The power of quantum computing ...on one page

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Classical bits

one: 0 **or** 1

two: 00 **or** 01 **or** 10 **or** 11

N bits describe one number 0…2^N

Quantum bits

$$|\Psi\rangle = c_0|0\rangle + c_1|1\rangle$$

$$|\Psi\rangle = c_{00}|00\rangle + c_{01}|01\rangle + c_{10}|10\rangle + c_{11}|11\rangle$$

N qubits: need 2^N numbers to describe the N-qubit state!

it's both 0 and 1 until measured (quantum superposition)

c_i are coefficients (numbers)

To describe only 265 qubits we need as many numbers than #atoms in universe (2^265) - by definition, this is impossible with classical information/physics.

-> The information is in quantum correlations (often entanglement)

But, after measuring, only ~N bits/numbers of information can be obtained

Don't forget: a single protein contains 10,000 atoms, assuming atoms are qubits, this space is far bigger (2^10000)! Apparently, the (possible?) amount of quantum information in our universe is much bigger than the maximum classical information content.

And, obviously, we cannot initialize even only 2^265 numbers. How can a quantum algorithm be useful?

Prepare all N qubits in some separable basis state (roughly N numbers needed)
N numbers

→ Let the state evolve in a (very) clever way, where qubits interact, generate quantum correlations + entanglement
2^N numbers

→ Measure each qubit
N numbers

Can this really be advantageous compared to classical information processing? We don't know yet for sure, but most likely it is!

Example: Deutsch algorithm with proven quantum advantage

- A function $f(b_1, b_2, b_3, \ldots, b_N)$ results either in the same answer (e.g. 0) independent of the input bits bi,
- or it is balanced: 50% of combinations of bi result in 0, 1 otherwise.
- **Classical**: need to test > 50% of possible inputs (= 2^N - 1)
- **Quantum**: one evaluation of f (but f must work on quantum inputs, this is a potential issue)