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Erasable PUFs: Formal Treatment and Generic Design

Chenglu Jin, Wayne Burleson, Marten van Dijk, and Ulrich Rührmair

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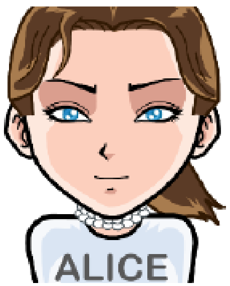
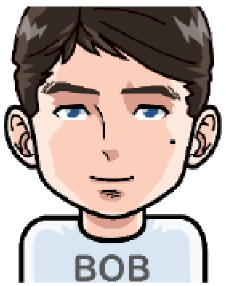
Today's Focus

Simplified PUF-based Key Exchange Protocol





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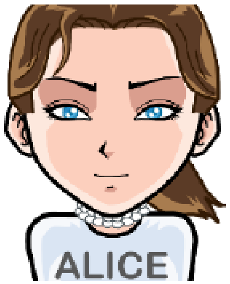
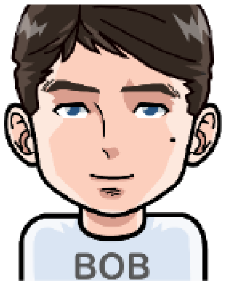
Simplified PUF-based Key Exchange Protocol





(C, R)

Public, Authenticated Physical Channel

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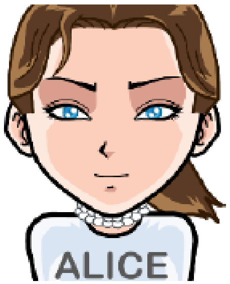

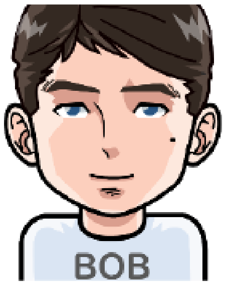

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Public, Authenticated Communication Channel

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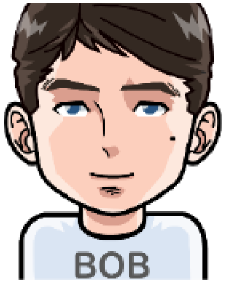

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The security of this protocol relies on the unpredictability of PUF responses given its challenges.

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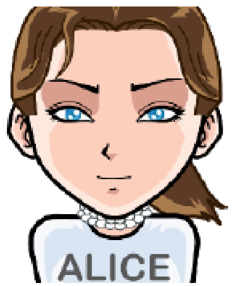

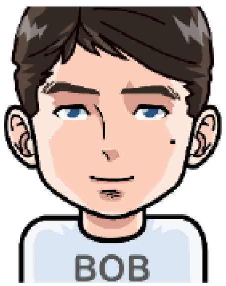

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Not Complete!

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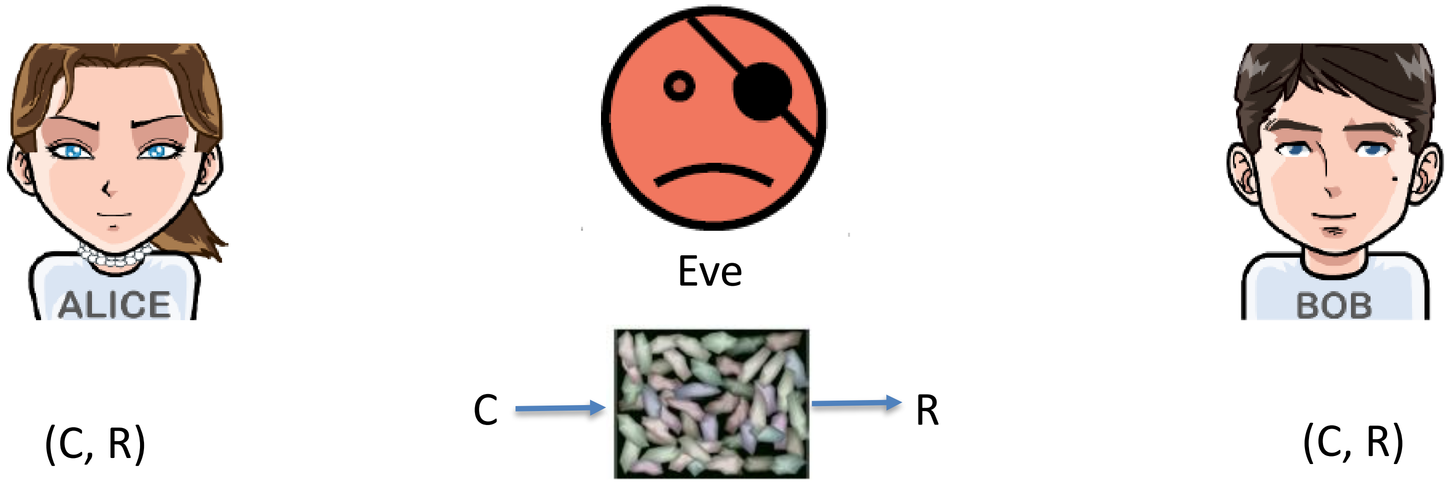

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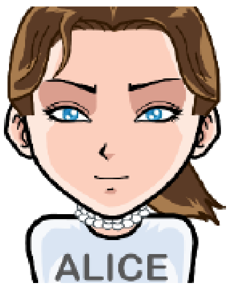
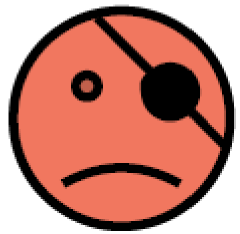
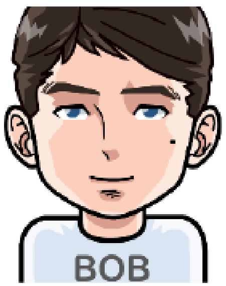




Eve



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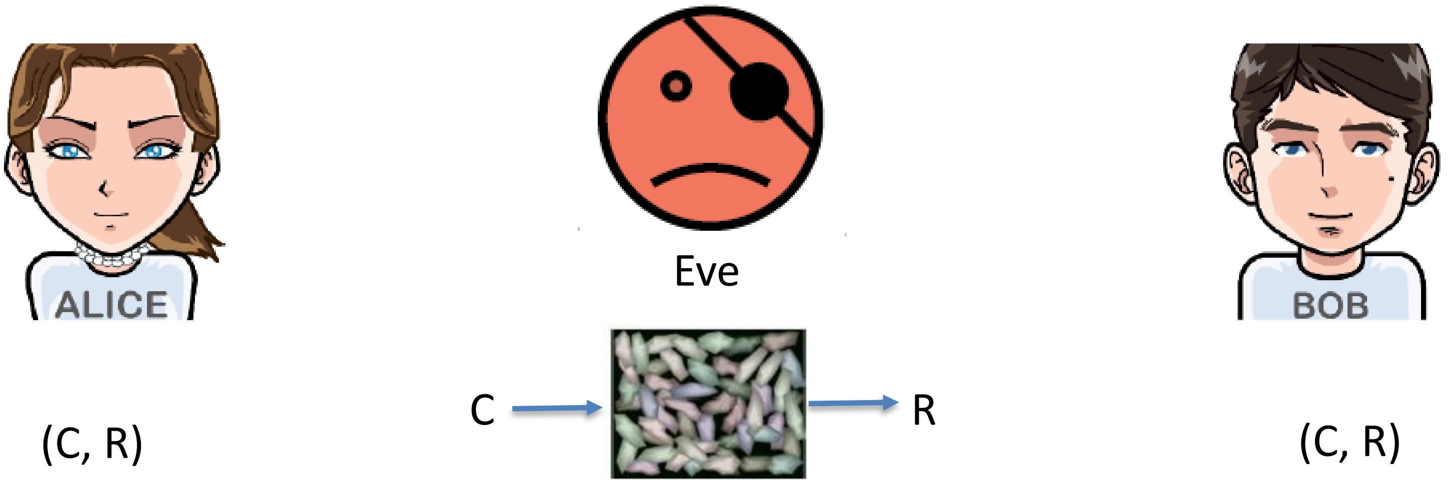

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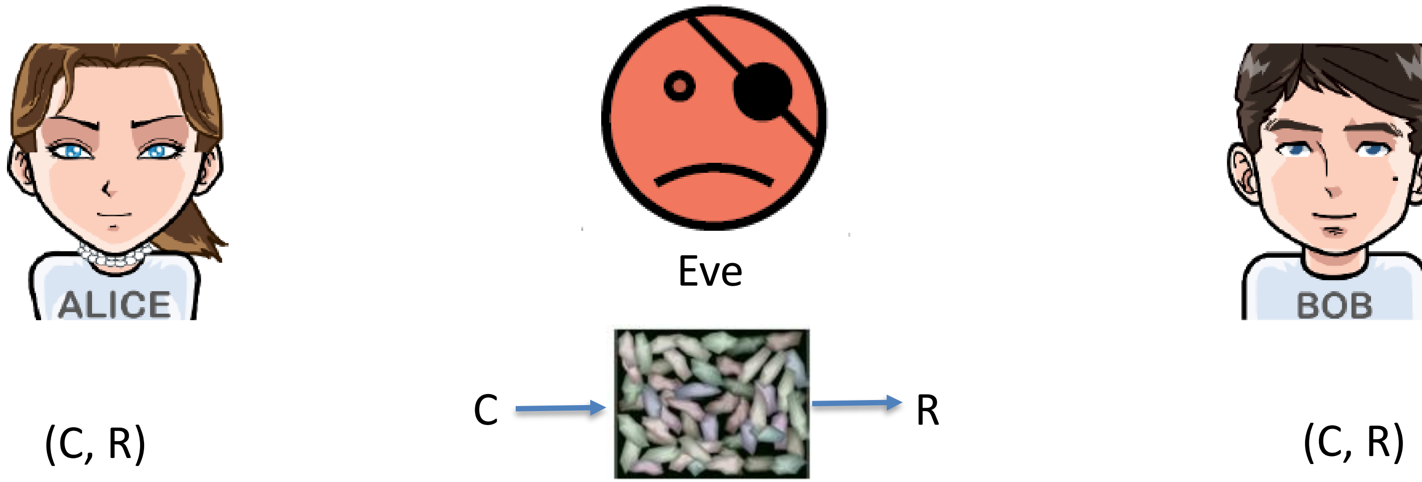

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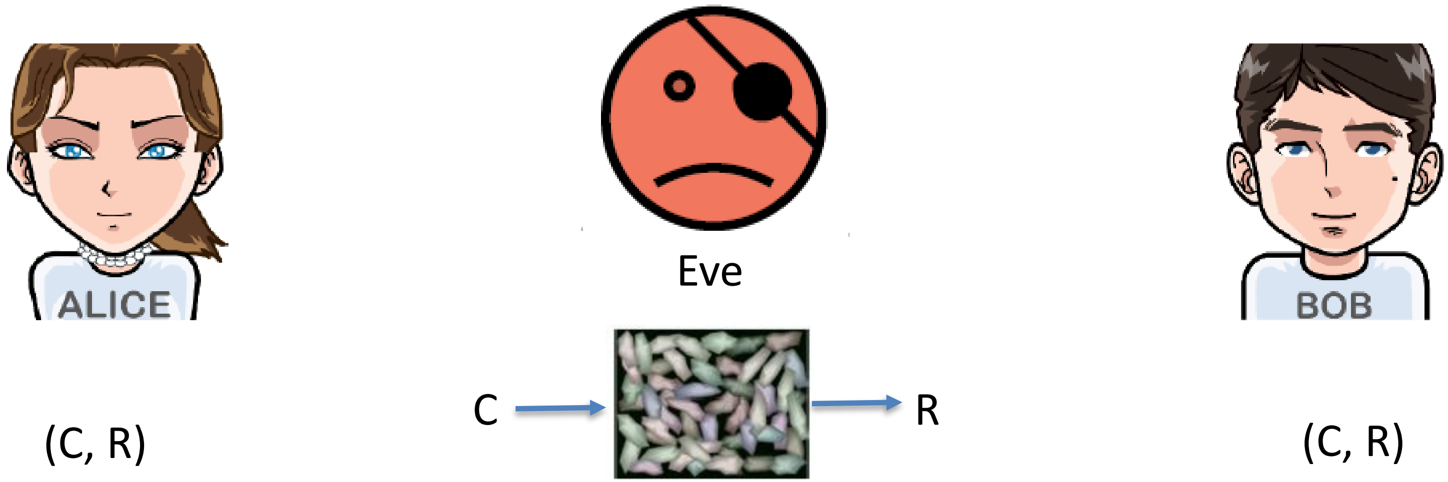

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- Highly realistic threat against PUF-based protocol, as destroying PUFs after one protocol execution is prohibitively uneconomic.
- Actually, impossibility results of constructing PUF-based crypto protocols like KE/OT in PUF Re-Use model have been proved.
- The issue has to be solved on the hardware level.

