SAND2022-7991D

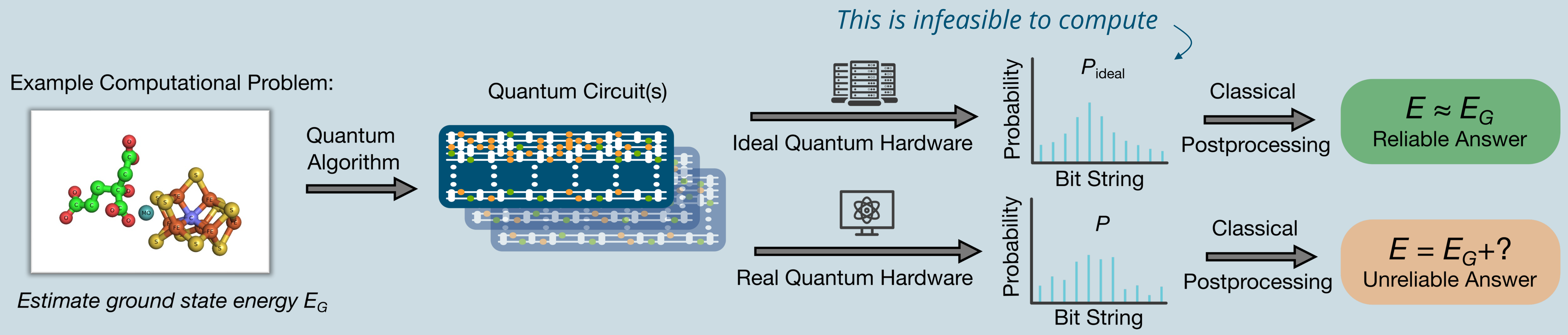
Sandia National Laboratories

Learning the Capabilities of Quantum Computers

Timothy Proctor, Daniel Hothem, Jordan Hines*, Stefan Seritan, Mohan Sarovar, Tommie Catanach, Kevin Young

Motivation: Quantum computing hardware is imperfect

- Quantum computers have applications across DOE's and SNL's mission space (e.g., materials science, energy). *But only if they can reliably run quantum algorithms!*
- The problem is that quantum computing hardware is imperfect. When they run a quantum computation *errors* sometimes occur, and this can cause them to return the wrong answer…

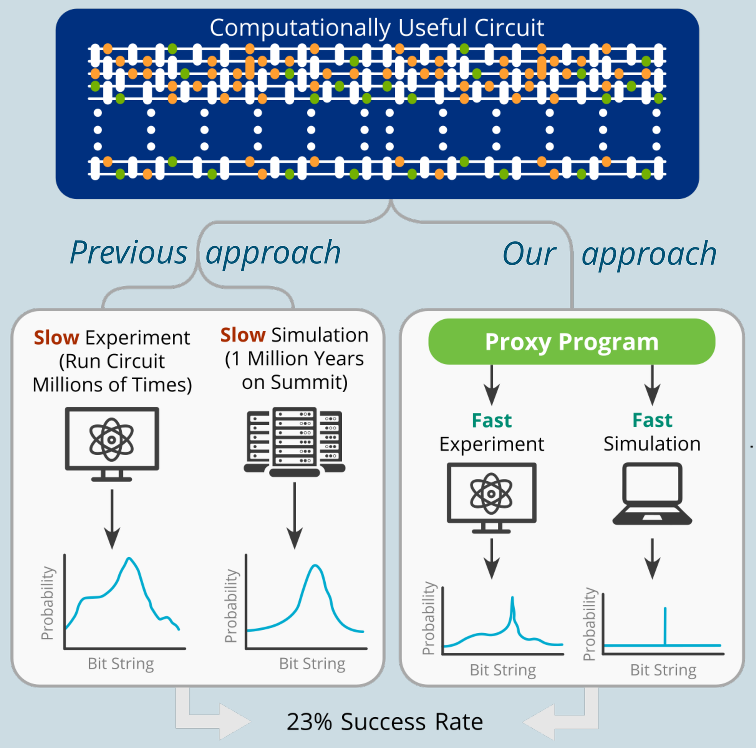


- …and it is difficult to tell if a quantum computation's result is correct! We can't simply compare to an error-free simulation on a classical computer – that's too expensive.
- It is *even harder* to predict, in advance, which quantum computations a particular quantum computer can and can't run!

