Recycable PUFs: Logically Reconfigurable PUFs

Ünal Kocabaş

unal.kocabas@trust.cased.de

TU Darmstadt (CASED), Germany

Joint Work with

Stefan Katzenbeisser, Vincent van der Leest, Ahmad-Reza Sadeghi, Geert-Jan Schrijen, Heike Schröder, and Christian Wachsmann

Outline

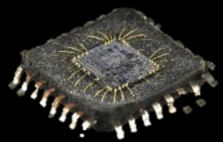
Physical Security

Physically Unclonable Functions (PUFs)

Logically Reconfigurable PUFs (LR-PUFs)

Application of LR-PUFs

Physical Security



Problem: Cryptography cannot protect against physical attacks

Secrets can be leaked by hardware and/or side-channel attacks

Approach: Use physical properties to build security solutions

- Example: Key exchange based on quantum physics
- Differences to classical cryptography/security:
  - *Based on physical instead of computational assumptions*
  - *Might protect against both algorithmic and physical attacks (tamper-evidence)*

Challenge: Find appropriate physical primitives that

- Provide reasonable and verifiable security features
- Are cost-efficient and easy to implement

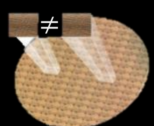
Promising: Physically Unclonable Functions (PUFs)

Physically Unclonable Functions (PUFs)

Device
(e.g., embedded system)

Physically Unclonable Function
(noisy function based on physical properties of the device)

Hardware Fingerprint
(unique intrinsic device identifier)



Inherently Unclonable

Due to unpredictable randomness during manufacturing

Infeasible to predict

Challenge/response behavior is pseudo-random

Tamper-evident

Tampering with the PUF hardware changes challenge/response behavior

Reconfigurability

Allows to change PUF's challenge/response behavior after deployment

Ideally, reconfiguration is equivalent to physically replacing the PUF

Extends existing PUF-based security solutions

Example: Secure key erasure/update of secret data bound to PUF

(reconfiguration of PUF "deletes" secrets bound to PUF)

Enables new PUF-based security mechanisms

Example: Protection against software downgrading attacks

(reconfiguration of PUF invalidates software versions bound to pre-reconfigured PUF)

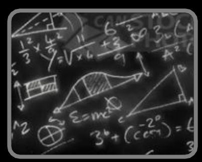
Enables new business models

Example: Recyclable PUF-based access tokens (e.g., RFIDs)

(reconfiguration of PUF allows secure and privacy-preserving re-use of tokens)

In this talk, we present

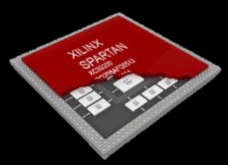
Logically Reconfigurable PUFs (LR-PUFs)



Formal security model

Introduces forward and backwards unpredictability

(specific for reconfigurable PUFs and not covered by previous PUF models)



LR-PUF constructions

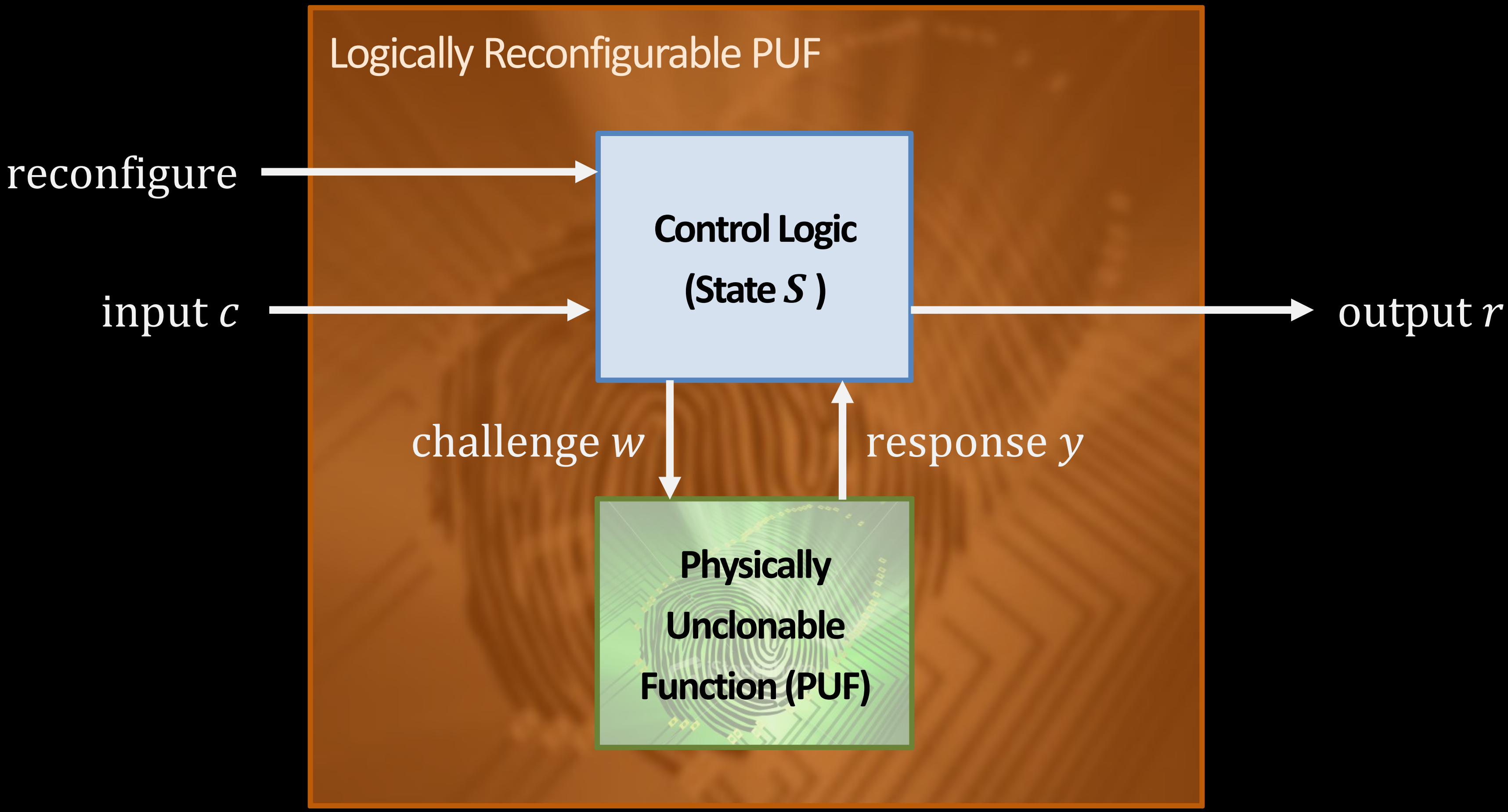
Simple and efficient instantiations and their implementation