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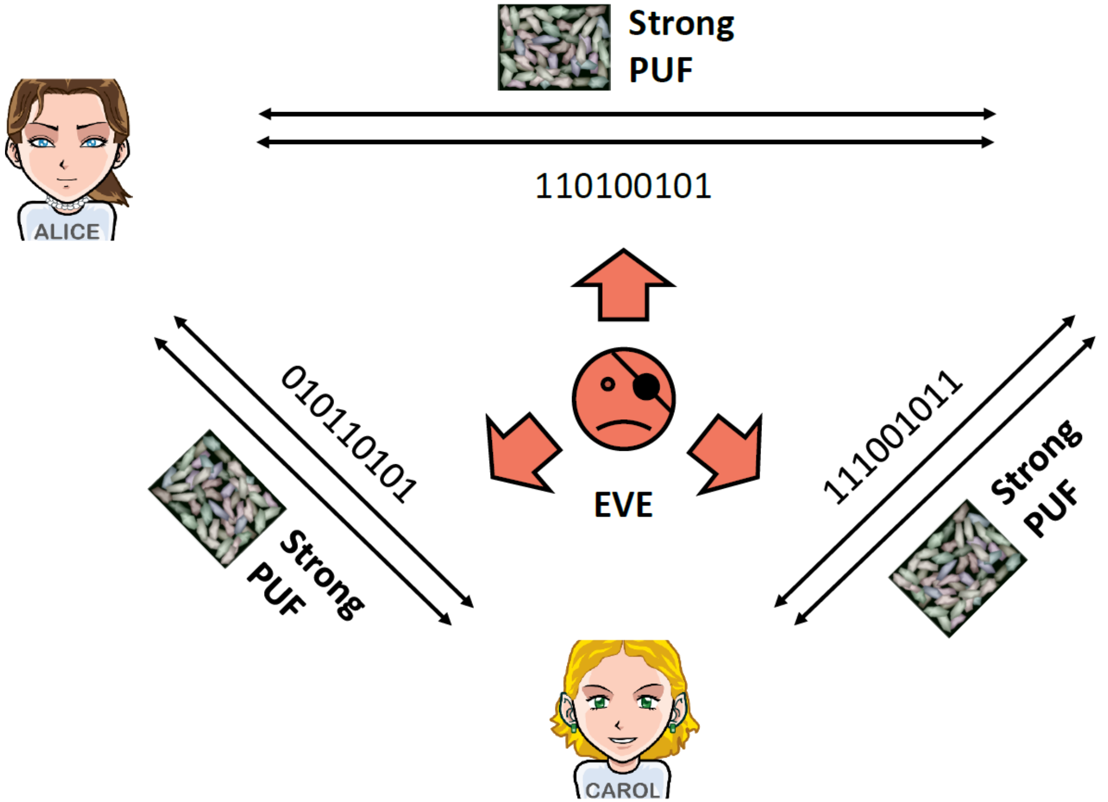
- Can a reconfigurable PUF solve the problem?
- A Reconfigurable PUF allows users to alter the responses of all challenges in one single operation (so-called “Reconfiguration”).

Stefan Katzenbeisser, *et al.* "Recyclable pufs: Logically reconfigurable pufs." Journal of Cryptographic Engineering (2011)

Multi-Party Use Case



Using reconfigurable PUFs in crypto protocols cannot support multi-party use case.

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- Erasable PUF-based crypto protocols can allow multiple parties to share one PUF and avoid repeated physical transfer of the PUF
- Users can only erase the used CRPs after protocol execution, without affecting the other CRPs

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- Drawback: The list should not be tampered with by adversaries, but the size of the list is growing when more and more challenges are erased. This implies that a large trusted memory is needed

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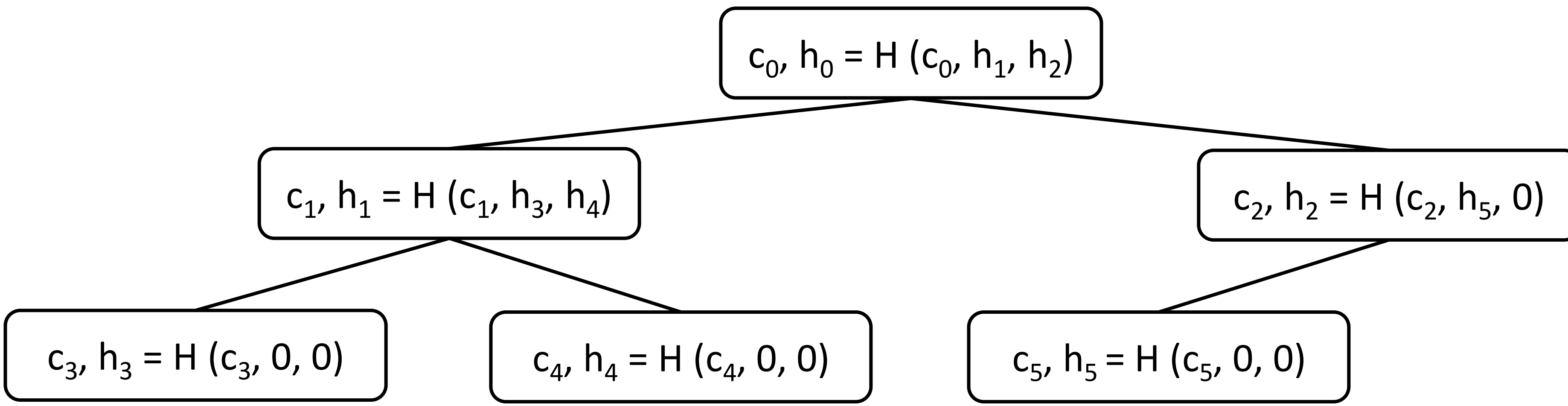
- Using the combined tree structure, the untrusted memory can provide a O(log(N)) size proof to the TCB to prove a challenge is (not) in the list of size N

Authenticated Search Tree Construction



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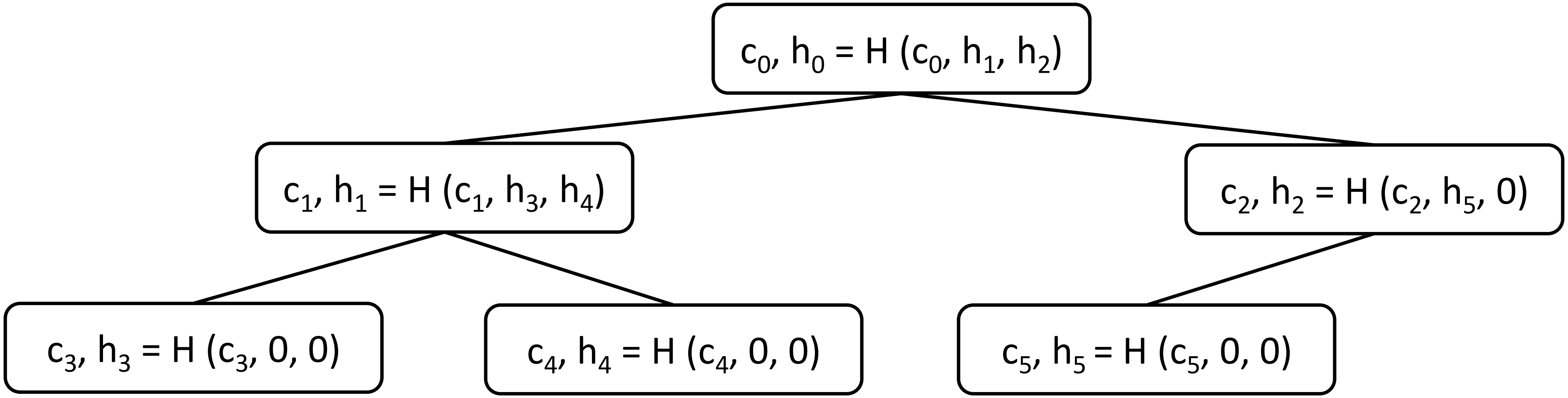

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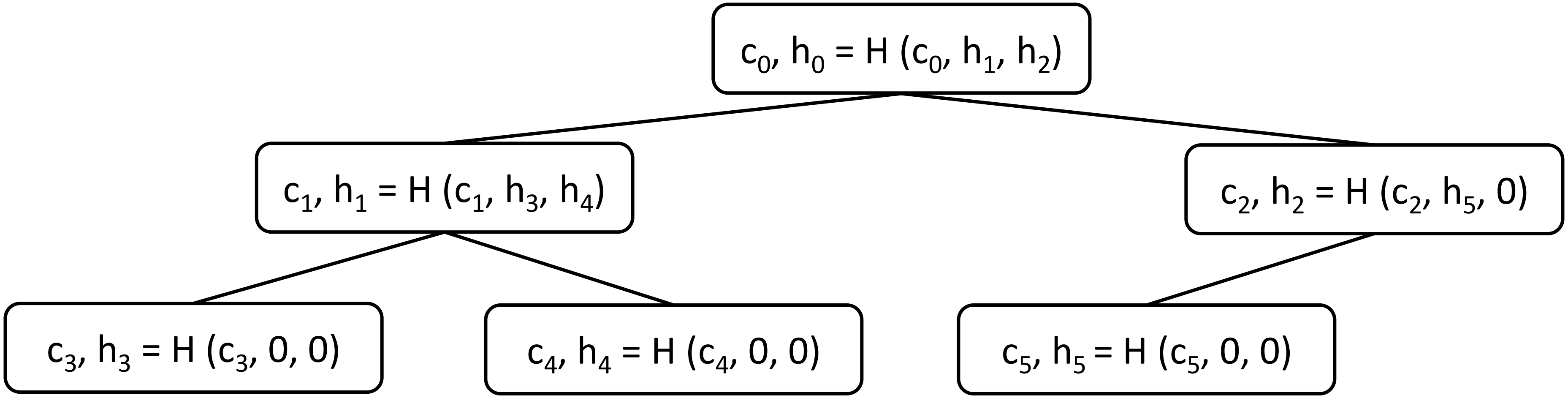

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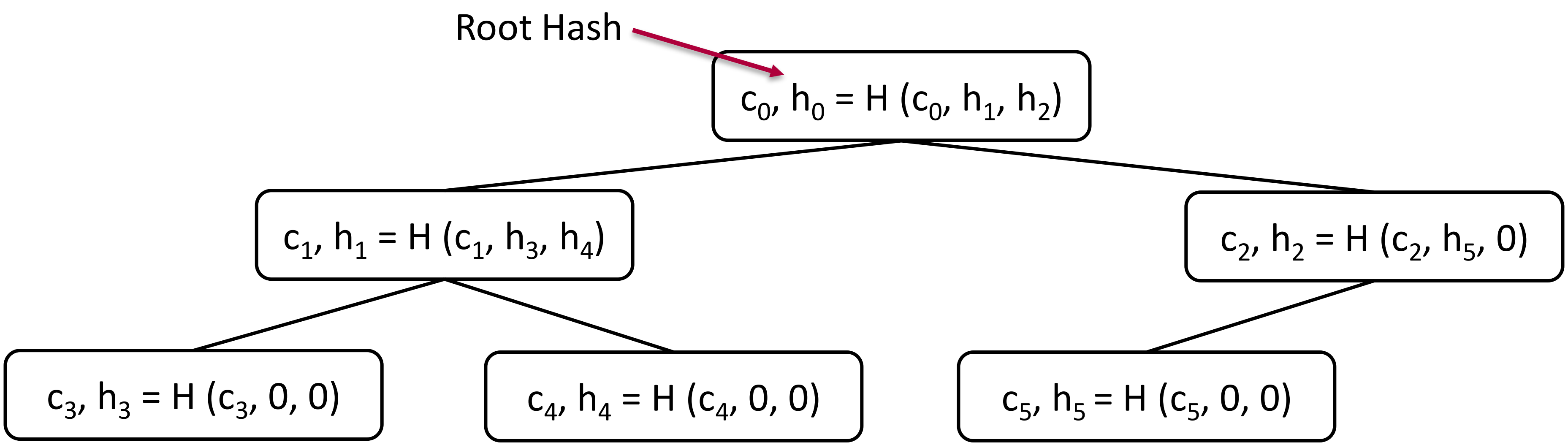

