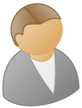
How do I authenticate myself in a post-quantum world?

Peeter Laud

Why and how do I authenticate myself?



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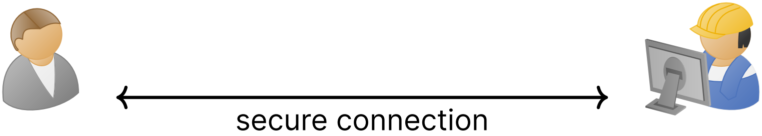

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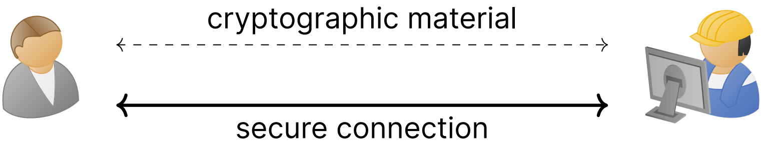

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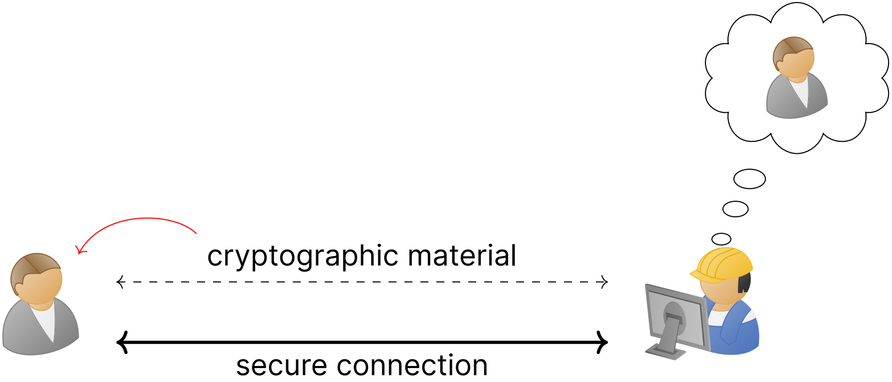

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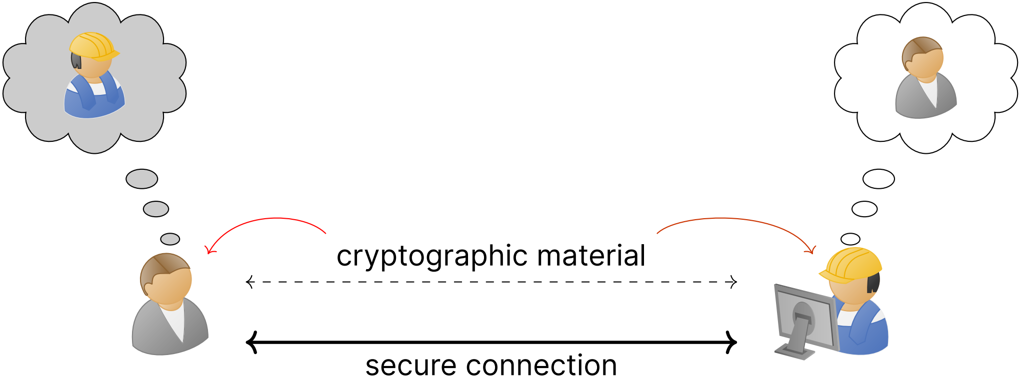

Identifying myself

What is "me"?

- Name?
- Date of birth?
- Personal code?
- Some biometrics?
- A combination of these?
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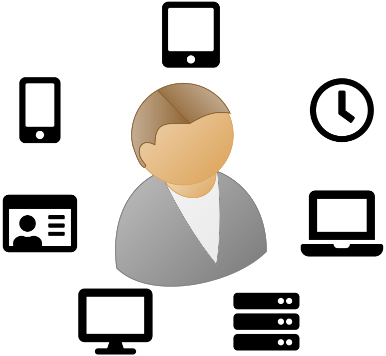
How do I use my public key?