(one optimized for speed and one for area consumption)

Application example

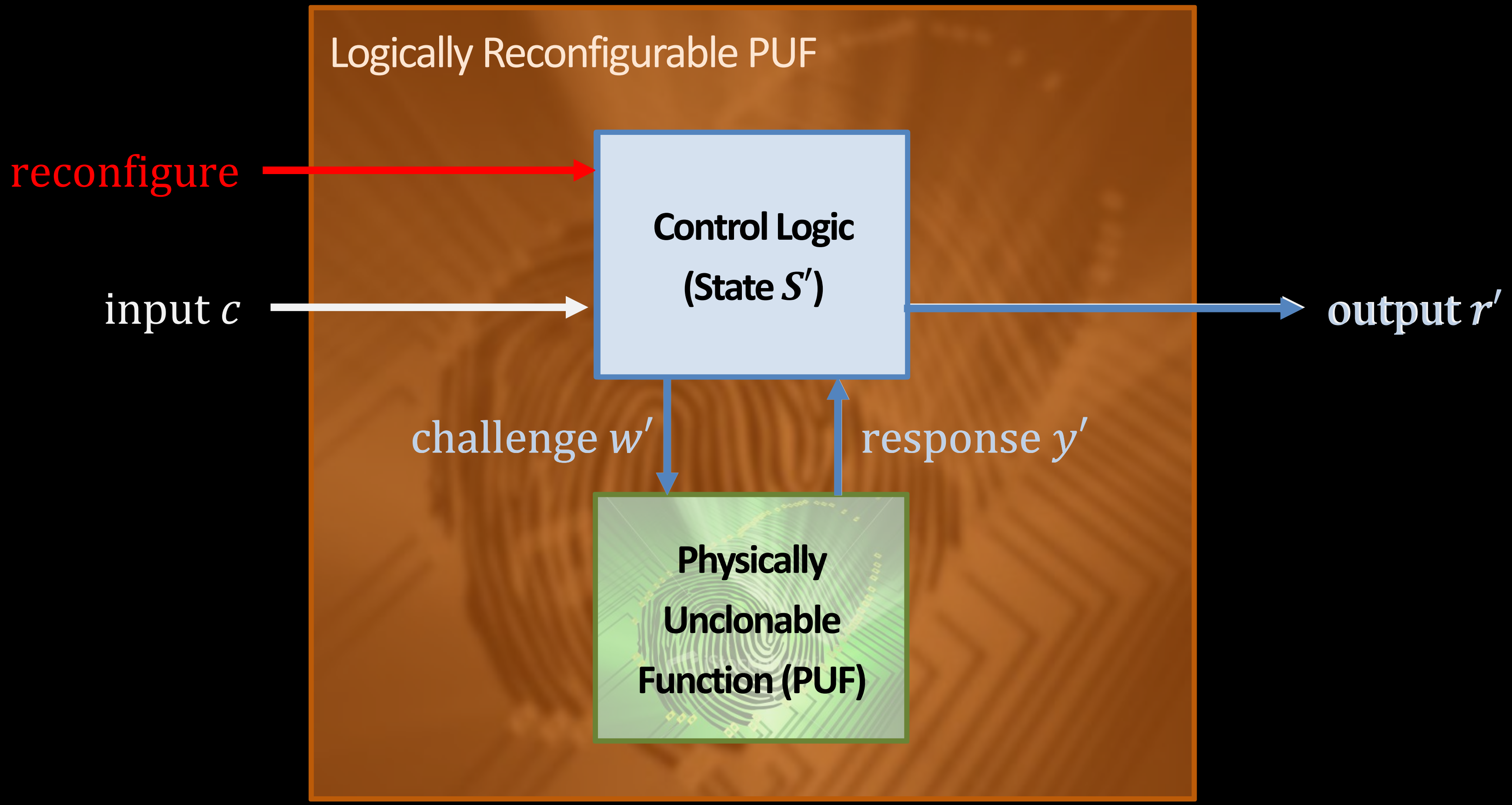
Recyclable (i.e., re-usable) access tokens based on LR-PUFs

LR-PUF Concept



A similar concept has been proposed independently by Lao et al. [LP11]

LR-PUF Concept



A similar concept has been proposed independently by Lao et al. [LP11]

Assumptions and Adversary Model

Underlying PUF is *unclonable* and *unpredictable*

Can be achieved by using, e.g., a controlled PUF

Algorithm of control logic is publicly known

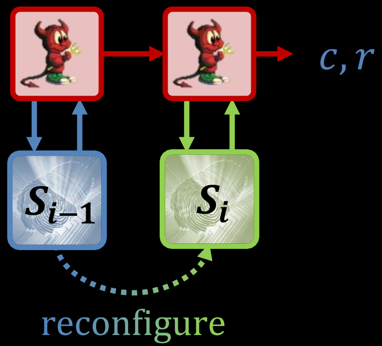
Typical assumption in cryptography (Kerckhoffs's Principle)

Adversary

- Can adaptively obtain challenge/response pairs of LR-PUF
- Knows current and all previous LR-PUF states
- Cannot set LR-PUF state to a specific value

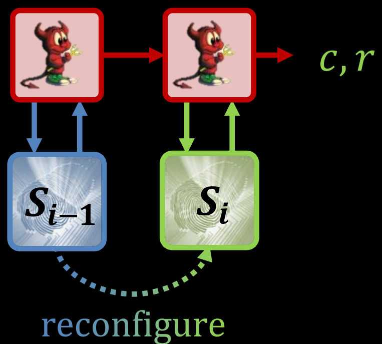
  (invasive attacks altering the state of specific memory cells infeasible in practice)

