The Future of Computing in a Quantum Age

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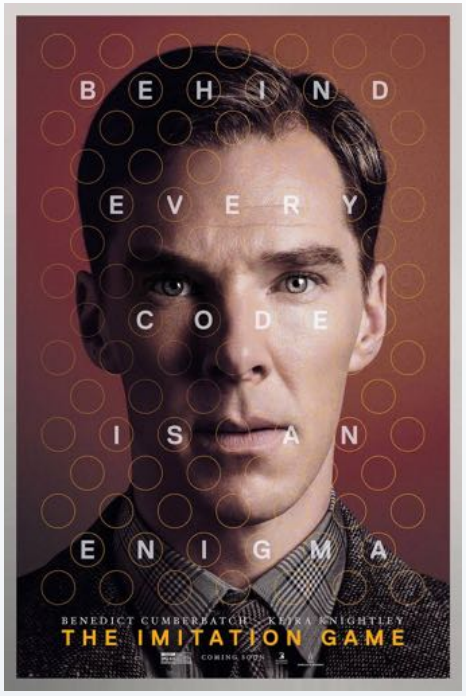
What is a Computer?

Question: What makes these all computers? Can you think of a good definition of a computer?

- A **computer** is a device that can be instructed to carry out an arbitrary set of precise operations automatically.

Turing Machines

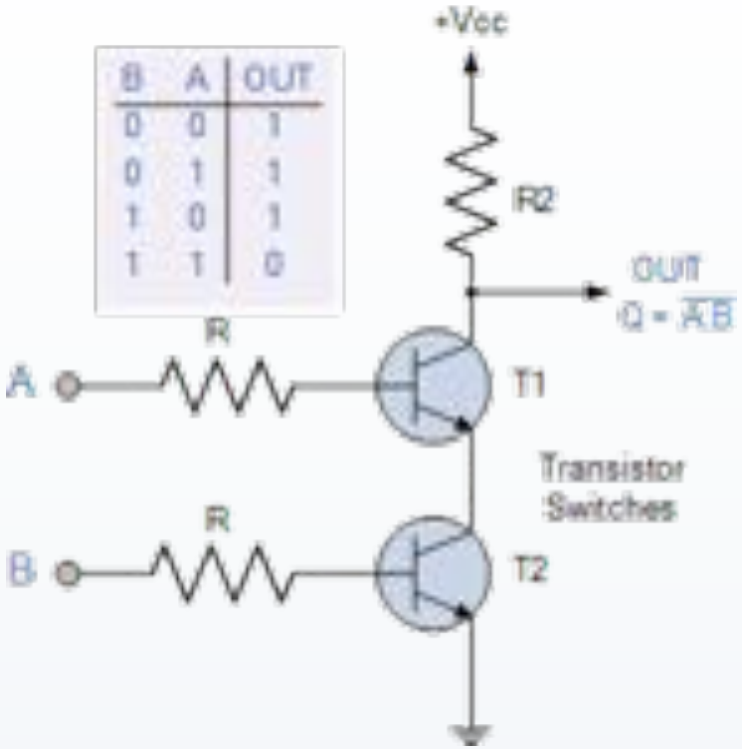
- Idea conceived in 1948 by Alan Turing.
- Most basic idea of what a computer is.
- Instructions given in form of ’1’s and ’0’s on a tape.
- The machine then outputs the tape with the answer encoded in ’1’s and ’0’s.

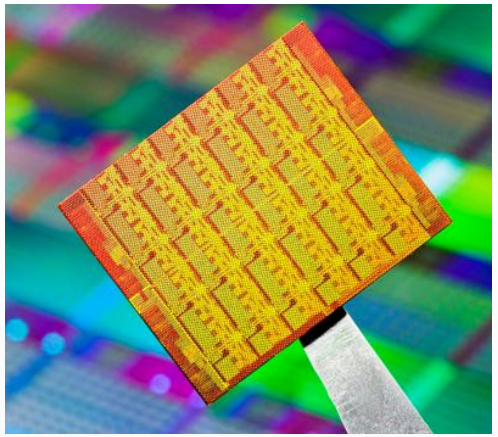


Turing Machines

Every modern computer is **equivalent** to a Turing machine.

How does a Modern Computer Work?





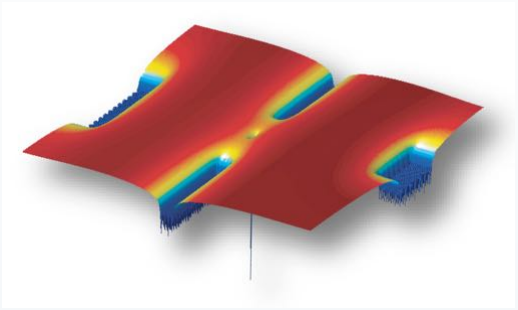
1.7 Billion Transistors!

