Mongrel Gravity

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Abstract: The various options for a quantum theory of gravity are canvassed. Worries about the consistency and physical plausibility of hybrid theories are laid to rest. These hybrid theories—mongrel gravity—comprise the only current, actual theories of gravity, and they also offer legitimate promise for discovering the full theory of gravity. These theories provide an interesting example of scientific revolution in action. Philosophers of physics should pay more attention to them.

Introduction

Little attention has been paid by philosophers of physics to an important class of techniques for constructing quantum gravity, and more generally for addressing the apparent tensions between general relativity and quantum mechanics. This class of techniques—including, for example, the construction of hybrids of classical gravity and quantum matter theory, and the working out of various new classes of expansion technique—is less directed toward the final stage of quantum gravity theory, and more toward the right response to current and pressing worries about our current theories. Since much of the work that any theory of quantum gravity is supposed to do toward illuminating the nature of our universe is actually being done by those with this orientation, it seems well worth our while to see just what is going on in that work. While philosophers have been intrigued by the development of quantum gravity for decades, they have been less interested in what is going on at the work-a-day level than they are in efforts to construct from theoretical principles alone the proper final theory of gravity. I think this is a mistake and that a great deal can be learned about quantum gravity, about physics research, and about theory construction in general by expanding our focus from the more flamboyant, pure breeds of quantum gravity to the more virile mongrels.

Lately the idea that gravity may not require quantizing after all has been receiving attention from philosophers of physics as well as physicists. Some of this attention has been focused on a negative project—showing that perceived grounds for the necessity of quantizing gravity are not as solid as has been advertised; some has been focused on positive projects—options that stake out entirely novel positions where the very notion that gravity should be quantized makes very little sense; some attention has been focused on seeing how far one can go without a commitment either to novel physics or to a strict quantization program—attempts to respond to issues in "quantum gravity" the way we do any other field of inquiry, by pushing the tools we have to their limit and building new tools on the fly as needed. Apparently, no-one entertains the notion that general relativity and quantum-mechanics (or quantum field theory, or string theory, or whatever) can co-exist in conceptual isolation from each other, where sometimes one is doing gravitation theory, and sometimes one is doing quantum theory. Though there will be important overlaps in these various projects, the possibilities naturally cleave into three distinct kinds of option: a quantized theory of gravity; a novel theory from the ground up; some horrid, unlovely and unloveable mongrel blend of a classical, dynamical spacetime theory and a quantum matter theory.

Here I briefly canvas the available options, and identify the important features of each and their important proponents. Then I focus on the mongrel theories and first respond very briefly to recent work that appears to establish their incoherence. My main focus here is to direct the attention of philosophers toward mongrel theories of gravity, and to present the outlines of these theories to a philosophical audience, but I also attempt to make plausible two important claims: (1) The current theory of quantum gravity is actually a mongrel theory; (2) The mongrel theory has a good chance at leading us in the direction of a full theory that combines gravitation theory with quantum quantum theory—a direction not available to other programs, though the final state may be. I illustrate the latter possibility by considering just one example of mongrel gravity, the stochastic semiclassical theory under development by Beilok Hu and his collaborators. I attempt to draw out from the specific example of stochastic mongrel gravity a general lesson about the development of physics.

1 The options

The traditional view of the proper way to treat the incompatibility between classical general relativity and quantum theories of matter it to assume that the gravitational field itself will be one quantum field among many. This field will have its own peculiar character that distinguishes it from the other component fields of the quantum theory of gravity, but it will share the important feature that it is directly governed by the Schrödinger equation and is subject to the uncertainty principle. Another important view of the proper treatment of that incompatibility between general relativity and quantum mechanics is that the conflict is itself a product of the fact that neither quantum theories nor dynamical, classical spacetime theories are fundamental but rather both arise out of some deeper theory of an entirely novel sort. The interesting question, of course, is what "arise out of" means in this context. Lee Smolin explicitly catalogues the options in this way in his popular 2001 book on quantum gravity *Three Roads to Quantum Gravity*. In that book the first option above is split into two distinct options: (1) begin with general relativity and make it quantum; (2) begin with quantum theory and apply it to spacetime. We then add (3) find some deeper theory and show how quantum theory and general relativity each arise out of that.

An option not traditionally identified and completely ignored in the philosophical literature is (4) begin where we are and push on until we reach a crisis. Proponents of this option remain (programatically) agnostic on the question of how to resolve the incompatibility between quantum theory and general relativity; they proceed by taking the two theories as given, and attempt to smooth over whatever incompatibilities arise from the radically different nature of the theories' fundamental entities. Inevitably the two pure breeds must intermix—mongrel gravity is the result.