Security Objectives



Forward Unpredictability

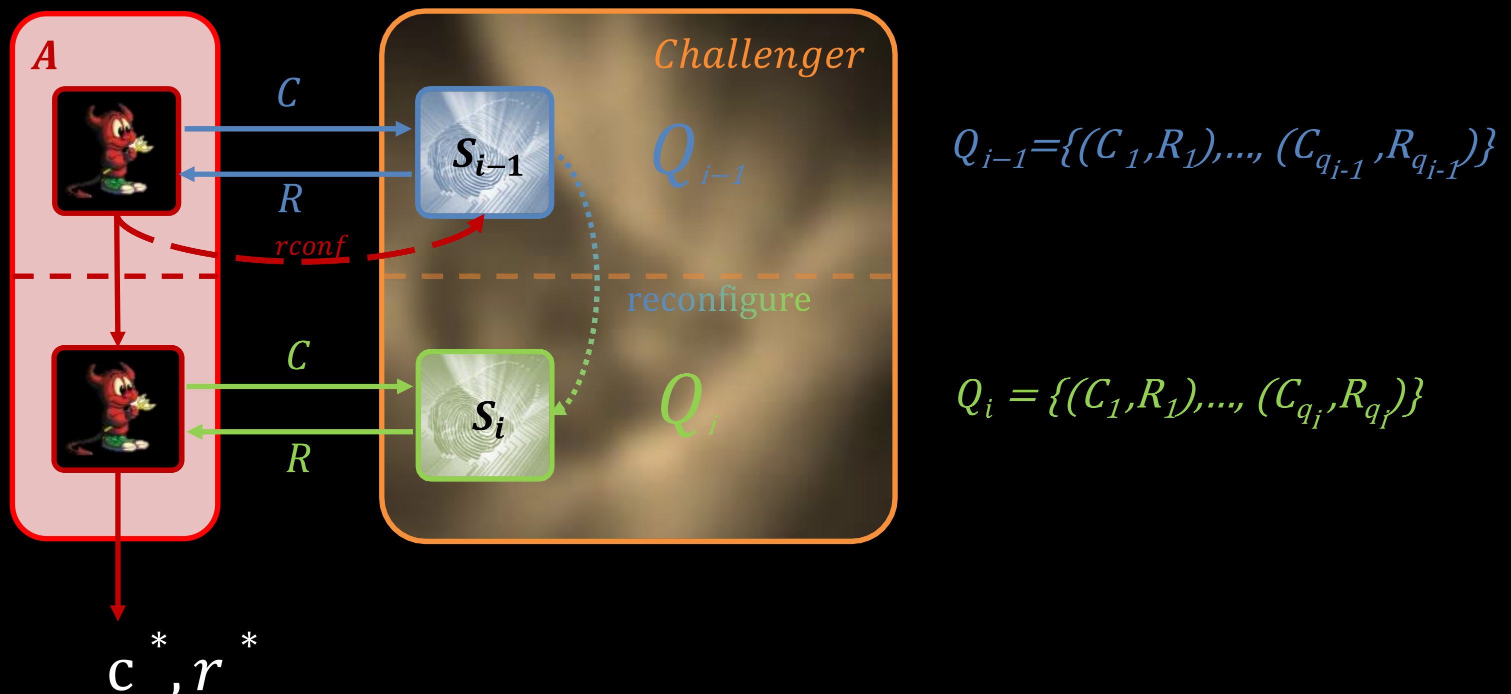
Adversary cannot predict LR-PUF response for previous states



Backward Unpredictability

Adversary cannot predict LR-PUF response for current state

Definition of Unpredictability Game



A wins the *backward-unpredictability* game if r^* is a valid LR-PUF response for state S_i and $c^* \notin Q_i$

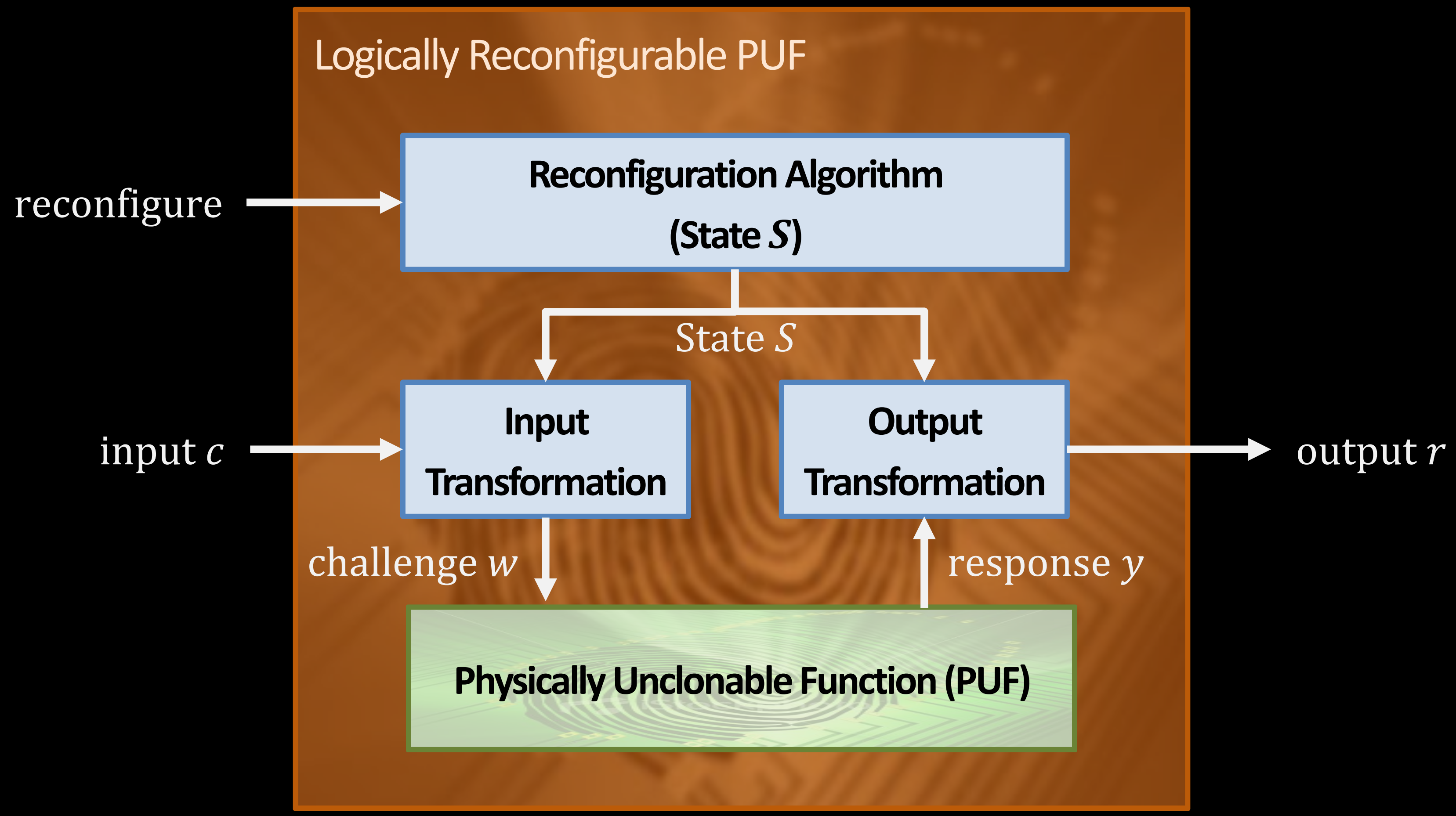
- *For instance, A may forge a PUF response in an authentication protocol.*