- I have the corresponding private key.
- I do cryptographic operations with it.

Me and computing devices



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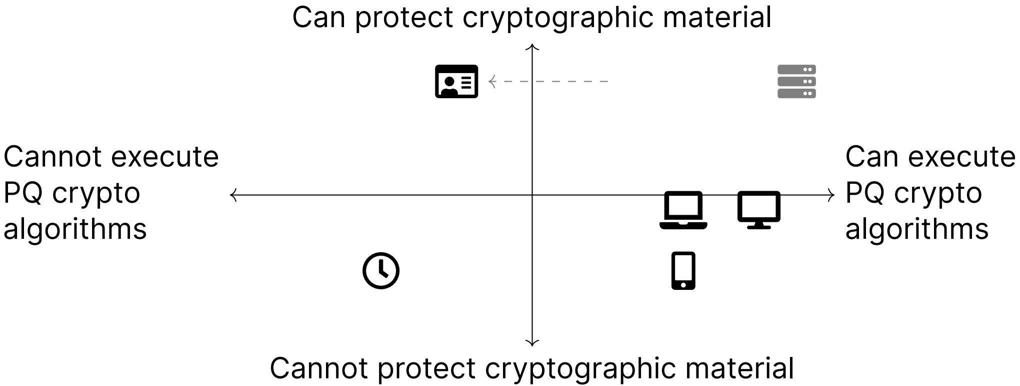

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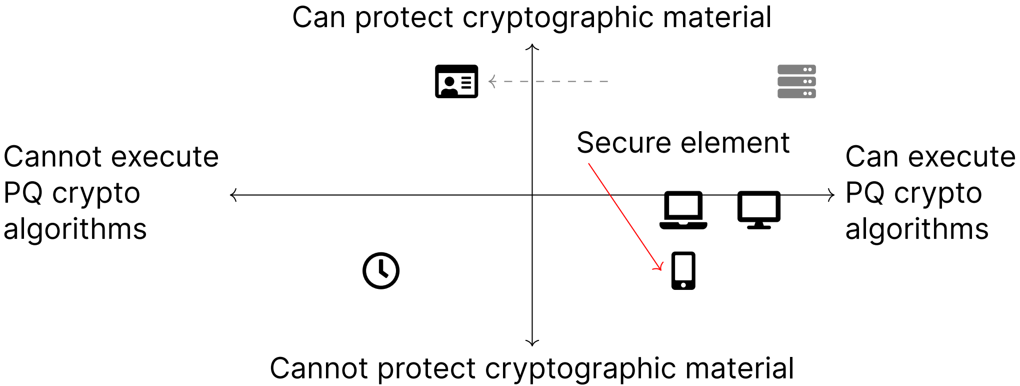

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What devices running authentication protocols are there?

For user

- Computers
- Smartphones
- Secure elements
- Embedded devices
- Smartcards, tokens, dongles, . . .

For relying party

- Computers (servers)
- Hardware Security Modules (HSM)

- These need to compute digital signatures

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Threshold signing

- Parties $P_1, \ldots, P_n$ hold shares $sk_1, \ldots, sk_n$ of the signing key
- The corresponding public key pk is known to everyone
- Given a message M, parties $P_1, \ldots, P_n$ can run a protocol and produce a signature σ
- Using pk, anyone can verify that σ is a signature on M
- This setting is particularly interesting when the verification procedure is a “standard” one

Support for PQ authentication

Smartcards

- Signing has been realized
  - … for Dilithium, Falcon
  - But no side-channel protection
- Side-channel protection requires too much memory
- Falcon's floating-point operations are hard to protect

Threshold cryptography

- There exist threshold signing protocols for Dilithium and Falcon
  - Too inefficient for Smart-ID
- Dilithium has inspired more efficient threshold schemes
  - Verification algorithm is different
- (Thresholdizing hash-based constructions is harder)