Those who study scientific transitions, beginning especially with Lakatos (e.g., 1970), commonly make a distinction between progressive and stagnating research programs. The guiding thought is two-fold, first that such a distinction is possible in general, and second that progressive programs are to be preferred. In cases of conflict between theory and observation a distinction is also made between ad hoc rescues and genuine predictions made by a theory. Again the guiding ideas are that the distinction is legitimate and that the ad hoc rescues are to be avoided. I will not explicitly challenge the validity of these distinctions nor the prevailing wisdom about which options are to be preferred. What follows however may be seen as an implicit challenge to one or the other. The fourth option above, the "road" Smolin does not consider appears at first blush to be a form of stagnating research program because it lacks a stable character and seems to be purely reactive to problems as they arise. Much in the manner of Ptolemaic astronomy or Lorentzian electrodynamics it begins not with a full-fledged theoretical account but instead with a few construction techniques and rules for their use. It then proceeds by self-correction. This kind of theory construction is typically taken to be scientifically unsound and that proper science is to be done along the model of Copernicus' revolutionary advance over Ptolemy, or Einstein's over Lorentz—making bold predictions that lead to new tests. Generally one takes these so-called degenerating programs to display a kind of cunning survival strategy rather any interesting methodological advances. However, while not uncontentious it is also not implausible to suppose that Ptolemaic and Lorentzian advances were not merely prior to their successor theories as a contingent historical matter, but that they also were necessary in clarifying the problems that were to be solved by the new theories. That is, there is a way to see the crises brought about by attempts to update the Ptolemaic account on the one hand, and by attempts to extend Lorentz's model of the electron on the other, as conceptually (and not merely historically or contingently) prior to their successor theories. It is not implausible either to suppose that the same is true for quantum gravity: continuing development of the naive view that continues to make do with the conceptual resources at hand may be necessary to clarify the true problem a fundamental theory of gravity is to solve. (See author in press.)

Here I present an all too brief account of the first three options and then, after presenting the fourth option and addressing the still popular idea that it is inconsistent somehow, I outline its important role in not only the present state of research into quantum gravity (broadly understood) but also for the future of that research.

1.1 Quantum gravity

Many good treatments now exist for philosophers interested in becoming acquainted with the basic problems of quantum gravity (e.g., Calender and Hugget 2001). Here I do little more than name the important strands in the development of the story.

First there is the attempt to quantize general relativity. The idea is pretty simple. Since we know how to quantize many classical theories once they have been put into canonical form, why not put general relativity into that form and then quantize it? Once we have done that we can begin to investigate the properties of the quantum system. Some problems arise immediately however. First is that the canonical part of the quantization procedure appears to break the symmetries that many believe to be at the heart of general relativity, since it requires that spacetime be broken-up into space and time with a preferred foliation. More serious however is that one does not really know what to do with the new system—a system governed by the Wheeler-deWitt equation. Nobody can solve the equation in its standard form, and it is non-renormalizable so it cannot be properly approximated. After half a century little progress has been made.

Recently however exciting advances have come from reconsidering the first step in the program. Instead of putting general relativity into canonical form using metric variables, some have now used connection variables. When this is done we find that, while we are still far from quantum gravity, we do have a much more tractable theory. And in this theory there are certain cases in which one can solve the Wheeler-deWitt equation. So there is hope that progress might be made in the direction of quantizing general relativity.

The second option is the begin with some quantum theory and attempt to introduce gravity. Chief among such approaches is string theory and its extended program m-theory. Again the basic idea seems pretty simple. Begin with a theory describing nature in terms of very small 2-dimensional objects propagating in Minkowski space. Notice that these objects have excitation modes that look like spin-2 bosons, which in turn look like gravitons. Identify these modes with gravity. The only trick now is to remove the background, and solve some extremely heavy-duty mathematics. Neither task has been accomplished.

Both of these programs remain strong and progressive despite their problems. However no longer are they the only options.

1.2 Novel gravity

There is by now a significant, and still growing, literature on options that do not involve a field that is a dynamical, gravitational, quantum mechanical object of some sort. This literature is quite various, but almost all of it involves the observation that general relativity itself can emerge as the low-energy limit of some other underlying theory. The various approaches build off of this insight in different ways. For example Smolin and Markopoulou (1997, 2003) and Hawkins, Markopoulou, and Sahlmann (2003) and others have explored the idea that the fundamental basis of spacetime is a network of spin-states related in various ways, and more radically that certain kinds of structured sets (understood as quantum histories) may be all there is to spacetime. These are in part generalizations of the idea of quantum gravity but also in large part examples of how to avoid having any theory that is a "quantum gravity" as that expression is commonly understood.