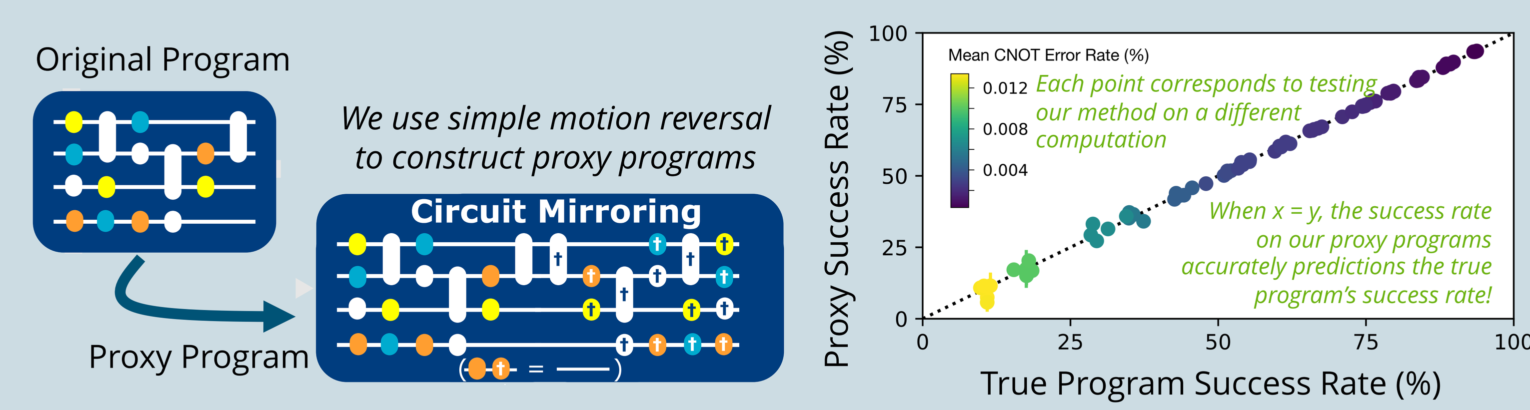
Designing efficient tests for quantum computers

- We're designing the first "proxy program" methods that enable efficiently measuring a quantum computer success rate on a quantum program.[1-4]
- We developed the first technique for turning a quantum program into a "proxy" that is similar but whose output is easily classified as "correct" or "incorrect".[1]
- We're developing foundational theory and methods, and implementing them in code.

***Proxy Programs**: We've introduced the idea of using proxy quantum programs to indirectly measure a quantum program's success rate, circumventing the exponential scaling problem of the "try it and see" approach (left hand side).*

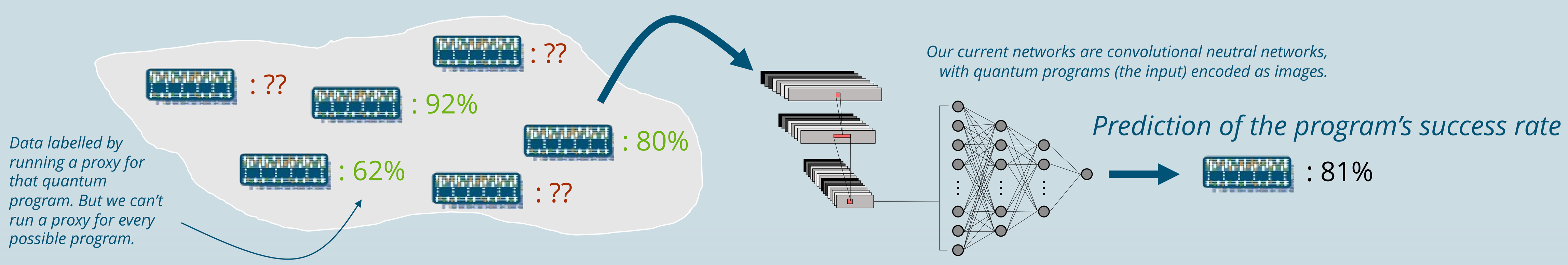


***Demonstration of first proxy program method.** We've demonstrated the power and accuracy of our "mirror circuit" method, using simulated data from a 100-qubit algorithm.*



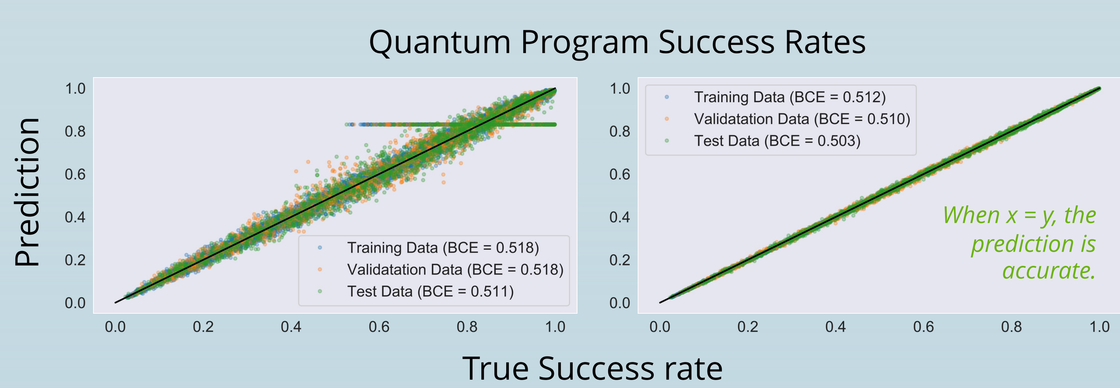
Learning a quantum computer's capability

- We're designing neural networks methods to predict the success rate of any quantum program, on a particular quantum computer, from a small labelled data set.[5]



- Our initial methods vastly outperform existing techniques in some important circumstances, while avoiding exponential scaling problems that plague other methods.

