Resource Theories of Quantum Processes

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Abstract. Environment induced noise is an ever-present challenge in the development of quantum technologies: almost every quantum computer must be treated as an open system, and every quantum thermal machine must interact with some form of thermal bath. However, not all noisy environments are equal — some effectively destroy information, while others only hide it. The latter class of environments are of key interest. We focus on the property of certain types of environments which have some ability to 'remember' the system's past — a widely present [1] phenomenon known as non-Markovianity. It has been suggested that non-Markovianity can be exploited to enhance performance in tasks such as quantum control [2] and work extraction [3]. Our contribution is to quantify this type of advantage by providing a consistent and generally applicable resource theory [4] framework for comparing the relative utility of processes induced by different environments.
To demonstrate the power of our newly developed framework for resource theories of multi-time quantum processes [5], we analyse a class of experimental scenarios with varying levels of control. In almost all of the corresponding resource theories, some form of temporally complex phenomena was found to be useful, including one where non-Markovianity is the precise quantity that aids the experimenter in achieving their goals. These resource theories also are applicable to a plethora of other physical scenarios; examples may include error mitigation for correlated noise, thermal machines with structured baths, or enhancing quantum communication between parties.

Resource Theories of Multi-Time Processes. Resources are uncontrolled background processes, represented by process tensors [6], while the transformations that induce the resource theoretic structure of convertibility are given by superprocesses [5]. The set of superprocesses corresponds to all possible experimental control in a given operational framework, but superprocesses are expressed as transformations between process rather than as transformations directly on the system itself. An uncontrolled background process is deemed useful if it can carry information about the system through time which the agent would be unable to on their own — this is measured via our resource monotones on process tensors.

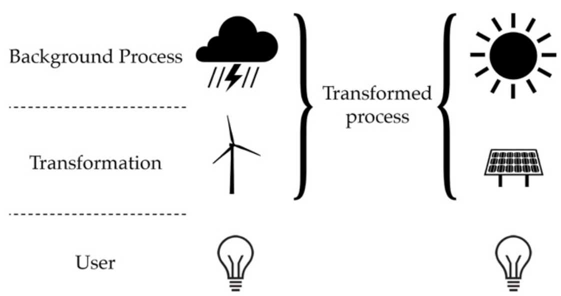

Figure 1 A restricted agent seeks to harness an uncontrolled background process (weather). They achieve this via a transformation of that process (converting energy into electricity) such that the resultant object can be utilised to perform a useful task (switching on a light-bulb). The ability to perform a task depends both on the background process (stormy or sunny weather) and the tools available to harness it (wind turbine or solar panel).

Keywords: Non-Markovianity, Resource Theories, Quantum Dynamics, Quantum Information

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