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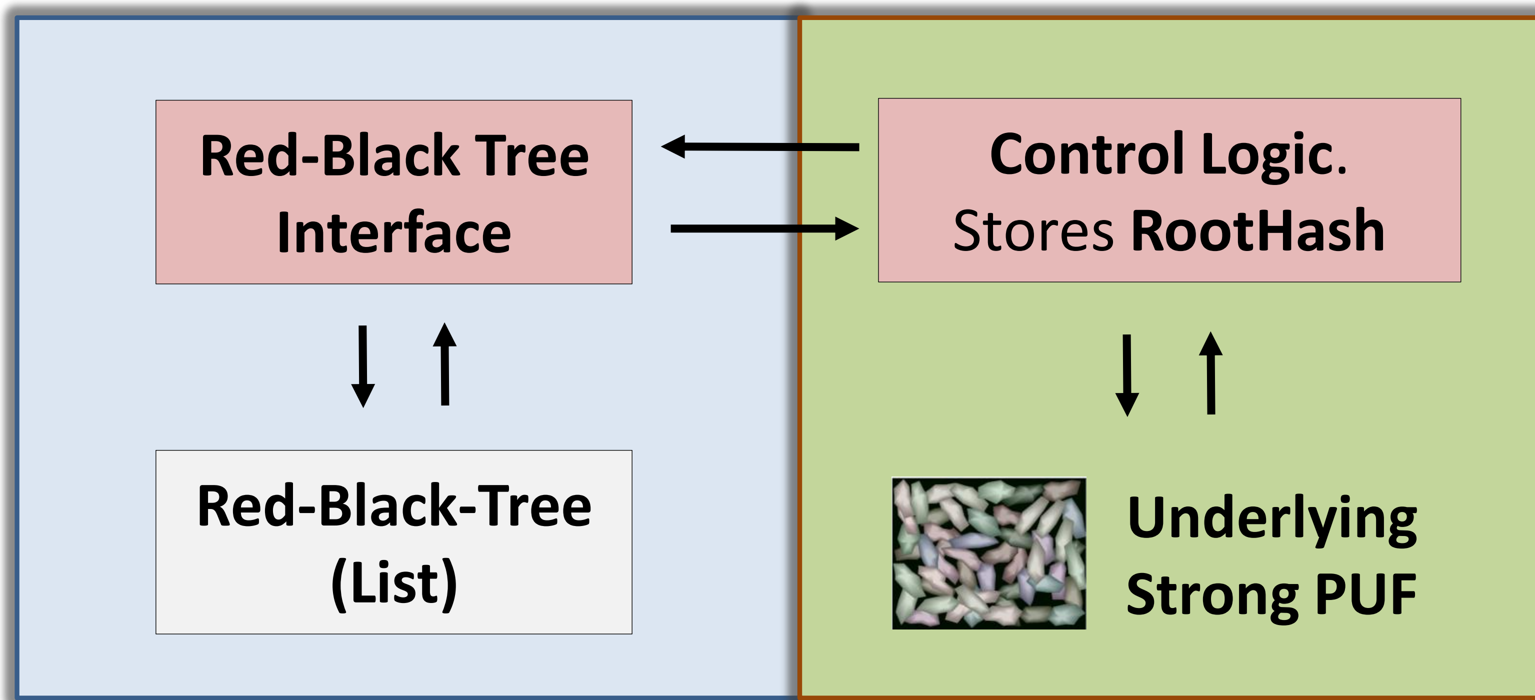
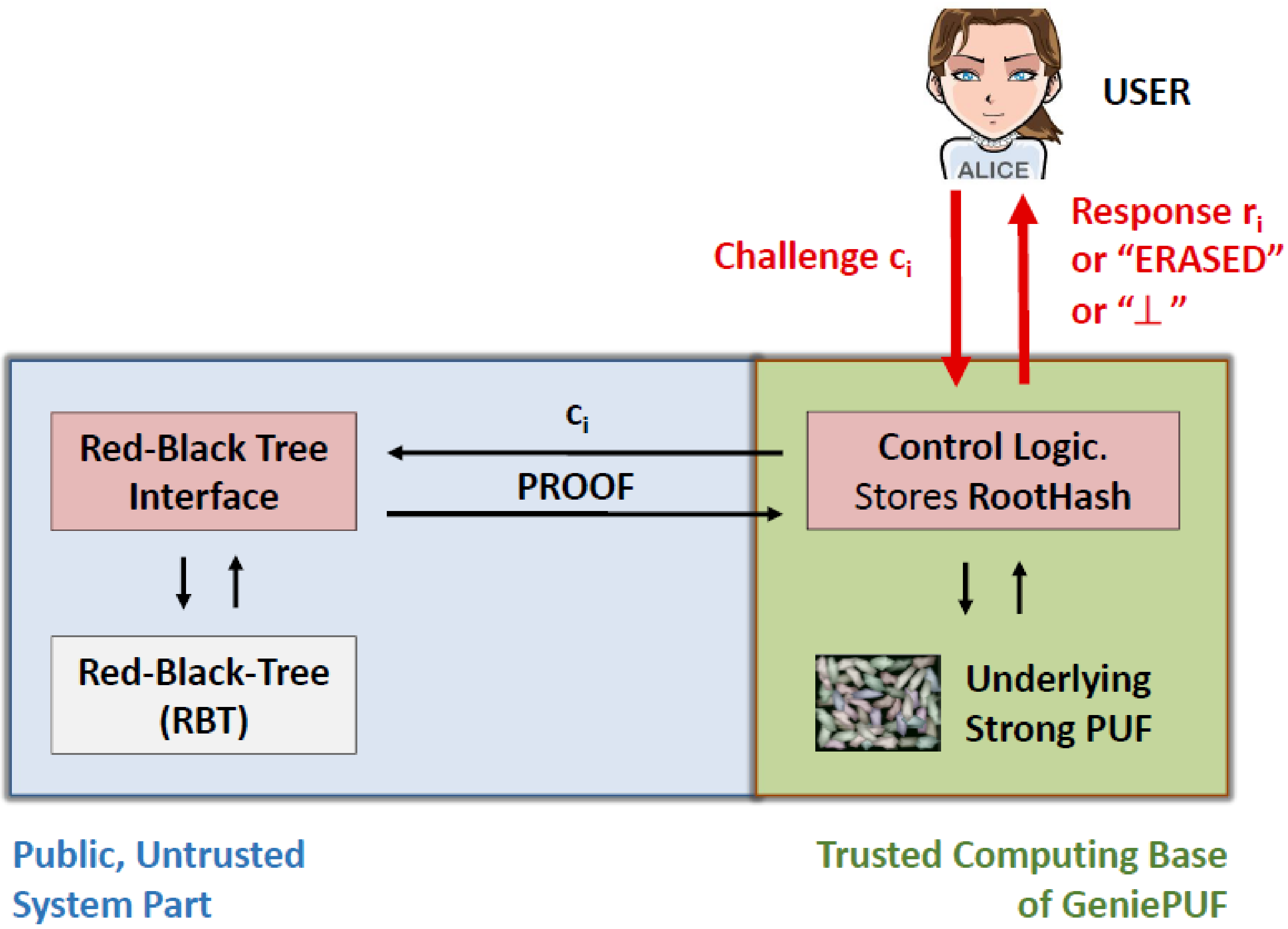
GeniePUF Architecture



Public, Untrusted System Part (Software)

Trusted Computing Base (Hardware) of GeniePUF

Read-Out Operation of Genie PUF



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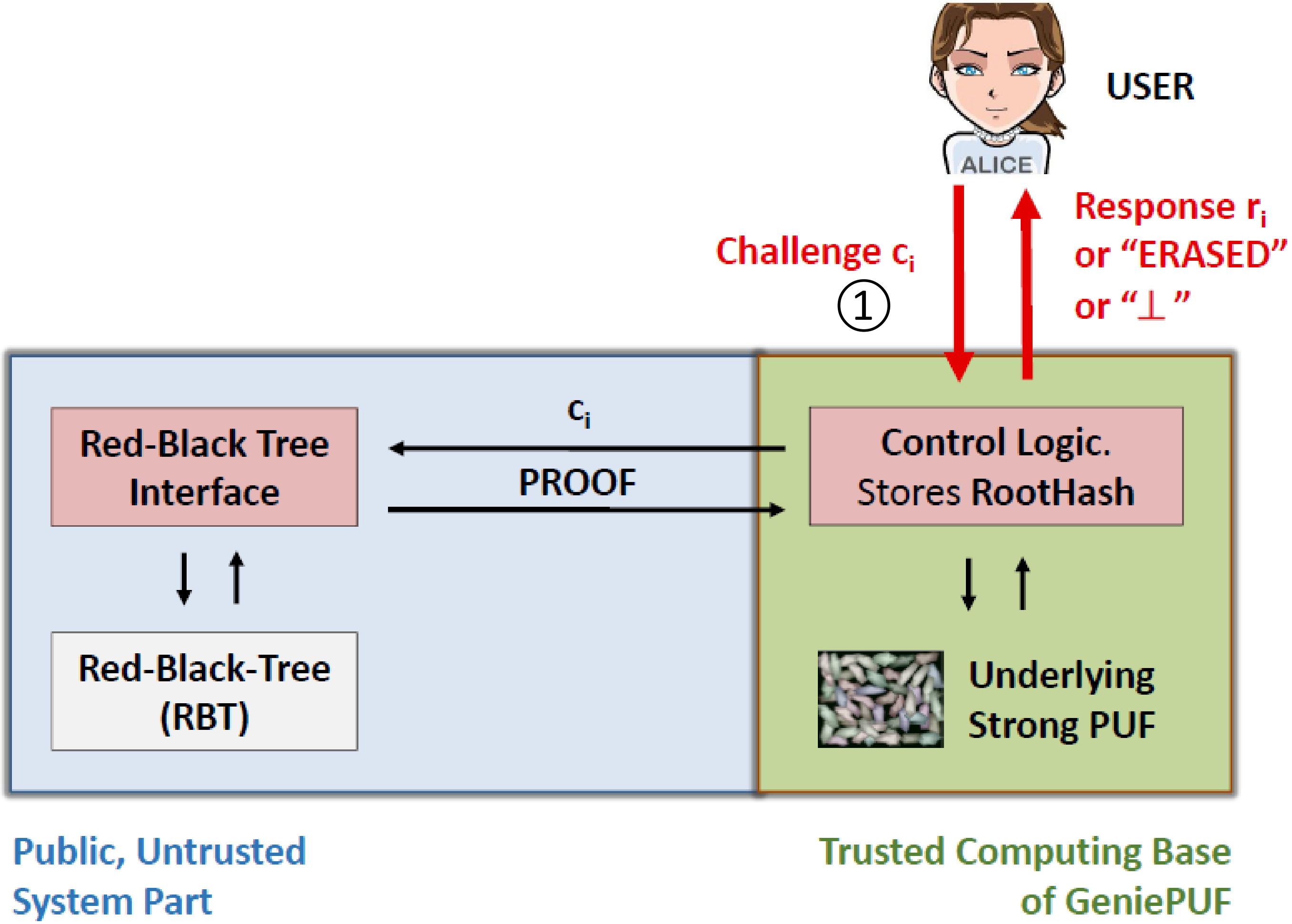

