Audition CNRS - Concours 06/02

Complexity-Theoretic Foundations of Cryptography

Willy Quach

Area of research: Theory of cryptography

- September 2023 - : Postdoctoral Fellow at the Weizmann Institute of Science. <u>Host:</u> Zvika Brakerski
- September 2017 - August 2023: PhD student at Northeastern University. <u>Advisor:</u> Daniel Wichs
- September 2013 - August 2017: École Normale Supérieure de Lyon

Cryptography is a core backbone for security and privacy

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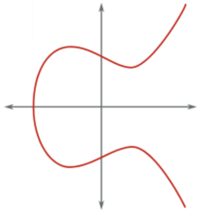
What makes modern cryptography reliable?

VS

$N = pq$



"Ancient" cryptography

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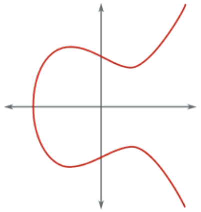

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Modern cryptography

We have **abstractions** to reason about security and **paradigms** to achieve them.

Formalize and quantify security (!)

Techniques to tie security to **complexity theory**

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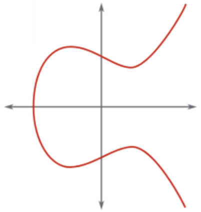

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What is there left to do?

My Research in a Nutshell

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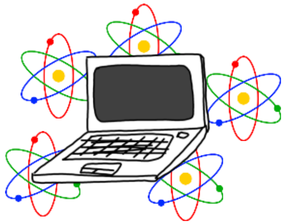
Address new threats



Devastating effects of
quantum attacks, side-channel attacks

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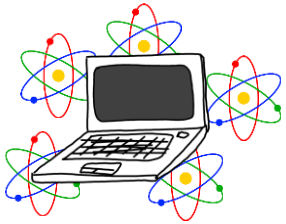

- Security against quantum computers
  - How to argue security? [TCC ‘22, **Invited to the Journal of Cryptology**]
  - Alternate ``quantum-secure’’ constructions [PKC ‘18, CRYPTO ‘19, TCC ‘21]

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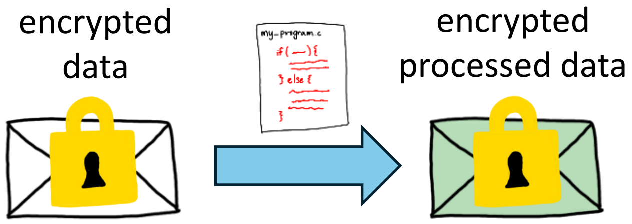
Provide stronger functionalities

Private data used in **computation**, not just transit



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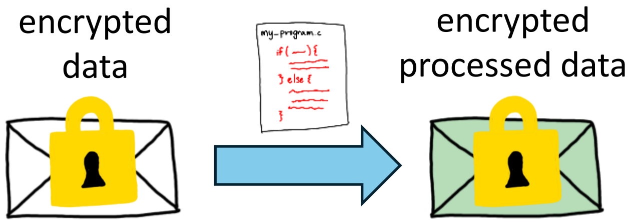

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  - Introducing new cryptographic tools [FOCS '18]
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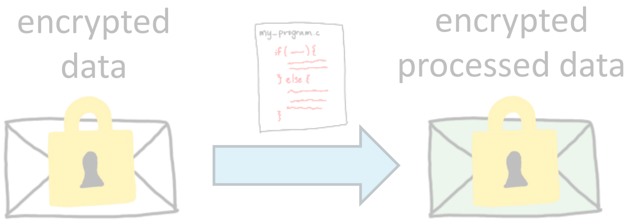

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Foundations are still poorly understood

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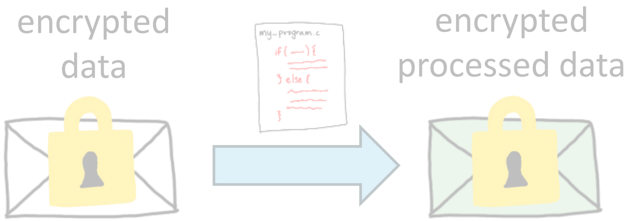

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- Refine ties with complexity theory

  Cryptographic proof systems [EUROCRYPT '19, CRYPTO '19, '21, '23]

  Alternate models of security [EUROCRYPT '22, '23, TCC '23]

A Global Lens: Computational Hardness

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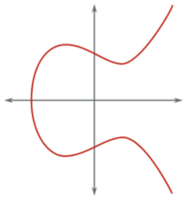