NAND logic gate is **universal**,
like the LEGO Turing machine

Problems with Computing Today

- *Moore's Law: The number of transistors you can fit on a chip doubles every 18 months.*
- This has held since the 1960's but is coming to an end.

- *Problem 1:* Transistors are now so small (nanoscale) that quantum effects are starting to affect performance.



Single-atom transistor! (2012)

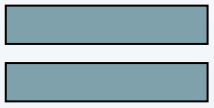
Problems with Computing Today

- *Problem 2:* There are computational problems that are so hard that we don't even attempt to do them. Bigger/faster ordinary computers won't help.
- But quantum computers might...

Computational Complexity Theory

- Language Computer Scientists use to describe computational problems in general.
- This way, we can talk about how different models of computing e.g. Turing machine vs. quantum computers compare to one another in a fundamental way.
- Note: As far as Complexity Theory is concerned, the LEGO Turing machine and your phone are the same!

Complexity theory



- **Definition:** A *problem* is a general task we're trying to get the computer to solve.
- Example: Navigation– get me from point A to point B in the shortest possible time, **wherever A and B are.**
- **Definition:** An *instance* of a problem is a particular case in a problem.
- Example: For the Navigation problem, get me from Tooting station to Brixton station in the shortest time.

Can you think of a computational problem/instances of the problem?

Solving a problem means having a procedure or algorithm that can find the answer to **any** possible instance of that problem.

Example: Google Maps solves the Navigation problem because it finds the best way to get from A to B, for any locations A and B.

Complexity Classes

- *A complexity class is a collection of problems*.
- If two computational problems are in the same complexity class, solving them has the same difficulty.
- P - class of problems where finding the answer is efficient on a Turing machine.
- NP – class of problems where checking if the answer is correct is efficient on a Turing machine.
- P problems = easy for Turing machine. For NP not so straightforward.

Some P problems

- Navigation.

- Checking if a number is prime.

- Searching a database.

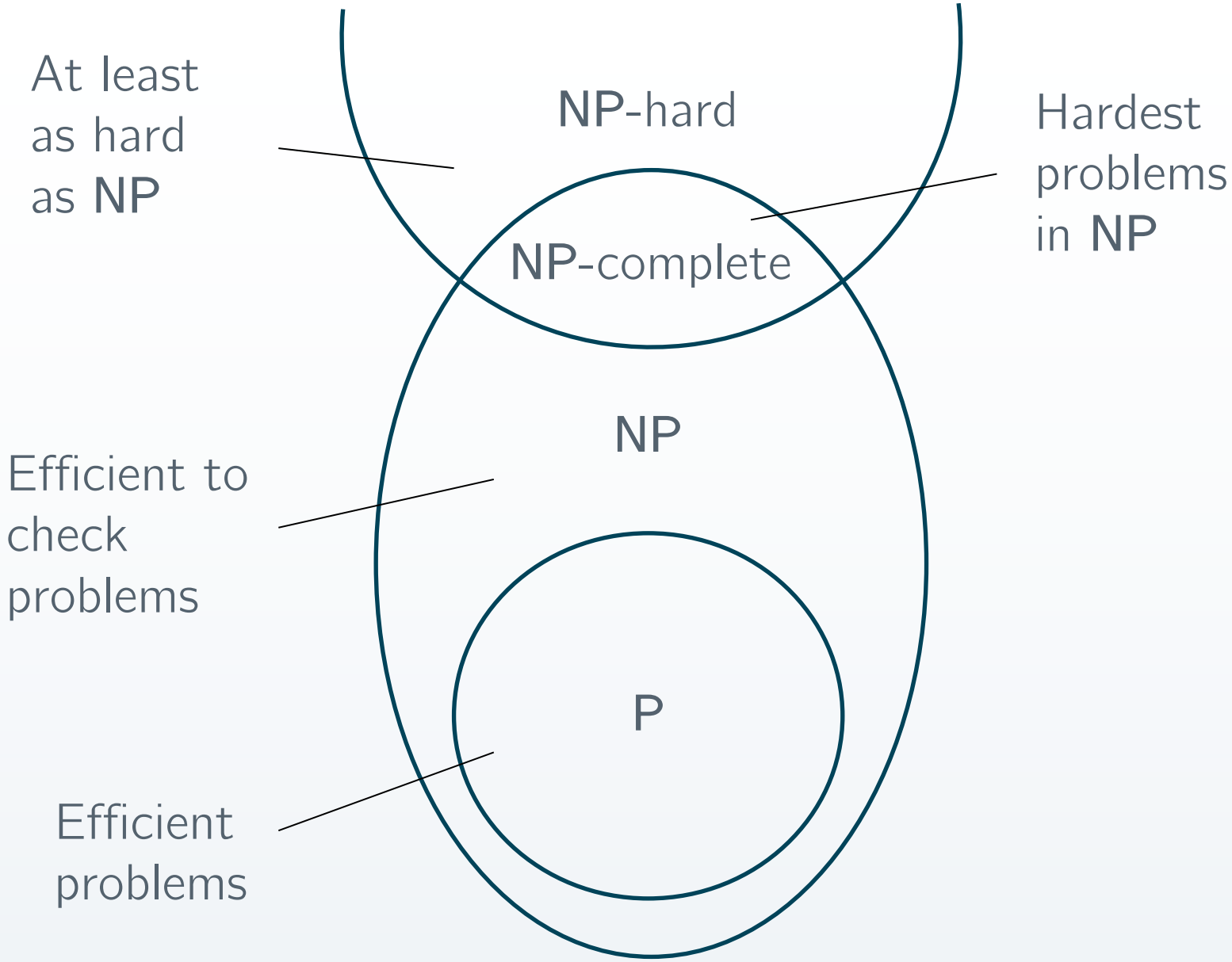
- Nearly everything you do on a computer.

