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Quantum Combinatorial Games: Structures and Computational Complexity

Recently, a standardized framework was proposed for introducing quantum-inspired moves in mathematical games with perfect information and no chance. Going beyond individual games, we explore the tractability of quantum combinatorial games as whole, and address fundamental questions including:

Quantum Leap in Complexity: Are there polynomial-time solvable games whose quantum extensions are intractable?

Quantum Collapses in Complexity: Are there PSPACE-complete games whose quantum extensions fall to the lower levels of the polynomial-time hierarchy?

Quantumness Matters: How do outcome classes and strategies change under quantum moves? Under what conditions doesn't quantumness matter?

PSPACE Barrier for Quantum Leap: Can quantum moves launch PSPACE games into outer polynomial space

We show that quantum moves not only enrich the game structure, but also impact their computational complexity. In settling some of these basic questions, we characterize both the powers and limitations of quantum moves as well as the superposition of game configurations that they create. Our constructive proofs-both on the leap of complexity in concrete Quantum Nim and Quantum Undirected Geography and on the continuous collapses, in the quantum setting, of complexity in abstract PSPACE-complete games to each level of the polynomial-time hierarchy-illustrate the striking computational landscape over quantum games and highlight surprising turns with unexpected quantum impact. Our studies also enable us to identify several elegant open questions fundamental to quantum combinatorial game theory (QCGT).