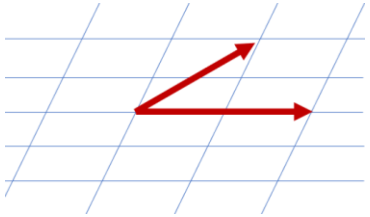

Hard algorithmic problem

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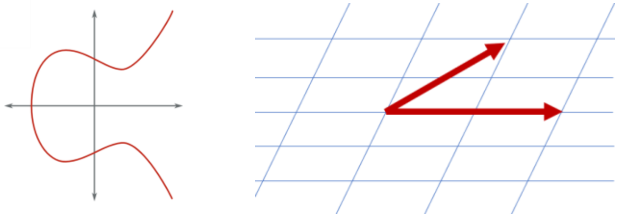

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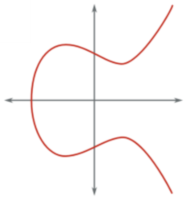

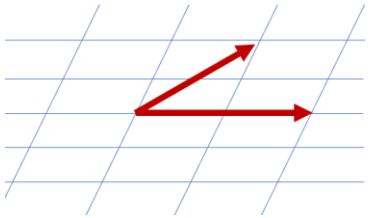

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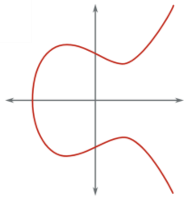

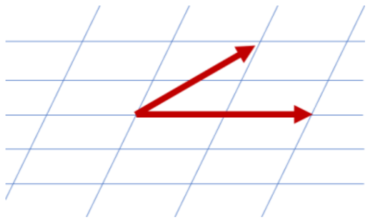

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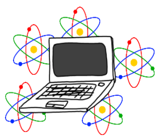

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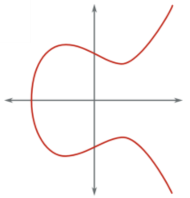

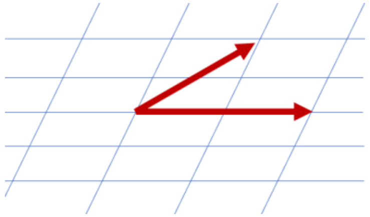

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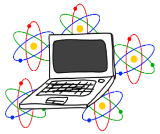
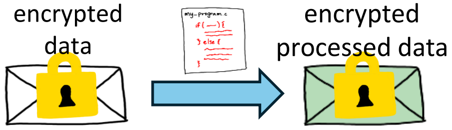


Hardness against quantum computers

2. Strong functionalities



Exploitable algebraic structure

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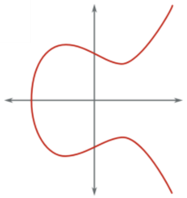

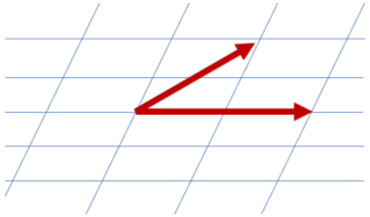

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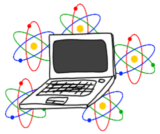

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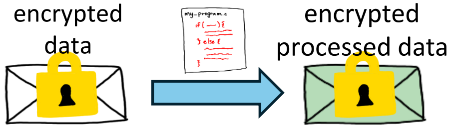

Exploitable algebraic structure

3 Foundations of cryptography

Strength of assumption

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Mo

lot!

Focus for today:

How (not) to argue security against quantum attacks

[LMQW, TCC '22, Invited to the Journal of Cryptology]

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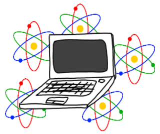
1 Security against quantum attacks  Hardness against quantum computers

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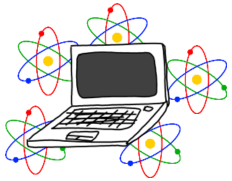
Post-Quantum Security

Quantum computers would **break** most public-key cryptography deployed.
via Shor's algorithm [Shor'94]



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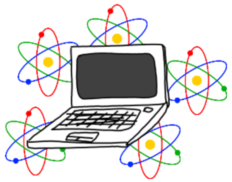

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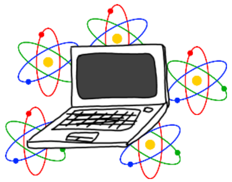

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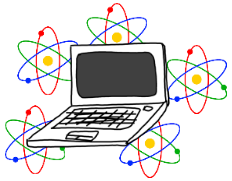

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How do we ensure security against quantum attacks?

