NOT THE HOLE STORY: RELATIONALISM AND LOOP QUANTUM GRAVITY

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Loop quantum gravity is a background-independent quantization of general relativity. Many of its proponents (e.g. Rovelli 1999, 2004) have long considered the theory to carry significant implications for the ontology of spacetime. In particular, they suggest that loop quantum gravity must be given a uniquely relationalist reading. Any form of substantivalism about spacetime (at least within the context of this theory of quantum gravity) is to be rejected. Dean Rickles (2005, 2006) and Oliver Pooley (2006) are among those who have raised doubts against this conviction. Rickles argues that a hole argument can be constructed for loop quantum gravity; he believes this to show that both substantivalist and relationalist interpretations of the theory are in fact possible. Pooley is sympathetic to Rickles' conclusion, but denies that an appropriate hole argument can be constructed. The discussion between Rickles and Pooley should therefore prompt us to at least review, and perhaps reconsider, the original arguments for background-independence in loop quantum gravity. Both the relationalist stance of Rovelli and Rickles' hole analogy seem to draw heavily on the traditional relationalist-substantivalist positions as they were developed in the context of the classical spacetime of general relativity. But do the commitments of either side change as we move from a continuous spacetime to a quantum one? My paper will shed some light on how the classical substantivalist-relationalist debate is to be framed within the context of quantum gravity in general, and the loop formulation in particular.

The crucial element of the loop formalism as far as concerns physical space is the spin network basis; elements of this basis are interpreted as quantum excitations of the geometry of space. A spin network state $|S\rangle$ with N nodes is interpreted as an ensemble of N quanta of volume, or N 'chunks' of space (Rovelli 2004, p.263). Spin network states $|S\rangle$ are not themselves diffeomorphism-invariant, and they represent discrete quantized 3-metrics. However, *s*-knot states $|s\rangle$ (which are projections of $|S\rangle$ onto a kinematical space) are diffeomorphism-invariant and are taken to represent the physical geometry of 3-dimensional space. 'In going from the spin network state $|S\rangle$ to the *s*-knot state $|s\rangle$ we preserve the entire information in $|S\rangle$ except for its localization on the 3d space manifold. This is precisely as the implementation of diffeomorphism invariance in the classical theory, where a physical geometry is an equivalence class of metrics under diffeomorphisms' (Rovelli 2004, p. 263). Rovelli argues that the formalism of loop quantum gravity is compellingly relationalist. The quantum excitations represented by spin network states do no occur *in* space: 'they are quantum excitations *of* space itself' (Rovelli 2004, 264). Indeed, 'localization must be defined in relation to them' (Rovelli 2001).

Rickles argues that there is nothing intrinsically relational about spin-networks. According to Rickles, an exact analog to the hole argument of classical general relativity can be constructed in the loop formalism. In particular, 'the quantum analog of Einstein's equation cannot determine where spin-networks are in the manifold. Thus, for any specification of initial data…the Einstein equation will fail to determine the data at t>0 since many diffeomorphic solutions will solve the equation' (Rickles 2005, p. 425). Since the original hole argument admits of both relationalist and substantivalist responses, Rickles claims, the same interpretative options should be available within the context of loop quantum gravity.

Pooley agrees that the loop formalism fails to settle the debate between relationalism and substantivalism. But he denies that a hole argument can be constructed from spin-networks, because (according to Pooley) they do not solve Einstein's equations. The only states which solve all the classical constraint equations are *s*-knot states, not spin-network states. Thus, an equivalence class of spin-network states generated by the diffeomorphism constraint does not play the same role as an equivalence class of 3-metrics of classical space under a diffeomorphism. The inapplicability of the hole argument in loop quantum gravity should prompt us to consider more carefully the ontology of quantum spacetime. 'Without an understanding of why there can be no hole argument in loop quantum gravity, it seems doubtful that progress will be made in providing a coherent interpretation of the theory's ontology' (Pooley 2006, p. 379).

My paper will review some of the principal arguments made for spacetime relationalism in the context of loop quantum gravity. This will be followed by a discussion of the Rickles-Pooley debate over the viability of a spin-network version of the hole argument from classical general relativity. In light of this discussion, I will conclude by describing the extent to which the relationalist and substantivalist interpretations of classical general relativity carry over to the loop formalism of quantum gravity.

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