On the Security of Proofs of Sequential Work in a Post-Quantum World

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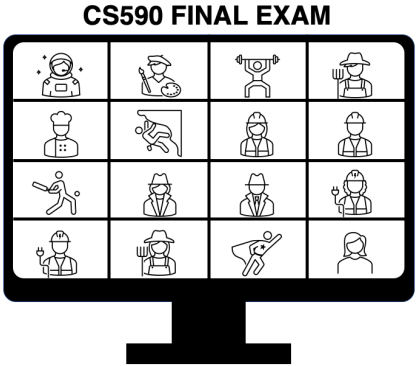
July 28, 2021

Conference on Information-Theoretic Cryptography (ITC) 2021

Motivation: Online Exams during the Pandemic



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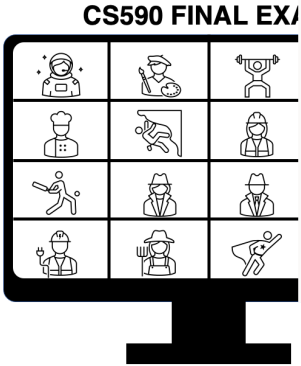

[CS590] 5 mins late - having internet issue

CG

Cinseer Goodman
Tue 5/2/2021 9:05 PM
To: Seunghoon Lee

answer-goodman.pdf
157 KB

Dear Professor,

My name is Cinseer Goodman who is taking CS590 this semester.
I hope this email finds you well.
I was not able to submit the final exam to the server on time due to an unexpected internet connectivity loss.
It just went back 5 minutes later so I send you the file via email.
I promise I have not done any extra work after the exam time. I hope it works.
Thank you.

Best,
Cinseer Goodman

Reply | Forward

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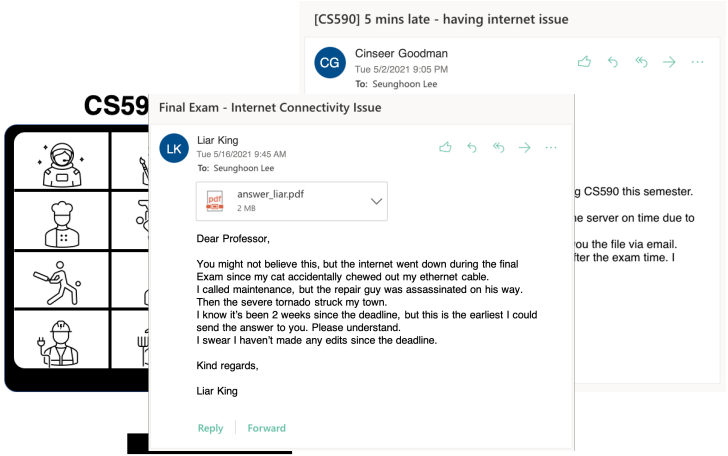

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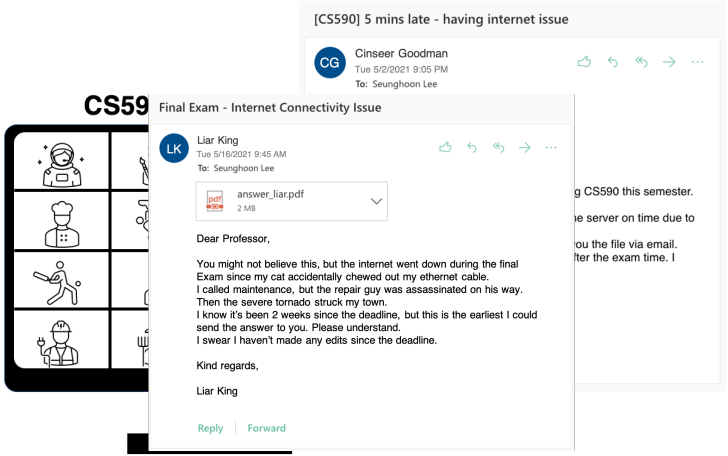