Surprisingly little attention given to this general question

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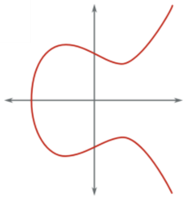

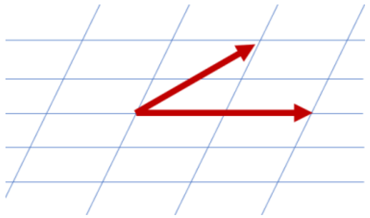

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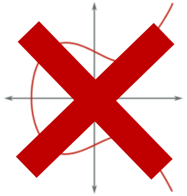

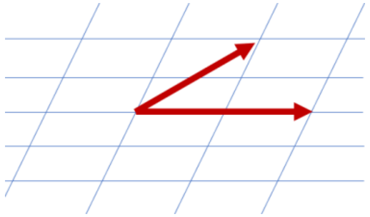

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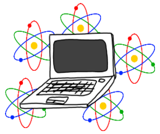

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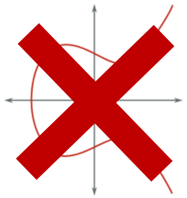

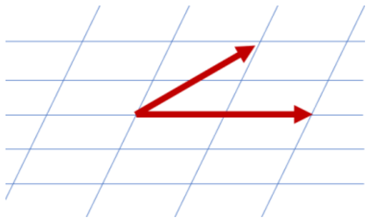

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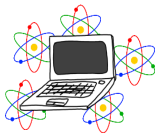

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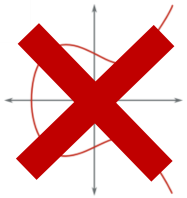

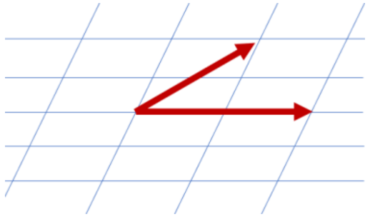

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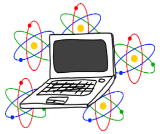

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Main Result

Is using post-quantum assumptions sufficient to ensure post-quantum security?

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Implicit in two decades of research

*”Non-interactive” cryptosystems such as **encryption schemes**, **signatures**…
As opposed to *interactive* or *heuristic* cryptosystems

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The folklore understanding is **wrong**!

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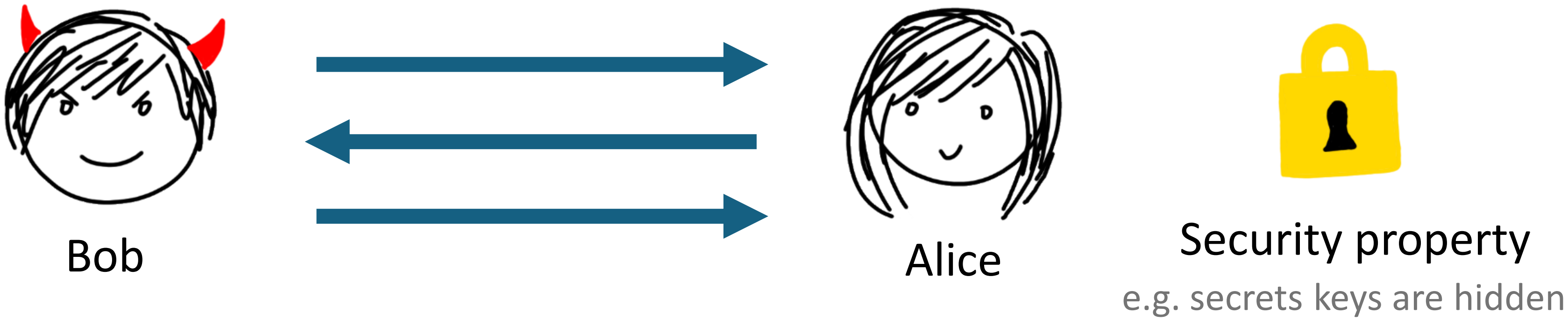
What Goes Wrong?



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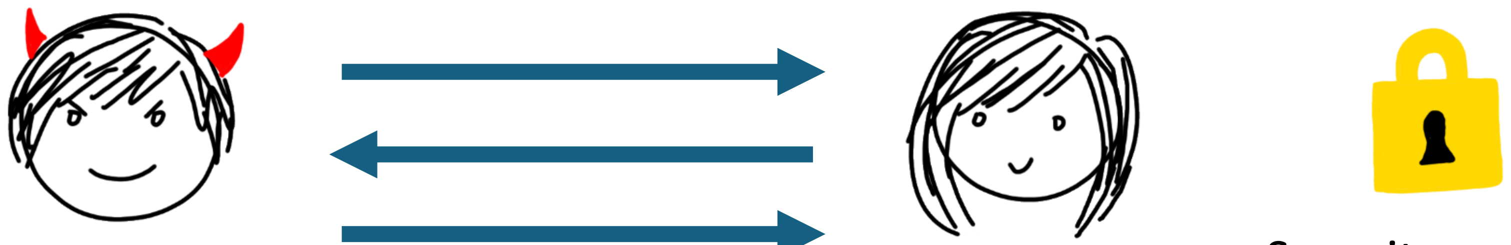

