Noise-Resilient Quantum Computing with Python

Nate Stemen
Unitary Foundation

~~Spicy~~ 2025
SciPy

Tacoma, WA

WHO AM I

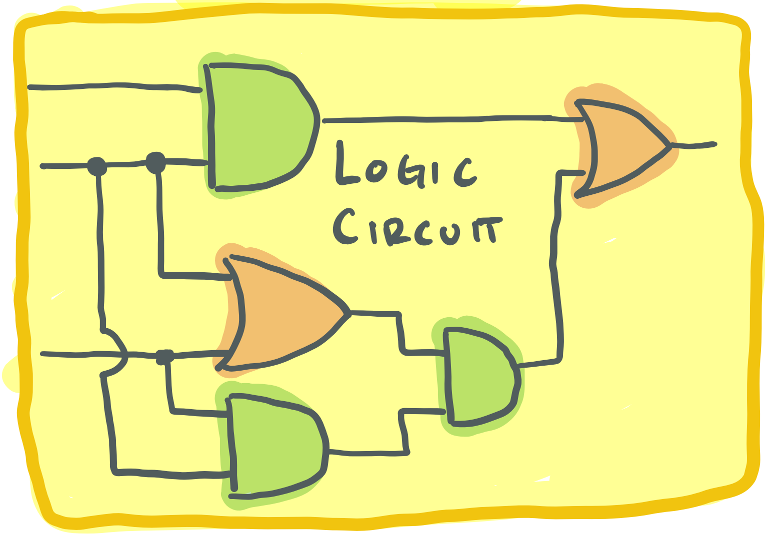
- M MATH
- EX-OVERLEAF DEV
- RESEARCH ENGINEER
- OPEN-SOURCE FAN
- OPEN-SCIENCE FAN
- NEW TO SciPy!

OUTLINE

1. INTRODUCTION TO QUANTUM
2. WHY **NOISE** IS A BIG PROBLEM
3. PYTHON'S ROLE IN FIGHTING THE **NOISE**
4. PYTHON'S FUTURE IN QUANTUM COMPUTING

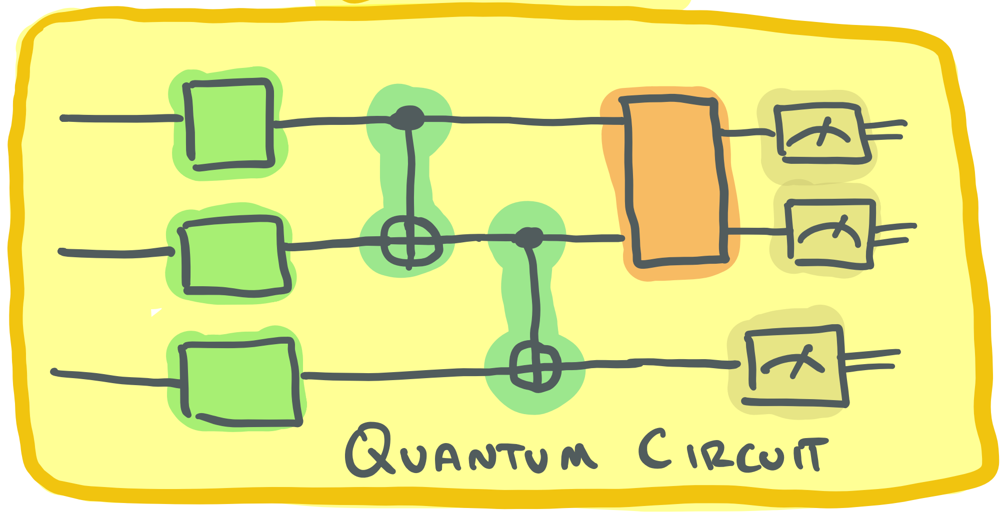
WHAT IS QUANTUM?