Key encapsulation may be simpler

TOPCOAT — our Dilithium-inspired threshold signature scheme

- Designed specifically for two signing parties
- Applies Dilithium’s compression techniques for public keys and signatures
- Relies on same lattice-based hardness assumptions as Dilithium
  - … with equally efficient security reductions
- Efficient in practice

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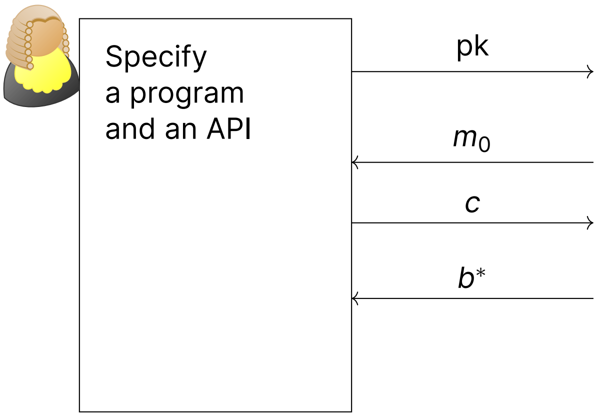
Everything OK with PQ authentication?

In practice, yes. In theory, ...

On details of security proofs

- There are (computational) hardness assumptions
  - E.g. factoring products of large primes, finding discrete logarithms, finding short vectors in lattices, learning with errors
- There are cryptographic primitives
  - E.g. digital signature, public-key encryption, hash function
- There a security definitions of these primitives
  - E.g. existential unforgeability under chosen-message attacks, collision-resistance

Hardness assumptions and security definitions



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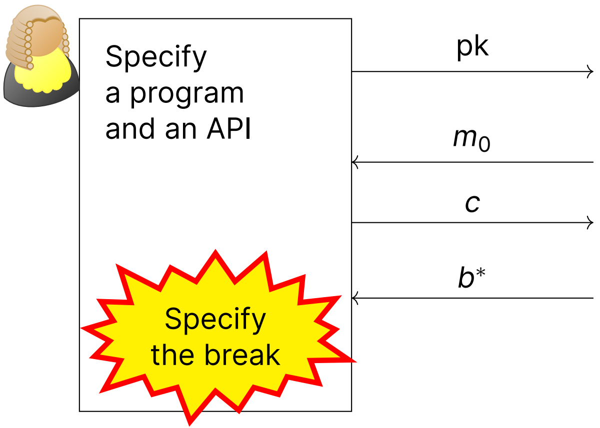

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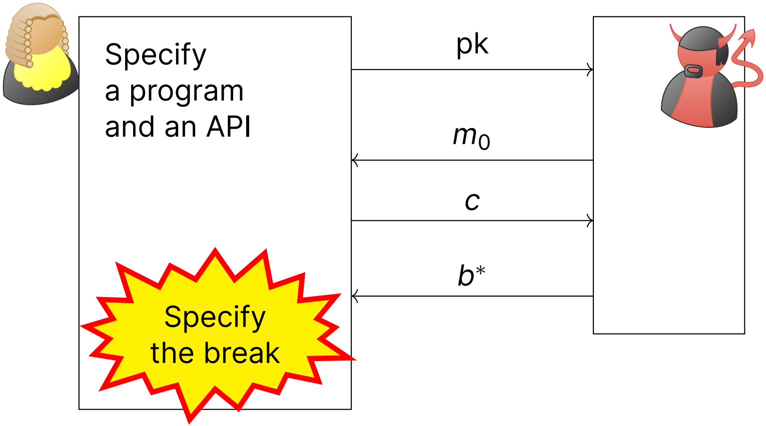
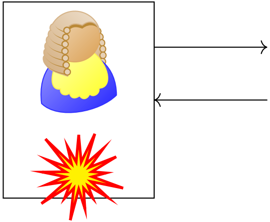