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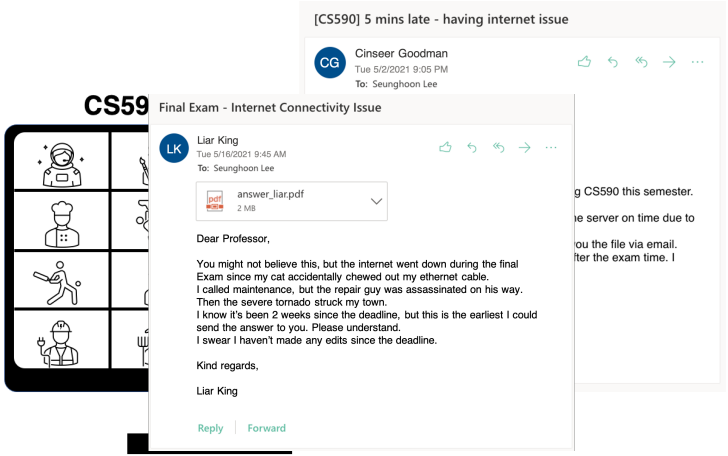

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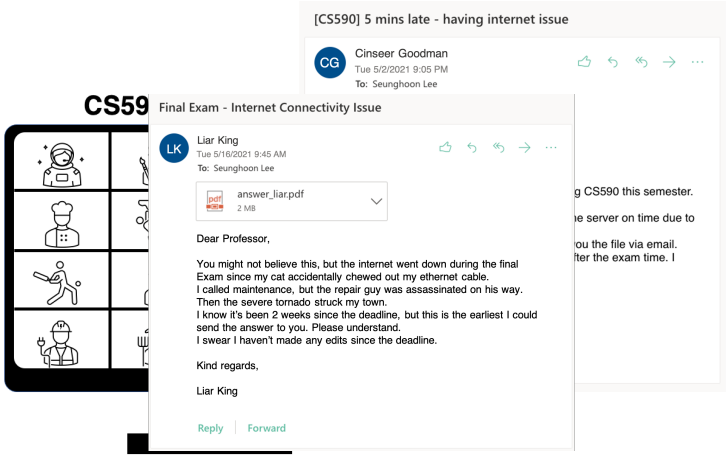

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Soundness: students (prover) should *not* be able to produce a *valid* proof faster (than sequential time , even if running in parallel).

PoSW Constructions

Mahmoody et al. [MMV13]: the first theoretical construction of a PoSW

- Verifier time , and prover time ,
- Parallel cheating prover running in sequential time cannot fool the verifier, and
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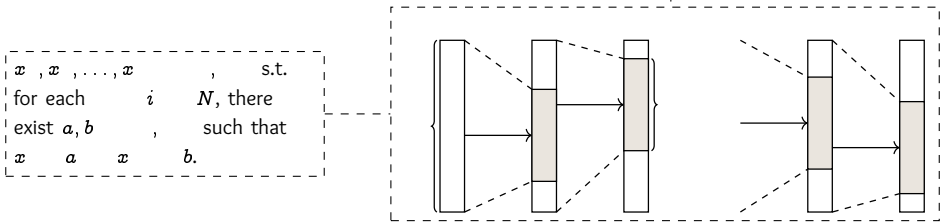

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Post-Quantum Security?

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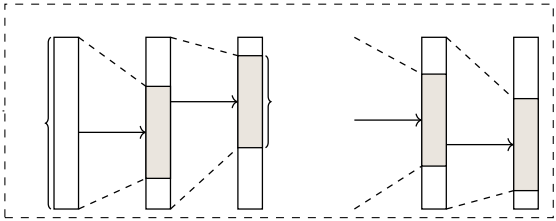
x , x , . . . , x , s.t.
for each i N, there
exist a, b , such that
x a x b.



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Short answer: NO!

Our Result. Hardness of Producing an -Sequence/PoSW in a Quantum Setting

Theorem (informal)

A quantum adversary making at most queries over rounds outputs an -sequence of length

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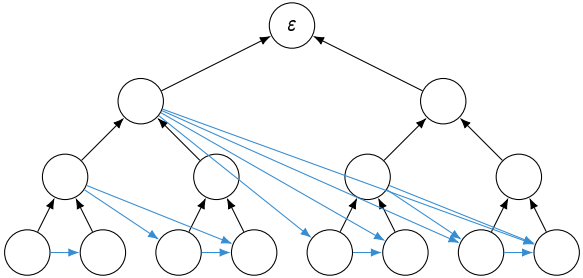
Concurrent/Subsequent Work.