CLASSICAL



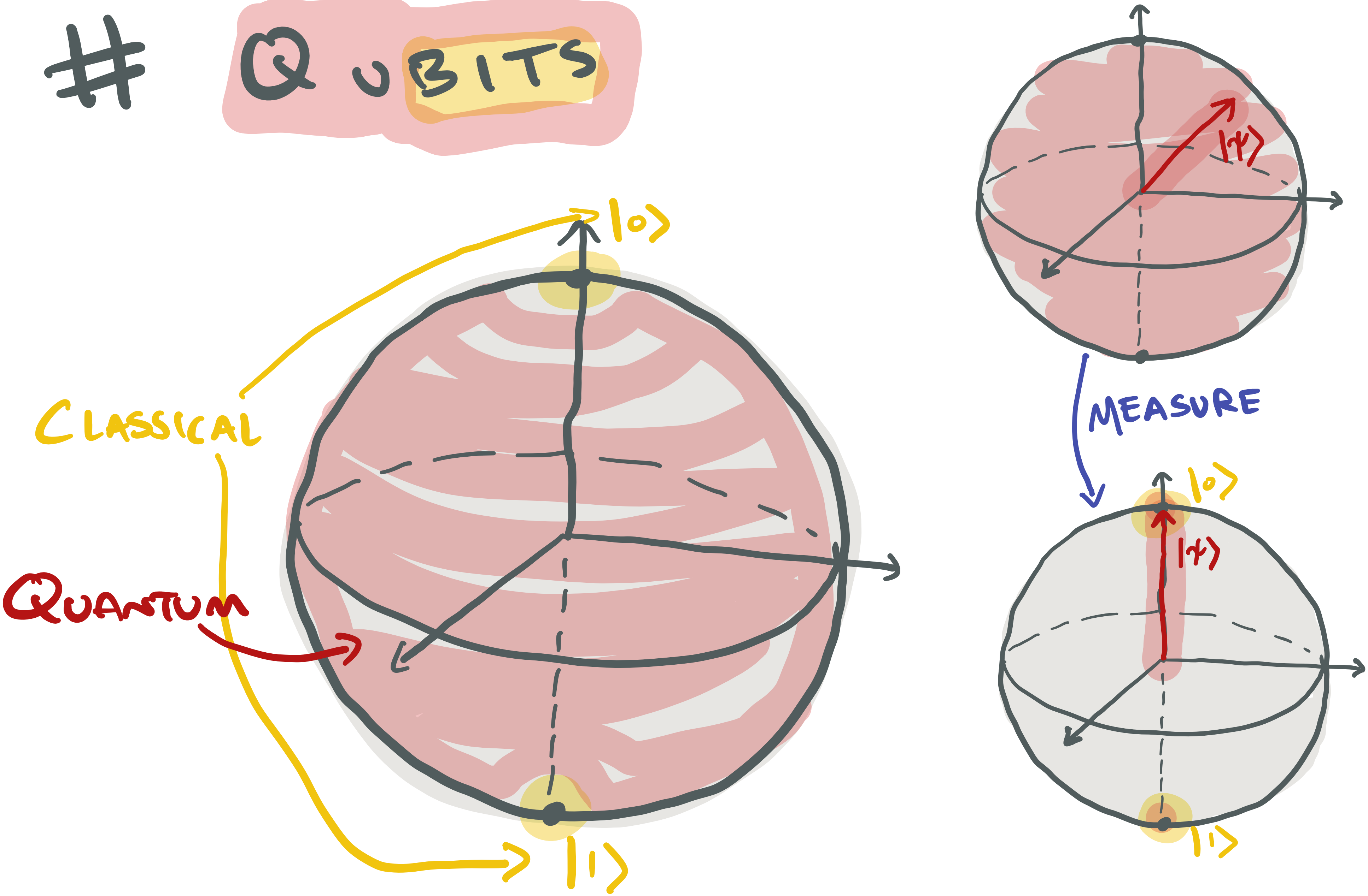
- AND, OR, XOR, ETC
- NOT REVERSIBLE

QUANTUM



- UNITARY OPERATIONS
- REVERSIBLE
- DESTRUCTIVE MEASUREMENTS

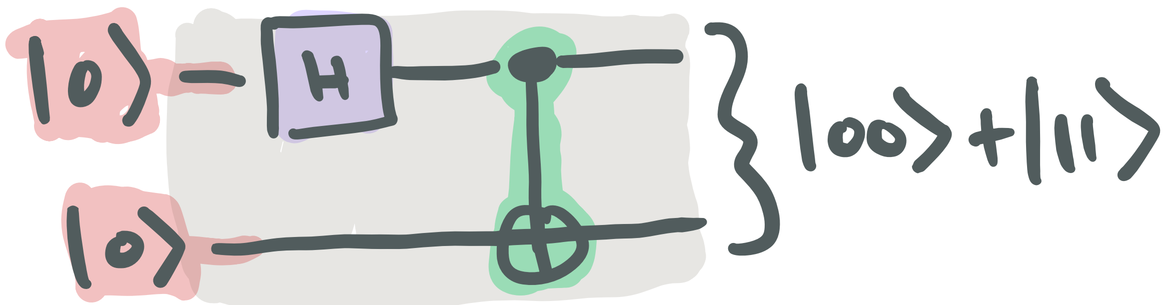
Qubits



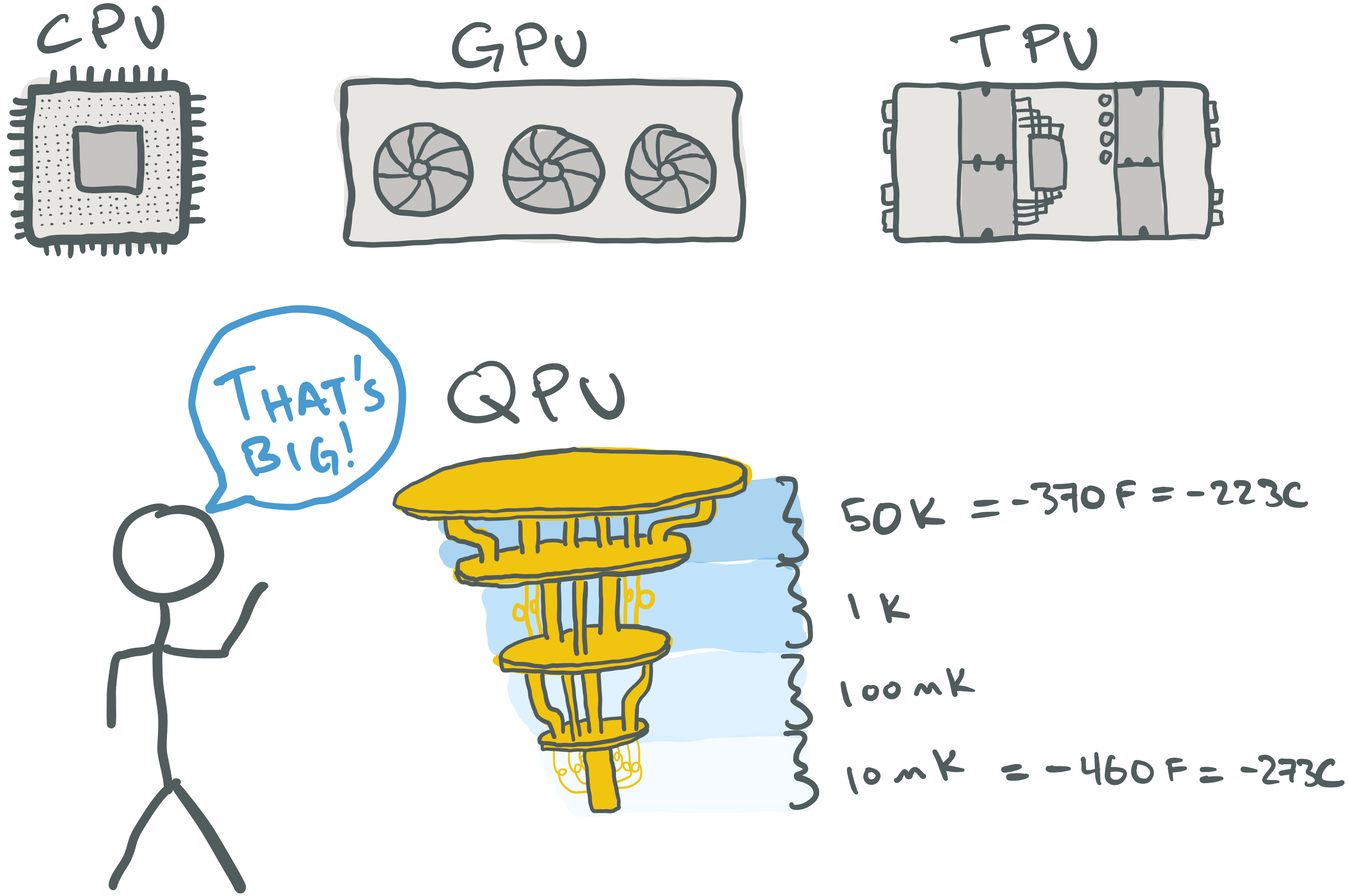
Quantum Programming

```python
import cirq

qreg = cirq.LineQubit.range(2)
circ = cirq.Circuit(
    cirq.ops.H.on(qreg[0]),
    cirq.ops.CNOT.on(qreg[0], qreg[1]),
)
```