Postulate that

there is no 
that causes the break

Reductions



If a computational problem is hard then a cryptographic primitive is secure

Reductions

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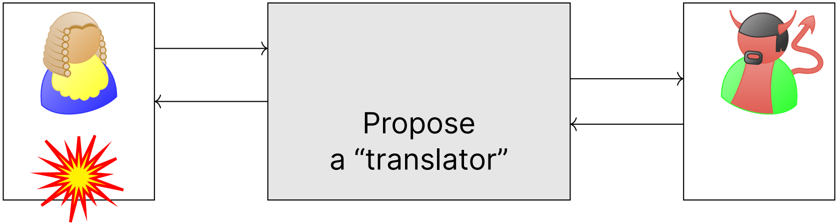

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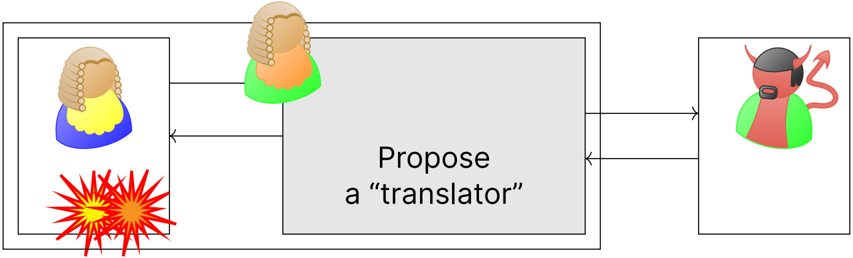

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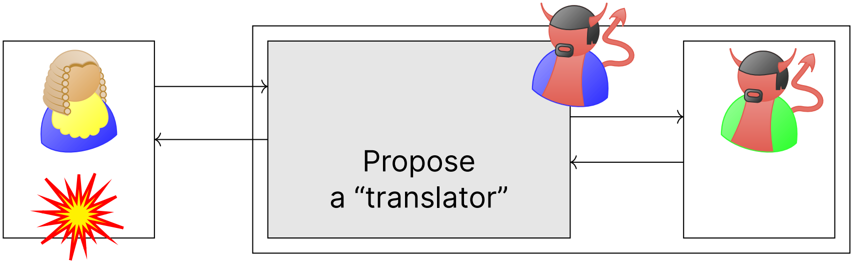

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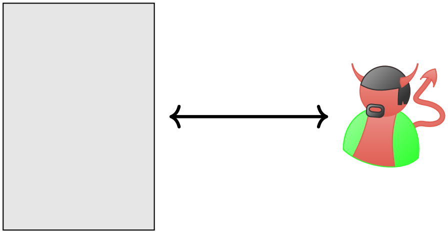

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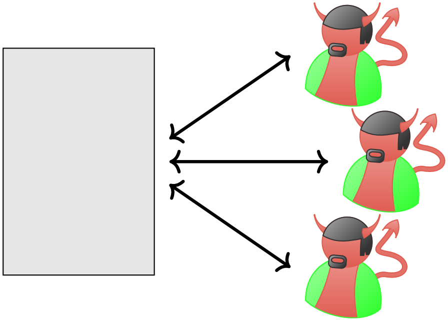

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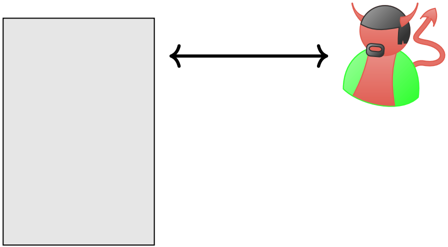

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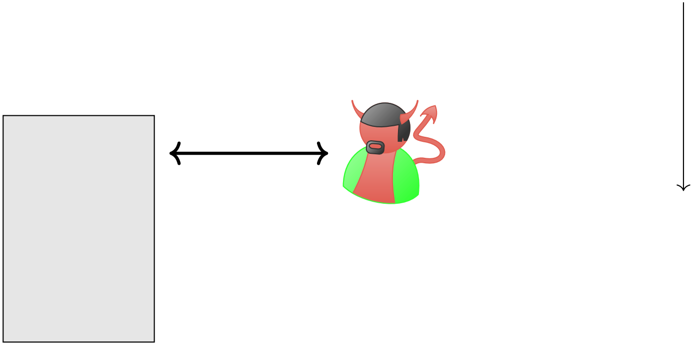