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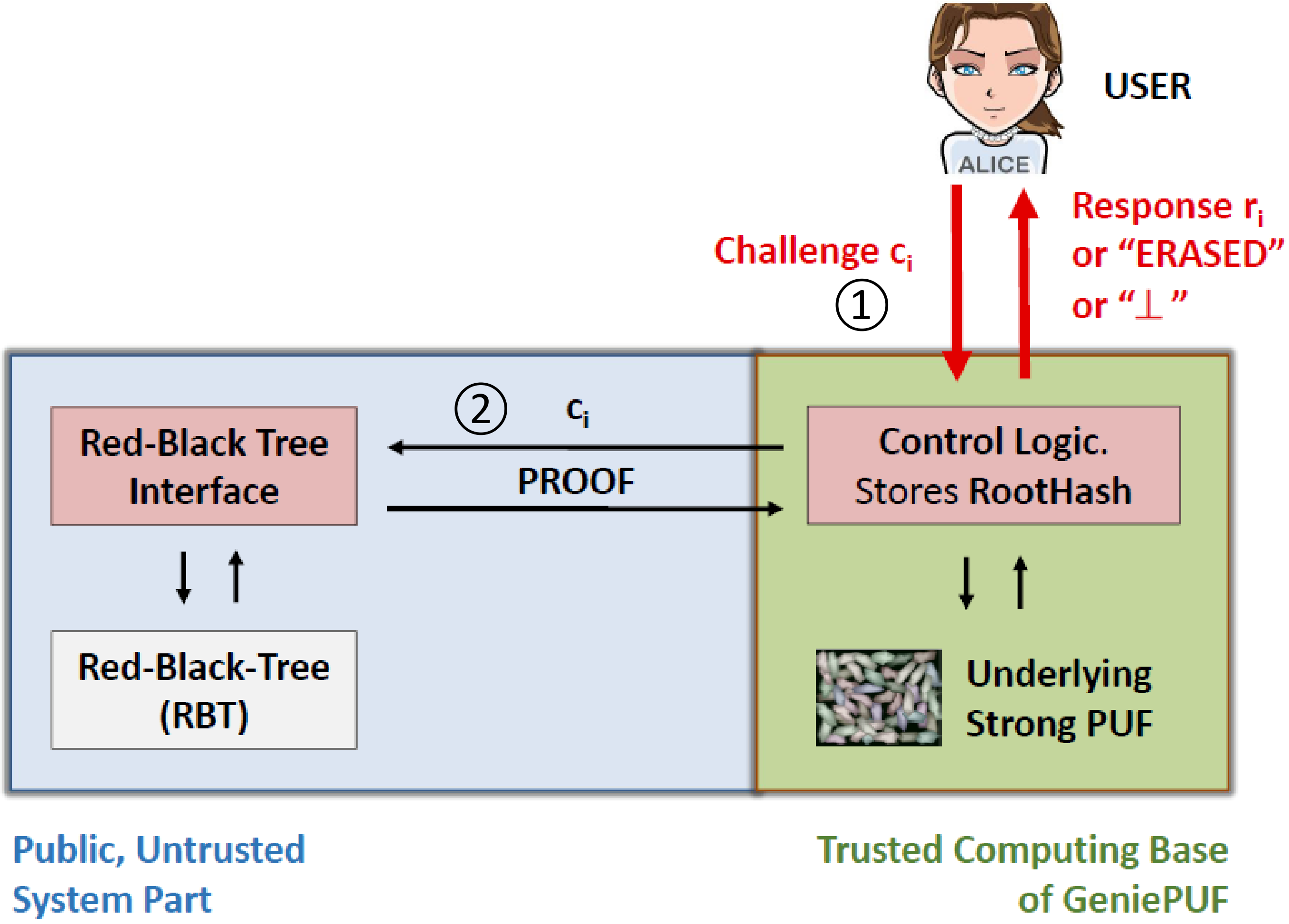

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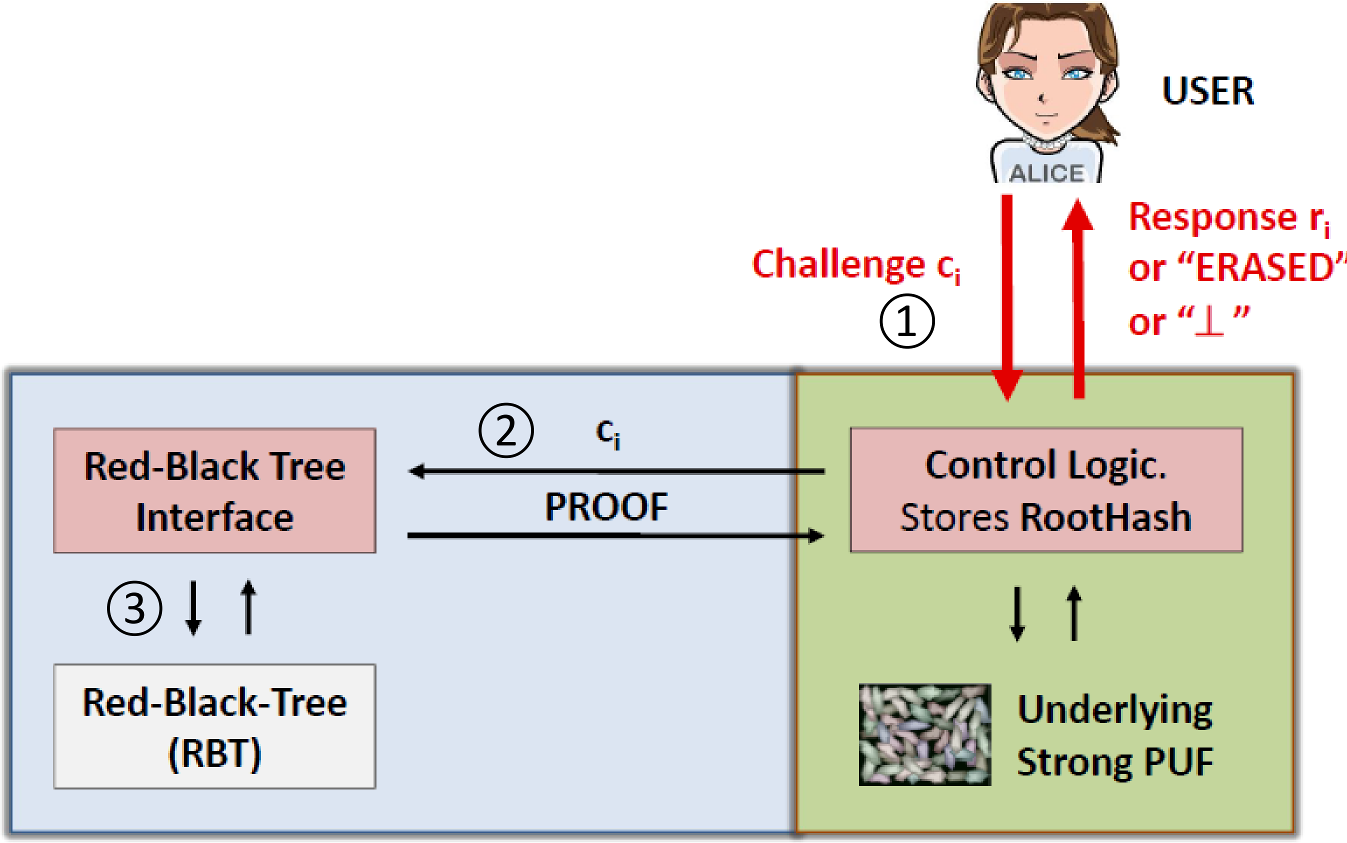

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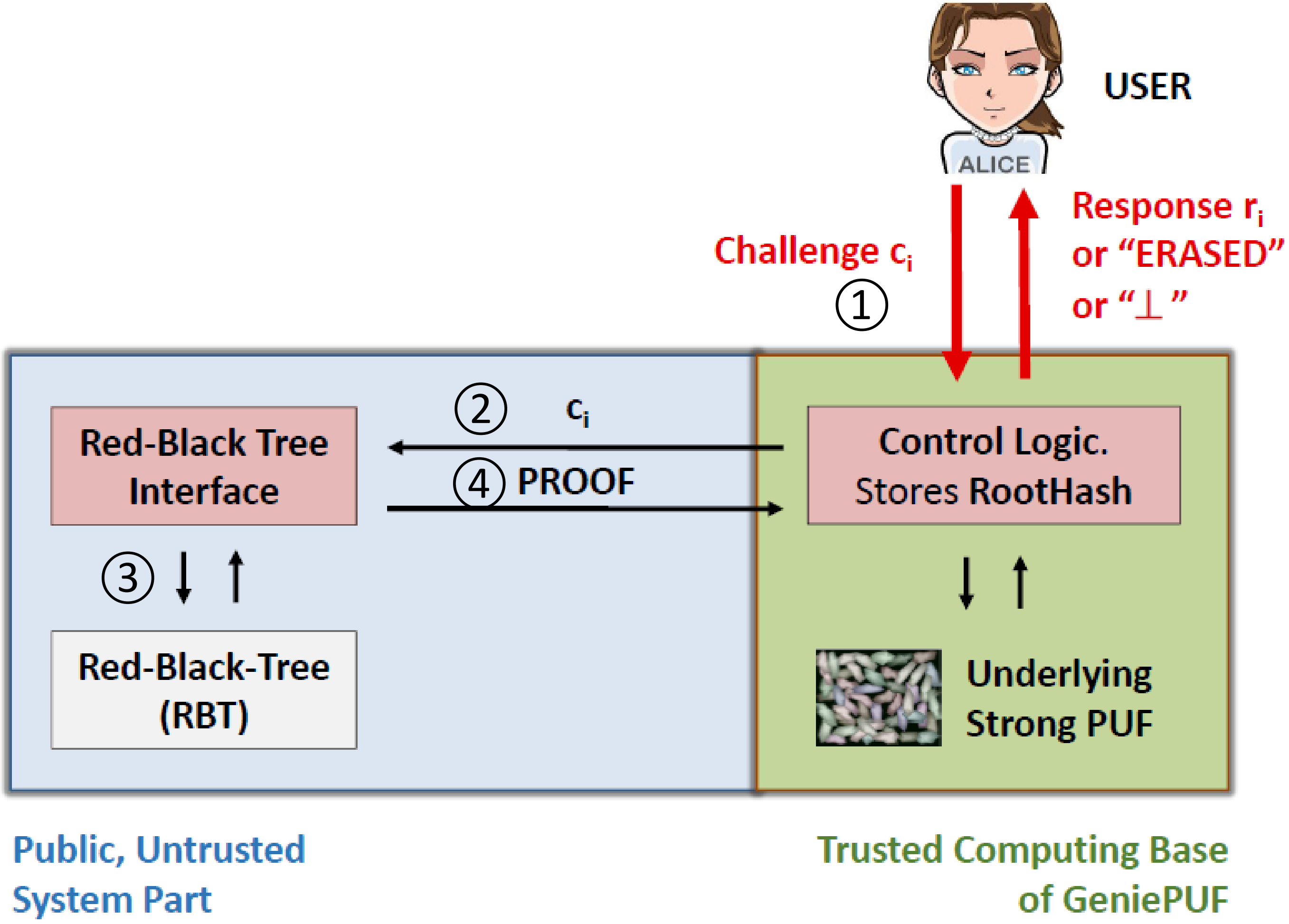

