Quantum walk on spin network

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Abstract

We apply a discrete quantum walk from a quantum particle on a discrete quantum spacetime from loop quantum gravity and show that the related entanglement entropy can drive an entropic force. We apply this concept and propose a model of a walker position topologically encoded on a spin network.

Introduction

One of the principal results from Loop Quantum Gravity (LQG) is a discrete spacetime, a network of loops implemented by spin networks [1] which are a digital/computational substrate of reality. So in order to better understand this substrate, it is natural to consider tools from the fields of quantum information and quantum computation. Gravity, from a general perspective, has been studied with thermodynamic methods and in recent years numerous questions on black hole entropy and entanglement entropy have made these intense fields of research. On the side of quantum information and quantum computation there have been large improvements, including the development of many tools and we will herein consider here the framework of the coined Discrete time Quantum Walk (DQW). We will see that the problem of a quantum particle on a fixed spin network background from LQG can be worked out with the DQW. This gives rise to a new understanding of entanglement entropy and entropic force, permitting the proposal of a model for dynamics. From an ontological viewpoint we will see that dynamics and mass emerge from the spin network topology, and that quantum walk implements it. In summary we will reinterpret some results from LQG trying to approach a quantum information perspective of a quantum geometric spacetime.

The start point is the Hamiltonian for a quantum particle on a quantum gravitational field from LQG [2]. In LQG, spin networks define quantum states of the gravitational field. To consider a quantum particle on this gravitational field, we take the state space built from the tensor product of a gravity state and a particle state. The quantum state of the particle contains information from the discrete geometry and cannot be considered independently from it. We consider the Hamiltonian and the classical random walk associated with it, a Markov chain. This random walk reproduces an entropic force [3, 4].

The associated DQW can be obtained by make use of Szegedy's DQW [6, 7]. We use this approach to obtain the discrete quantum walk on the spin network under consideration. We can interpret that the coin space, the space of decisions encapsulating a non-deterministic process and getting memory such that we have a unitary evolution (deterministic), makes the usual Entropy convert into Entanglement Entropy between steps in time.

To calculate entanglement entropy we consider the Schmidt decomposition and we obtain the local entanglement entropy between previous the step and the current step (similar for current and next). Entanglement entropy is maximal when the move is for a node of largest valance. Which gives an entropic force for gravity. Here we have different interpretations and applications. With the DQW we have unitary evolution by encoding the non-deterministic nature of the classical Markov Chain. This gives an internal structure for the particle, and entanglement entropy. In this digital physics substrate, the particle is walking to maximize entanglement entropy related to memory of its walking path and this generates an entropic force.

Another point we address with this framework is entropy of Black Holes. Note that the DQW implies a local entanglement entropy in the sense that the chain/network is always under construction in this pixelated, animated view. This resembles the Isolated quantum Horizons formulation from LQG [8, 9, 10, 11, 12] that lets us understand the origin of black hole entropy in LQG. In this scenario, the Horizon and the area is emergent from the stepwise animated reality at the Planck scale, which we simulate by using the DQW. We can propose that this DQW is the black hole quantum horizon, where the particle mass is the black hole mass in a random quantum walk on a fixed

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spin network. We conjecture that the states of maximal entanglement entropy are dominant to black hole entropy. So we can think of Bekenstein-Hawking entropy as emergent from the local entanglement entropy above.

We finish with a toy model of walker position topologically encoded on spin network. The Clebsh-Gordan condition at each node is implied by covering the graph with loops. The local entropy at each node is color coded. A massless particle moves along the same color and a massive particle moves along constant absolute color differences. The walker position, or the presence of a particle at one node is encoded by a triangle. Its move is a couple of 3-1 and 1-3 Pachner moves on neighbour positions, piloted by the walk probability.

Conclusions

Results from Loop Quantum Gravity suggest the interesting idea that we can apply the results and tools from quantum information and quantum computation to a quantum spacetime. This is a field of research very promising. In this work we start a project to apply this tools like DQW to spacetime. We considered a DQW of a quantum particle on a quantum gravitational field and studied applications of related entanglement entropy. This memory-time related entanglement entropy can drive an entropic force and give a contribution to black hole entropy. With this, we proposed a model for walker position that is topologically encoded on spin network. This results in anomaly cancellation because the particle is no longer a point, but has Planck scale size. We note that more complex models can be built, with more dimensions and 8 quantum numbers in an E8 model [13] and models with realistic emergent masses can be explored by computation.

A better understanding of entanglement entropy on black holes and applications to cosmology are under investigation, as well as relating this model to an E8 based QuasiCrystaline model [14]: the spin network can be chosen as the dual of a quasicrystal and the digital physics rules can be implemented by the quantum walk.

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