Bob

Alice

Security property

e.g. secrets keys are hidden

Successful attacks against implicitly solve a hard problem

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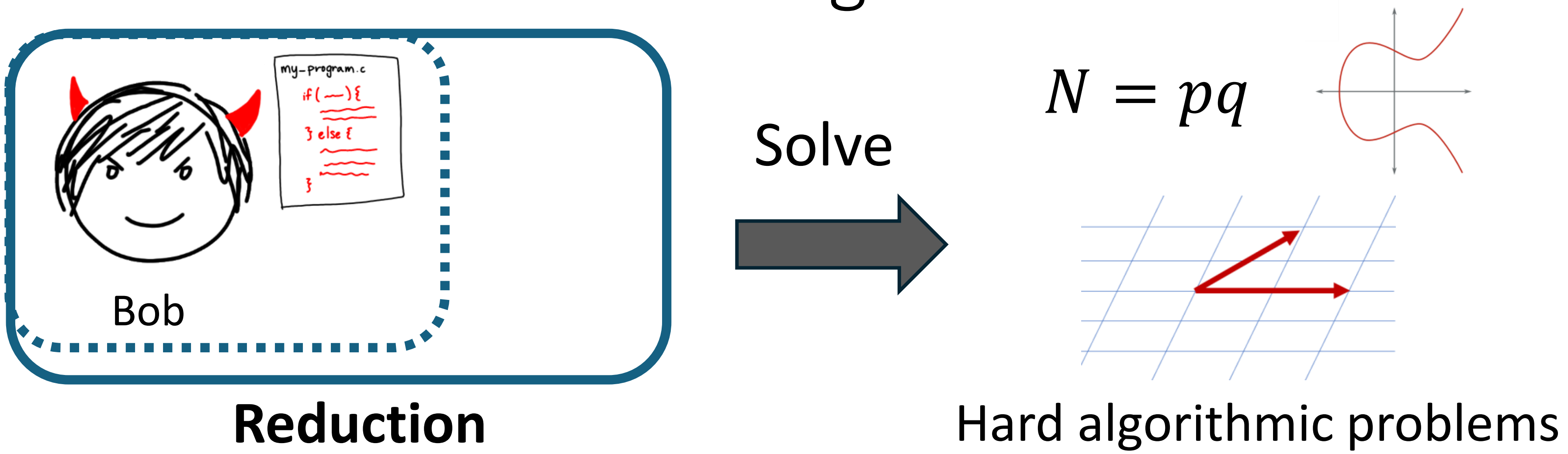

Reduction turns successful attacks into efficient algorithms

a.k.a **proof of security**

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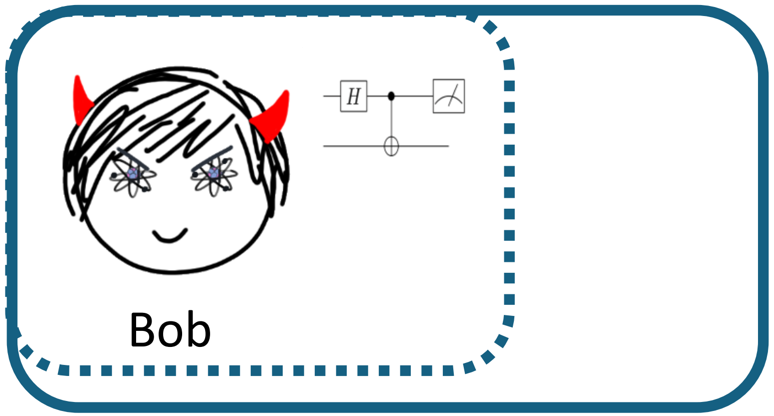
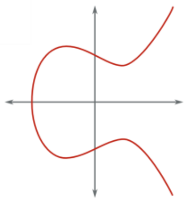
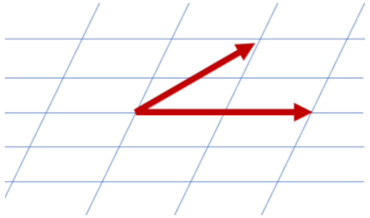


Reduction

Solve

$$N = pq$$





Quantumly hard problems

Reduction turns successful **quantum** attacks into efficient **quantum** algorithms

