(Again) A Philosopher Looks at String Theory

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When Craig Callender and I published an anthology on the philosophical implications of quantum theories of gravity (2001) we were able to include pretty much the entire literature concerning the philosophy of string theory – two papers (Weingard 198? and Witten 1995)! In the last six years the situation has not much improved (an exception is Dawid 200?). This paper is an attempt to show that string theorists are dealing with philosophical issues, and to encourage philosophers to pay attention (as they have to canonical quantum gravity).

I focus on an issue found in Witten's paper, but its philosophical implications are explored far more clearly in Greene (200?), who is expanding on a point originally made by Brandenberger and Vafa (199?). Consider a string on a circle of radius R: its Hamiltonian has two quadratic terms, one corresponding to kinetic energy (so quadratic in momentum) and another due to its being stretched around the circle (quadratic in the number of times it is wound around). Momentum (P) is quantized in the usual way as an operator on wavefunctions on the circle in which the string lives, so that $[X, P] = i$ (where X is the observable for position in space). Winding (W) can be quantized in the same way, to act on wavefunctions on *another* circle, with conjugate 'position' U (i.e., simply imposing periodic boundary conditions): formally we quantize winding by demanding $[U, W] = i$.

The kinetic energy contributed by n wavelengths around the circle is (in suitable units) equal to $(n/R)^2$ – momentum is inversely proportional to the wavelength. But the winding energy is $(mR)^2$, where m is the number of times the string wraps around – the energy due to stretching the string goes like the length squared. By comparison, we see that states of definite winding are waves of m wavelengths around a circle of radius $1/R$: *U is the position operator on a circle with radius reciprocal to the string circle*.

The first observation is that within the formalism, U and X are on a similar footing as conjugate to observables appearing (quadratically) in the string Hamiltonian. But if they both formally behave like position observables, shouldn't it be possible to interpret either as the phenomenological position of the system, the quantity measured in experiments on the string? (Of course, whether either can be so interpreted for some particular system depends on which, if either, predicts the correct values for measurements.) Following this line of thought, Brandenberger and Vafa claim that phenomenological position is a 'derived' notion in string theory – we experience space through the spatial properties of matter, so ultimately of strings, but the string properties we experience as spatial may in fact arise from its winding, not its position. So the first philosophical issue is that of the possible 'emergence' of spacetime from something more fundamental: Has this happened here? What about other, richer string theories? What in general would it mean? (In another context, Maudlin (200?) has criticized the idea.) Certainly some clarity on the issue is needed.

Second, from what has been said we see that the total energy contributed by momentum and winding is invariant under the simultaneous exchanges $R \leftrightarrow 1/R$ and $n \leftrightarrow m$: a state in a theory in which the string lives in a space of radius *R* has the same energy as a state (in which momentum and winding excitations are exchanged) in a theory in which space has radius 1/*R*. The equivalence is in fact total, and the theories are 'dual' under the exchange of momentum and winding observables: the values of expectation values in one equal the values of expected values in the other for dual observables. Insofar as expectation values capture the physical content of quantum theories, the two theories are the same – a view argued for by Greene. That is, there is no fact of the matter about whether the string lives in a space of radius *R* or 1/*R* – perhaps *R* is the order of the Planck length, making the difference very large indeed. (How can this be? According to the first theory phenomenological space corresponds to winding space, according to the latter to the string space.) This line of thought is reminiscent of earlier metrical indeterminacy theses, but I argue that it turns on physical considerations, not epistemological theses. It is thus immune to critiques of those epistemological views, and offers a new kind of underdetermination.

However, the argument turns on the assumption that expectation values do capture the content of a quantum theory, something at odds with many interpretations of quantum mechanics. For instance, the intuitive way of formulating a Bohmian theory for our string involves specifying a specific metrical spacetime, radius either *R* or 1/*R*; the equivalence could show at best that the value was underdetermined, not indeterminate. Maybe not even that; perhaps we have to take the radius to be that of phenomenological space. Issues in the foundations of quantum mechanics have important implications for both the philosophical arguments discussed, and I will tease some of these out.

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