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Quantum local time

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The trajectory of a quantum particle during unitary evolution between its preparation and a later measurement can not be studied without measuring the particle, but measurement disturbs the state and the statistics of the measurement outcomes no longer pertain to the original evolution. We show how using path integral methods a sensible quasi-probability can be assigned to the event of passing multiple points along the trajectory, or to entire trajectories, in a position- and time-discrete system. We show that by extension of the weak measurement protocol this quantity is actually experimentally measurable with asymptotically zero disturbance. Joint, conditional, marginal quasiprobabilities can be defined consistently, and reduce to familiar probabilities in scenarios where a standard measurement is possible. We use this to define a quantum version of local time, a random variable studied in random processes, and illustrate by practical examples. By asking the probability of this being zero at the initial node of a discrete time quantum walk on a graph, for example, we introduce a new notion of weak recurrence and weak Pólya number, which we calculate for the Hadamard walk. The result is different, both in meaning and in value, from two related quantities studied by Grünbaum et al. (2013) and Štefaňák et al. (2008). Nevertheless, the results and methods in their current form are usable for any time-discrete quantum system in a Hilbert space spanned by a countable preferred basis.

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