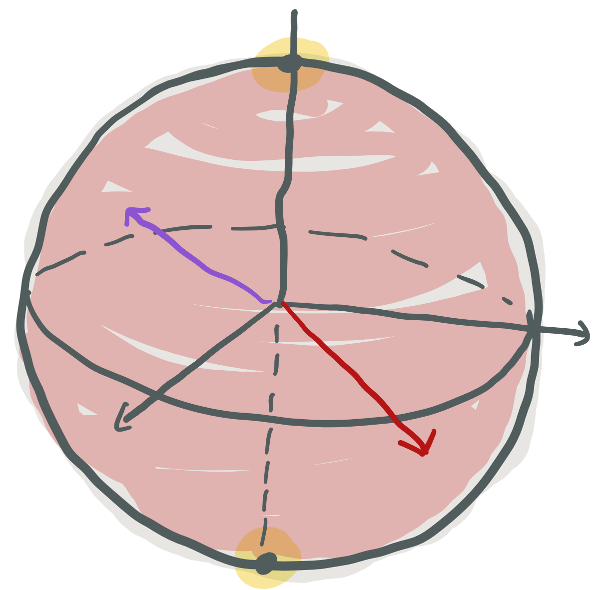


Quantum as an Accelerator

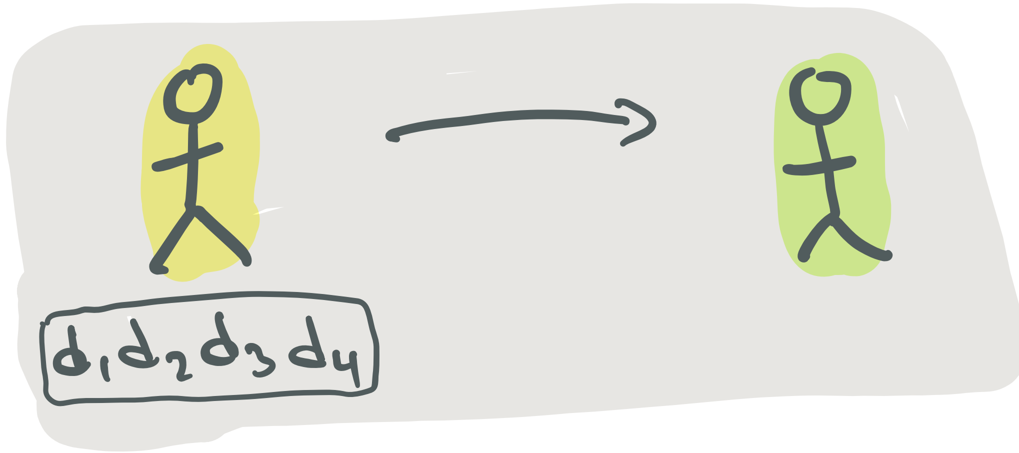


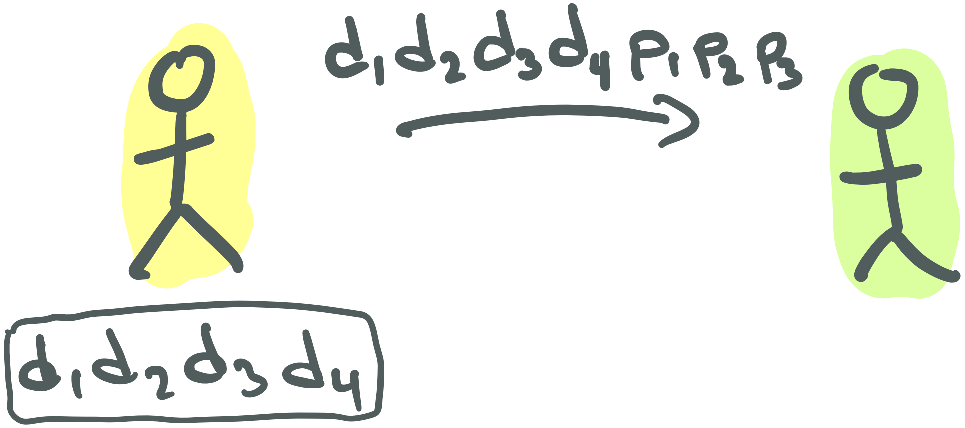
Take Aways

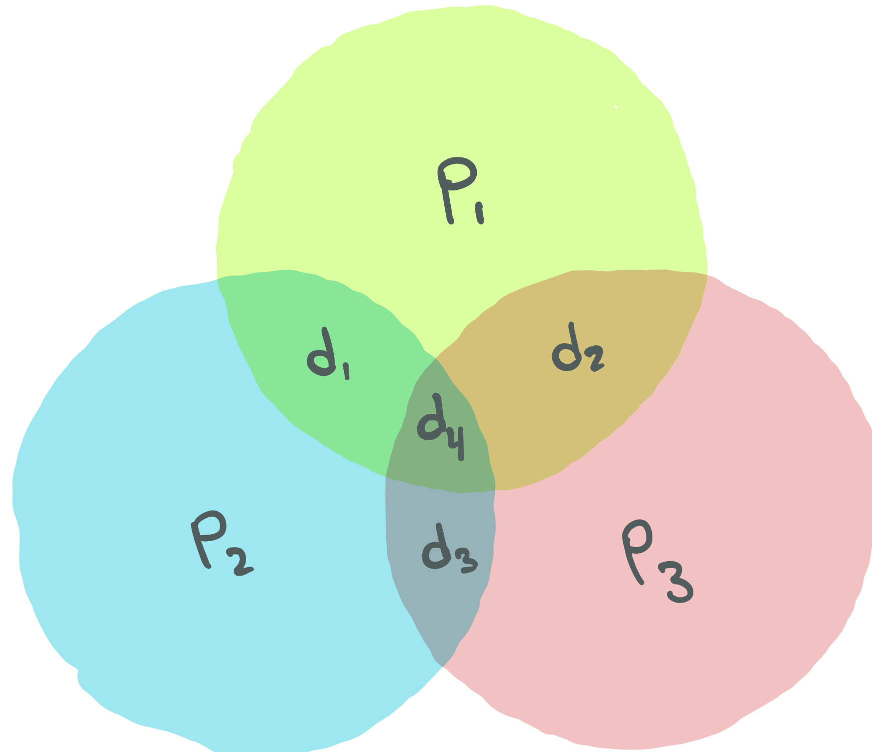
- **VERY** Early Days of Quantum
- Quantum Noise isn't just bitflips
- Quantum Power is also its fragility



NOISE





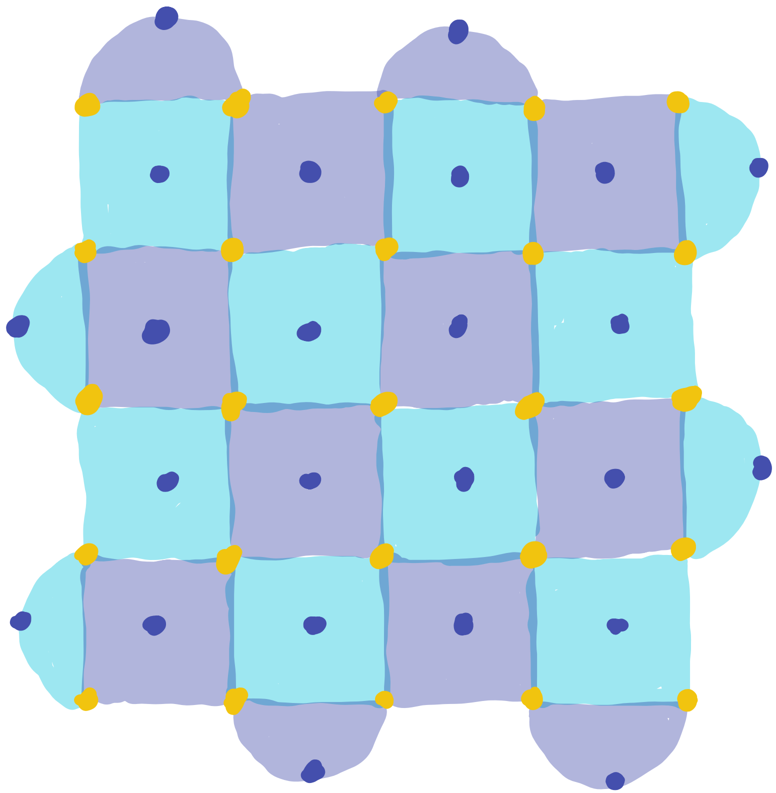


$p_1 = d_1 + d_2 + d_4 \mod 2$

$p_2 = \dots$

$p_3 = \dots$

QUANTUM ERROR CORRECTION



1 LOGICAL QUBIT

49 PHYSICAL QUBITS

2 CORRECTABLE ERRORS

CURRENT DEVICES HAVE 100-1000 QUBITS

NEED TECHNIQUES THAT DON'T REQUIRE MORE QUBITS

Quantum Error ~~Correction~~ Mitigation

Error mitigation for short-depth quantum circuits

Kristan Temme, Sergey Bravyi and Jay M. Gambetta
IBM T.J. Watson Research Center, Yorktown Heights NY 10598
(Dated: November 7, 2017)

Two schemes are presented that mitigate the effect of errors and decoherence in short-depth quant… The size of the circuits for which these techniques can be applied is limited by the rate at which … the computation are introduced. Near-term applications of early quantum devices, such as quantum … rely on accurate estimates of expectation values to become relevant. Decoherence and gate errors le… estimates of the expectation values of observables used to evaluate the noisy circuit. The two … discuss are deliberately simple and don't require additional qubit resources, so to be as practically … current experiments as possible. The first method, extrapolation to the zero noise limit, subseque… powers of the noise perturbations by an application of Richardson's deferred approach to the limit. … method cancels errors by resampling randomized circuits according to a quasi-probability distributi…

Error-Mitigated Digital Quantum Simulation

Sam McArdle,[*] Xiao Yuan,[†] and Simon Benjamin[‡]
Department of Materials, University of Oxford, Parks Road, Oxford OX1 3PH, United Kingdom
(Received 8 August 2018; published 8 May 2019)

Variational algorithms may enable classically intractable simulations on near-future quantum computers. However, their potential is limited by hardware errors. It is therefore crucial to develop efficient ways to mitigate these errors. Here, we propose a stabilizerlike method which enables the detection of up to …