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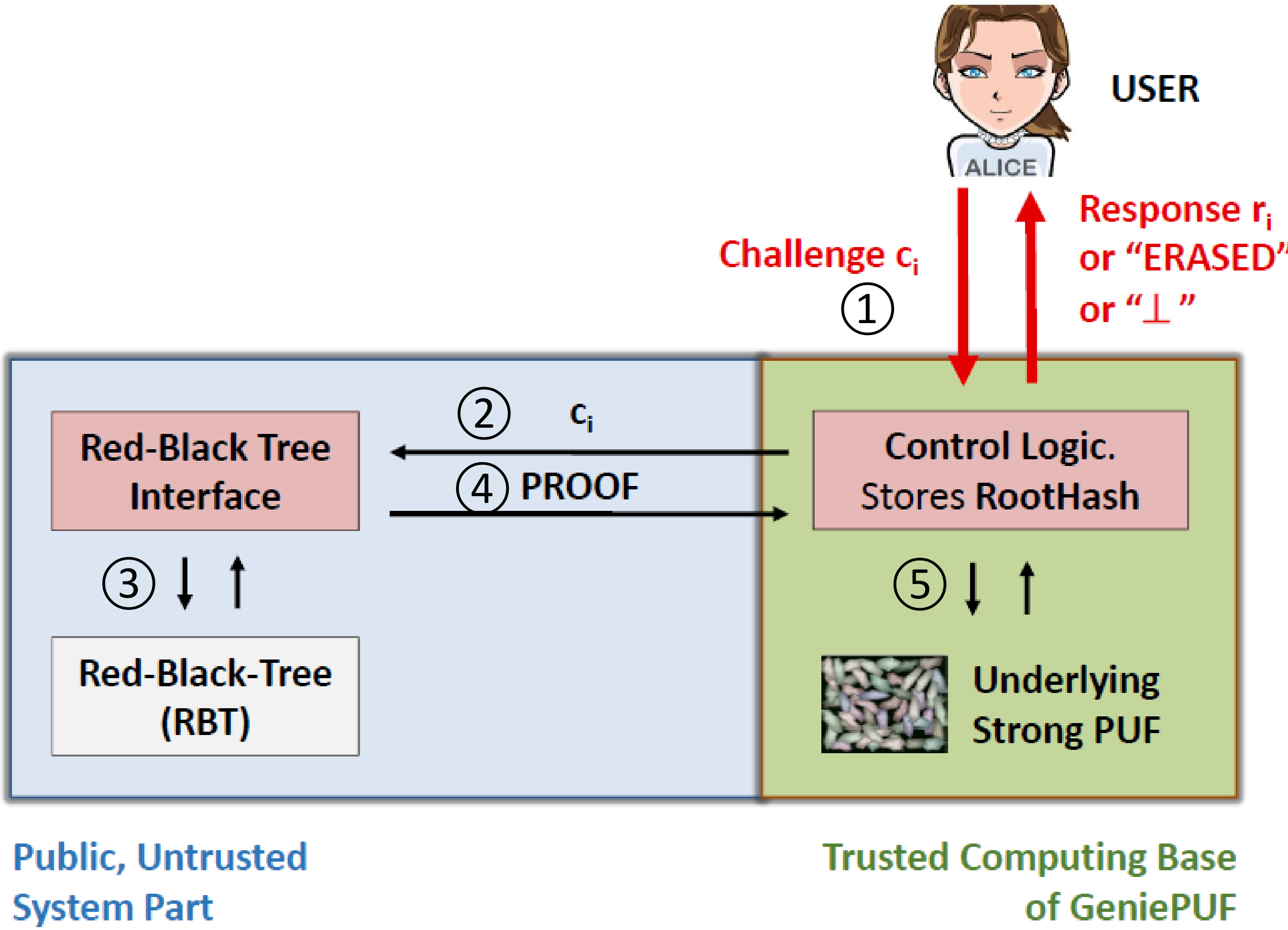

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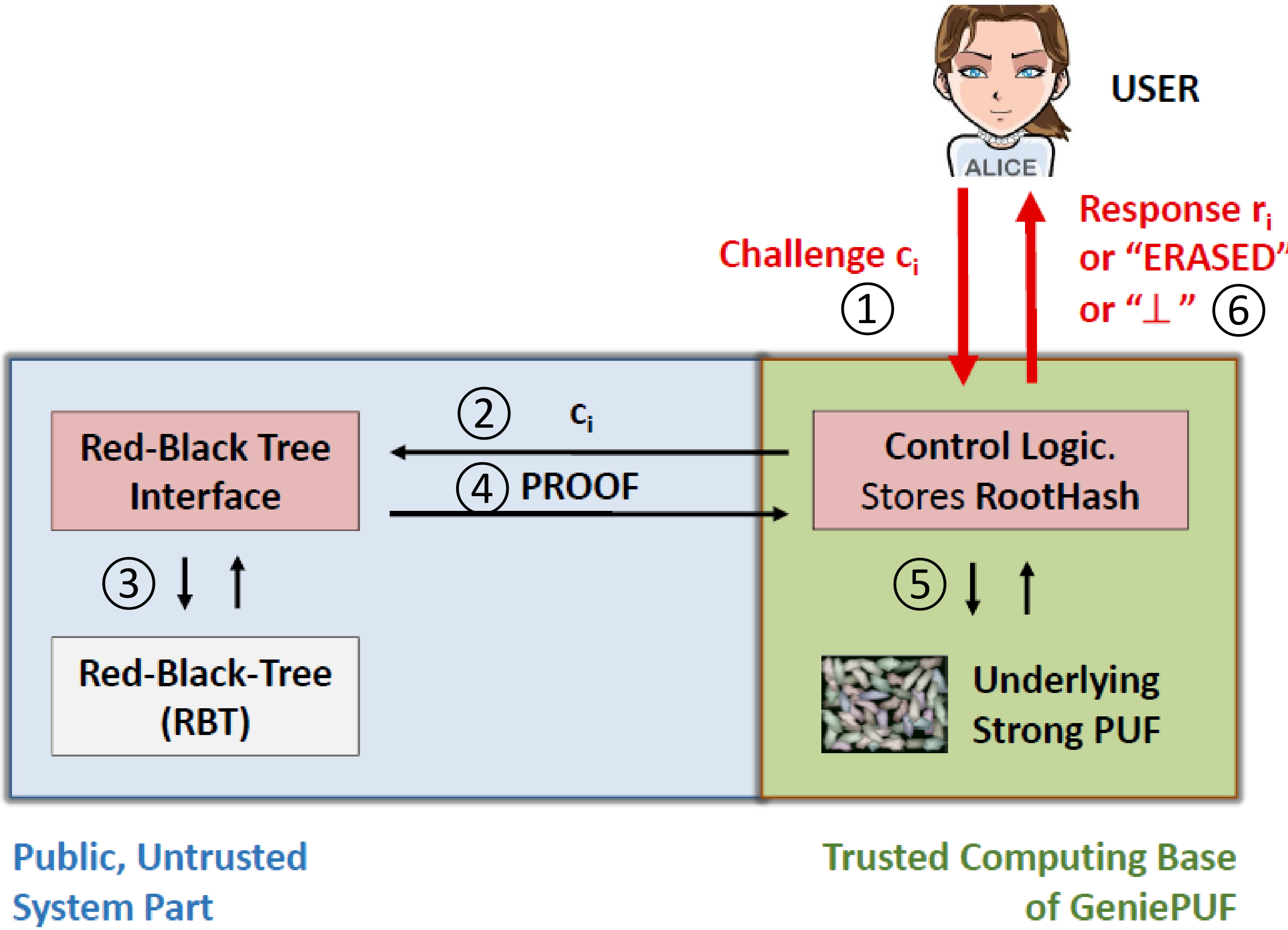

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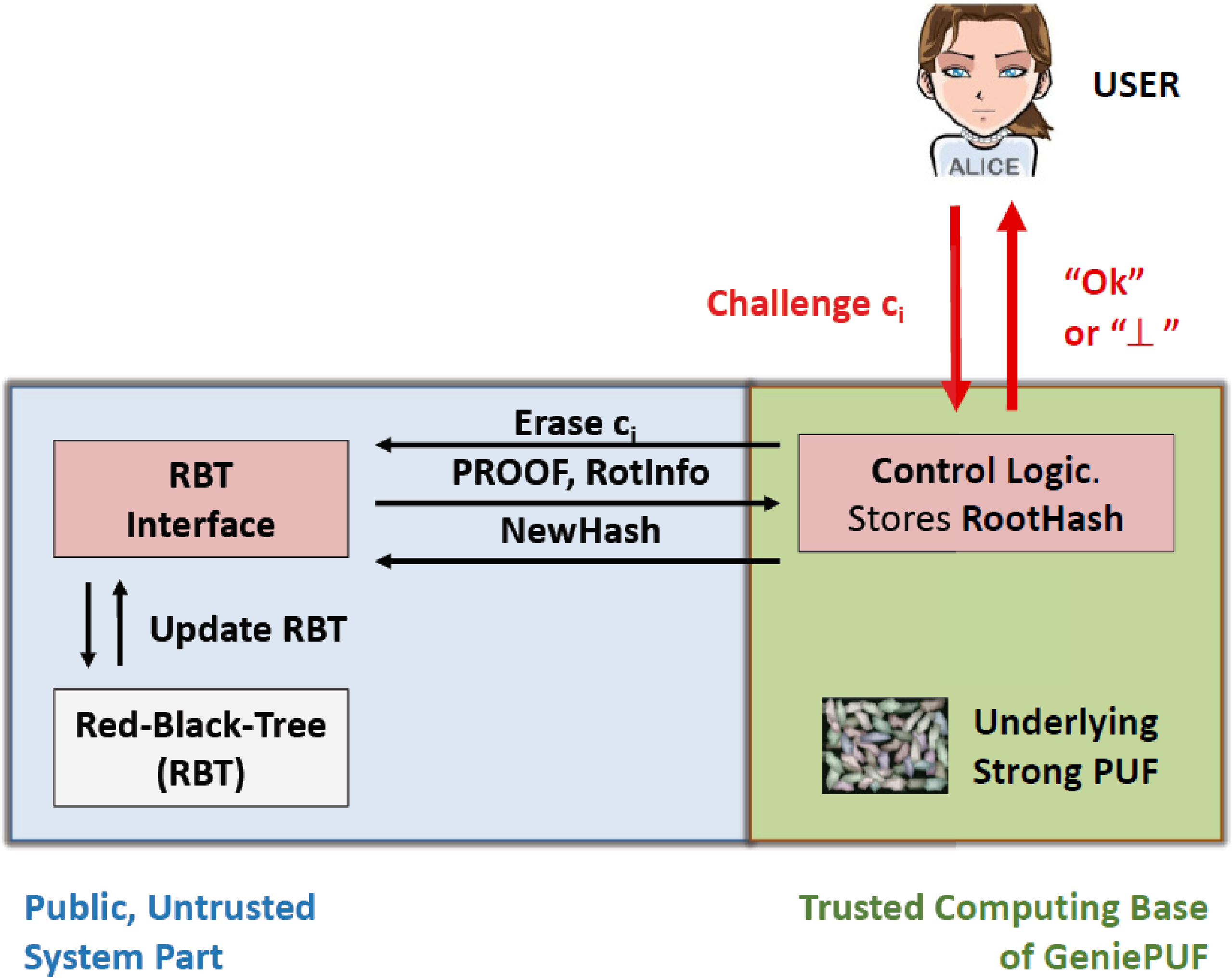

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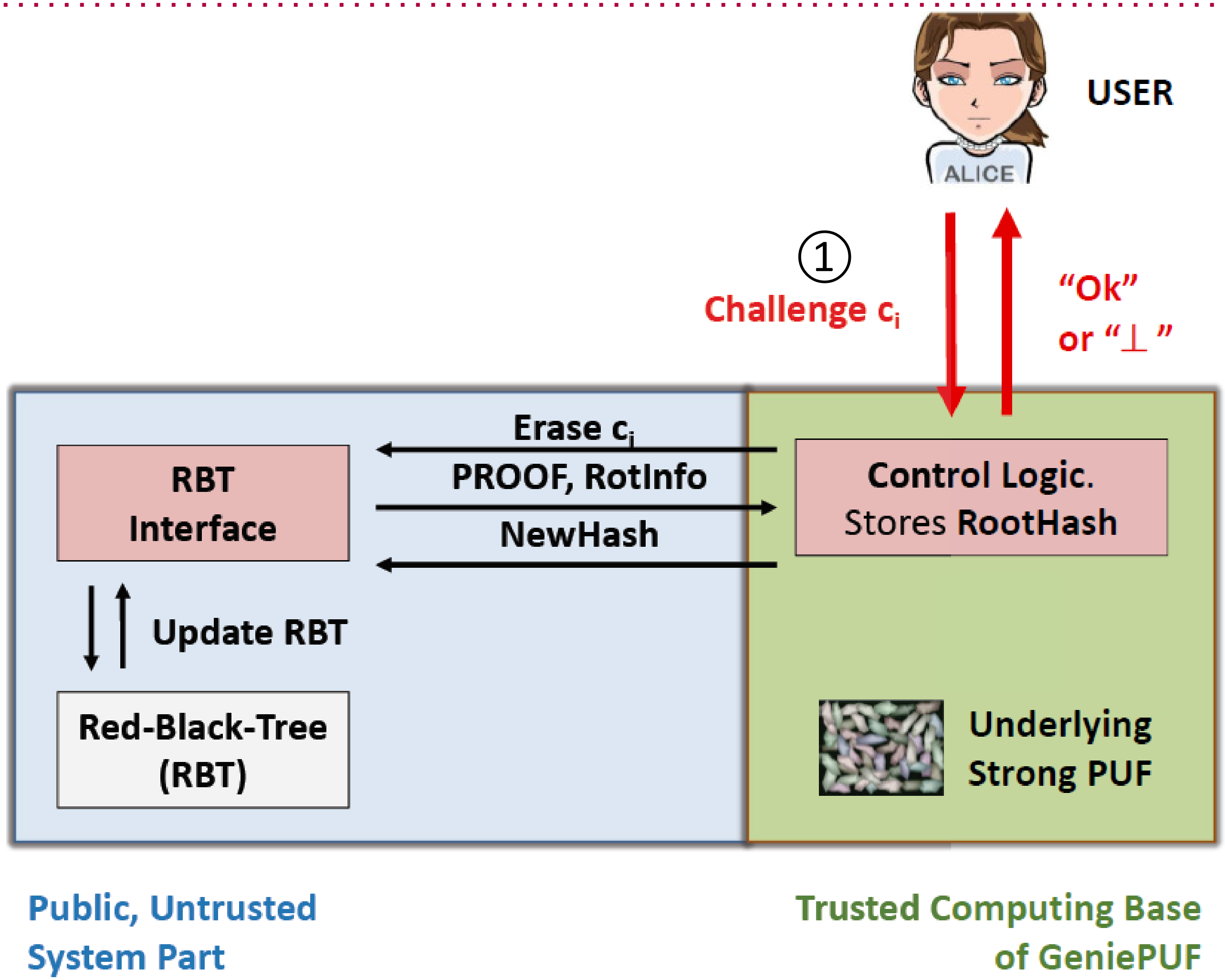