Execute

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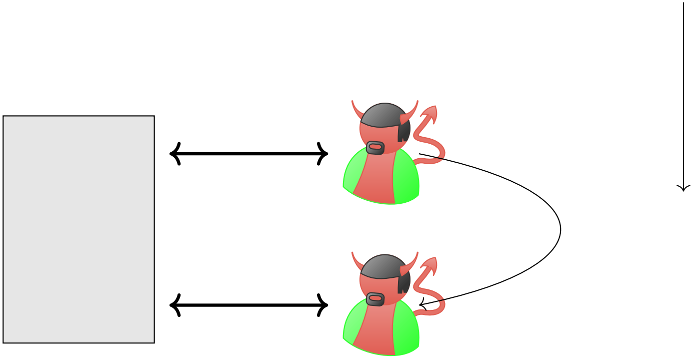
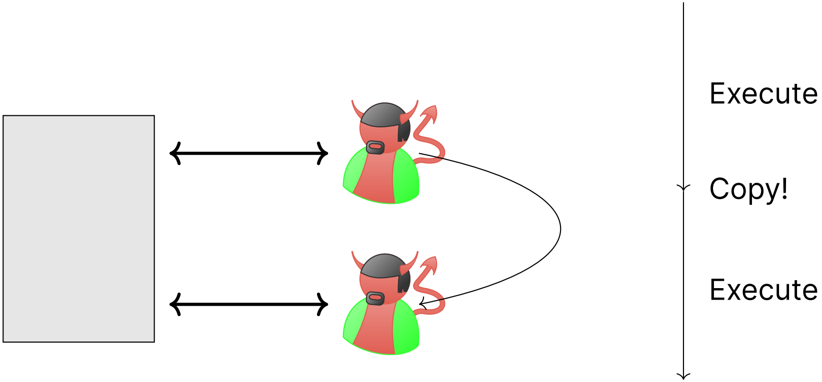


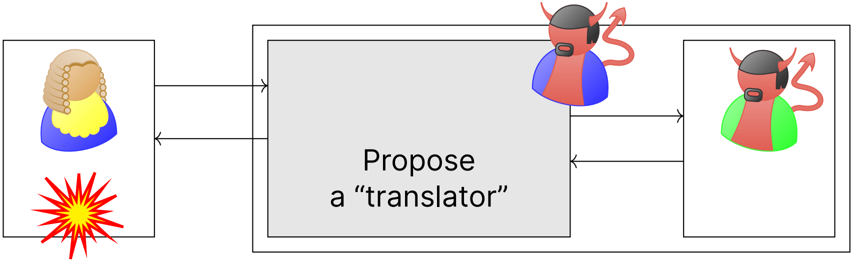
Execute

Copy!

How reductions may use 



Quantum reductions



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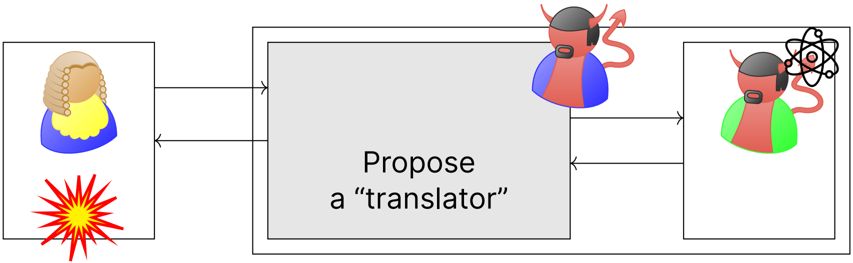

