What is Quantum Computing? (&Y@SNOLAB?)

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SNODAY 2.0

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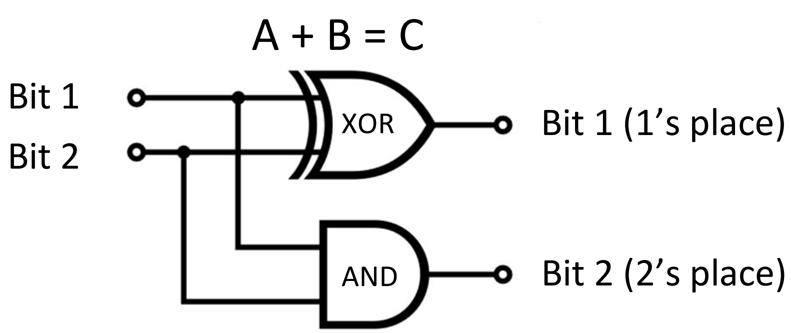
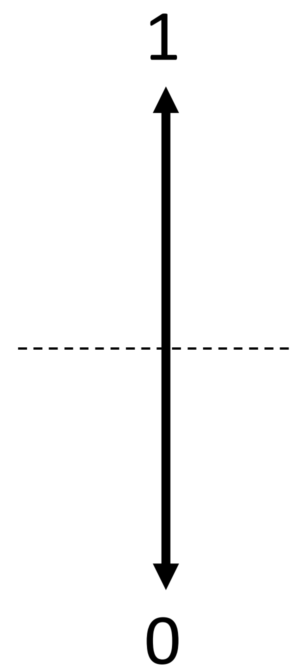
A quantum computer entangled with a dark matter detector in SNOLAB two kilometers underground, pencil drawing, rainbow. Generated with the assistance of AI.

Classical computing utilizes bits to perform mathematics and store information

- Bits are the fundamental unit of information in a classical computer
- Bit arrays can be manipulated to perform mathematics, and bit arrays can be stored to preserve information
- Classical computers are widely used for science, art, and business





A classical bit can be a 1 or a 0.

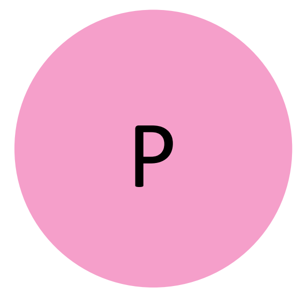
Classical computing algorithms are classified by their scaling into complexity classes

- Scaling classification is by characterizing the function that relates number of inputs to number of calculations

$$Number\ of\ calculations = F(number\ of\ inputs)$$

- Many algorithms scale as a polynomial function of the inputs
  - Basic arithmetic, simple sorting algorithms
  - Considered easy to solve (they scale well)
  - Labelled **P problems**

