and I did not yet see any concrete, experimentally based reason to go beyond it. But then, in a course on nuclear physics, I spent many hours pondering certain curves for nuclear exchange reactions. In these interactions, a proton which is sent whizzing past a resting neutron will often turn into a neutron itself, even when the nuclear interaction is very weak and distant. It seems that a neutron "knows" that it is OK to emit a charged "virtual pion" when there will be a proton there to receive it, *in its future*. There is no nonlocal model proceeding forwards in time which really fits this in a natural way – but it is all quite simple if we accept that the neutron "sees the future," that the charged virtual pion is a kind of excitation which depends on boundary conditions both in the past and in the future.

More recently – a new field of basic physics has arisen, which revolutionizes our understanding of some similar phenomena. Once again, empirical reality has quietly changed the rules, in a way which the introductory textbooks have not yet assimilated. It's not just a matter of needing to use density matrices. *Cavity QED* has shown that the traditional form of quantum electrodynamics simply does not work at all, when confronted with a wide variety of practical physical systems. Traditional QED *appears* local in spirit, because it is all based on an interaction $\psi(\underline{\mathbf{x}})A(\underline{\mathbf{x}})\psi(\underline{\mathbf{x}})$ which takes place at a single point in space; an electron "knows" it can emit a photon when the information it has available says that it can. The many-worlds version of this obeys at least a restricted kind of locality. But it doesn't actually work that way. In actuality, an electron at the edge of a cavity "senses" the entire cavity; its "decision" is based on the shape of things far away; it "senses" whether the cavity can accommodate a certain amount of light energy resonating in a certain pattern across the entire cavity, and emits that energy only if the boundary conditions are there to receive it in the future. This is not an obscure phenomenon, like the T violations of superweak nuclear interactions; it is a large and useful phenomenon, which is the basis of a new generation of advanced video display systems, using Vertical Cavity Surface-Emitting Lasers – but it has many other applications, and is a well-developed fundamental alternative to traditional QED, fully consistent with BTI.

There is still a lot of work to be done to evaluate various forms of the hypothesis presented here. For example, what are the possible mechanisms for "thermalizing" the universe? Logic suggests two possibilities – boundary conditions, leading to something like a Boltzmann relation, or stochastic sources and sinks operating to perturb the soliton dynamics. The analysis is complicated by the need to use (local) Markhov Random Field methods over Minkowski space-time, so as to avoid the inappropriate asymmetries of the usual time-forwards local Markhov models. The assumption of stochastic sources and sinks results in a theory which is 100% phenomenologically consistent with special relativity, whereas a traditional Boltzmann relation inserts a kind of preferred direction in space (i.e., a temperature vector which multiplies the energy and momentum operators in the canonical grand ensemble); however, since no one has measured the size of zero-temperature decoherence effects in objects moving near the speed of light, I do not yet know enough to rule out either possibility. Of course, it is well-known that a Boltzmann distribution about a local minimum of energy can be approximated as a kind of Gaussian distribution (as assumed in the Q hypothesis) in the right units, and that the approximation is good when the temperatures are relatively small (compared with the masses of the electrons, quarks, etc.).

Another possible direction for follow-on work: if the original "P" classical hypothesis and the new "Q" hypothesis provide upper and lower bounds for energy levels which are very hard to calculate directly in standard QFT (e.g. for strong nuclear forces), they might have some practical value even if P, Q and QFT all turn out to be approximations.

Acronyms and Symbols

AM Amplitude Modulation
BTI Backwards Time Interpretation (of Quantum Mechanics)
CFT Classical Field Theory
H Hamiltonian – energy functional of operator
IJBC International Journal of Bifurcation and Chaos
P, Q, W mappings: see section 3(b)
PDE Partial Differential Equatoins
QED Quantum Electrodynamics
QFT Quantum Field Theory
$\rho(t)$ Density matrix (quantum theory) at time t
S(t) State of classical fields at time t
$\psi(t)$ Wave function (quantum theory) at time t