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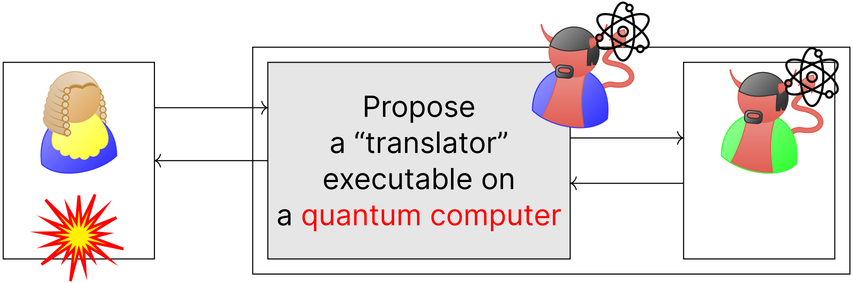

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“Plausibly quantum-secure” constructions

- Some hardness assumptions do not hold in presence of quantum adversaries. Others do
  - A hardness assumption holds in presence of quantum adversaries $\Rightarrow$ it holds in presence of only classical adversaries
- Dilithium, Falcon, etc. have proofs that quantum-reduce their security to some quantum-valid hardness assumption
- Many other constructions have proofs that only classically reduce their security to some quantum-valid hardness assumption
  - This includes TOPCOAT and other threshold lattice-based signatures

Way forward

- Certain steps cannot be executed on a quantum computer
  - Rewinding
  - Gradually defining a function
    - ... that is meant to be executed in quantum superposition
  - Enumerating the queries to such a function
- There are theorems stating that under certain conditions, these steps in reductions can still be emulated by a quantum computer
  - These conditions do not appear too onerous
- There is hope that we get a quantum reduction for TOPCOAT

Authentication vs. signing

Authentication

- Takes place in a single moment of time

Signing and verification

- There is a significant window of time b/w signing and verification

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Commonality

“Digital signature” cryptographic primitive tends to be important for both*

Post-quantum digital signing?

Can threshold cryptography help?

- As we said, existing threshold protocols for Dilithium are too inefficient
- But these protocols are “generic”. E.g. for any number of signers
  - Also, existing implementations are “generic”
- If we try to take advantage of the details of our setting, can we overcome the inefficiencies?
  - Number of parties is 2
  - The algorithm to be implemented is Dilithium
    - Optimize the components and their compositions

Secure multiparty computation (SMC)

- There's a function $(Y_1, \ldots, Y_n) = f(X_1, \ldots, X_n)$ (may be randomized)
- There are n parties $P_1, \ldots, P_n$. Party P_i has a value x_i
- There is an *access structure* $\mathcal{A} \subseteq 2^{\{1,\ldots,n\}}$ if $n = 2$, then $\mathcal{A} = \{\{1, 2\}\}$

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- Π may provide security against *passive* or *active* corruptions
  - Kinds of active security: fail-stop, identifiable abort, . . . , full security

A common technique of SMC

- A private value v is **additively shared**:
  - Fix a modulus N of suitable size
  - Party P_i holds $v_i \in \{0, \ldots, N-1\}$, s.t. $v_1 + \cdots + v_n = v \pmod{N}$
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- Addition (modulo N) of private values requires no communication
- There are protocols for other operations with private values
  - These are composed to a protocol for f

Typical performance profile of SMC protocols

- Additions (and linear combinations) are “free”
- Revealing a value takes some communication
  - Entering a value may be free, or take some communication, too
- Multiplications take more time / communication
- Equality checks take even more time
- Inequality checks take even (a lot) more time

Off-/online constructions of SMC protocols

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- $P_1, \ldots, P_n$ may use more heavyweight protocols to generate correlated randomness
  - This may happen during “downtime”
- Or, there may be some extra “trusted” party that generates correlated randomness

Correlated randomness for (in)equalities

- Faster protocols for inequalities are currently an active research area
- Involve novel forms of correlated randomness
- Proposals are often secure only against passive adversaries