Error-Mitigated Quantum Simulation of Interacting Fermions with Trapped Ions

Wentao Chen,[1,*] Shuaining Zhang,[2,1,3,†] Jialiang Zhang,[1] Xiaolu Su,[1] Yao Lu,[4,1] … Mu Qiao,[1] Ying Li,[6,‡] Jing-Ning Zhang,[3,§] and Kihwan Kim[1,3,7,8,¶]
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…epartment of Physics, Renmin University, Beijing 100872, China
…g Academy of Quantum Information Sciences, Beijing 100193, China
…enzhen Institute for Quantum Science and Engineering, Southern …University of Science and Technology, Shenzhen 518055, China
…ratory of Fundamental Physical Quantities Measurement, Hubei Key Laboratory …nd Quantum Physics, PGMF, Institute for Quantum Science and Engineering, …sics, Huazhong University of Science and Technology, Wuhan 430074, China
…School of China Academy of Engineering Physics, Beijing 100193, China
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…ier Science Center for Quantum Information, Beijing 100084, China

…red to increase the accuracy of the quantum …nputation, where quantum error correction … Among various error-mitigation schemes, …sed as a general and systematic protocol …and quantum algorithms. However, PEC …conducting multi-qubit system by learning …g up to four trapped-ion qubits. For the …rmions with or without spins by applying …ng the error model and incorporating other …mmetry constraints, we are able to increase …nics of the Fermi-Hubbard model, including …ur demonstrations can be an essential step …s toward practical quantum advantages.

Virtual Distillation for Quantum Error Mitigation

William J. Huggins,[1,2,*] Sam McArdle,[1,3] Thomas E. O'Brien,[1,4] Joonho Lee,[5] Nichol… C. Rubin,[1] Sergio Boixo,[1] K. Birgitta Whaley,[2] Ryan Babbush,[1] and Jarrod R. McClea…
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[2]Berkeley Quantum Information and Computation Center, Challenge Institute for Quantum Computation… University of California, Berkeley, C…
[3]Department of Materials, University of Oxford, Parks…
[4]Instituut-Lorentz, Universiteit Leiden, 230…
[5]Department of Chemistry, Columbia Uni…
(Dated: August 3, …

Contemporary quantum computers have relatively hi… them to perform useful calculations, even with a large n… is expected to eventually enable fault-tolerant quantum … it will be necessary to use alternative strategies to mit… near-term friendly strategy to mitigate errors by entan… state ρ. This enables us to estimate expectation values…

Independent State and Measurement Characterization for Quantum Computers

Junan Lin,[1] Joel J. Wallman,[2,3] Ian Hincks,[3] and Raymond Laflamme[1,4]
[1]Institute for Quantum Computing and Department of Physics and Astronomy, University of Waterloo, Waterloo, Ontario, Canada, N2L 3G1
[2]Institute for Quantum Computing and Department of Applied Mathematics, University of Waterloo, Waterloo, Ontario, Canada, N2L 3G1
[3]Quantum Benchmark Inc., Kitchener, Ontario, Canada, N2H 4C3
…terloo, Ontario, Canada, N2L 2Y5

Practical Quantum Error Mitigation for Near-Future Applications

Suguru Endo,[1] Simon C. Benjamin,[1] and Ying Li[2,1]
[1]Department of Materials, University of Oxford, Oxford OX1 3PH
[2]Graduate School of China Academy of Engineering Physics, Beijing 100193, China

It is vital to minimise the impact of errors for near-future quantum devices that will lack the resources for full fault tolerance. Two quantum error mitigation (QEM) techniques have been introduced recently, namely error extrapolation [1, 2] and quasi-probability decomposition [2]. To enable practical implementation of these ideas, here we account for the inevitable imperfections in the experimentalist's knowledge of the error model itself. We describe a protocol for systematically … efficient QEM circuits. We find that the effect of …ated by inserting or replacing some gates with certain … Finally, having introduced an exponential variant of …M techniques using exact numerical simulation of up … circuit. Our optimised methods dramatically reduce …he qubit count or time requirements.

Hybrid Quantum-Classical Hierarchy for Mitigation of Decoherence and Determination of Excited States

Jarrod R. McClean,[1,*] Mollie E. Schwartz,[2] Jonathan Carter,[1] and Wibe A. de Jong[1]
[1]Computational Research Division, Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA
[2]Quantum Nanoelectronics Laboratory, Department of Physics, University of California, Berkeley, Berkeley, CA 94720, USA

Using quantum devices supported by classical computational resources is a promising approach to quantum-enabled computation. One example of such a hybrid quantum-classical approach is the variational quantum eigensolver (VQE) built to utilize quantum resources for the solution of eigenvalue problems and optimizations with minimal coherence time requirements by leveraging classical computational resources. These algorithms have been placed among the candidates for first to achieve supremacy over classical computation. Here, we provide evidence for the conjecture that variational approaches can automatically suppress even non-systematic decoherence errors by introducing an exactly solvable channel model of variational state preparation. Moreover, we show how variational quantum-classical approaches fit in a more general hierarchy of measurement and … increasingly accurate solutions with additional clas… …n a sample electronic system that this method both …ed electronic states as well as reduces the impact of …tum coherence time or formal error correction codes.

Error mitigation with Clifford quantum-circuit data

Piotr Czarnik, Andrew Arrasmith, Patrick J. Coles, and Lukasz Cincio
Theoretical Division, Los Alamos National Laboratory, Los Alamos, NM 87545, USA.