a.k.a **proof of post-quantum security**

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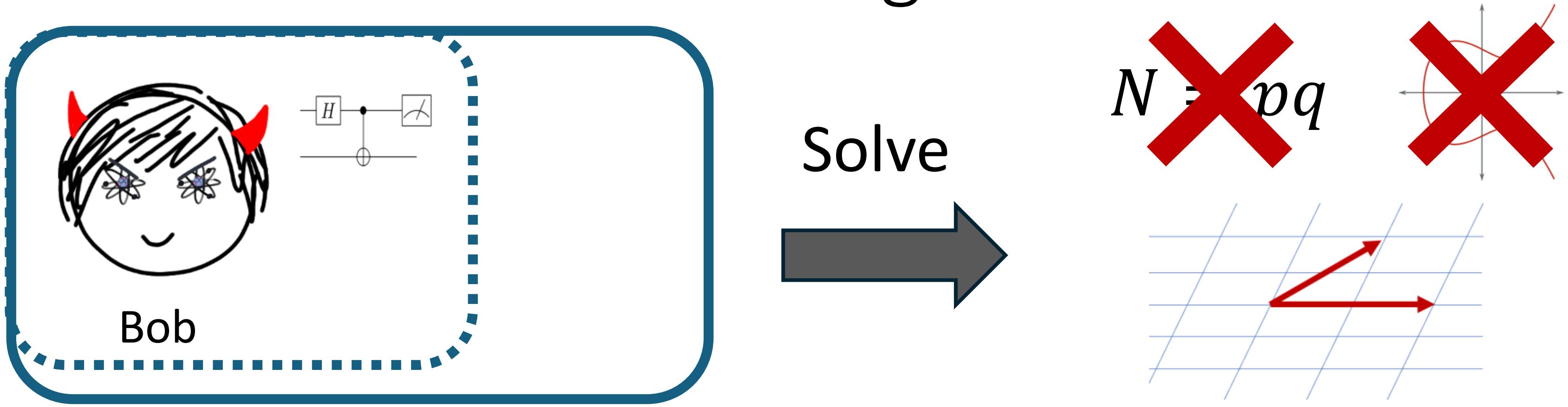

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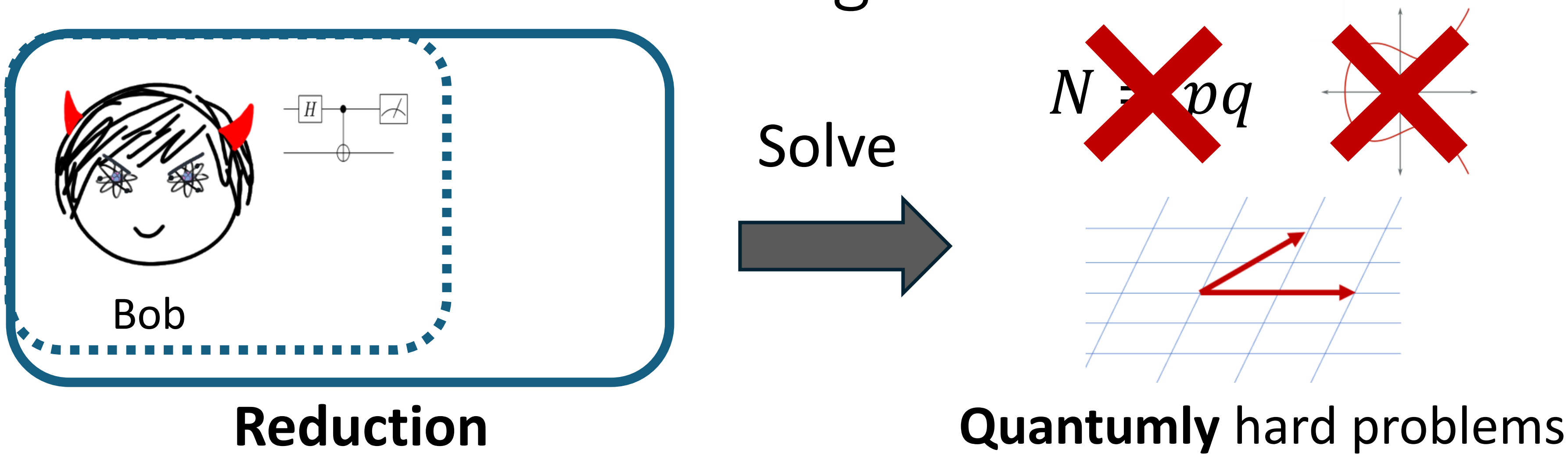