In another approach in this direction Jacobson (1995) suggests that if we start with the generalized entropy theorem we can derive Einstein gravity from consistency demands arising primarily from the Unruh effect. But such an approach transcends differences between classical and quantum matter—it is simply the way that gravity must behave to preserve consistency. Then it makes no sense to talk about a quantization of gravity.

2 The fourth road: Mongrel gravity

Mongrel gravity will be my expression to cover all theories that attempt to marry dynamically a spacetime of classical character to matter that has quantum character. So it is very broad and in particular I do not intend the term to be restricted to pure semiclassical general relativity. Even understood thus broadly, there are persistent arguments to the effect that there can be no such theory that is consistent (or at least physically possible), so it is worth pointing our how, while not red herrings, these arguments fail. At the same time there has been a great deal of work done sorting out precisely what follows for our understanding of spacetime when we ignore the worry about consistency and attempt to couple the fields and conduct research as usual. In this section I first outline the worry about incoherence and respond to it. I then indicate how it is that work in the mongrel program has proceeded independently of considerations of logical coherence, and how that work has set the agenda for much of what amounts to research in quantum gravity in the last century.

2.1 Semiclassical Standards for Quantum Gravity

Semiclassical gravity is a particular class of attempts to marry the quantum nature of matter to the classical nature of spacetime geometry. The idea is very simple. The expectation of any quantum operator is a classical function, a c-number. Thus one can use expectation values of quantum operators in equalities involving classical fields. Semiclassical, linearized general relativity is one example of a theory with a classical spacetime metric coupled to the expectation value of a quantum field. The semiclassical Einstein equation $G_{\mu\nu} = \kappa\langle T_{\mu\nu}\rangle$ expresses the mutual influence of the spacetime metric and the expectation value of the stress energy tensor.

One necessary point to observe is that one strand of the mongrel gravity program, semiclassical gravity, is effectively *the* theory of quantum gravity in use today. For semiclassical gravity sets the standard by which quantum gravity proposals are judged: any contender for the quantum theory of gravity must meet various minimal requirements, and these minimal requirements are all deduced from the semiclassical theory. Among these are that the theory get right (at least in the appropriate limits) the Hawking spectrum for blackhole radiation. This by itself is an astonishing fact about contemporary physics—it takes as empirical data not only the existence of black holes, but also the general form of their radiative spectrum. The semiclassical theory, and mongrel gravity more generally is producing empirical knowledge through its predictions. It is, indeed, our effective theory of quantum gravity.

2.1.1 Back Reaction Terms

However as presented the semiclassical theory has serious limitations. The most important is that it is difficult to construct meaningful expressions for the stress energy tensor. Moreover it is difficult to understand how that stress energy would act on the metric itself. The obvious worry is that while G is classical, T is quantum mechanical and therefore will exhibit fluctuations. These fluctuations will become comparable to the expectation value itself in many circumstances of interest. A more subtle worry, addressed below, is that such a coupling may not be mathematically consistent.

Consistent or not an adequate semiclassical theory (indeed any mongrel theory) will have to address the problem of back reaction—the influence of the stress energy on the metric—and that will involve deciding how to handle quantum fluctuations. This will be considered more fully when we examine the stochastic program.

2.2 Objections to mongrel gravity in general

While still generally accepted in much of the physics community and the philosophy of physics community, arguments indicating the impossibility of a mongrel gravity are being treated with ever greater critical scrutiny (Hugget and Calendar 2001, Mattingly 1999 [2005], 2006, Wuthrich 2006). As a result some of the standard arguments have been laid to rest. Briefly put this scrutiny has shown that an experiment by Page and Geilker (1981) is applicable only to pure semiclassical Einstein gravity, and even then it isn't clear that it is a decisive refutation of that theory (Kibble 1981, Mattingly 1999). Similarly a powerful thought experiment by Eppley and Hannah (1977), the germaneness of which has been called into question (Calendar and Hugget 2001, Mattingly 1999, 2005) has now been shown to be itself incoherent (Mattingly 2006). These two experiments appear to exhaust the actual empirical data on the matter.