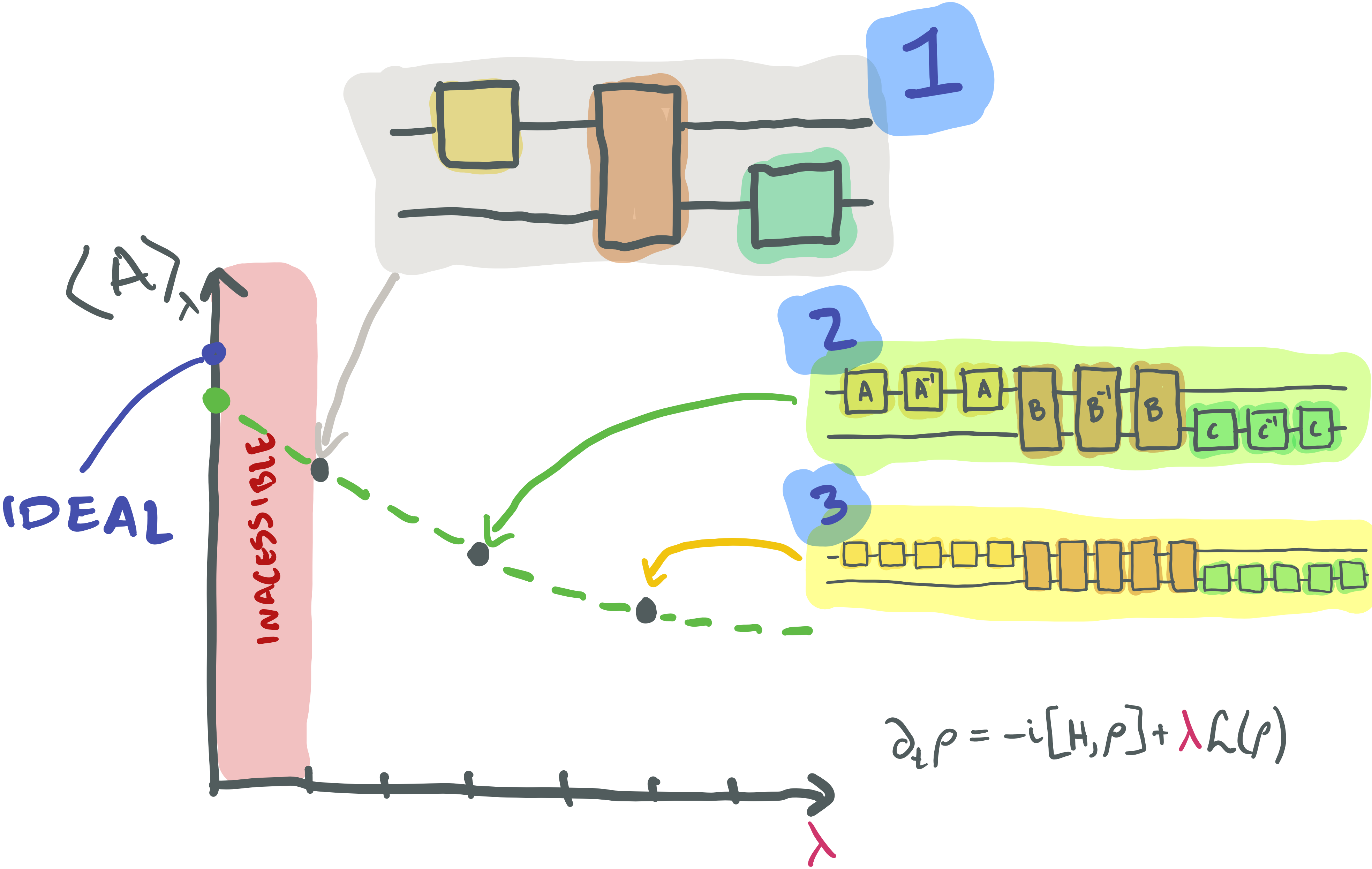
Achieving near-term quantum advantage will require accurate estimation of quantum observables despite significant hardware noise. For this purpose, we propose a novel, scalable error-mitigation method that applies to gate-based quantum computers. The method generates training data $\{X_i^{\text{noisy}}, X_i^{\text{exact}}\}$ via quantum circuits composed largely of Clifford gates, which can be efficiently simulated classically, where X_i^{noisy} and X_i^{exact} are noisy and noiseless observables respectively. Fitting a linear ansatz to this data then allows for the prediction of noise-free observables for arbitrary circuits. We analyze the performance of our method versus the number of qubits, circuit depth, and number of non-Clifford gates. We obtain an order-of-magnitude error reduction for a ground-state energy problem on 16 qubits in an IBMQ quantum computer and on a 64-qubit noisy simulator.

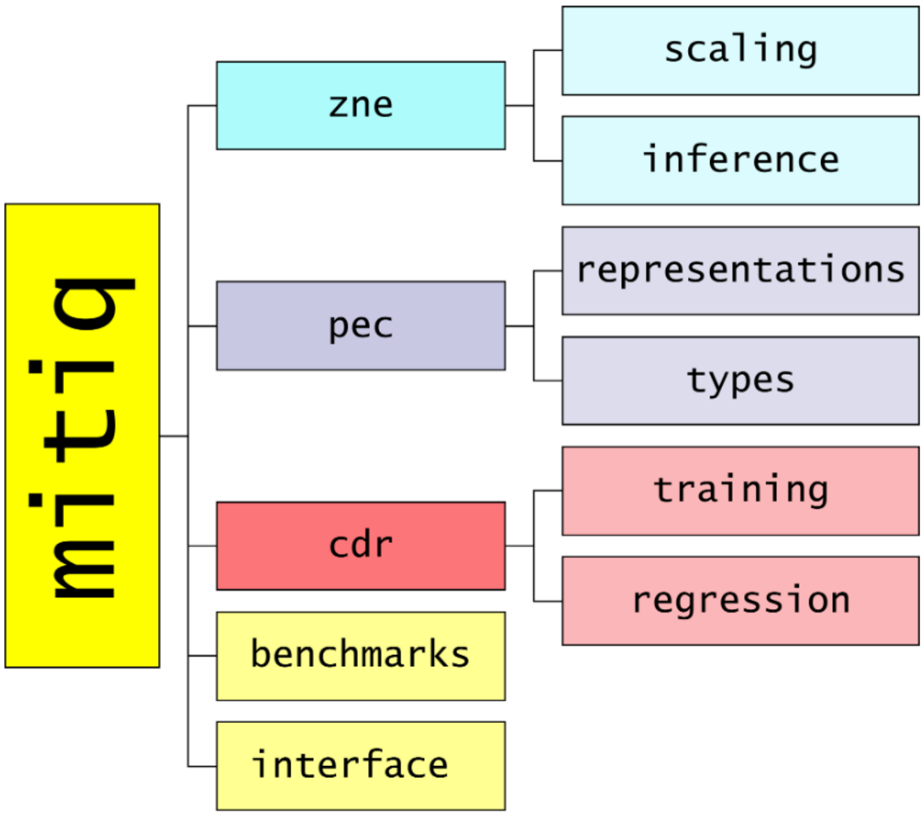
Scalable mitigation of measurement errors on quantum computers