A wins the *forward-unpredictability* game if r^* is a valid LR-PUF response for state S_{i-1} and $c^* \notin Q_{i-1}$

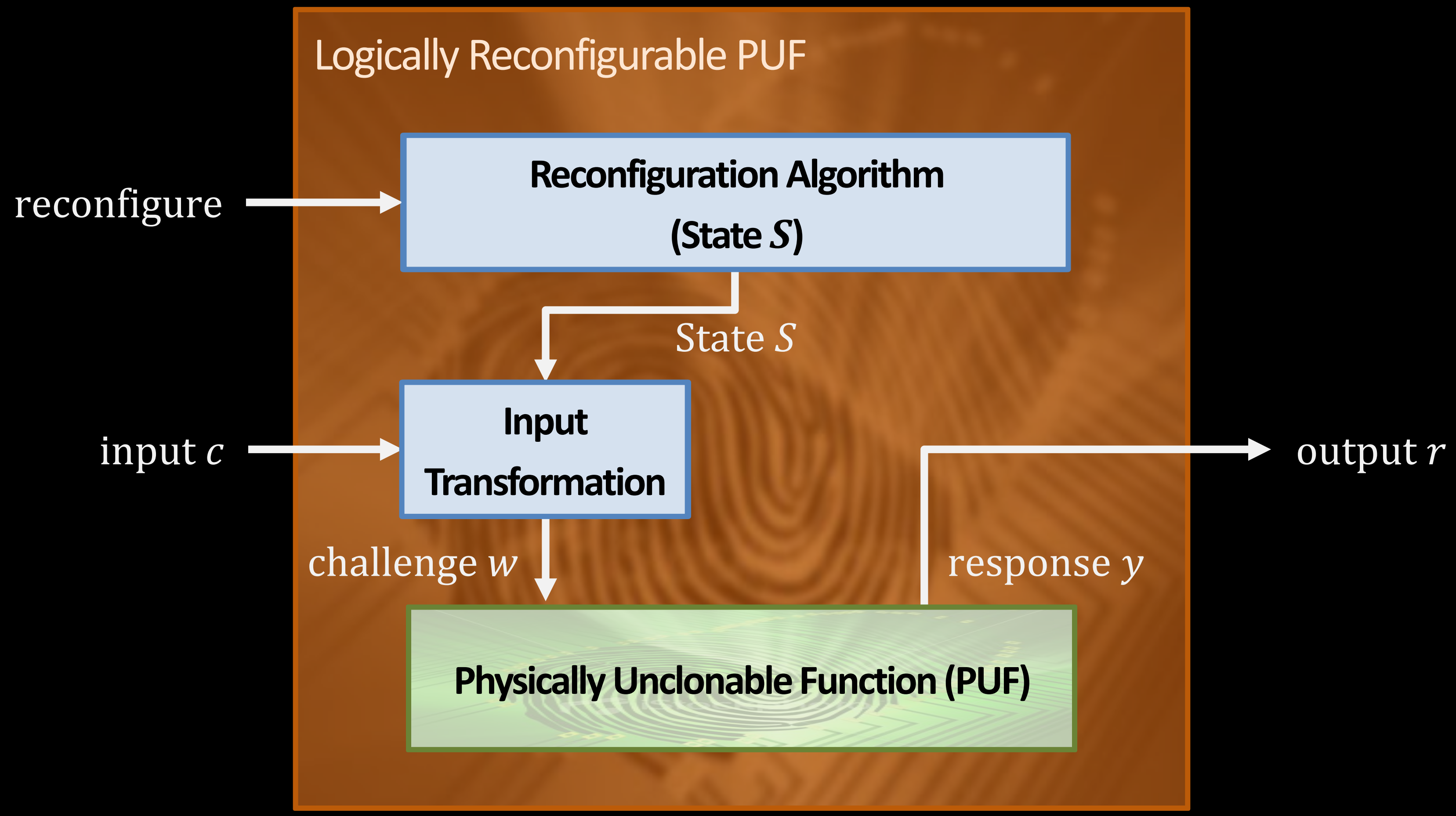
- *For instance, A may recover an old key bound to the PUF.*

Formalization follows game-based approach of Armknecht et al. [AMS+11]