Chung et al. [CFHL21]: also gave a comparable security bounds for the PoSW in the pqROM

The [CP18] Construction



statement being proved,
e.g., final exam solution

For all leaf nodes , add an edge for any that is a left sibling of a node on the path from to the root

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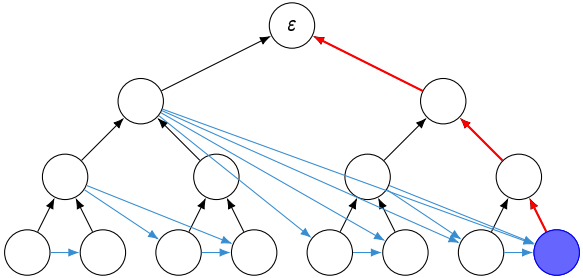

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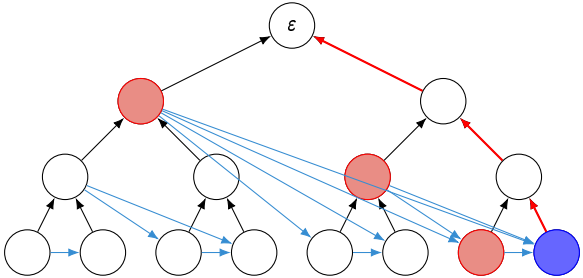

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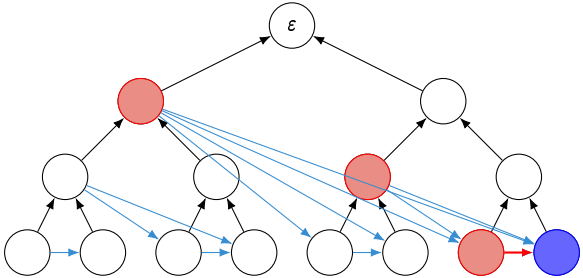

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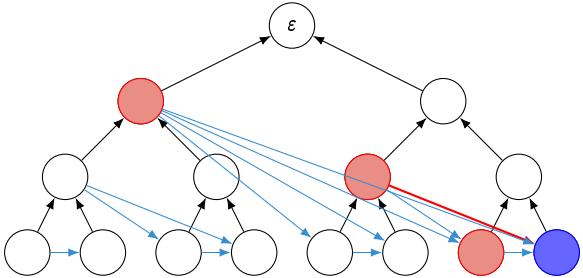

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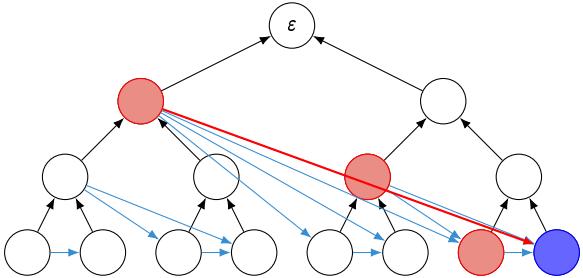

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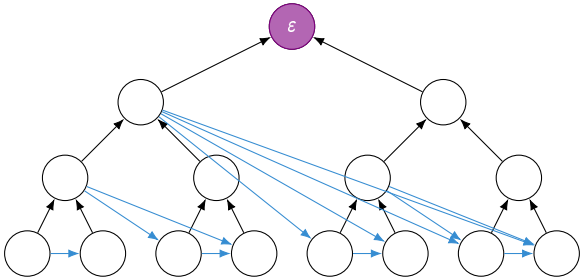

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Each node has a label, a hash of its parents

The label of root node forms a Kcpijc rpcc amk kgrkclr of all the other nodes

- Verifier can audit the prover by forcing the prover to open certain labels
- Show that they are locally consistent

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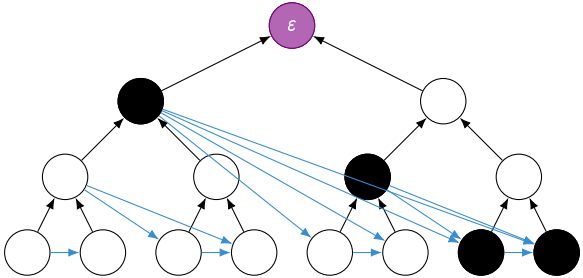

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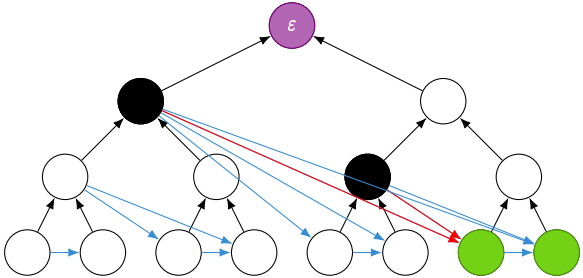