On the other hand there have been many theoretical arguments against the possibility of mongrel gravity. Most of these target the much narrower field of semiclassical gravity. For example, in their monograph on quantum gravity Borzeszkowski and Treder (1988) endorse Dirac's claim that the very idea of a theory that couples quantum expectation values to classical field values is somehow incoherent. Not much by way of justification is offered for this claim, and Borzeszkowski and Treder treat it as unremarkable.

However, the semiclassical theory of gravity as proposed in Wald's (1989) gives the lie to this incoherence claim. As he shows, the theory is fully consistent, and this consistency includes a particular proposal for how to handle back reaction terms. While not a proposal for *the* theory of quantum gravity, it is certainly a consistent theory with back reaction, and a theory that couples a classical field to a quantum expectation value.

Bare points about consistency aside however, there is still the question of whether a truly viable theory of gravity can be had without finally making the metric itself quantum mechanical, and that question is not so easily answered. Interesting new work on this question by Terno (2004) and Peres and Terno (1996, 2001) is discussed in Wuthrich (2006). Wuthrich, correctly in my view, sides with Calender and Hugget and Mattingly in rejecting the claim that gravity must be quantum mechanical in any quantum gravity (again broadly construed). However I believe that he too quickly accepts Peres and Terno's claims that mongrel gravity itself is impossible.

Peres and Terno argue as follows: Suppose that there is a theory that is a dynamical combination of classical and quantum fields. This theory can be expressed in a combined Hilbert space using Koopman's formalization method. Then a completely general analysis of the necessary dynamical evolution of such a system can be performed. Peres and Terno show that a combined system of classical and quantum variables can be consistently constructed, and indeed an interacting system of quantum and classical variables is also possible. But they argue that such a system cannot be a successful hybrid between the classical and quantum realms because the correspondence principle fails for such a system. That is to say that the equations of motion for the combined system when one passes to the classical limit differ from the equations for an analogue system where there are only classical variables.

There are a few salient points to observe about this argument. First, the Koopman formalism they employ is not the only formalism possible. And indeed, it is not that one should adopt this formalism as the standard for treating combined quantum and classical systems. It is true that the formalism suffices to represent adequately such systems when they do not interact, but as Peres and Terno themselves show it is not capable of representing such systems when they do interact if it is true that such systems obey the correspondence principle. Peres and Terno (Terno 2004 explicitly) take this latter fact as proof that there can be no hybrid (i.e., mutually interacting) quantum and classical systems. As presented however there is a major lacuna in their argument. If the Koopman formalism is the only formalism adequate for representing hybrid classical and quantum systems then their result is established. But we know already that other options exist. In particular Wald's formalism suffices to characterize back-reaction in semiclassical gravity—and the correspondence principle is obeyed there. See as well critical discussion in (Sudarshan, 2004). So what is going on?

Koopman's formalism, as developed by Peres and Terno, represents the mixing of classical variables and quantum operators through a special interaction term. While there is, as Peres and Terno observe, nothing incoherent about this (despite the peculiar mixing of classical and quantum terms), such an interaction term does alter the equations of motion from those of the classical analogue system. Peres and Terno merely establish that for a hybrid system where classical observables mix with quantum operators the correspondence principle fails. But mongrel gravity is not committed to such mixing, and indeed that kind of hybrid has had little influence in the development of mongrel gravity.

So where are we left at the present state of discussion of the possibility (conceptual or physical) of mongrel gravity? It seems that there is a narrow class of theory that has been ruled out (Koopmanian interacting systems) and an even narrower class that may have been ruled out (the semiclassical Einstein theory). However there is little indication that mongrel gravity itself has been ruled out, and some strong indication that it is viable.

An important point to appreciate here is that even were there an inconsistency between general relativity (or some other version of classical gravity) and quantum mechanics, such an inconsistency would not show that gravity itself must be quantum mechanical; nor would the discovery that even if consistent any such theory would be physically implausible. There are many more conceptual possibilities on the table now than there were even twenty years ago, and these have radically transformed our appreciation of the conceptual landscape in which we will look for a happy co-existence of fundamental physics and the phenomenal, low-energy limit that is well captured by our current physics. Given the broader and richer conception we are gaining of this conceptual landscape we are faced with the considerable task of attempting first to map that landscape while finding our way through it. The stochastic gravity program offers itself as a reasonable guide.

2.3 Stochastic Gravity

Despite the claim above that Wald's version of semiclassical gravity is immune to many of the criticisms that have been leveled against mongrel gravity in general, his theory is still not viable. Despite formally accounting for back-reaction of the stress energy on the metric, the theory is blind to fluctuations in the expected stress energy $\langle T_{\mu\nu} \rangle$. But in the neighborhood of black holes and other regions where quantum mechanics and gravity are expected to play comparable roles in the physical system, the fluctuations in the stress energy will be of the same order as the stress energy itself. Then it is clear that such a theory is inadequate for such situations. But if we do not adopt either a quantum gravity of some type, or one of the novel gravity programs it is not at all clear how to overcome this issue.