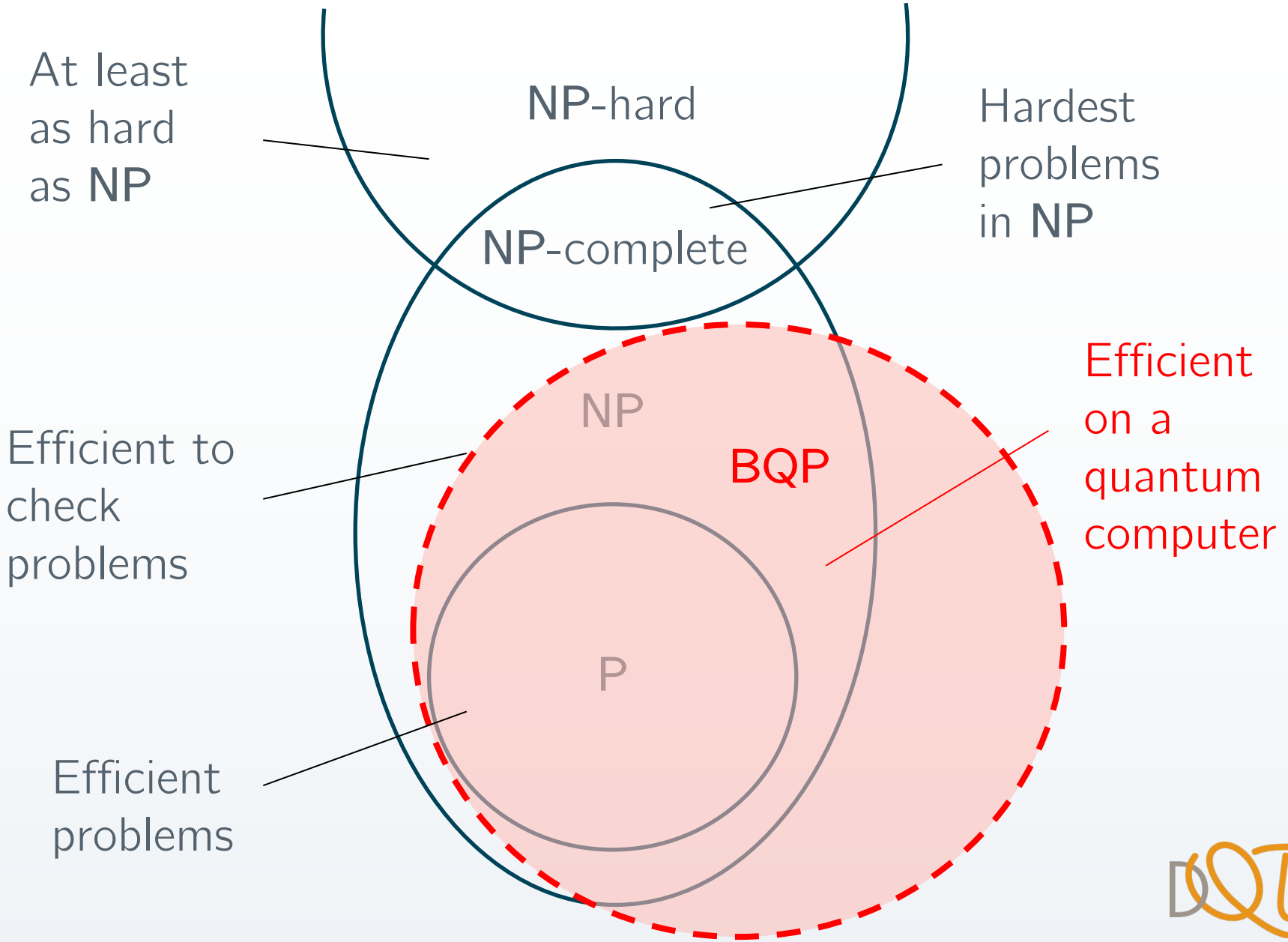
Some **NP** problems

- Travelling Salesman.