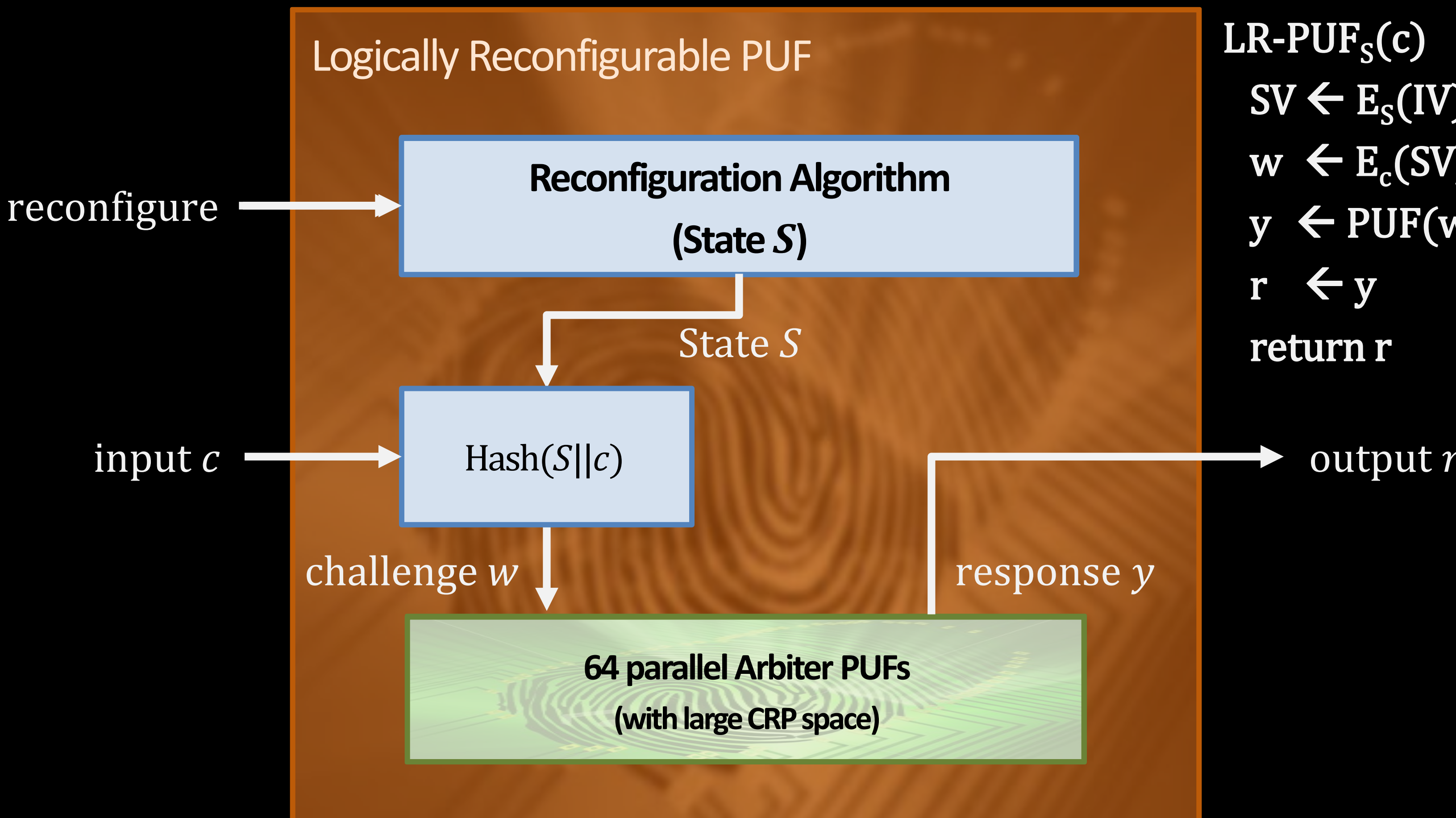
Generic Construction



Speed-Optimized Construction



Speed-Optimized Implementation



$LR\text{-}PUF_S(c)$

$SV \leftarrow E_S(IV)$

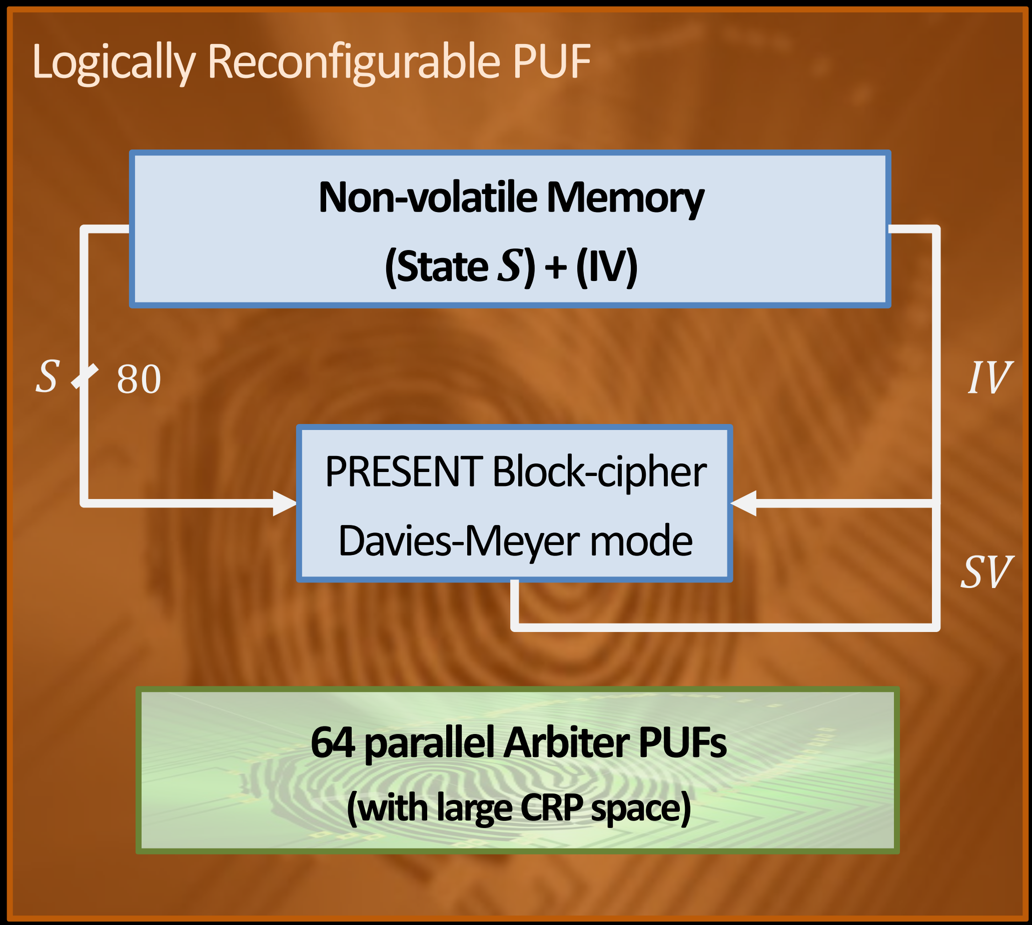
$w \leftarrow E_c(SV)$

$y \leftarrow PUF(w)$

$r \leftarrow y$

return r