$$Number\ of\ calculations = (number\ of\ inputs)^2$$



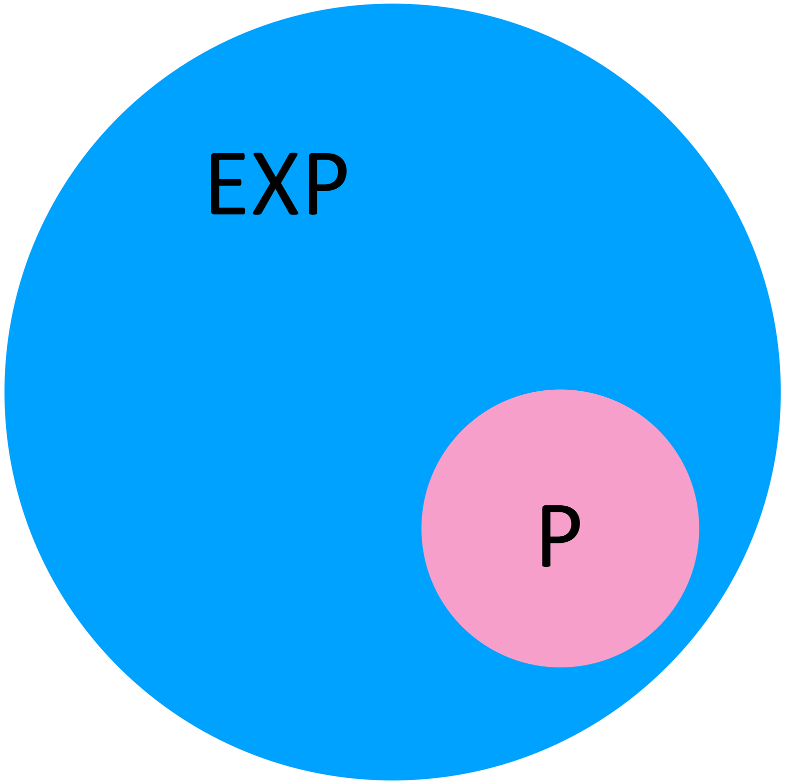
Classical computing algorithms are classified by their scaling into complexity classes

- Scaling classification is by characterizing the function that relates number of inputs to number of calculations

$$Number\ of\ calculations = F(number\ of\ inputs)$$

- Many algorithms scale as an exponential function of the inputs
  - Brute force problems, poorly written algorithms
  - Considered hard to solve (they scale poorly)
  - Labelled **EXP problems**

$$Number\ of\ calculations = e^{number\ of\ inputs}$$



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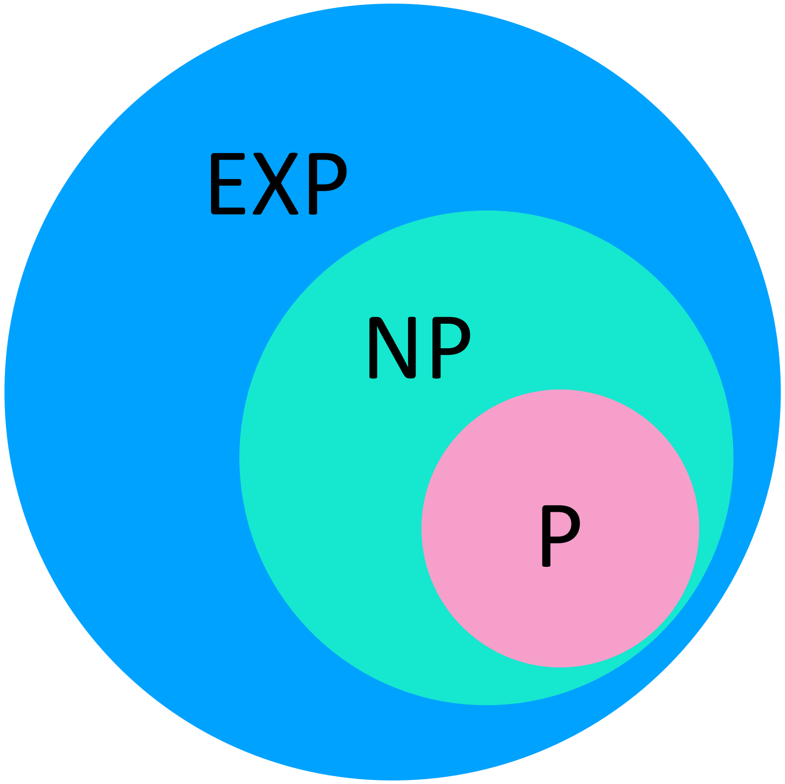
Classical computing algorithms are classified by their scaling into complexity classes

- Scaling classification is by characterizing the function that relates number of inputs to number of calculations

$$Number\ of\ calculations = F(number\ of\ inputs)$$

- Some problems are EXP to solve, but P to verify the solutions
  - Factoring numbers
  - Considered useful (e.g. basis of cryptography)
  - Labelled **NP problems**