Our in-progress work

- Three parties: Phone, Server, Correlated Randomness Generator (CRG)
- Security against one of the parties:
  - against actively corrupted Phone, or
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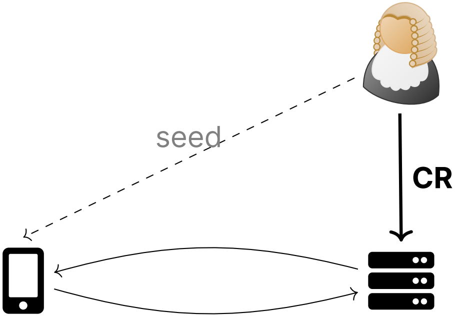
- ca. 20 rounds of communication
- Hundreds of KB of exchanged messages
- Megabytes of correlated randomness going to Server

Deployment?



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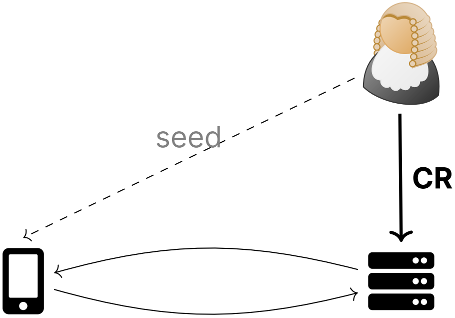

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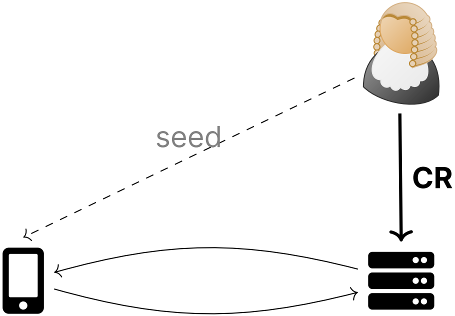

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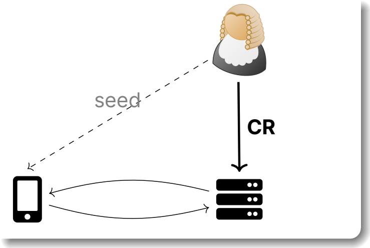
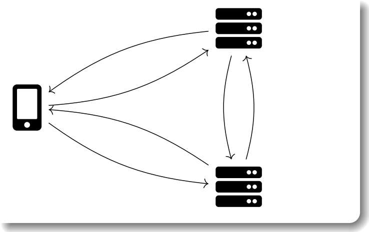
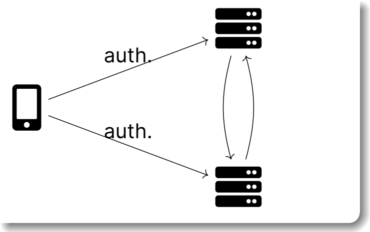
Performance?

Will it be acceptable?

Alternative 3-party, 1-corruption deployments







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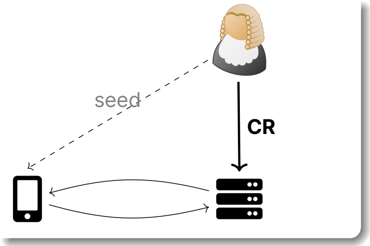
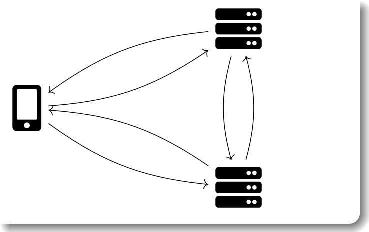
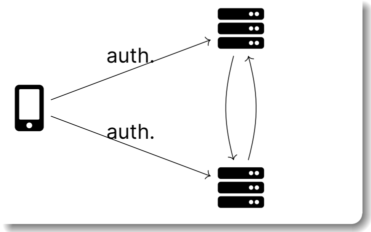


✅ Easiest to deploy



✅ Simplest protocol



✅ Simplest for phone

❌ No keyshare in phone

Conclusions?

Excellent, but not hopeless…