Negative Probabilistic Bits in Quantum Theory and Beyond

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We have already entered the era of commercial quantum computing and quantum information processing [1]. Our understanding of quantum Turing machines uses Hilbert space representation of quantum theory. However, one can look at quantum mechanics as quasi-probability processes in phase space [2]. One of the pragmatic reasons to do this is our rather poor understanding of quantum speedup origins, or more colloquially, what makes quantum computer tick. There are also fundamental reasons to explore this alternative picture, some of which I would like to discuss here.

I will show how you can represent quantum mechanics as a positive probability theory with positive stochastic processes, controlled by a negative probabilistic bit (nebit). Nebit produces 0 with probability 1+ x and 1 with probability -x. Avoiding any philosophical interpretations of quasi-probabilities I will discuss basic information properties of nebit and argue that you can see it as a source of non-classical properties of quantum theory, including the origins of quantum speedup in some class of oracle based quantum algorithms [3].

In the last segment of the talk, I will use nebit to discuss a wider class of probabilistic theories not observed in Nature but consistent with some of its fundamental principles such as finite speed of information propagation and locality.

[1] F. Arute et. al., Nature 574, 505 (2019)

[2] R. P. Feynman, Negative Probabilityin Quantum Implication: Essays in Honour of David Bohm, edited by B. Hiley and F. Peat (Routledge, London, 1987) 235-248.

[3] D. Kaszlikowski and P. Kurzynski, Found. Phys. 51 (2021)