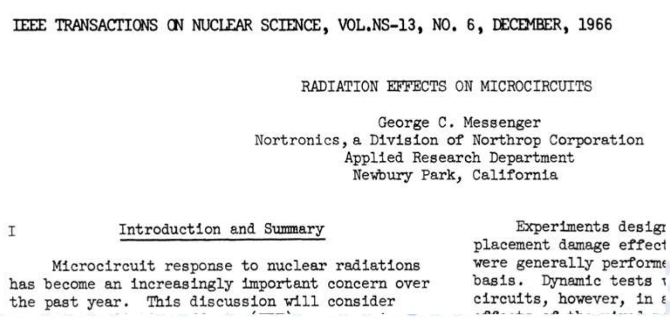
$$Number\ of\ calculationsto\ verify\ solution = (number\ of\ inputs)^2$$



NP stands for non-deterministic polynomial

Classical computers suffer from soft errors due to radioactivity

- Bits can flip due to alpha particles and cosmic rays
- Significant field of research in the 1960s and onward
- Computing devices are packaged in clean rooms to avoid alpha contamination
- Specific transistors design rules are implemented to avoid soft errors
- Error correction is done in software
  - E.g. make multiple copies of the information


IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL.NS-13, NO. 6, DECEMBER, 1966

RADIATION EFFECTS ON MICROCIRCUITS

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I Introduction and Summary

Microcircuit response to nuclear radiations has become an increasingly important concern over the past year. This discussion will consider

Experiments desig
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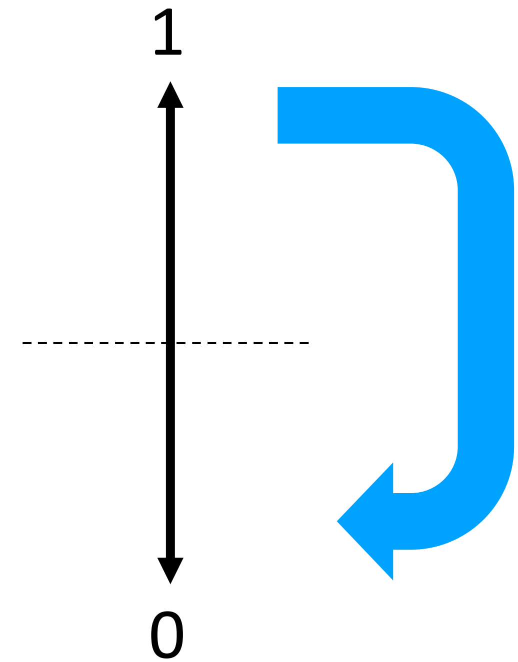
were generally performe
basis. Dynamic tests
circuits, however, in



A classical bit can suffer from a soft error, flipping the bit

Classical computers suffer from soft errors due to radioactivity

- Bits can flip due to alpha particles and cosmic rays
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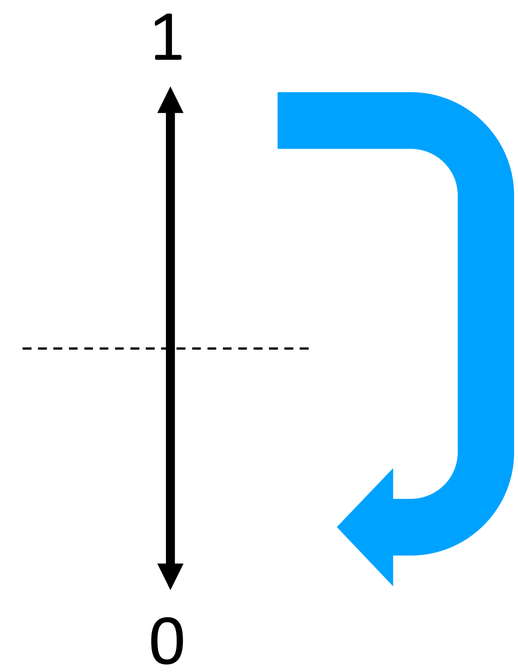
Soft errors can still affect classical computing
https://www.thegamer.com/how-ionizing-particle-outer-space-helped-super-mario-64-speedrunner-save-time/