Paul D. Nation,[*] Hwajung Kang, Neereja Sundaresan, and Jay M. Gambetta
IBM Quantum, Yorktown Heights, NY 10598 USA
(Dated: August 31, 2021)

We present a method for mitigating measurement errors on quantum computing platforms that does not form the full assignment matrix, or its inverse, and works in a subspace defined by the noisy input bit-strings. This method accommodates both uncorrelated and correlated errors, and allows for computing accurate error bounds. Additionally, we detail a matrix-free preconditioned iterative solution method that converges in $\mathcal{O}(1)$ steps that is performant and uses orders of magnitude less memory than direct factorization. We demonstrate the validity of our method, and mitigate errors in a few seconds on numbers of qubits that would otherwise be intractable.

Zero-Noise Extrapolation





Why Python?

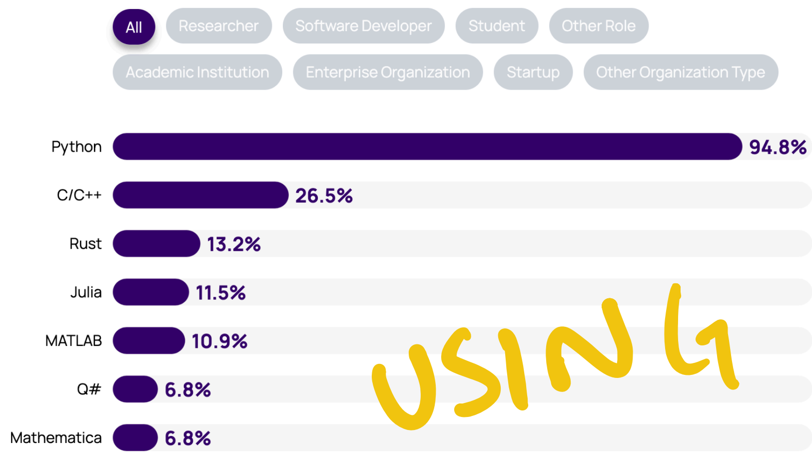
- Rich scientific stack
- Most popular quantum SDKs in Python
- Quick to implement
- Encourage contribution

But Quantum is Changing

31) Programming languages the respondents use in developing quantum software

+ *show full text*

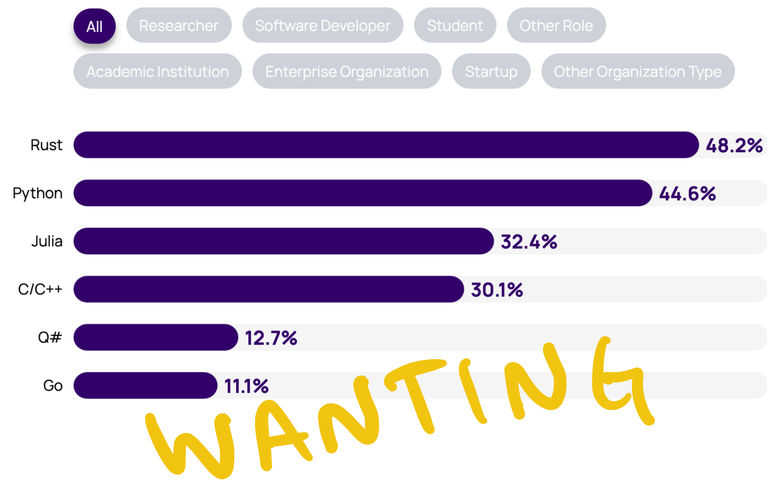
Total answers: 615



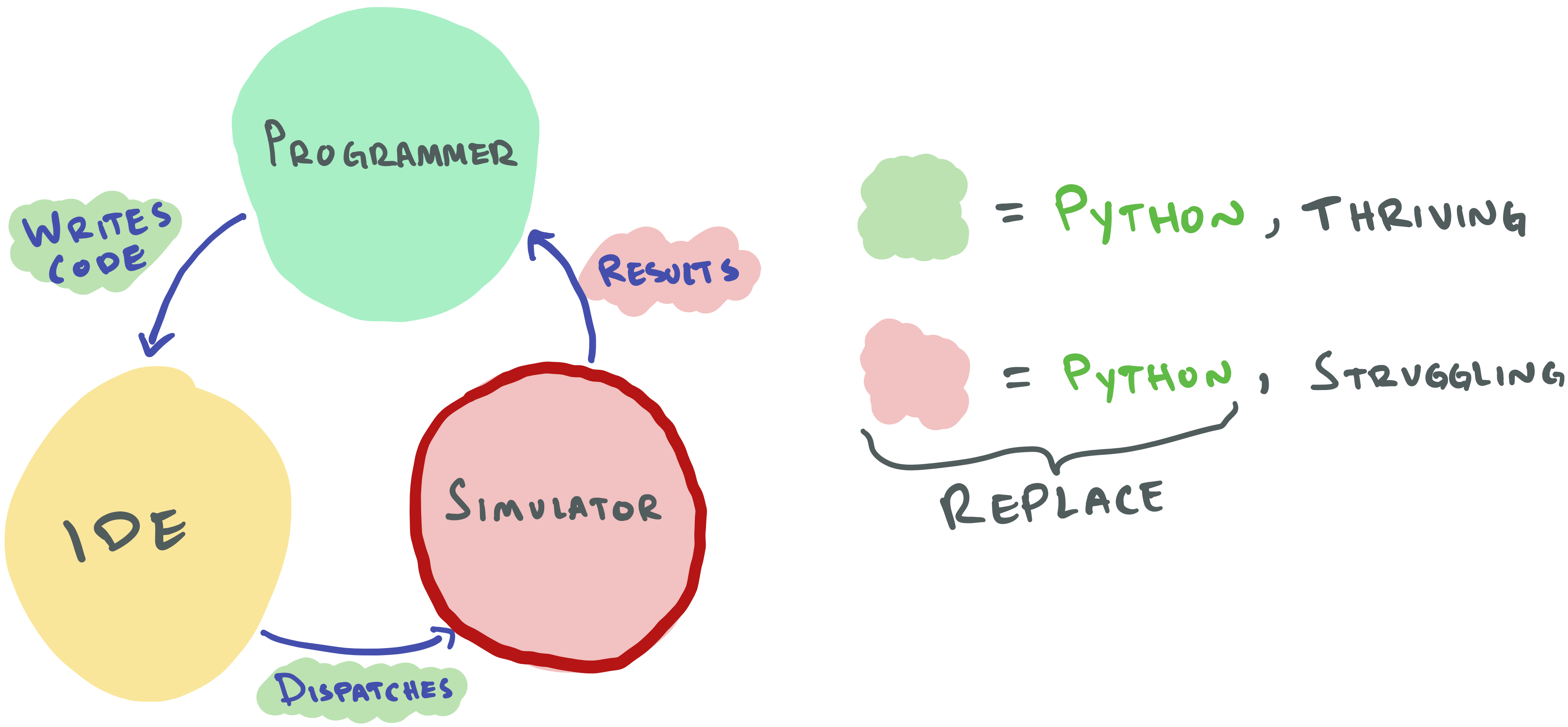
32) Programming languages the respondents would like to learn, or consider to be the most promising for future use