- Scheduling.

- Many video games, Super Mario, Call of Duty, Portal, GTA.


At least as hard as NP
NP-hard
Hardest problems in NP
NP-complete
NP
Efficient to check problems
P
Efficient problems


At least as hard as NP
NP-hard
Hardest problems in NP
NP-complete
Efficient to check problems
NP
BQP
Efficient on a quantum computer
P
Efficient problems

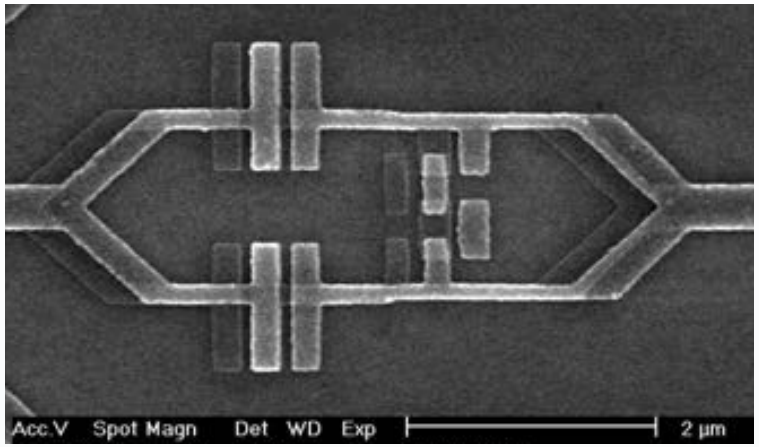
What does a Quantum Computer look like?

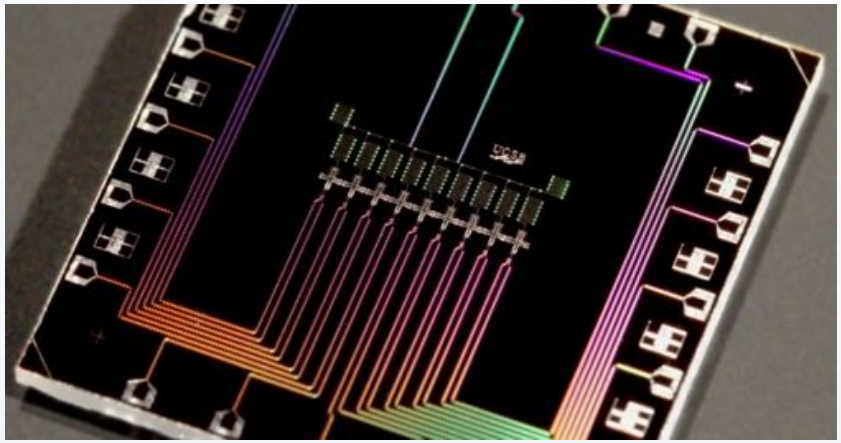
Micrometre size loops of superconducting wire make the up the quantum bits (qubits).

Controlled by electrical pulses (quantum equivalent to NAND gates).

Currently, at most 9 quantum bits, so very early on.

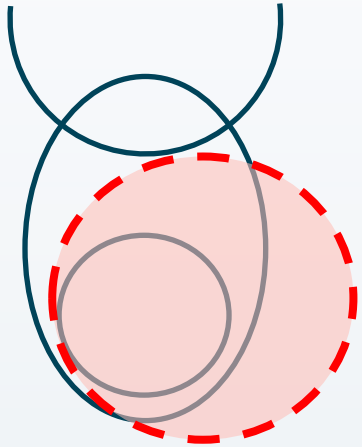
50-100 quantum bits expected by the end of 2017.





What's Next?

- 'Quantum Supremacy' experiment coming in the next couple of years.
- Google have run a computational problem requiring their Edison supercomputer to run for days.
- This would take seconds on quantum computer with 42 qubits!
- If they achieve this, quantum computers are proven to be something truly new!



Summary

- Increases in traditional computing performance are slowing down rapidly.
- Quantum computers promise to solve a new class of problems inaccessible to current computers.
- Massively growing field, will need many engineers, scientists/mathematicians over the coming years

Thanks for Listening!

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https://uwaterloo.ca/institute-for-quantum-computing/quantum-computing-101

http://www.research.ibm.com/quantum/

http://uknqt.epsrc.ac.uk/