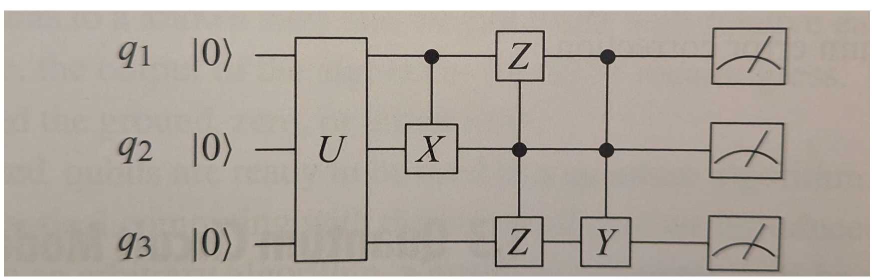
A classical bit can suffer from a soft error, flipping the bit

Quantum computing utilizes the correlations of quantum mechanics to solve complex problems

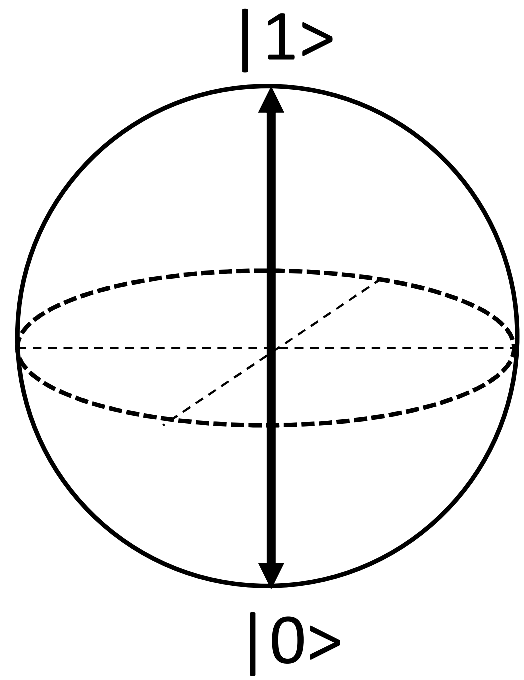
- Quantum bits are in a complex superposition of two states

$|\psi> = \alpha\ |0> + \beta\ |1>$, α and β are complex numbers

- Qubit arrays can form superpositions of 2^N states
- The hope is that entanglement and interferences in this large, complex space can enable new types of calculations