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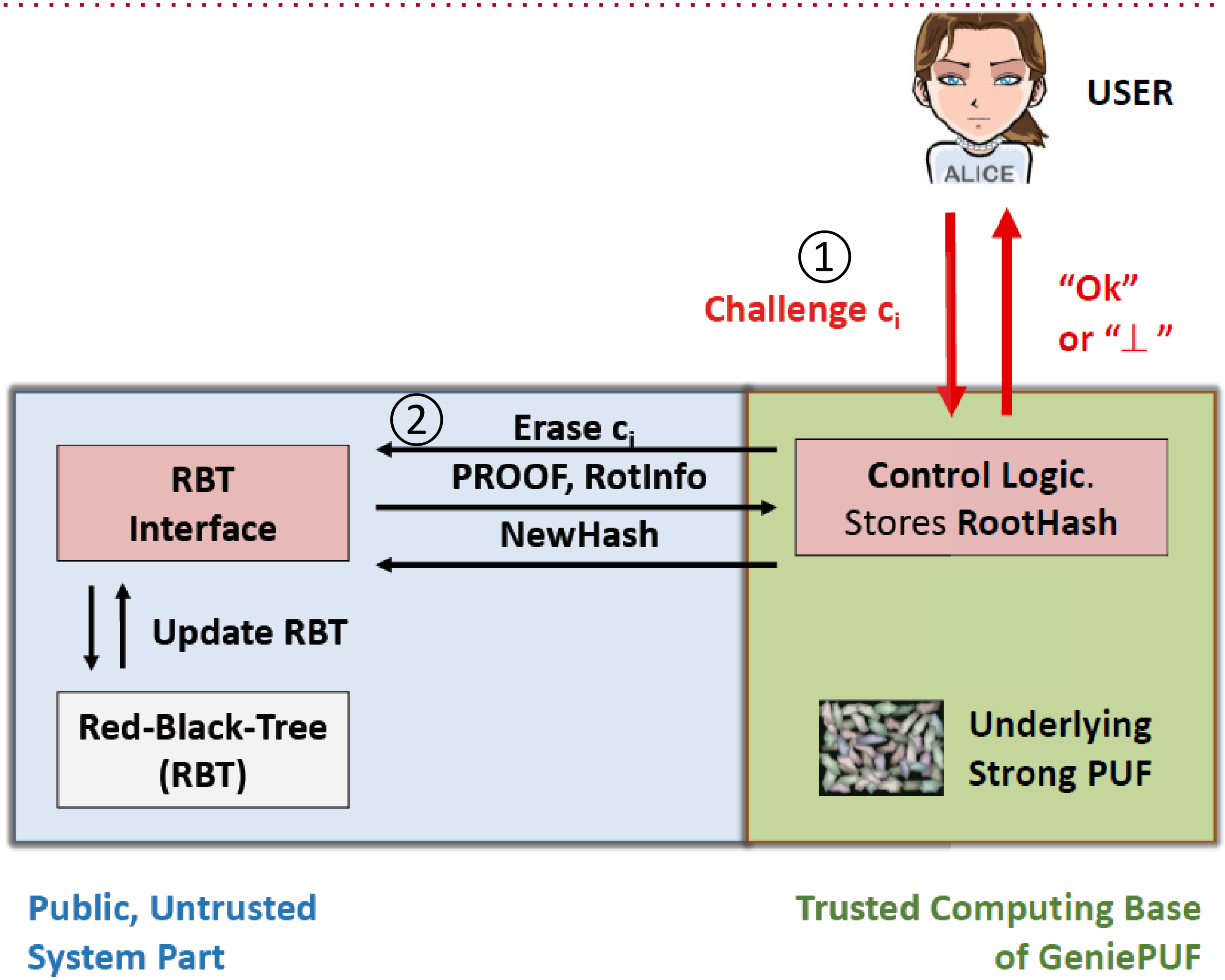

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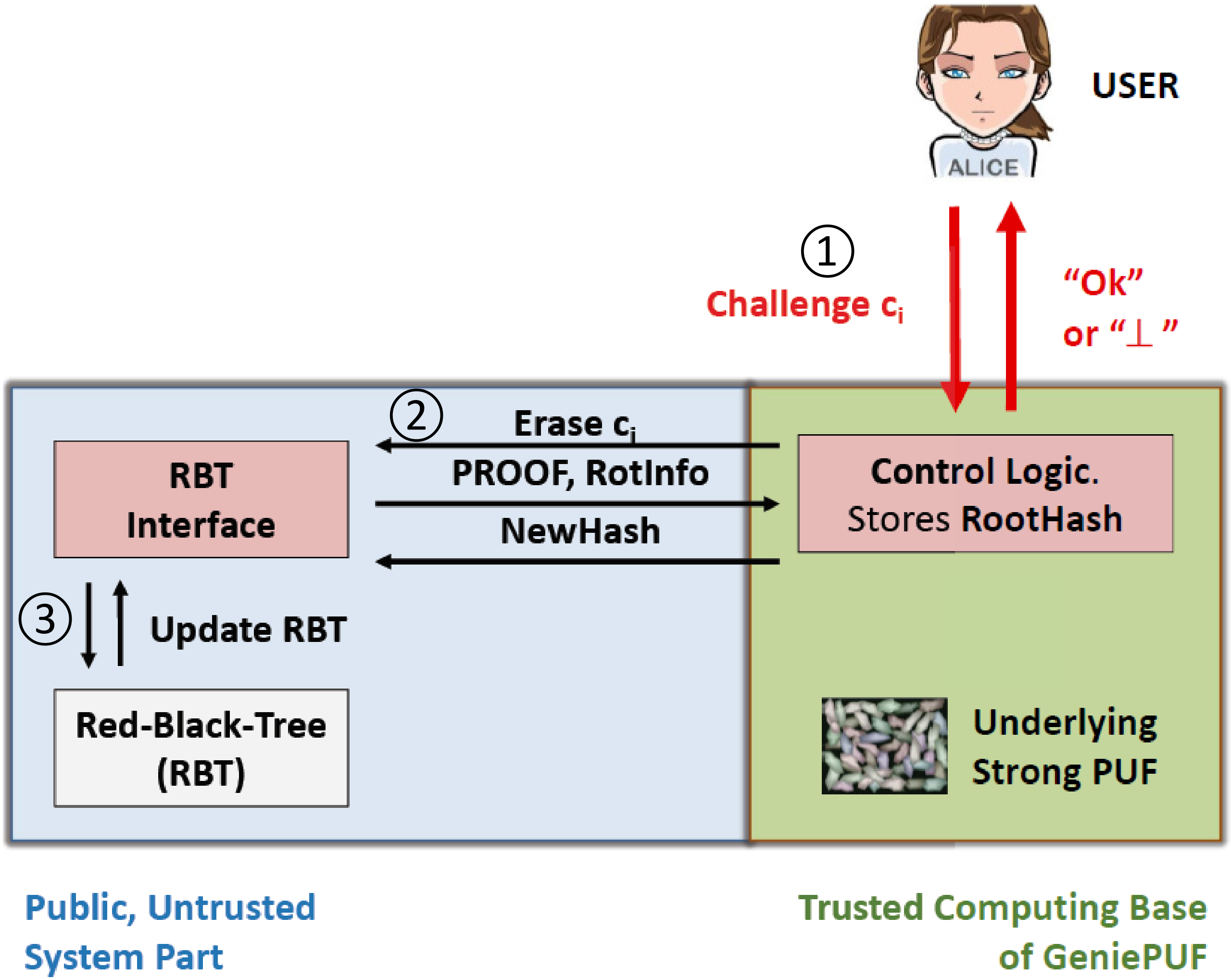

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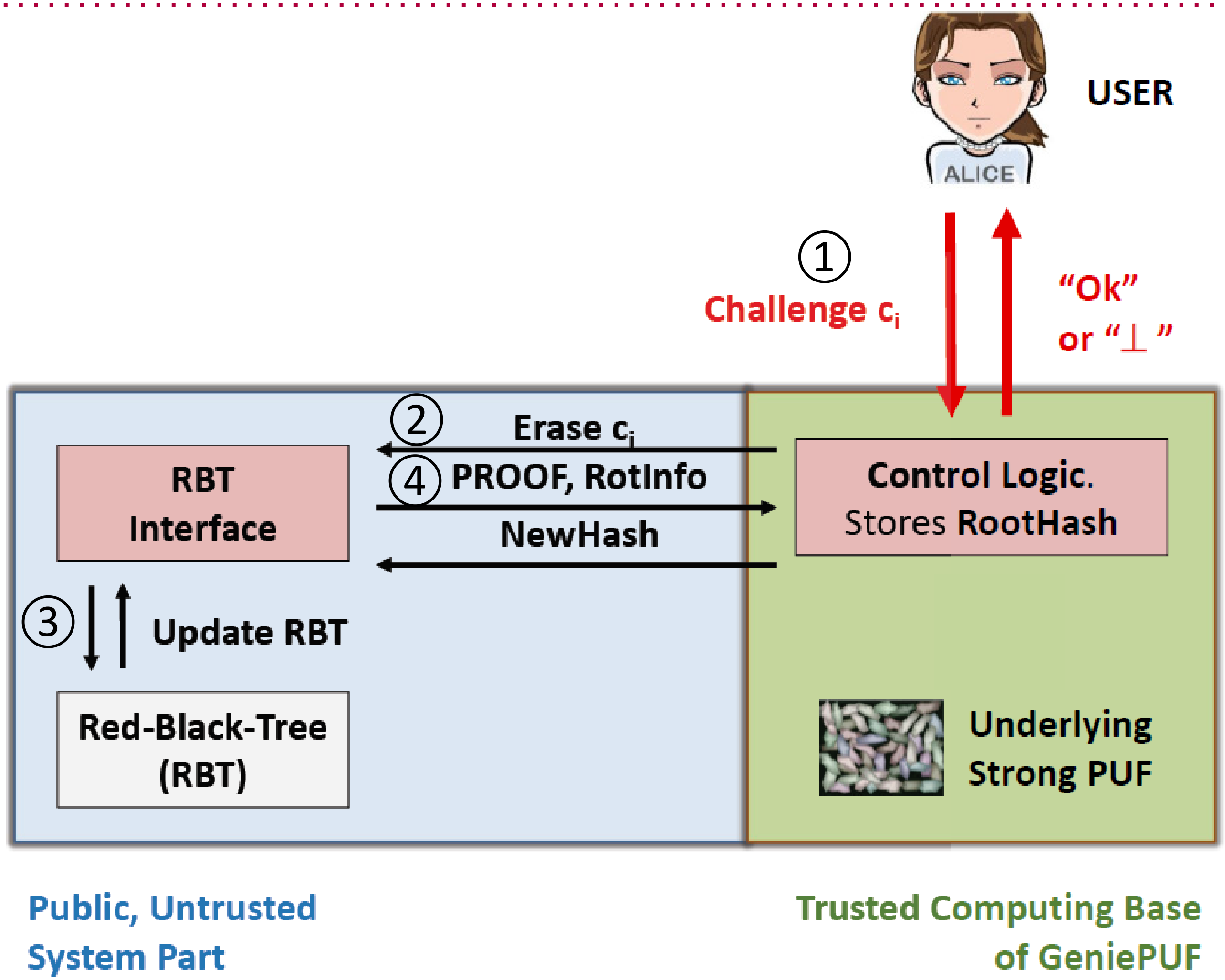