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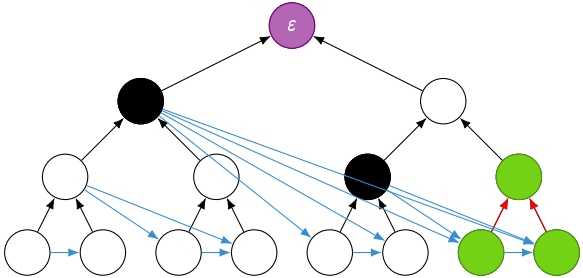

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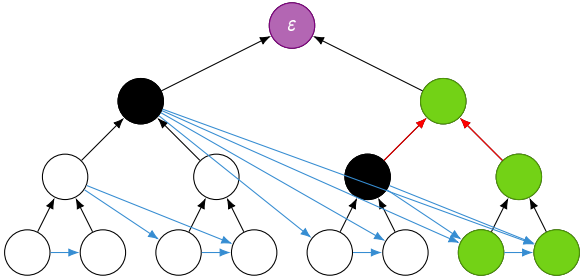

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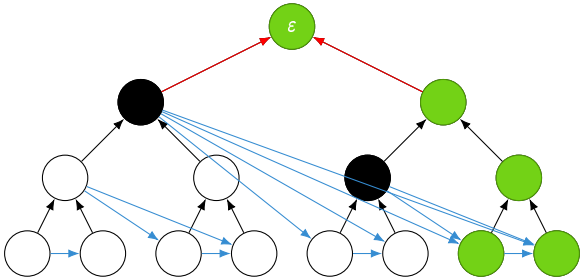

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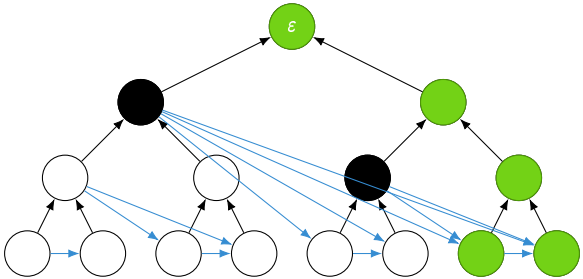

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Audit process: interactive or non-interactive (Fiat-Shamir)

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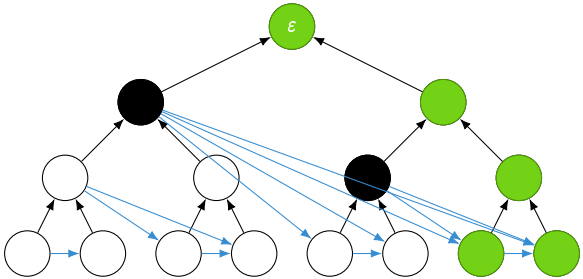

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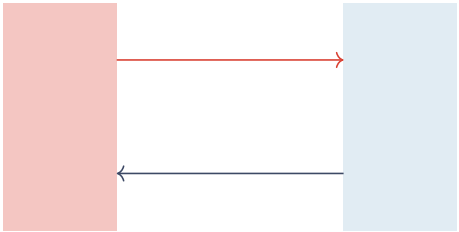
Any classical ROM attacker that produces a valid PoSW in time must produce a long -sequence

ROM vs qROM [BDF 11]

‹Classical ROM›



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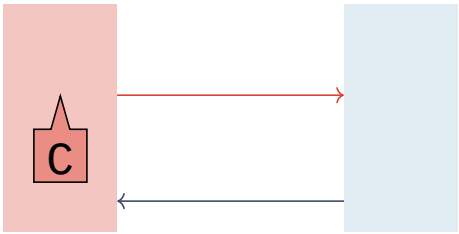

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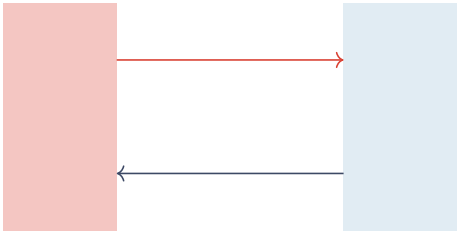