From “Building Quantum Computers”, Majidy, Wilson, and Laflamme

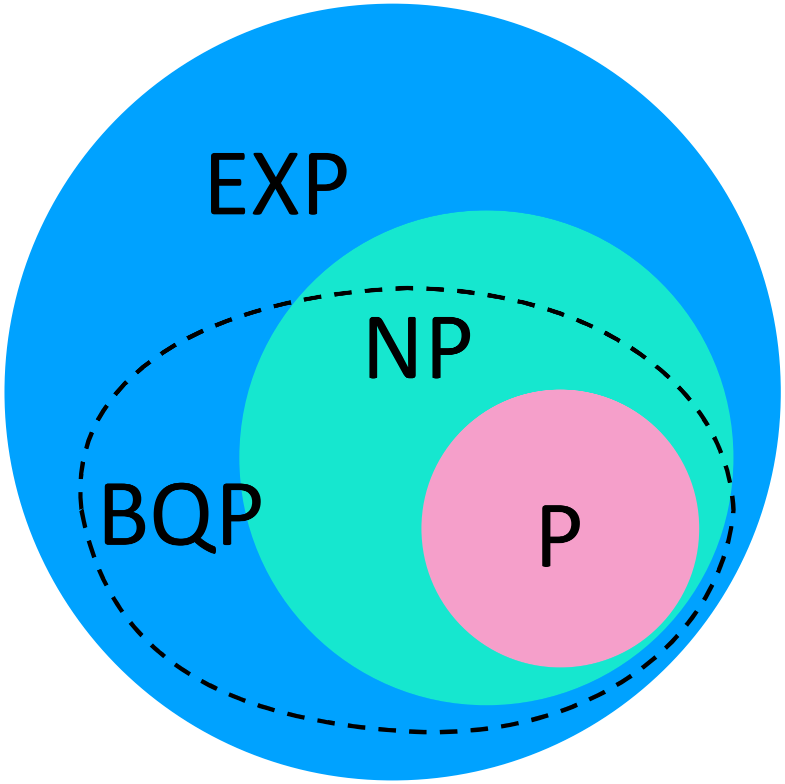


A qubit is in a superposition of 1 and 0. This graphical representation of a qubit state is called the **Bloch sphere**.

Quantum computing algorithms hold the promise of calculating solving problems more efficiently

$$Number\ of\ calculations = F(number\ of\ inputs)$$

- Problems that quantum computers can solve efficiently are called bounded error quantum polynomial problems, **BQP problems**.
- All P problems are BQP problems
    - A quantum computer can perform classical calculations.
- There are some NP problems that are BQP problems.
- The bounds of BQP problems are unknown.



There are many qubit candidates, but they all suffer error problems

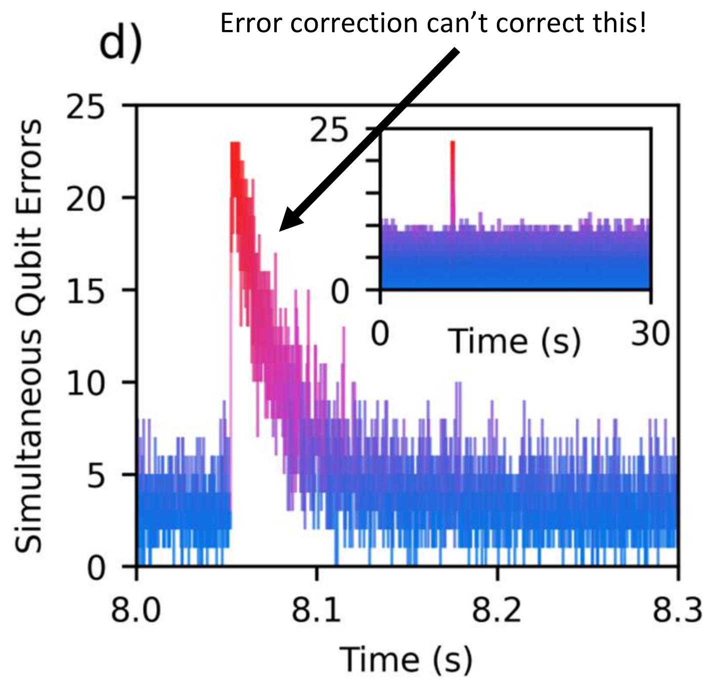
- Qubits suffer from bit flips, phase errors, and decoherence
- The errors are currently too frequent for the promised applications
- No established design rules for each qubit candidate
- Error correction is a large field and holds promise to address this issue
    - Different from classical error correction because states cannot be copied

Current most promising qubit candidates

- Spins in NMR
- Photons
- Trapped ions
- Superconducting circuits

Quantum error correction relies on *uncorrelated* qubit errors

- Search for simultaneous errors with a superconducting quantum processor
- Clear evidence of particle interactions
- Watched evolution of errors start locally, but spread across all qubits
- This represents a fundamental limit on the time for any quantum calculation
- This is the reason to explore quantum computing at SNOLAB!



M. McEwan, et al., Nat. Phys. **18**, 107 (2022)


Questions?
Discussion