***Previous methods** using traditional statistics often cannot model the complexities of errors in quantum computers*

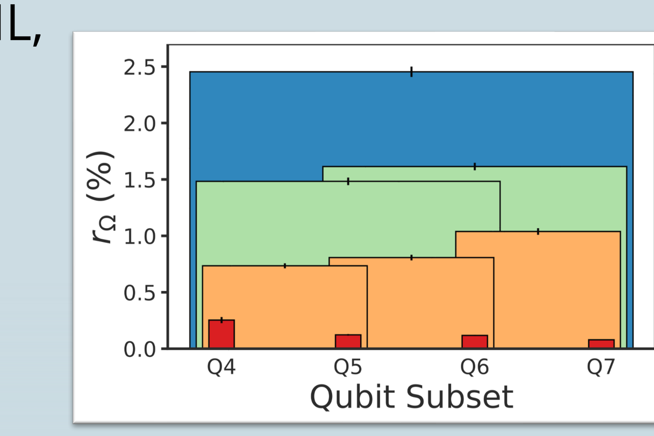


***Our initial methods** use convolutional neural networks to learn a surrogate model for a quantum computer's capability.*

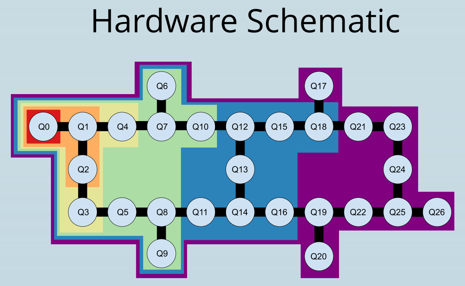
- This is a first step towards surrogate models for a quantum computer's capability.

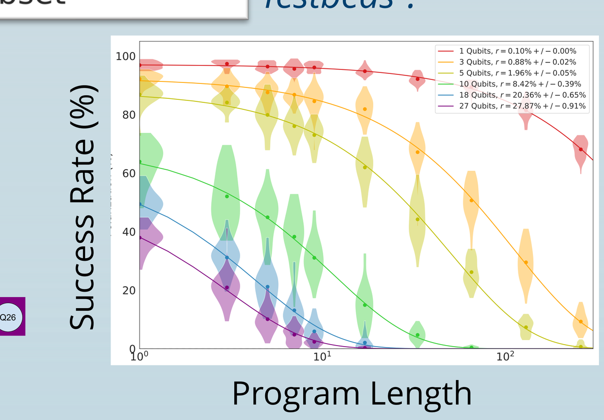
Impacts: Understanding cutting-edge hardware

- Our code is in `pyGSTi`, which is Sandia's open-source software for quantum computer testing used by leading quantum computing groups around the world (e.g., DOE's testbeds).[9,10]
- We're collaborating with other national labs (ORNL, LBL) to deploy our methods.[4,6]
- Our methods are being used by industry (e.g., Quantum Economic Development Consortium, Honeywell).[7,8]
- We're publishing in high-impact journals.[1-3]
- We're part of a large effort, at Sandia's Quantum Performance Laboratory (QPL)[8], to study errors in quantum computing hardware.
- Our techniques are a first step towards studying hardware that cannot be simulated classically.
- Project has led to a 2022 DOE Early Career Award.



***Deploying our techniques to test LBNL's quantum computer.** We've used our methods to comprehensively test the DOE's 4-qubit "Advanced Quantum Testbeds".[4]*





***Using our methods to implement the first scalable testing of "universal" gates.** We've implemented the first ever robust, randomized tests of universal gate sets on 20+ qubits.[4]*

Primarily supported by an LDRD (3 years, 09/2020 – 09/2023, ~$470K / year). Additional support from DOE/SC/ASCR projects.
For references 1-10, see the project information sheet.
*Graduate student at UC Berkeley, funded by Sandia LDRD.

QUANTUM SYSTEMS ACCELERATOR
Catalyzing the Quantum Ecosystem

BERKELEY LAB

Berkeley
UNIVERSITY OF CALIFORNIA

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology &Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.
SAND No. ___________

LDRD LABORATORY DIRECTED RESEARCH & DEVELOPMENT
WHERE INNOVATION BEGINS

Quantum Performance Laboratory

Sandia National Laboratories