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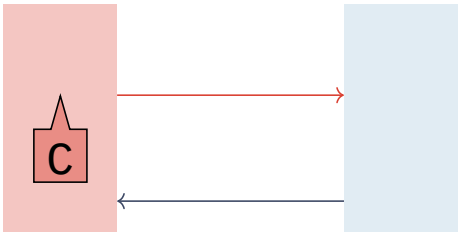

Security proofs are much more challenging in the qROM

- Programmability & Extractability (ROM: 4, qROM: 8)
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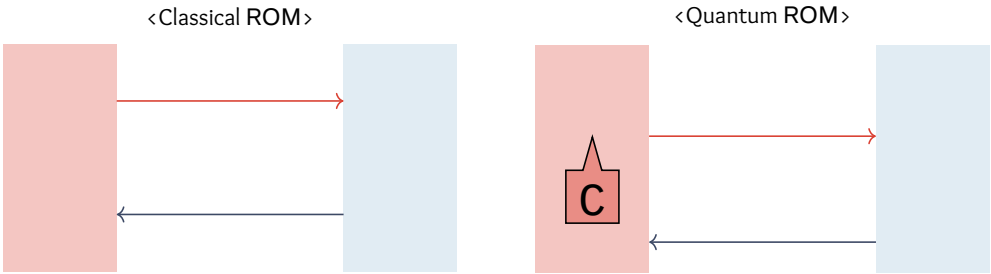

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Compressed Oracle Technique [Zha19]: change of view (compressed phase oracle (CPhsO))

Compressed Phase Oracle (CPhsO)

A database , where .

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Extending Compressed Oracle Technique to the pqROM: the oracle CPhsO^k

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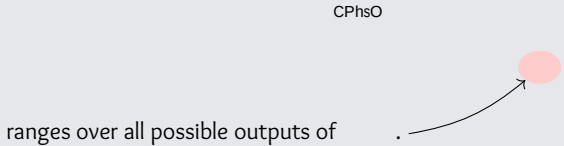

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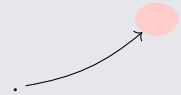

Example: Parallel Query (simplest case)

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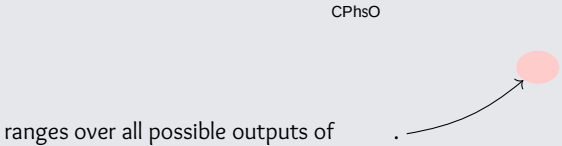

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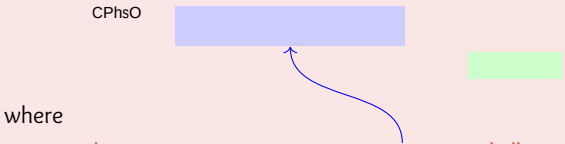

Extending Compressed Oracle Technique to the pqROM: the oracle CPhsO^k

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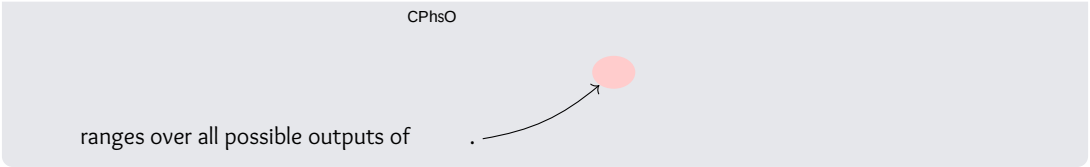

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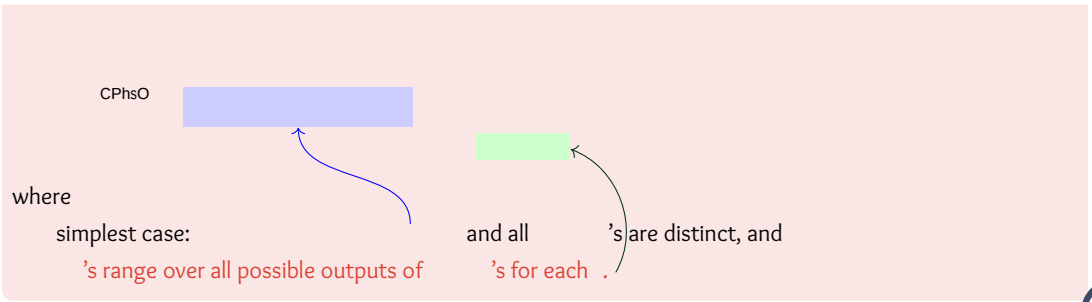
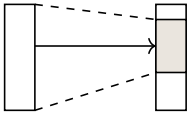
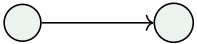


Notations

Given a database , define a directed graph on nodes such that:





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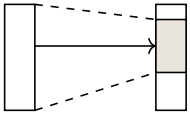

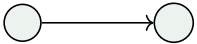

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contains an -sequence of length

PATH

Proof Ideas: Hardness of Producing an -sequence in a Quantum Setting

Lemma

: an initial state, and let CPhsO *. Then* PATH PATH .