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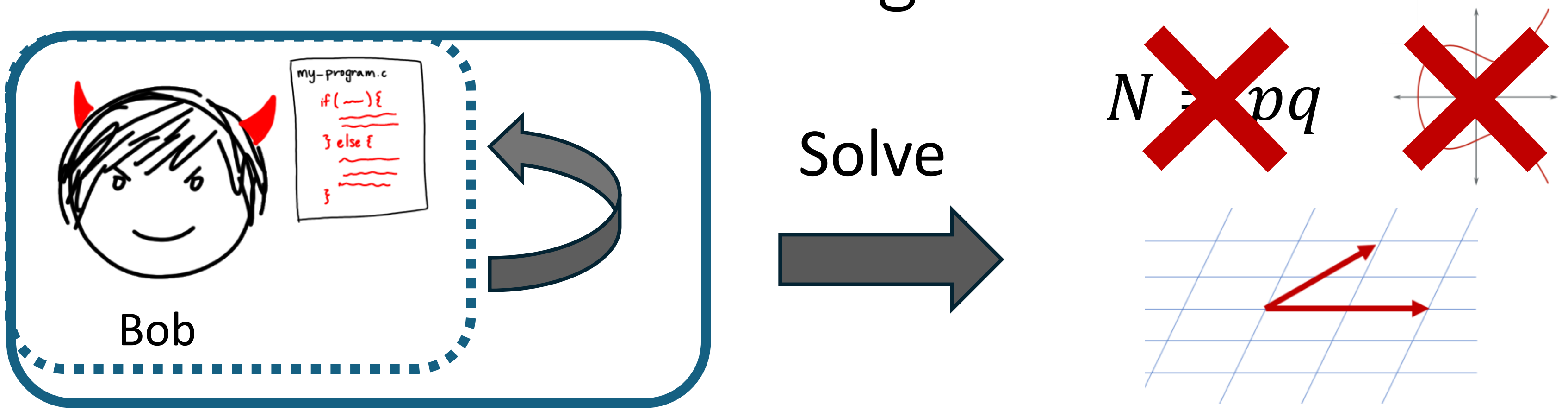

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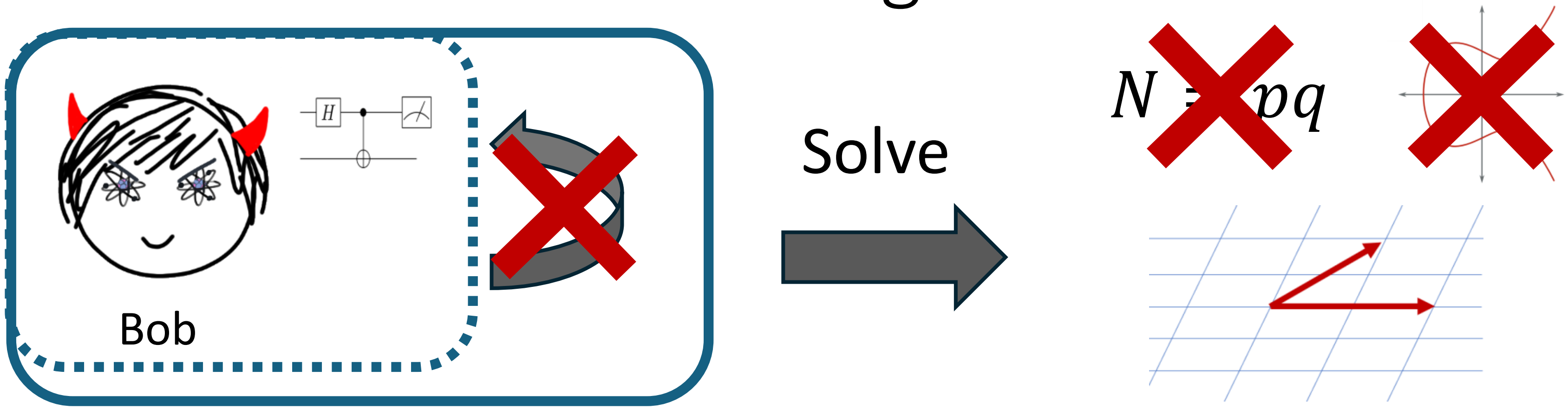

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- Stateful classical algorithms can be run several times (rewinding)
- Stateful quantum algorithms ***cannot*** be run several times (measurements are destructive)

Main Result (2)

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Main Theorem [LMQW TCC'22] **: Explicit counter-examples:**

- Proven secure (classically) **under a post-quantum assumption**
- **Quantumly broken**

Includes symmetric-key encryption, digital signatures…

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Technique: constructions of "**cryptographic proofs of quantumness**" with **stateless verifiers**

Conceptually: Proofs of quantumness $\equiv$ Counter-examples

$\Leftarrow$ breaking security "proves quantumness"

Takeaway: cannot simply plug-in post-quantum assumptions, **need special-purpose proofs of post-quantum security**

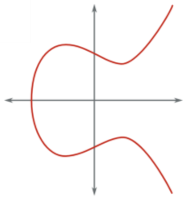
Research Project

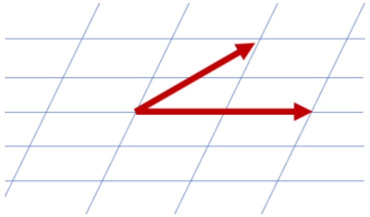
Back to Computational Hardness (Again)

Cryptographic security is proven under computational assumptions

Most cryptography can be broken in $NP \implies$ need to assume algorithmic hardness / that $P \neq NP$

$$N = pq$$



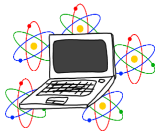


The choice of assumption matters a lot!

