Quantum Cyber Security
Lecture 1: Introduction

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14th January 2025

This Lecture

1. Logistics
2. Motivation: Quantum Computers and Security
3. Quantum Cyber Security: Definition and Course Content

Logistics

Contacts

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- Laura Lewis (Tutor)

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Structure of Course

- Lectures
  - Two per week

    (Tuesday at 11:10 - 12:00; Thursday at 10:00 - 10:50)
  - In-person at: Lister-Learning-and-teaching-centre LLTC 2.3
  - Recoding (and live-streaming) available

- Tutorials
  - Once per week (Group 1 Wednesday 10:00 - 10:50; Group 2 Wednesday 11:10 - 12:00)
  - Two groups (randomly allocated)
  - In-person at: AT 2.07 **MAY CHANGE**
  - **Starts at week 3** (29th January)

- Q& A after classes (altern. contact us via email or at Teams)

Assessment

- Coursework 25%
  - One assignment released 7th March 2025
  - Due at 21st March 2025 (details to follow)
- Exam 75%
  - Two questions to choose out of three
  - Further advice at the revision lecture (last)

Resources

1. **Main textbook** (additional references and resources will be given for each topic if not covered in this):

   "Quantum Computation and Quantum Information"
   by Michael A. Nielsen & Isaac L. Chuang

2. Review paper: Advances in Quantum Cryptography (link here)

3. **Lecture Notes:**
   `https://opencourse.inf.ed.ac.uk/qcs/schedule`.
   Recordings from the Learn page of the course.

4. You can also register at the piazza of the course for questions (mainly for students interactions)

Motivation: Quantum Computers and Security

Quantum Computers

- Quantum Physics is a very successful theory
- Quantum Physics has many **counter-intuitive properties**
- Size of transistors in microchip are approaching quantum scale

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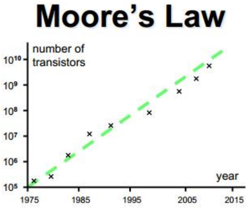
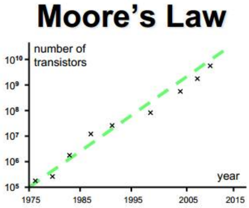
- Q: What computational power would a QC have?
- A: Greater than classical probabilistic $\mathrm{BPP} \subseteq \mathrm{BQP}$
- Q: Is it possible to built such computing device?
- A: Yes! No fundamental reason stopping us (engineering)


Moore's Law
number of transistors
10^{10}
10^9
10^8
10^7
10^6
10^5
year
1975
1985
1995
2005
2015



Bit	**Qubit**
Takes values either 0 or 1	Can behave as being simultaneously 0 and 1: $\alpha \|0\rangle + \beta \|1\rangle$
Measurement reveals value	Measurement disturbs
Can be copied	*Cannot* be copied
Strings are described w.r.t. single bits (local)	Strings cannot be described w.r.t. single qubits (non-local)
Behave probabilistically	"Complex probabilities"

Quantum Computers: Is it a serious threat?

- Quantum Computers can solve efficiently **factoring** and **discrete log** (Factoring, RSAP, Discrete Log, DHP)
- Intractable problems (classical hardness guarantees security)
  $\Rightarrow$ Tractable problems (for Quantum Computers)

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Take-home message

If a scalable quantum computer is built, most of current cryptography breaks (from emails, bank transactions to national security secrets)!

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- Known since 1990's
- Requires unprecedented control of quantum systems

Why act now?

- Huge recent initiative in Quantum Technologies
  Companies: Google, IBM, Microsoft, Amazon, Intel, D-Wave, Rigetti, IonQ, etc
  Governments: UK, EU, USA, China, Canada, etc (£billions)
  Developments in Quantum Technologies are accelerating and the prospect of practical QT is becoming real

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Take-home message

There is a serious medium-time threat that scalable quantum computers will become available. Counter-actions should start now.

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- Can perform more types of operations
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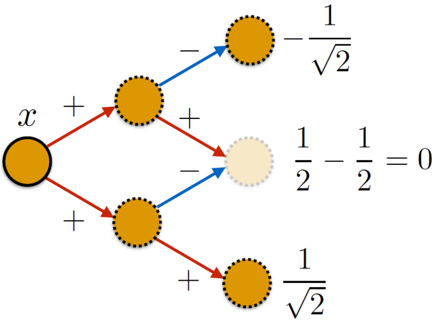
- Quantum computers behave as probabilistic computers but with complex-valued "probabilities"
- Probability is the mod square of the sum of the complex amplitudes