Speed-Optimized Implementation



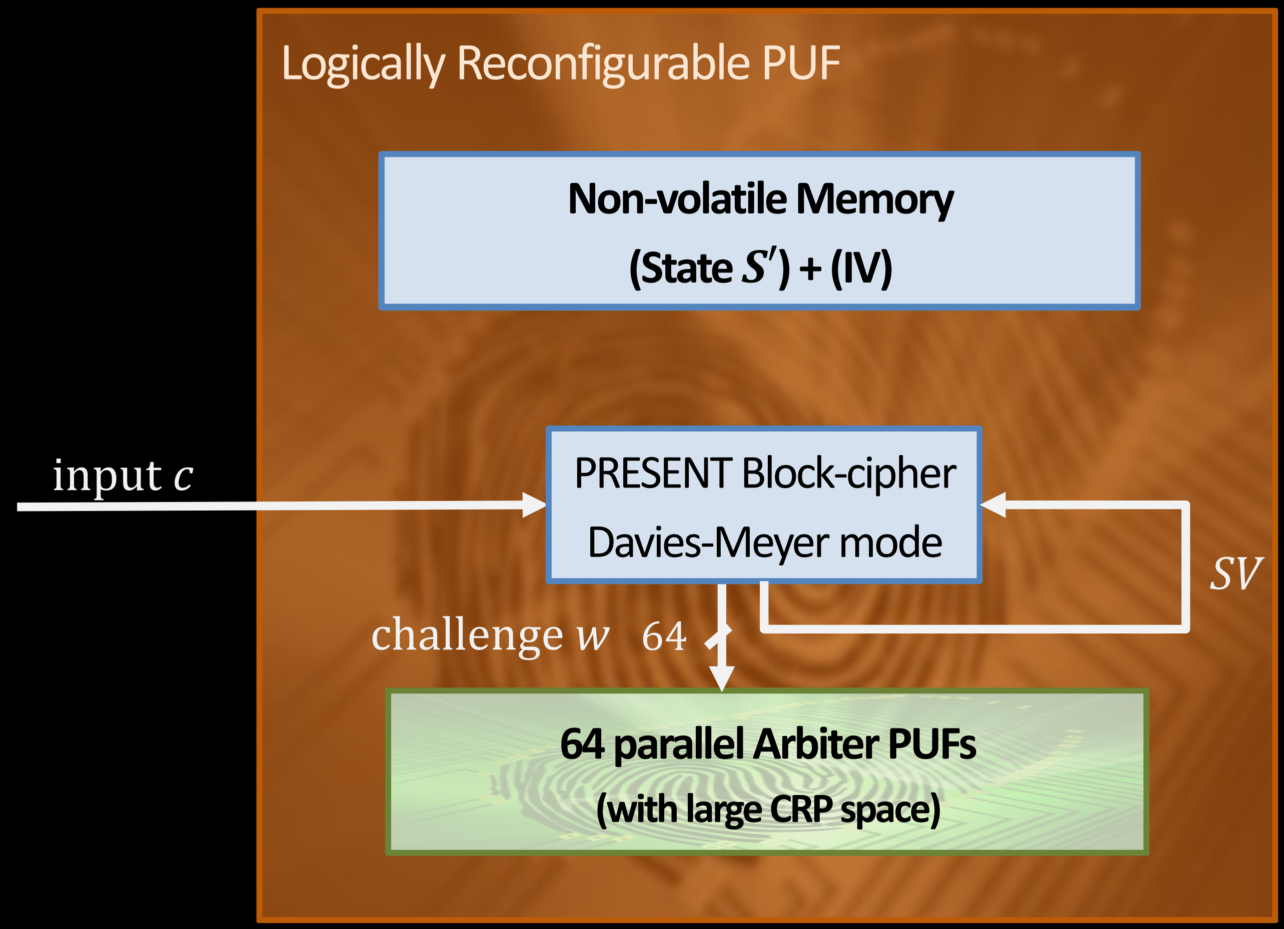
$LR\text{-}PUF_S(c)$

$SV \leftarrow E_S(IV)$

IV : Initialization vector – 64-bit

SV : Session vector – 64-bit

Speed-Optimized Implementation



LR-PUF_S(c)

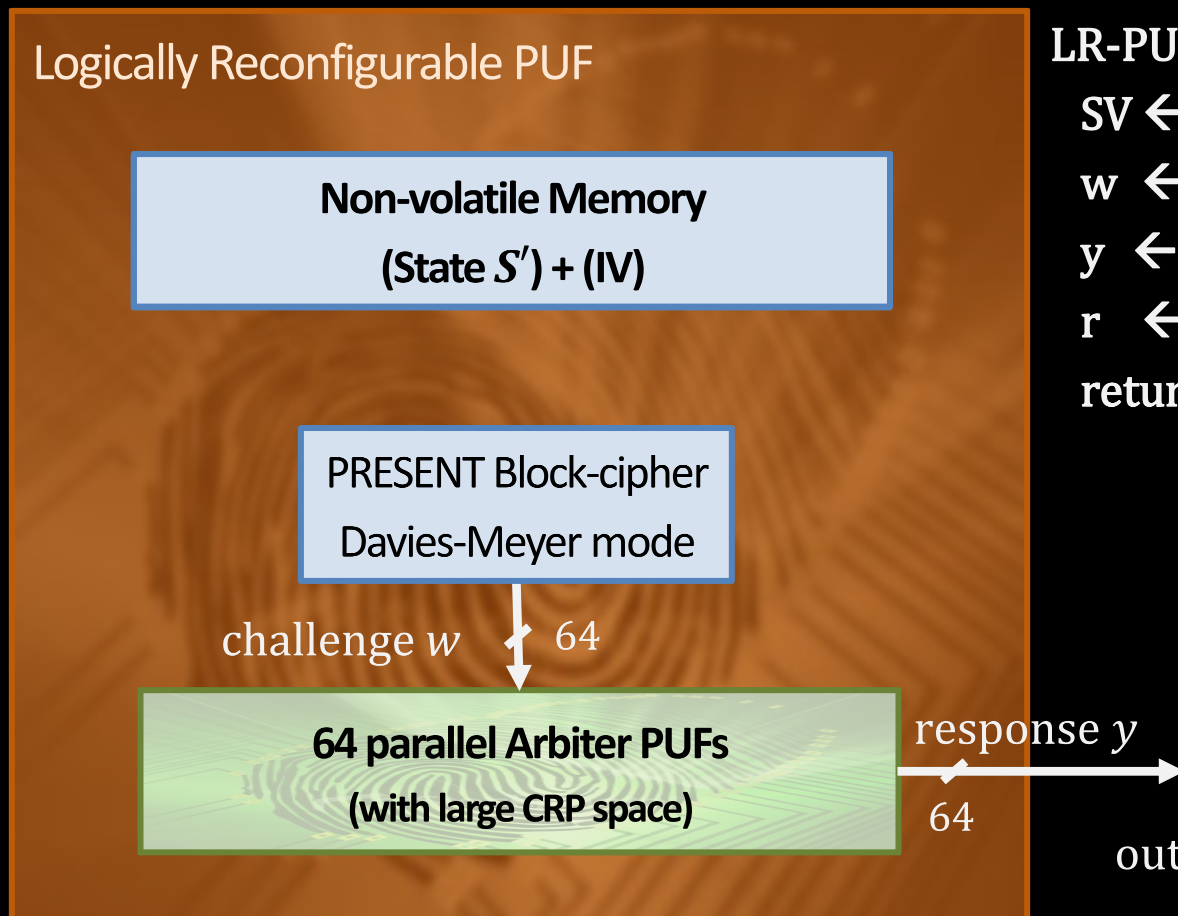
SV ← E_S(IV)