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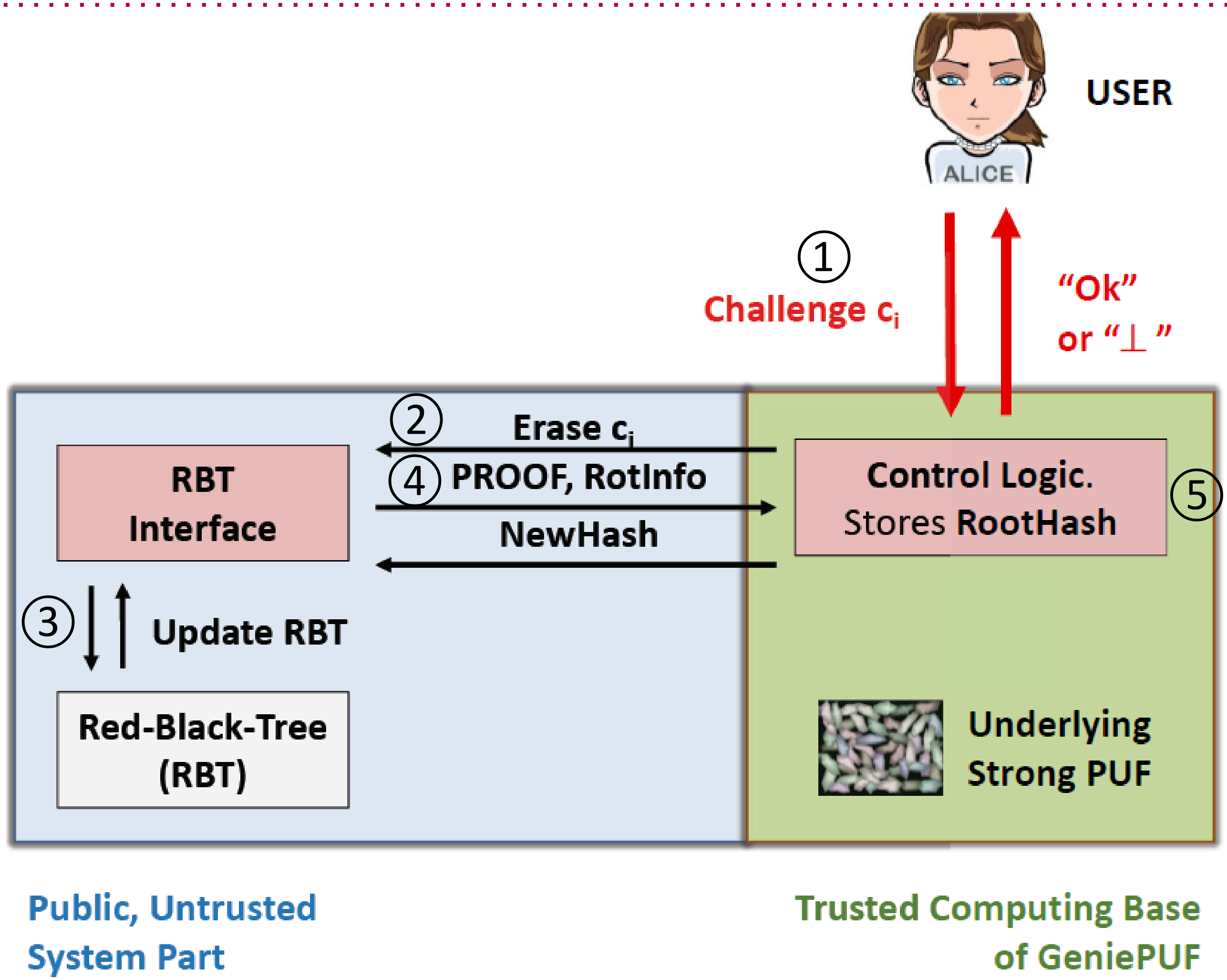

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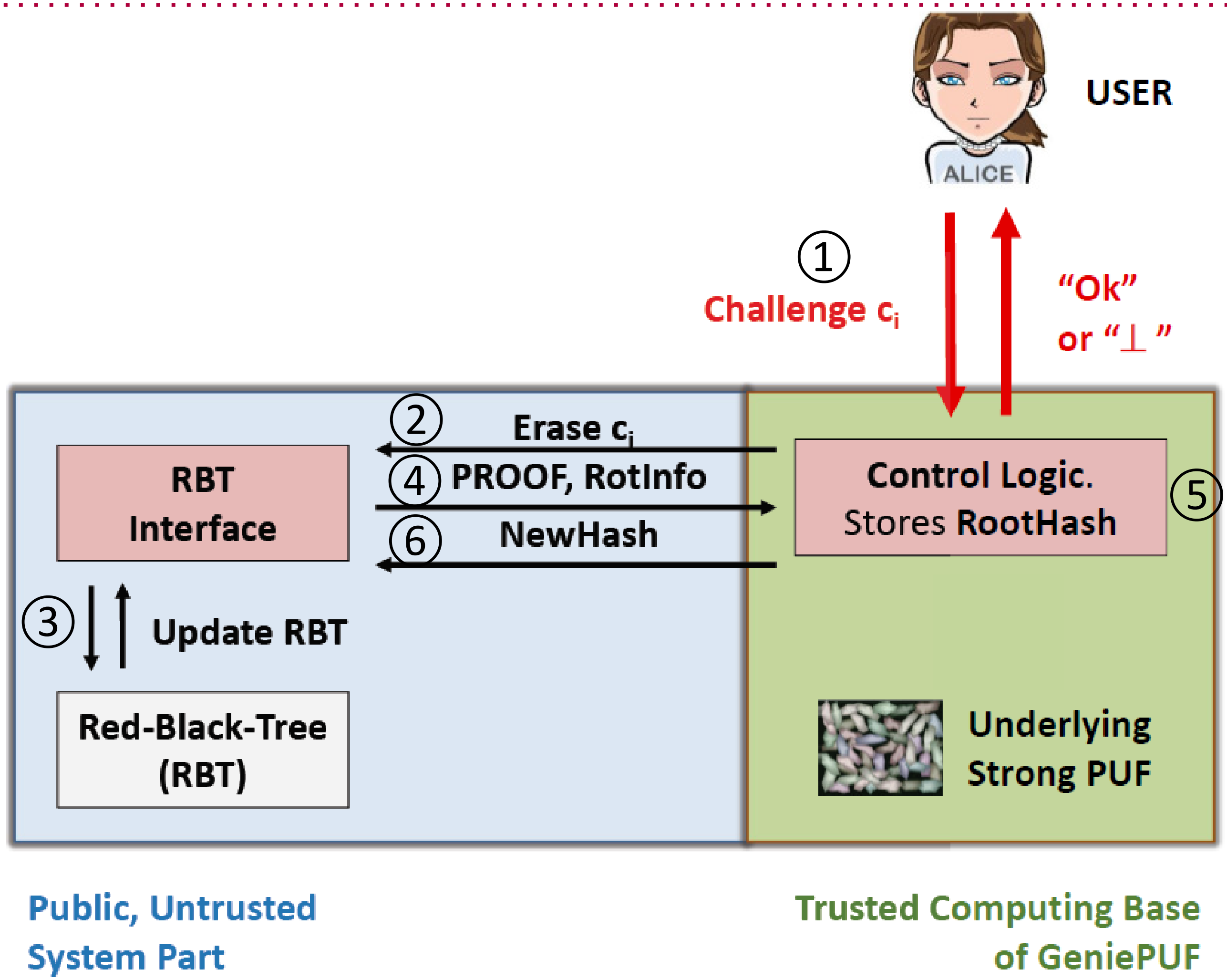

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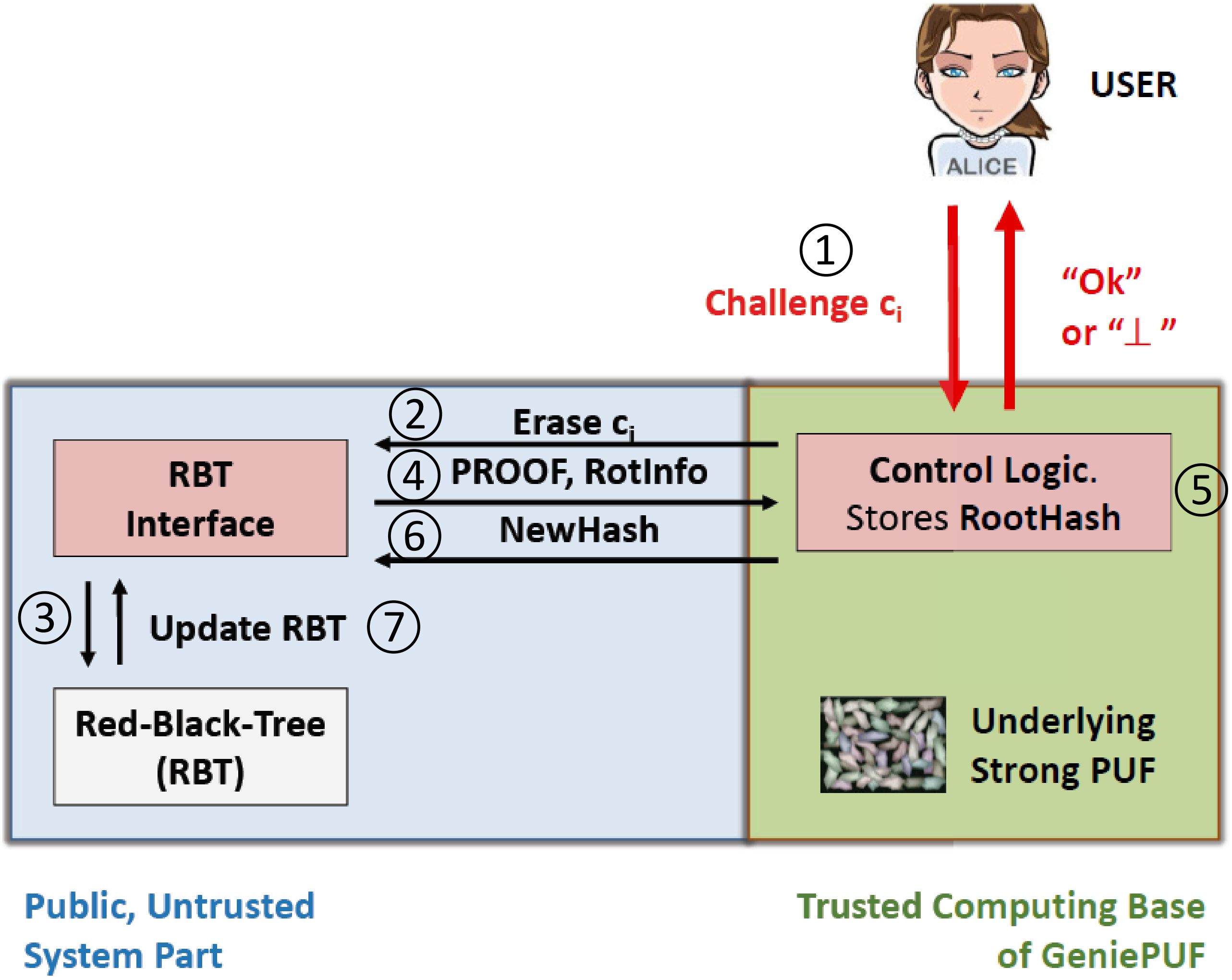