Hard algorithmic problem

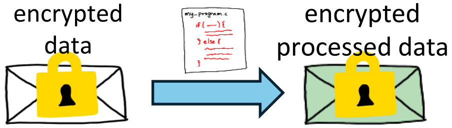
Property about the assumption:

1. Security against quantum attacks



Hardness against quantum computers

2. Strong functionalities



Exploitable algebraic structure

3. Foundations of cryptography

Strength of assumption

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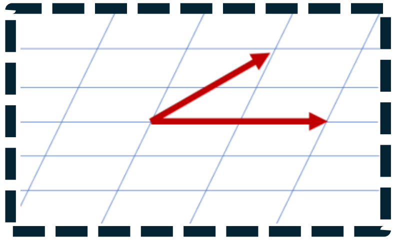

Hard algorithmic problem

Lattices are extremely convenient!

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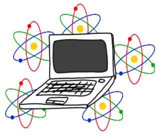

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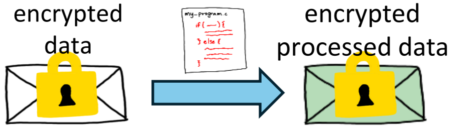

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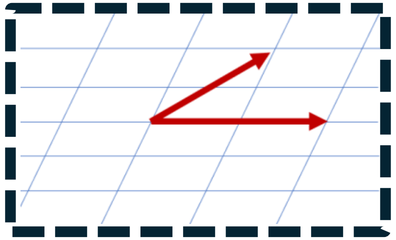

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⇒ Main **post-quantum candidates**, only credible **homomorphic encryption**…

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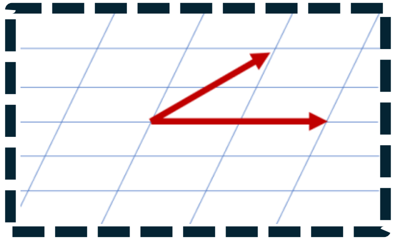

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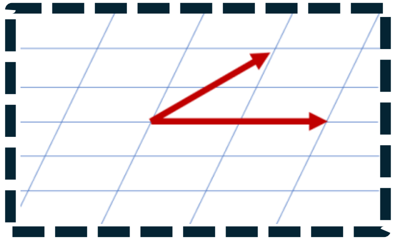

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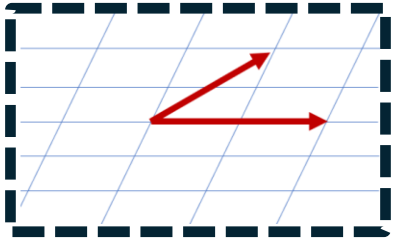

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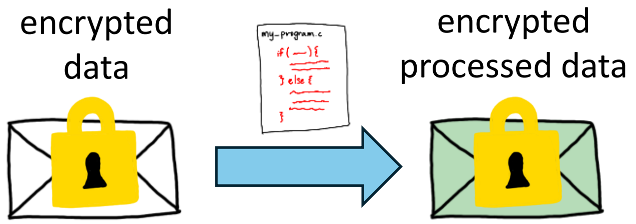
My goal: Decouple cryptography from specific hardness assumptions

Diversifying Assumptions in Cryptography

1

Strong functionalities from a **wide range of assumptions**



Diversifying Assumptions in Cryptography

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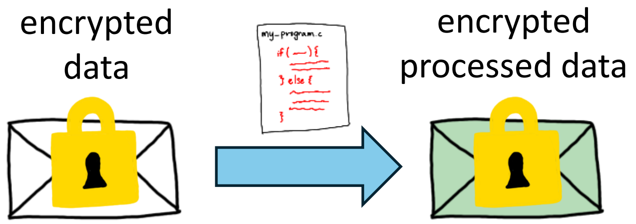

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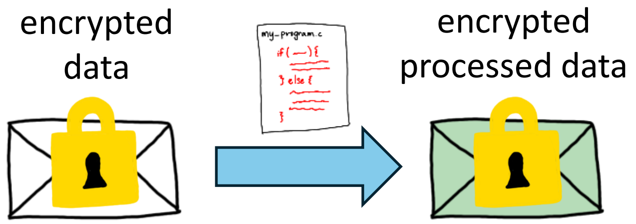

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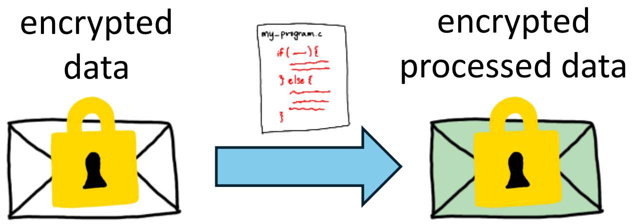

