Demonstration of Cognitive Bias on a Noisy Intermediate-Scale Quantum Processor

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Abstract. The decision-making process of the individual is analogous to the collapse of a quantum system at the moment of measurement, whereby quantum system we mean the decision-maker, his mental processes and the environmental context that influences him in his choices. Classical probability depends on the lack of information, quantum probability is instead intrinsic to the system to be studied, meaning that the system, consisting of the decision-maker and the context, is in a superposition of states, each with its own amplitude of probability. Only the measurement process (the decision) selects in the decision maker a specific state among those in which he was overlapping. We demonstrated on a Noisy Intermediate –Scale Quantum Processor the model of the "order effect", one of the most important cognitive bias.

1 INTRODUCTION

Classical financial models have been developed with reference to several theories (e.g., Efficient Markets Theory [1] and Expected Utility Theory [2]) based on the assumption that market provides all the information necessary for decision-making processes and that investors, fully informed and therefore able to calculate the probability of all different possible alternatives and the consequent risks, make their decisions in a completely rational manner. Markets, however, frequently exhibit trends not consistent with the presumed rationality of investors, in clear violation of the classical theories. It does not always seem true that an individual rationally chooses the alternative that maximises expected utility, especially regarding situations of ambiguity, in which investors must decide between different alternatives to which it is not possible to associate an objective probabilistic evaluation [3]; well known in this context are the Ellsberg [4] and Allais [5] paradoxes. Many studies have confirmed that the rational choices are not fulfilled in practice because the way individuals think is different; some specific conceptual structures (optimism, pessimism, suspicion, etc.) act as a decision-making context and influence the choices of subjects in situations of ambiguity, driving them away from the rational behaviour predicted by the classical theories [6].
There is therefore a need to define a new mathematical model that can include also cognitive bias that are not captured by rational approaches to behavioural finance based on efficiency and rationality. Quantum formalism allows to model, at a statistical level, behavioural phenomena influenced by subjective contexts due to the specific situation in which the subject must make a choice, including many complex cognitive biases not consistent with classical models, such as the conjunction [7] and disjunction [8] effects. Just as Quantum Physics responds to the need to define a theoretical apparatus capable of explaining physical phenomena observed at the microscopic level that cannot be explained by classical physics (e.g. the black-body radiation, the stability of atoms, the photoelectric effect), the quantum approach to decisional cognitive processes originates from the need to find new theories that can justify the occurrence of important cognitive biases, resulting in numerous and systematic violations of the rational logic underlying classical behavioural processes [9]; "quantum-like" mathematical models allows to make more reliable forecasts regarding the "real" choices made by individuals. One of the most important cognitive bias is: the "ordering effect". In numerous experiments it has been observed that the order in which subjects are presented with decisions to be taken determines how decisions are taken. For example, in case of questions regarding the same context, each of which involves a number of possible alternative answers, the answers given by subjects will change if the same set of questions are asked in a different order. This behaviour has been observed in numerous statistical surveys. Quantum formalism provides a reason and simulates the influence of context on decisional processes. The projection operators do not commute and the answer to a first question in a survey changes the mental state of the interviewee, so he/she will be differently predisposed to give a specific answer to a second question.
We defined a quantum circuit allowing to reproduce the effect of the context (answer to the first question) on the subsequent decision process (answer to the second question), and we implemented the quantum circuit on a NISQ photonic processor.

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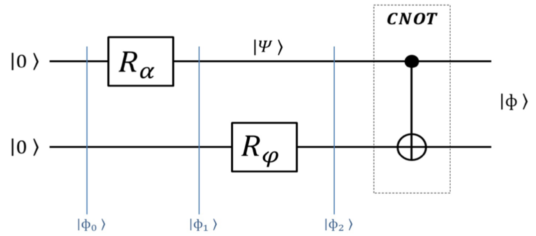

Fig. 1. Quantum circuit simulating the influence of context (operator $R\alpha$) on decision making process (operator $R\varphi$)

2 EXPERIMENTAL IMPLEMENTATION ON A NISQ PHOTONIC PROCESSOR

There are several architectures on which a quantum computer can be built, each of which is based on a different physical system: ion or atomic traps, magnetic resonance, Jopheson junctions, quantum dots, nuclear spin or photonic circuits. An interesting perspective is related to quantum computation that uses l**inear photonic circuits**: it has the advantage that the smallest unit of quantum information, the qubit, is potentially free from decoherence, i.e. the information stored in a photon tends to remain unchanged. Light-based "on chip systems" deliver on the promise of scalability for quantum information applications through high-density component integration and parallelization. **The novel on chip photonic device [10]**, reduce the overhead due to multiple single photon sources with very high degree of reciprocal coherence and exploits the possibility to encode the whole state space in a complex optical circuit based on **MultiRail (MR) Architecture**: a particular state in input is encoded in the quantum superposition of a coherent light beam trough the different waveguides, so that it is possible to design quantum gate that show deterministic and not probabilistic behavior, as quantum entanglers, Bell measurements and teleportation schemes. Multirail Architecture provides a novel class of NISQ processors. that -although far from fault tolerant- support the execution of heuristic quantum algorithms, with a quantum advantage when applied to combinatorial optimization problems. In this case we implemented the circuital model shown in Fig.1 where the first qubit (at the top of the circuit) represents the context, i.e. the answer to the first question of a survay; and the second qubit represents the decision process, i.e. the answer to the second question of a survay. The results (see Fig.2) are in good agreement with the theory. More in general, within the Quantum Cognition the examined circuit can be used in order to simulate every scenario in which a decision B can be influenced from a context A (a previous decision, the result of a test, some meaningful information for the decision B).

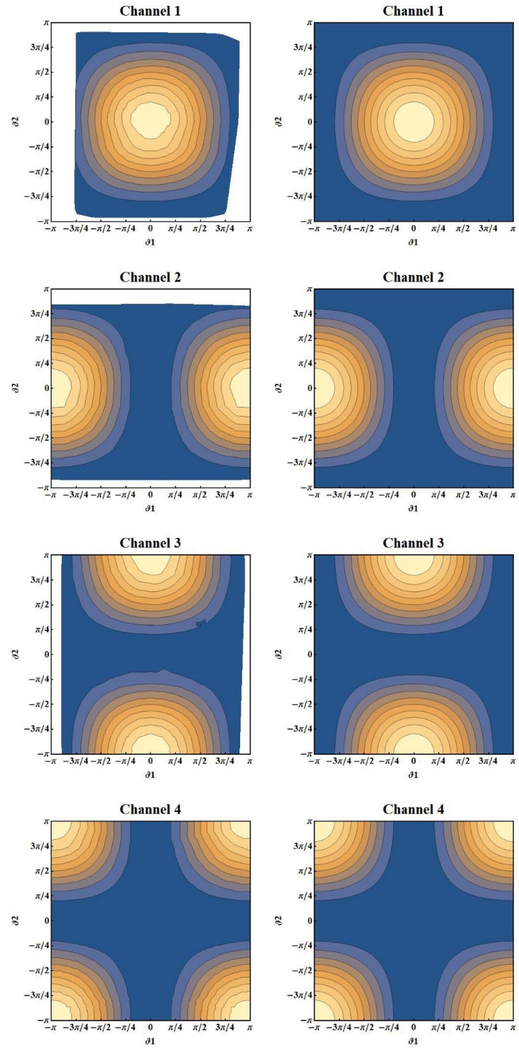

Fig. 2. Experimental Demonstration of Cognitive Bias (Left: Experimental results. Right: Theory)

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