Interpretation/Intuition:

PATH : 2-norm of the projection of onto PATH , i.e.,

PATH

PATH

If we start with the state that is nearly orthogonal to PATH , then after applying the oracle CPhsO , the resulting state is also nearly orthogonal to PATH .

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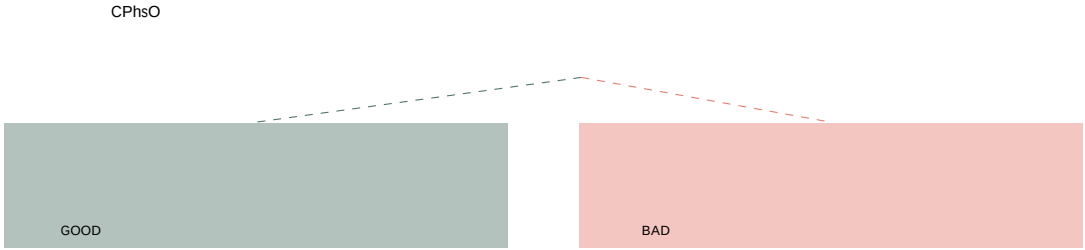

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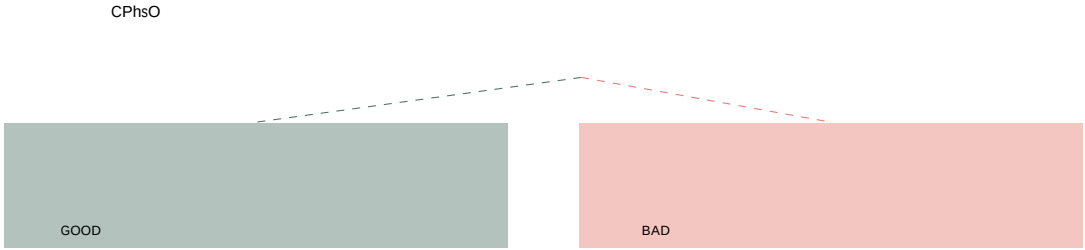

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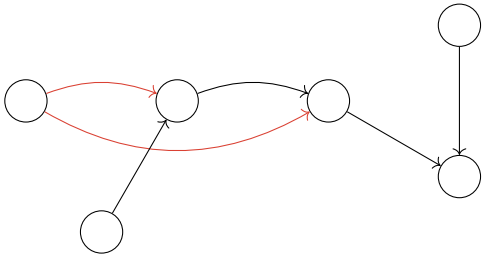

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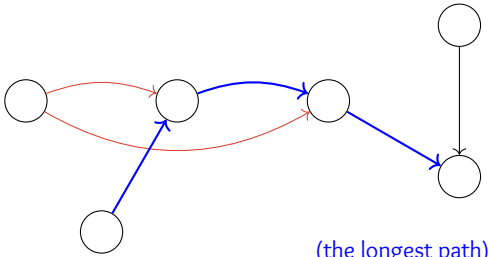

(the longest path)=

PATH but PATH

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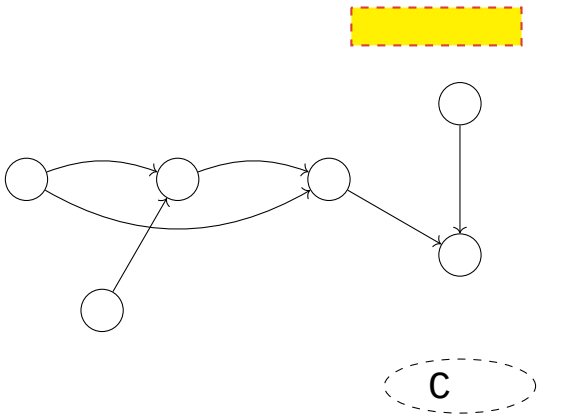
Suppose we have one query: (where). Then the updated database is:



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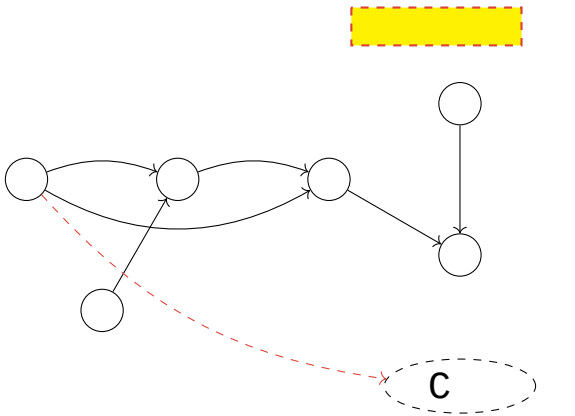

superposition over 's

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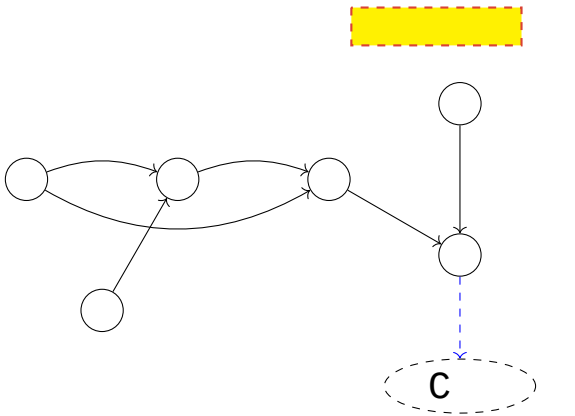

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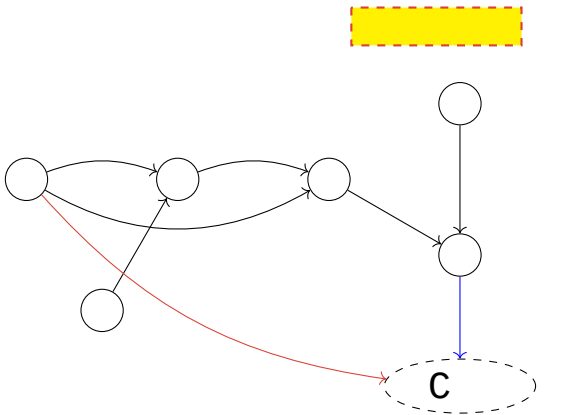

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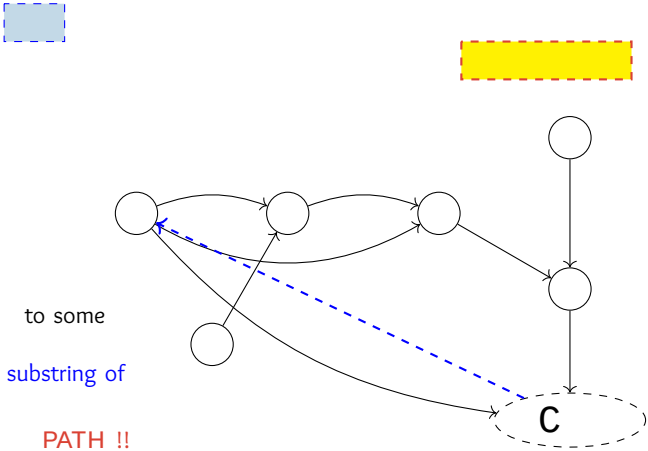

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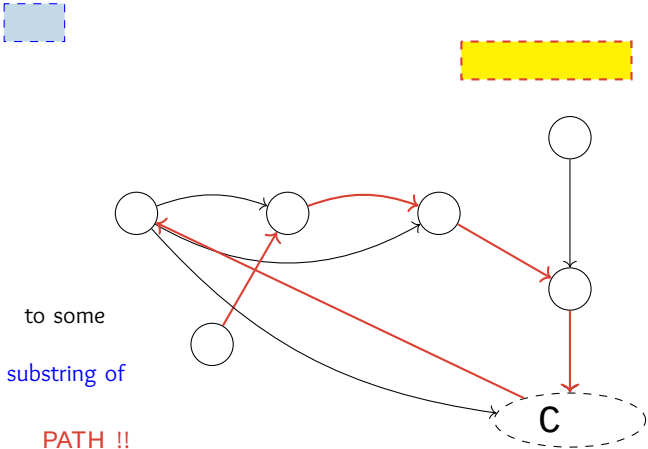