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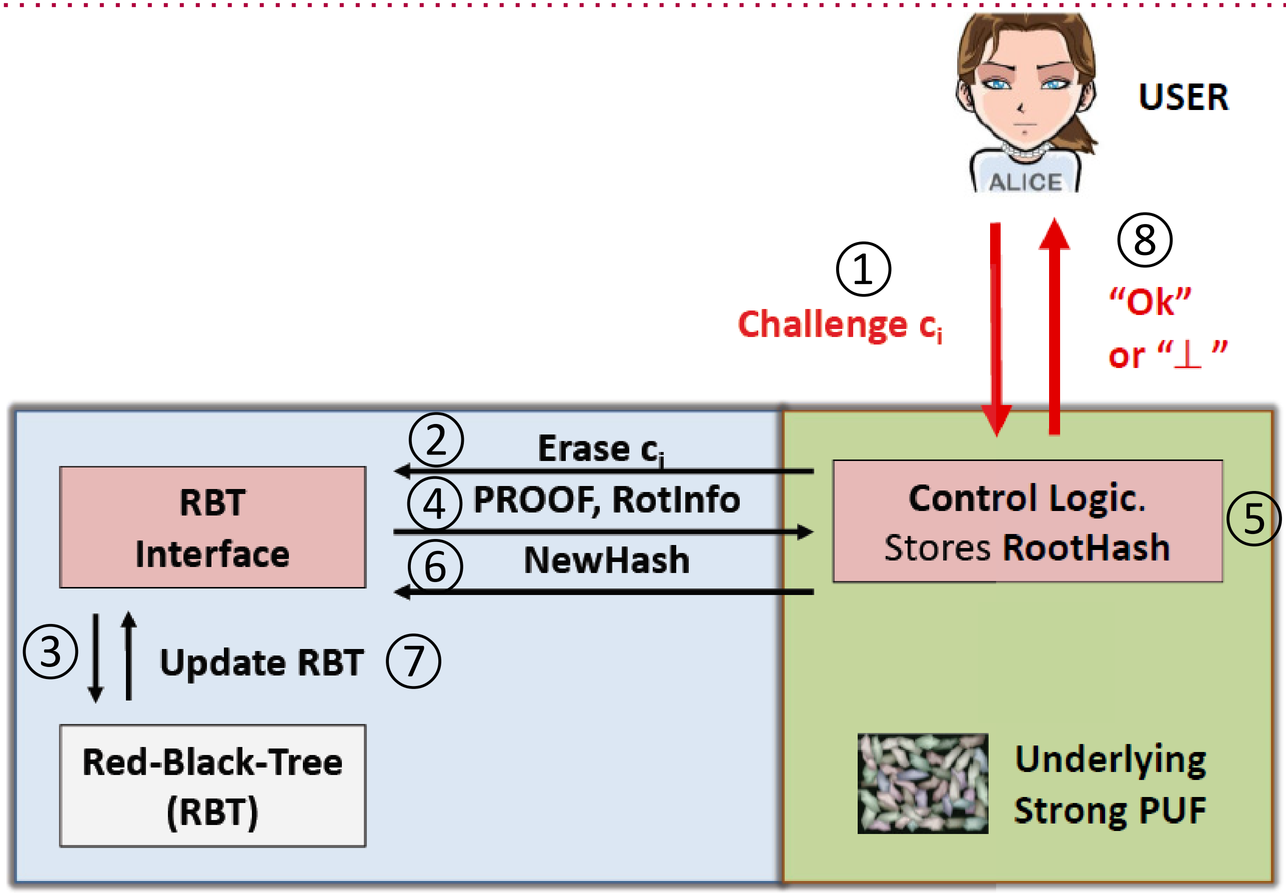

Public, Untrusted
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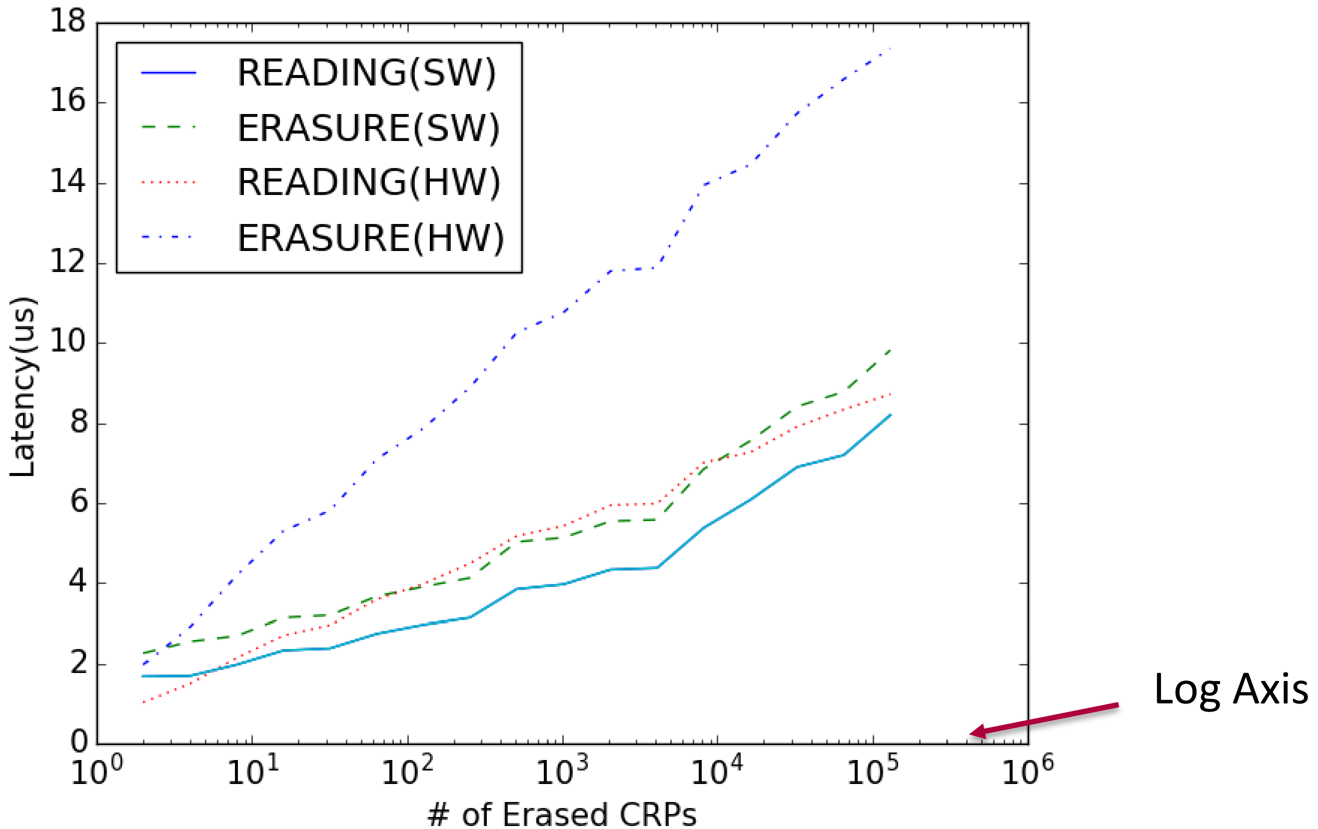
Performance Evaluation



- Implement the TCB on Zynq FPGA (HW) and the RB Tree Interface on Processor (SW)
- Latency grows logarithmically w.r.t. the number of erased challenges

Security Analysis

- Security Assumptions for Genie PUFs

1. Adversaries cannot circumvent the Control Logic (CL), applying their own challenges directly to the underlying Strong PUF, reading out the corresponding responses r_i.
2. Adversaries cannot modify the CL, for example such that it cannot correctly verify the validity of PROOF.
3. Adversaries may read the stored RootHash, but not modify it. It is public, but authentic.

A New Definitional Framework of PUFs

- Easily accessible, yet precise style PUF definition
- Parameterized Game-based PUF definition (ϵ, t_{att}, k)
- Intuition of Secure Erasable PUF Definition:

The security of an erasable PUF is measured by the upper bound ϵ of the accuracy of guessing one out of k randomly chosen CRPs by an attacker which takes time t_{att} for computation, physical actions, and k times game interactions with the challenger, where in each game interaction a randomly chosen CRP is erased.

Main Results of Formal Analysis

- Erasable PUFs are Strong PUFs
- Let P be a (k, t_{att}, ϵ)-secure Erasable PUF with respect to some adversary A. Then P is a (k, t_{att}, ϵ)-secure Strong PUF with respect to the same adversary A.

- The Security of Genie PUFs
- Let P be a PUF with challenge set C_P . Let A be an adversary for GeniePUF(P). Then GeniePUF(P) is $(k, t_{att}, \epsilon + \rho)$-secure Erasable PUF with respect to A, where ρ represents the collision probability of the used hash function.

Conclusion

- Fixed the issue of PUF re-use model in PUF-based cryptographic protocols by using erasable PUFs.
- Introduced a generic erasable PUF design (Genie PUF) that can turn any strong PUFs to erasable PUFs.
- Proposed a rigorous, yet easily accessible definitional framework of PUF and proved our main theorems in the framework

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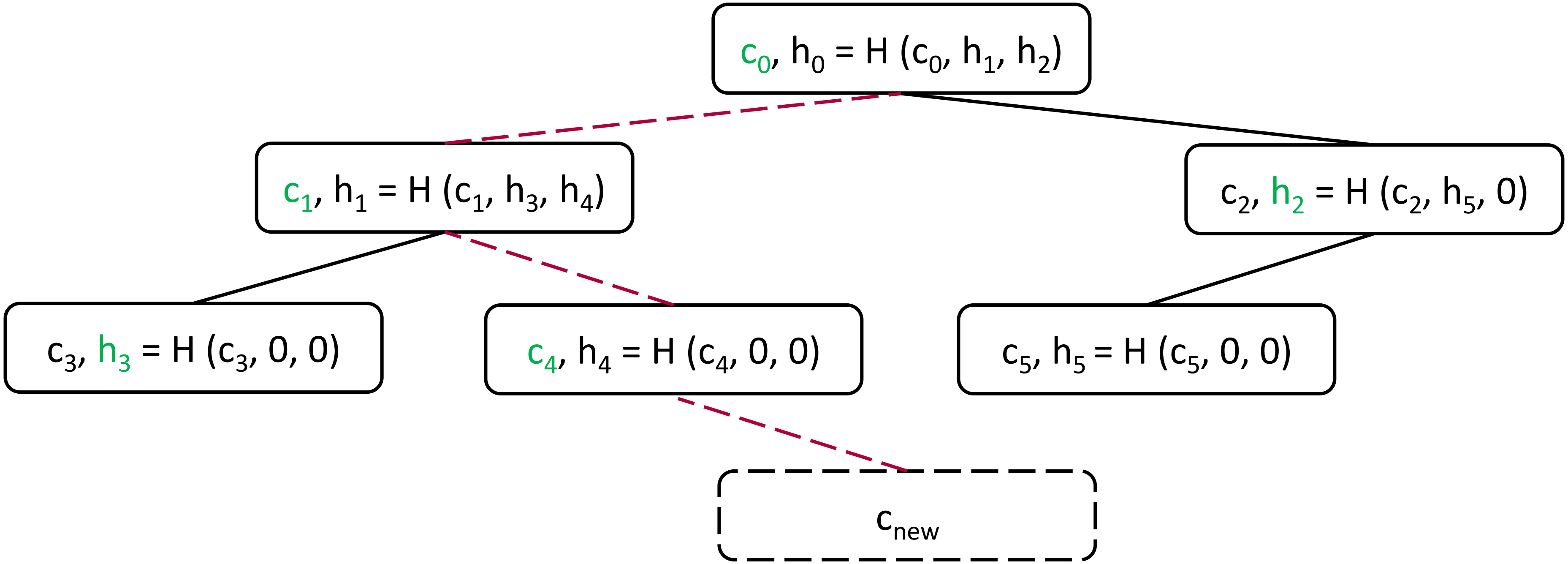
Thank you for your attention!

Questions?

Authenticated Search Tree Proof Generation



1. Locate where the new challenge is supposed to be stored
2. Find a path from the new node for c_{new} to the root
3. Fetch all the challenge values and all sibling hash values to construct a proof of (non)-existence

Red-Black Tree Background

- Self-balancing Binary Search Tree
- Guarantee O(log N) worst-case search time with a tree of size N