w ← E_c(SV)

IV : Initialization vector – 64-bit

SV : Session vector – 64-bit

Speed-Optimized Implementation



output r

LR-PUF$_S$(c)

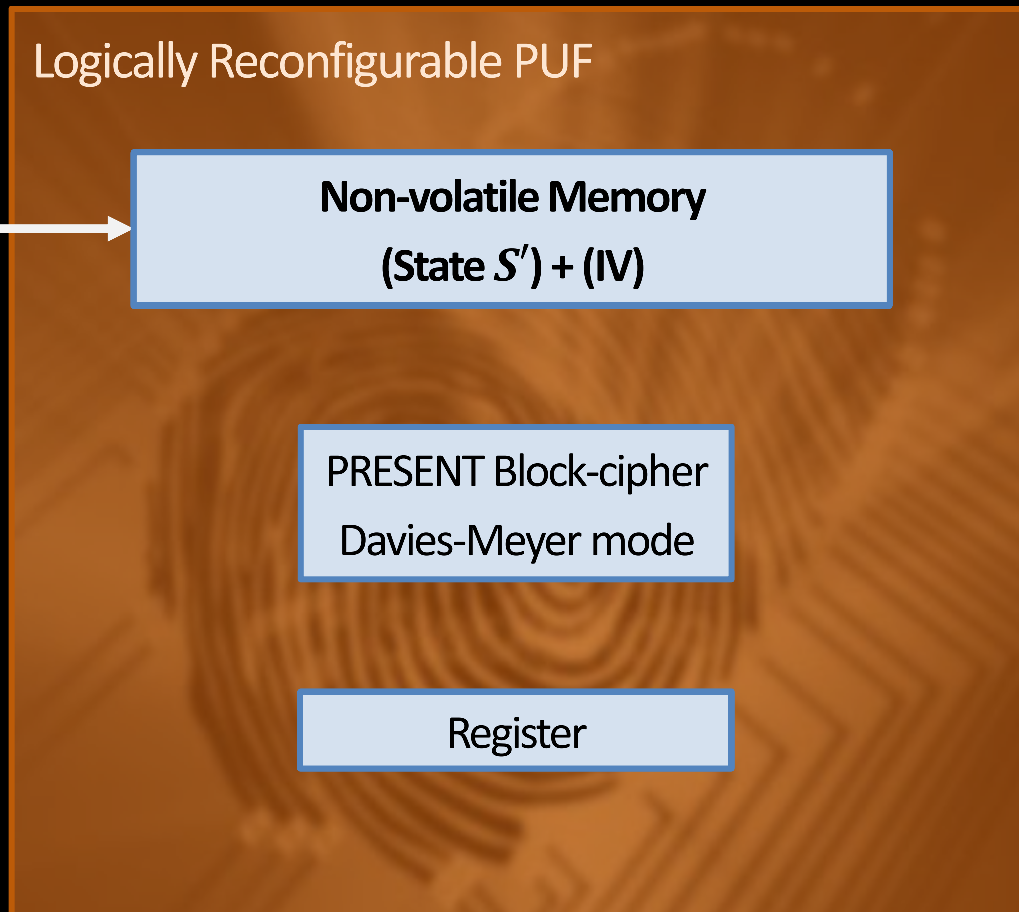
- SV ← E_S(IV)
- w ← E_c(SV)
- y ← PUF(w)
- r ← y
- return r