In stochastic gravity we have a novel solution to the back reaction problem. Rather than attempt to develop a quantum theory of gravity with a quantized gravitational field from scratch so that the spacetime will be in dynamical interaction with the matter distribution *ab initio* stochastic gravity proceeds term by term to replicate what that dynamical interaction would be like in approximation. The stochastic program grows out of the observation that one can add a noise-like term to the Hamiltonian and first-order fluctuation terms will naturally arise.

Hu and Verdaguer (2002) illustrate the basic idea behind the proposal with a completely solvable toy example. In that example a complete quantum theory of a system is presented. Then a semiclassical version of the system is constructed. By comparing the two systems we see that the semiclassical version misses the fluctuations in the metric like term. But then Hu and Verdaguer point out that one can add a classical noise term to the semiclassical equations. We find then that the noise term produces modifications in the semiclassical system that mimic precisely the first order corrections due to the fluctuation in the expectation value of the analog of the stress energy for the toy system. And they show that this carries over to the semiclassical theory of gravity. This by itself is an interesting and important accomplishment that philosophers of physics should be aware of.

Whatever else one can say about this program, the addition of a stochastic fluctuation term shows again quite clearly that claims that the gravitational field must be quantized are not supported by appeals the back reaction problem have no bite. The back reaction problem is definitively solved here and in a physically plausible way since we have a completely definite proposal for how quantum matter can influence the classical metric and also take into account the fluctuations in the metric. (Of course sorting out just how this works in the gravitational case, and determining whether an empirically adequate and well-motivated theory can be developed from these beginnings takes more work.)

2.3.1 The kinetic theory

More however follows from the program. Hu (2002) has outlined a complete program for quantum gravity—the kinetic theory approach—that goes beyond the stochastic theory. This like the stochastic theory is an inherently approximative, and now incremental approach. At each stage of development the program gives guidance on how to produce further corrections to the previous stage. The idea is that whatever the underlying microstructure spacetime possesses we can work our way down to this structure by progressive approximations. But this is not the failed program of attempting a renormalization of the Wheeler-deWitt equation. Rather than starting with a given theory and deriving approximations from it—a strategy that runs into trouble with self-interacting force carriers—the kinetic theory approach begins with the effective theory and attempts to determine what the next lowest level of theory it is an approximation to. The plan for the program goes like this (Hu 2002, 15): 1) Deduce the correlations of metric fluctuations from correlation noise in the matter field; 2) Reconstitute quantum coherence from the correlation functions; 3) See what spacetime counterparts are required by metastable structures in kinetic and hydrodynamic regimes of quantum matter theory.

The essential Lorentzian strategy should be obvious here. We take what we are given and resolve contradictions and inconsistencies as they arise. In the contemporary version we hope for an Einstein to make the leap forward, but we don't wait for that and instead try to develop a stable place from which to make that leap.[1]

Conclusion

Hu and his collaborators' task is quite ambitious and has only begun in earnest. But it clearly has a number of points of interest to philosophers of physics. First it is unlike any other program in quantum gravity (though it bears some similarity to Jacobson's equation of state view) in being unconcerned with what the final theory might itself be—instead it takes that theory for granted and concentrates on the next step that must be taken to make our effective theory conform to the final theory as manifested at this stage. Second it is likely to lead directly to further predictions that will (i) provide a check on other quantum gravity theories and (ii) lead to a better understanding of what the theory should be like at the next stage. Third, and important to those who wish to derive general lessons for philosophy of science from the progress of physics, it provides an opportunity to re-evaluate our understanding of scientific theory change. We have in front of us one of the slowest revolutions in the history of science—the quantum gravity revolution. What can it tell us about the nature of revolutions in general? One thing we might see is that the apparently ad hoc theory modifications that are often taken to be signals of degeneration in a program are rather better understood as important propaedeutics to their revolutionary replacements. In the same way that one might think that special relativity was impossible until the real tension between Maxwell's theory and Newton's was made manifest in Lorentz's electrodynamics, one might also think that a quantum theory of gravity is impossible until the true tension between general relativity and quantum mechanics is made manifest. In any case philosophers of physics with an interest in quantum gravity should spare some attention for mongrel gravity.

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