Gauge potentials, gravity, and nonlocal constraints

Steven Weinstein
University of Waterloo and Perimeter Institute

July 10, 2009

Foundations of quantum mechanics

- Overall goal: make sense of quantum mechanics. On the one hand, it explains the stability of matter, and predicts strong nonlocal correlations. On the other hand, the measurement problem suggests that the theory is somehow incomplete, and attempts to include an account of measurement (Bohm theory, many-worlds, etc) to date do not address the cosmological constant problem.
- Viewpoint: quantum mechanics is a phenomenological theory, and its statistical character simply reflects limitations on our knowledge.
- Though such a viewpoint might seem to run up against Bell's theorem, this is not necessarily the case: a theory in which states are subject to nonlocal constraints is one in which the statistical independence assumption of Bell's theorem is violated. (See SW 2009, 'Nonlocality without nonlocality'.)

Nonlocal constraints

- Recent work by Walter Craig and SW on multiple time dimensions (SW 2008, 'Many Times'; SW & WC 2009, 'On determinism and well-posedness in multiple time dimensions') shows that one can have a well-posed codimension-one problem for a scalar field in multiple time dimensions via the imposition of an explicit nonlocal constraint on the initial data.
- An even simpler example of a theory with a nonlocal constraint is a scalar field on a temporally compact spacetime; the initial data must be periodic.
- Aaronson & Watrous (2009) have recently shown that the presence of closed timelike curves renders classical and quantum computing equivalent, suggesting that some theories with nonlocal constraints may allow one to generate quantum phenomena, or at least certain aspects thereof.

Gauge potentials and gravity

- Though CTCs are clearly sufficient to generate nonlocal constraints, they are not necessary.
- The Aharonov-Bohm effect suggests that gauge potentials may have physical significance.
- The action

$$S = S_g + S_m + S_{em} + S_q \tag{1}$$

$$S_q = -\int A_\mu \mathcal{J}^\mu \mathrm{d}^4 x \tag{2}$$

  is not invariant under gauge transformations, though the equations of motion of the electromagnetic field are.
- Jonathan Hackett (U Waterloo) and I are investigating whether an interesting ambiguity in the variation of this action with respect to the metric gives rise to a nonlocal constraint via the coupling of the potential to gravity.
- Preliminary results suggest that the vector potential enters as part of a nontrivial surface term which survives the variation of the action. We are investigating its physical significance.

References

- S. Aaronson & J. Watrous 2009, Closed timelike curves make classical and quantum computing equivalent, *Proc. R. Soc. A* 465, 631-647, arXiv: 0808.2669.
- SW 2009, Nonlocality without nonlocality, forthcoming in *Foundations of Physics*, arXiv:0812.0349.
- W. Craig & SW 2009, On determinism and well-posedness in multiple time dimensions, forthcoming in *Proc. R. Soc. A*, arXiv:0812.0210.
- SW 2008, Many Times, http://www.fqxi.org/community/essay/winners/2008.1, arXiv:0812.3869.