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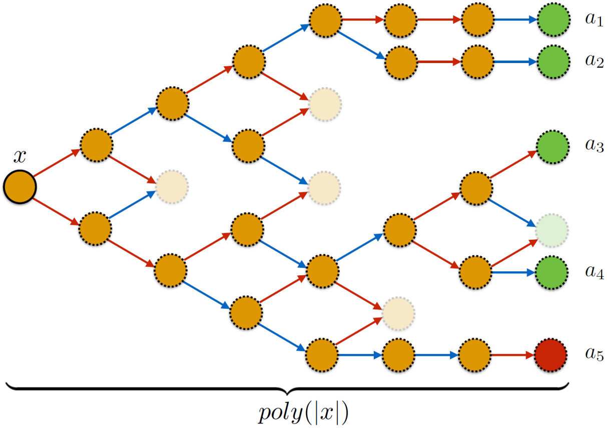

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  Second term: Amplify or cancel probability (interference)
- **Classical systems:** random amplitudes $\rightarrow$ interference $\approx$ zero

On the Power of Quantum Computation

Myth 1

Quantum Computers are much faster in performing operations than Classical Computers

On the Power of Quantum Computation

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Reality

Quantum computers are **not** faster. Speed-up is obtained because quantum theory allows algorithms/operations impossible for classical computers.

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Reality

QC span the space of possibilities in a peculiar way (behave as complex probabilities). However, at the end of the computation the result is obtained by a **single read-out/measurement** and "unrealised" paths do not contribute.

On the Power of Quantum Computation

Myth 3

Quantum Computers give equally impressive computational speed-up to all problems

On the Power of Quantum Computation

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Reality

Quantum computers can give from exponential speed-up (factoring) to much smaller quadratic speed-up (search). The exact optimal quantum algorithm depends on the problem and is crucial for quantum cryptanalysis.

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Reality

Quantum computers give speed-ups, but are real devices with well defined limitations. Can base crypto on quantum computational assumptions provided (i) there isn't an efficient quantum algorithm, as for some major cryptosystems (RSA, EC-DSA) and (ii) new security analysis is performed and security parameters are chosen

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Myth 5

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Myth 5

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Reality

This is **necessary but not sufficient** condition. New quantum cryptanalysis, new security definitions and new proof techniques are also needed.

Part III

Quantum Cyber Security: Definition and Course Content

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- **Disruptive**: Adversaries with Quantum Computers or QTech
  E.g. Quantum computers solve efficiently factoring and discrete log $\Rightarrow$ RSA, DSA, ECDSA break

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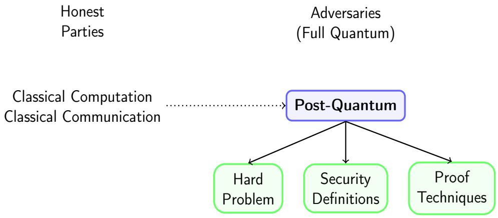
- **New Opport**: Honest with QTech better security/efficiency
  E.g. Quantum Key Distribution (QKD). Quantumness used to enable Key Distribution with information theoretic security

Quantum Cyber Security Landscape: Three Categories



See our review "Cyber Security in the Quantum Era" in CACM

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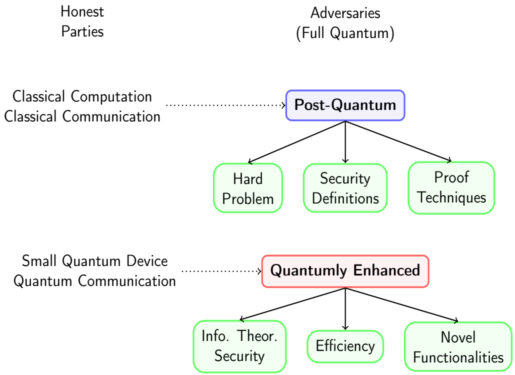

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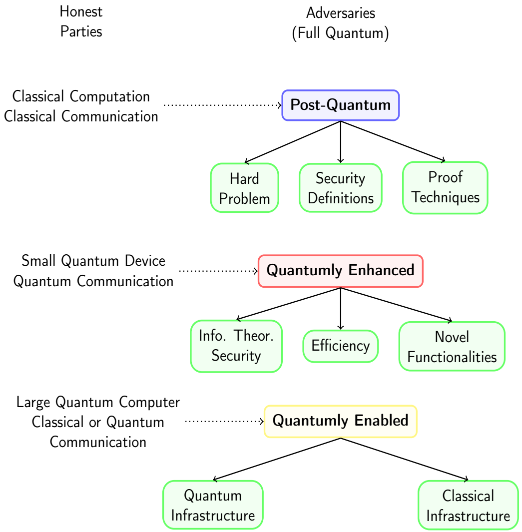

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- Post-quantum cryptography (3 Lectures)
- Guest Lecture (tbc), Revision (2 Lectures)

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- Practically, once used in the notation, it becomes much more easy to follow and use

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- But this is NOT the case in this course!

  We hope you will enjoy it!