Project Summary

Overview. This is a *theoretical* investigation of *experimental* physics using *computational methods*. All experiments and computations are processes bounded in space, time, and other resources. Yet, for centuries, the mathematical formalization of such processes has been founded on the infinitely precise real or complex numbers. Indeed, almost every description of quantum mechanics, quantum computation, or quantum experiments refers to entities such as e, π, $\sqrt{2}$, etc. From a computational perspective, such numbers do not exist in their entirety "for free." One must expand increasingly large resources to represent such numbers more and more accurately.

We propose to revisit quantum mechanics, quantum information, and quantum computation from this resource-aware perspective that is at the core computer science. Instead of starting with infinitely-specified but not directly observable quantum states, we focus on observable measurable properties of quantum systems and their probabilities. Furthermore, we insist that our theories of measurement and probability only refer to finitely communicable evidence within feasible computational bounds. It follows that states, observations, and probabilities all become "fuzzy", i.e., specified by intervals of confidence that can only increase in precision if the available resources increase proportionally.

Proposed Activities. We propose to develop a complete computational model of quantum mechanics from a computational perspective with the salient property that every entity of interest must be finite and efficiently computable with feasible resources. This point of view entails somewhat radical, but well-justified, choices: quantum states disappear as a separate reality and are replaced by interactive systems (not unlike a web server for a crude but useful analogy). The observable properties of such an interactive system are local to each independent observer (client) and totally depend on the amount of resources available to the observer and past interactions with that particular observer. We anticipate any positive results to strongly influence the design of potential quantum computers and negative results to guide this search towards fruitful approaches.

Intellectual Merit. Despite over one hundred years of history, the *how* of quantum mechanics remains a mystery. We argue that the revolution in quantum computing will only happen when we *understand* the inner working of quantum mechanics. How exactly is quantum information processed by Nature? Our proposal directly attacks this questions and aims at providing positive or negative answers to various algorithmic approaches for quantum information processing, and resolving many intellectual paradoxes along the way. The key foundation we aim to completely solve is to revise the entire framework to be based on finite communicable pieces of information.

Broader Impact. This project will have broader impacts with respect to technology transfer, education, and outreach. Quantum properties are keys to the future of computing and communication with several governments and major industrial companies heavily invested in harnessing them. It is also a source of constant intrigue attracting the interest of students and professionals at large.

Key Words: probability; Bayes; measurement; algebra; finite fields; algorithmic complexity; models of computation; interpretations of quantum mechanics.