+ *show full text*

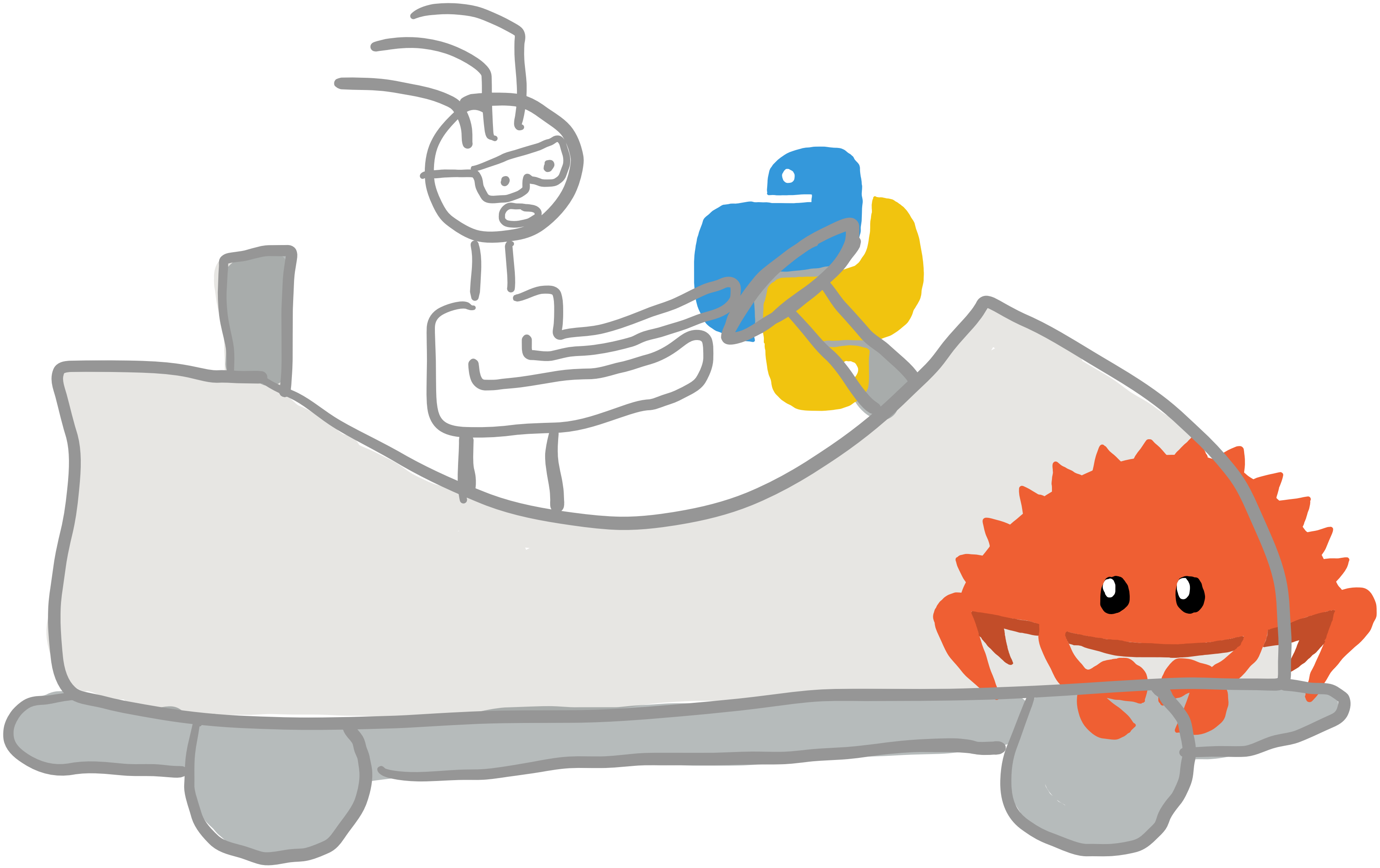
Total answers: 558



THE NEED FOR SPEED



THE FUTURE



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LF

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Microgrants

- $4K, no strings attached
- >100 grants
- >400 contributors
- 31 countries
- >400 citations
- 3 startups, 1 nonprofit

Research

- Error mitigation
- Benchmarks
- Compilers

Community

Discord

5K quantum enthusiasts

Quantum Wednesday

Quantum Open-Source Software Survey

unitary HACK

Closing thoughts

1 Quantum is weird

2 Noise is hard

3 Python is ergonomic

THANK YOU!

@loglog.wtf on BLUESKY

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