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Toward a conceptual foundation of Quantum Information Processing

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Quantum Information Science has brought to light an enormous amount of new protocols showing that the structure of quantum theory dramatically impacts the way in which information can be processed. It also made clear that the rules of information processing are dictated by physics and that different physical theories entail different models of information processing. Quantum Information poses an exciting challenge to foundational research: the challenge is to reduce the multiplicity of quantum protocols to a small number of basic physical principles and to answer questions like "What are the physical roots of the power of quantum information?" A satisfactory answer to these questions calls for the solution of a long-standing problem: deriving quantum theory from physical principles, as opposed to the abstract mathematical principles of the Hilbert space formulation. In this talk I will show that quantum theory can be derived from few principles about information processing. The central principle of the derivation will be the purification principle, stating that ignorance about a part (subsystem) is always compatible with maximal knowledge of the whole (compound system). A large number of quantum information features, including e.g. teleportation and no-cloning, are direct consequences of the purification principle, which appears a strong candidate for the conceptual foundation of Quantum Information Processing. Moreover, the derivation of quantum theory from purely informational principles provides a rigorous justification of the diffuse claim that quantum theory is ultimately a theory of information.