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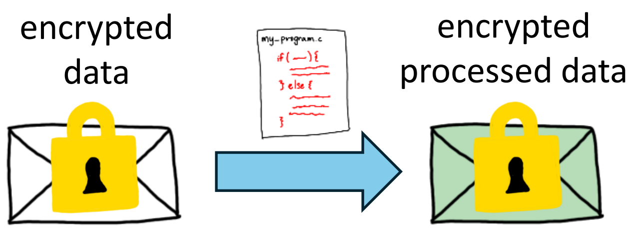

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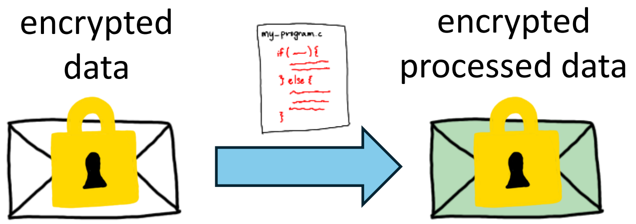

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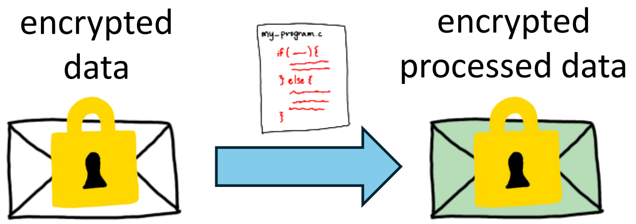

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- Develop techniques suited to **other assumptions**

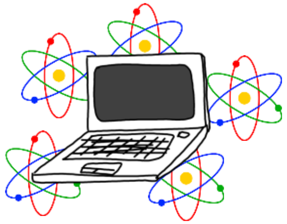
  New assumptions ignored by theory: lattice isomorphisms, isogenies, multivariate systems…
  But also old assumptions! (elliptic curves, coding theory…)

... or explain the absence of such techniques

Diversifying Assumptions in Cryptography (2)

2

Quantum computation and cryptography



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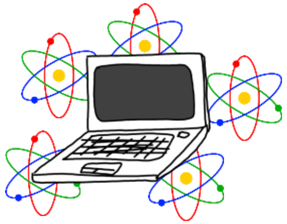

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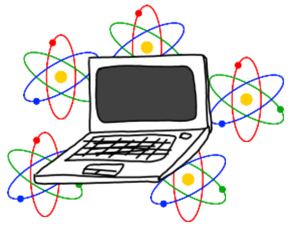

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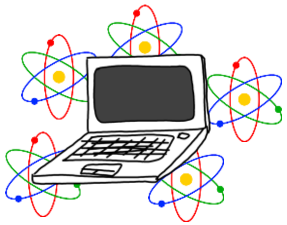

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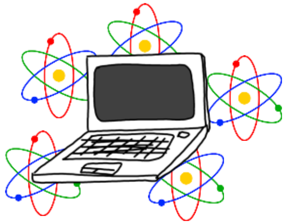

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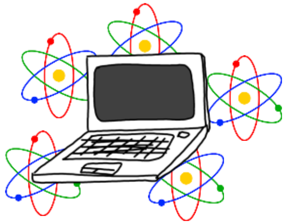

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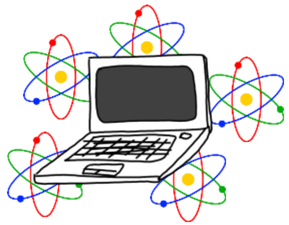

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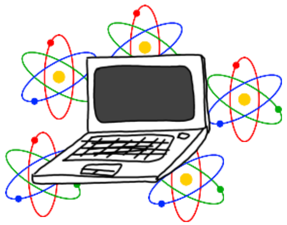

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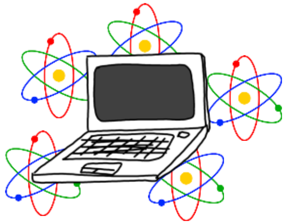

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Need a new theory to reason about **inherently quantum problems**

e.g. breaking security of a *quantum* ciphertext

Integration in Teams

- DI-ENS, Paris, équipe CASCADE
  - David Pointcheval (elliptic curves, functional encryption…)
  - Phong Nguyen (lattices, quadratic forms…)
  - Brice Minaud (searchable encryption…)
  - Céline Chevalier (quantum uncloneable cryptography…)
- LIP6, Paris, équipe ALMASTY
  - Damien Vergnaud (randomness in cryptography, leakage-resilience...)
  - Charles Bouillaguet (alternate assumptions…)
  - QI team (Alex B. Grilo…) (foundations of quantum cryptography…)

Highlights

- Research area: **theory of cryptography**
  - Keywords: advanced forms of security and functionality, **foundations**
  - Research project: **Diversifying sources of hardness in cryptography**

- 17 publications ("A* conferences": CRYPTO x6, EUROCRYPT x3, FOCS)

- 25 co-authors

- Program committees (PKC '23, CRYPTO '24, TCC'24)