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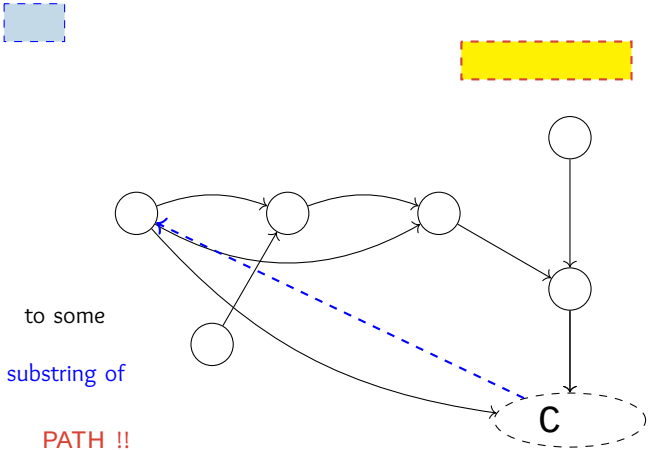

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The fraction of such 's is negligible! (out of)

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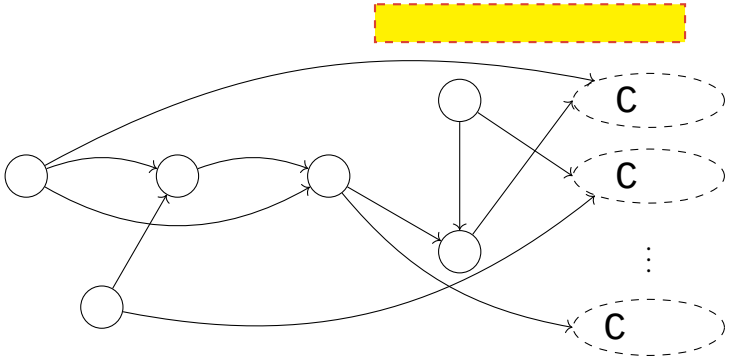
For a parallel query: (where and all 's are distinct for simplicity),



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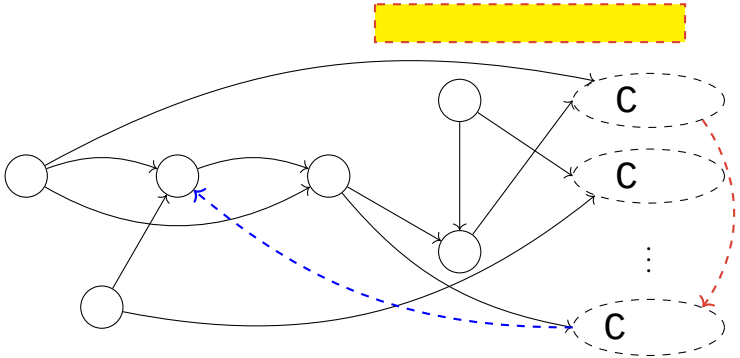

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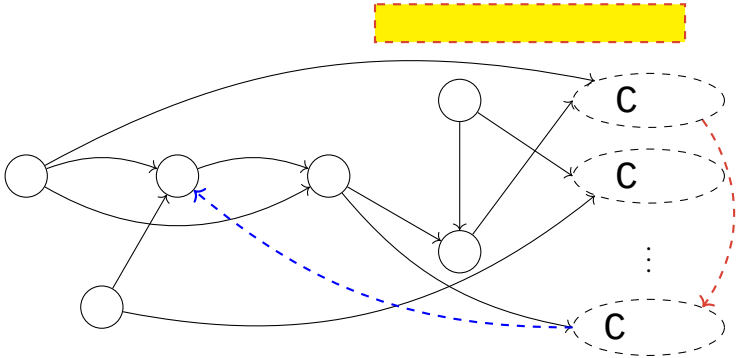

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Security of a non-interactive PoSW: similar argument using the result above - details in the paper

(M f f K f f < 8 8 @ K ; 8 C A ⊁ K

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Can techniques extend to other primitives, e.g., Proofs of Space, Memory-Hard Functions, etc.?

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