IV : Initialization vector – 64-bit

SV : Session vector – 64-bit

Speed-Optimized Implementation

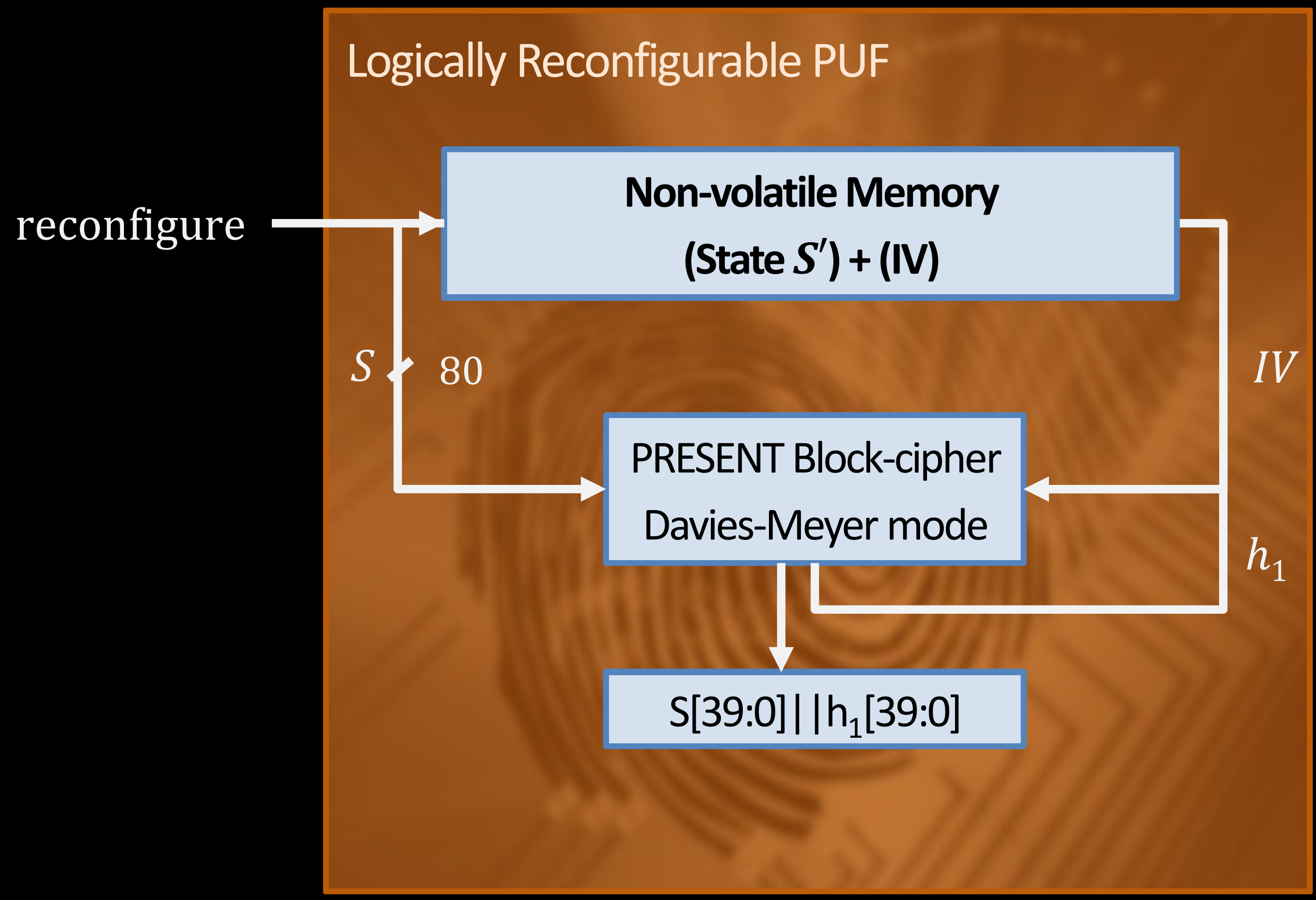
reconfigure



$S' \leftarrow \mathrm{Hash}(S)$

IV : Initialization vector – 64-bit

Speed-Optimized Implementation



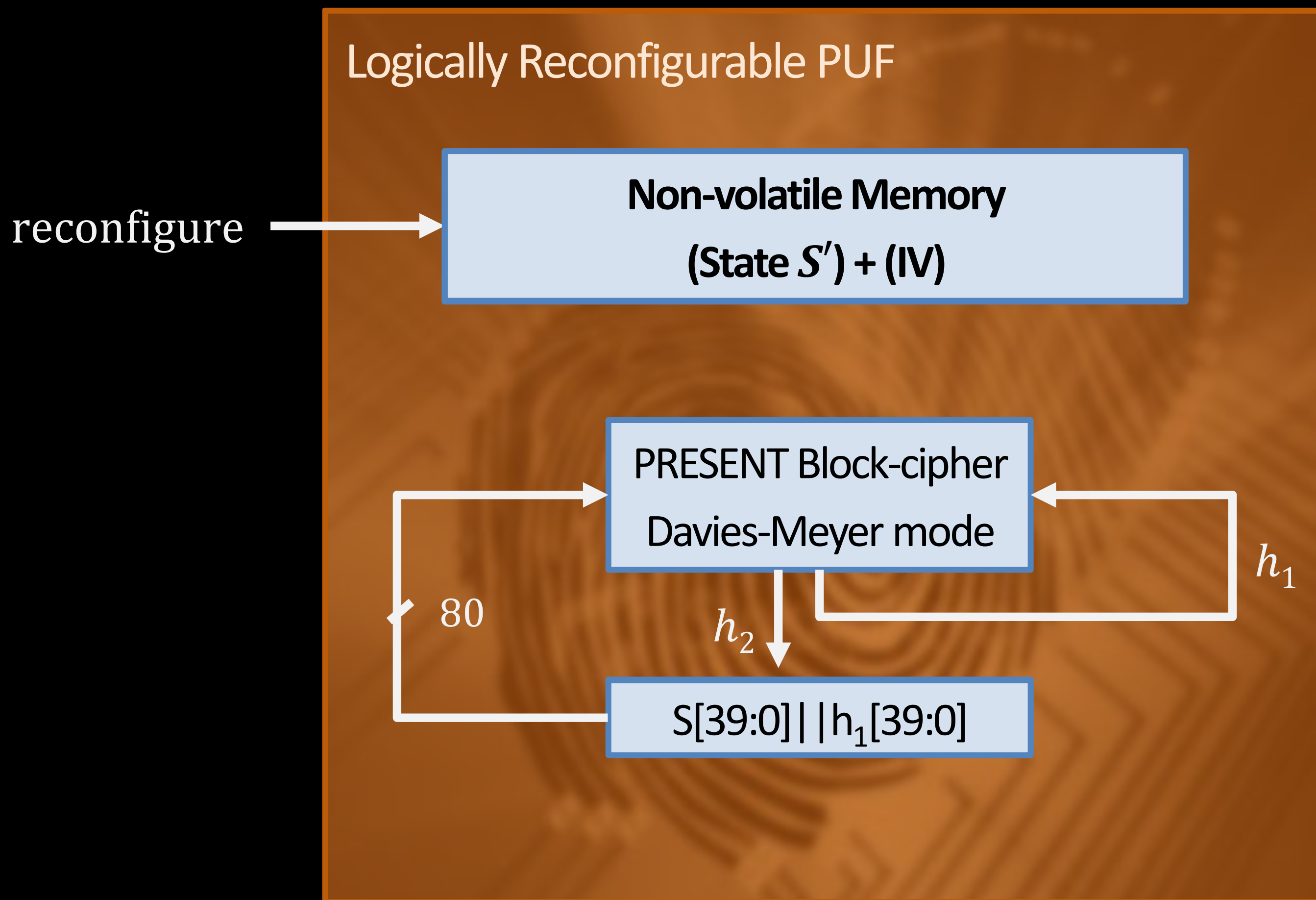
$S' \leftarrow$ Hash(S)

$h_1 \leftarrow E_S$(IV)

IV : Initialization vector – 64-bit

h_1 : hash-1 – 64-bit

Speed-Optimized Implementation



$S' \leftarrow \text{Hash}(S)$

$h_1 \leftarrow E_S(IV)$

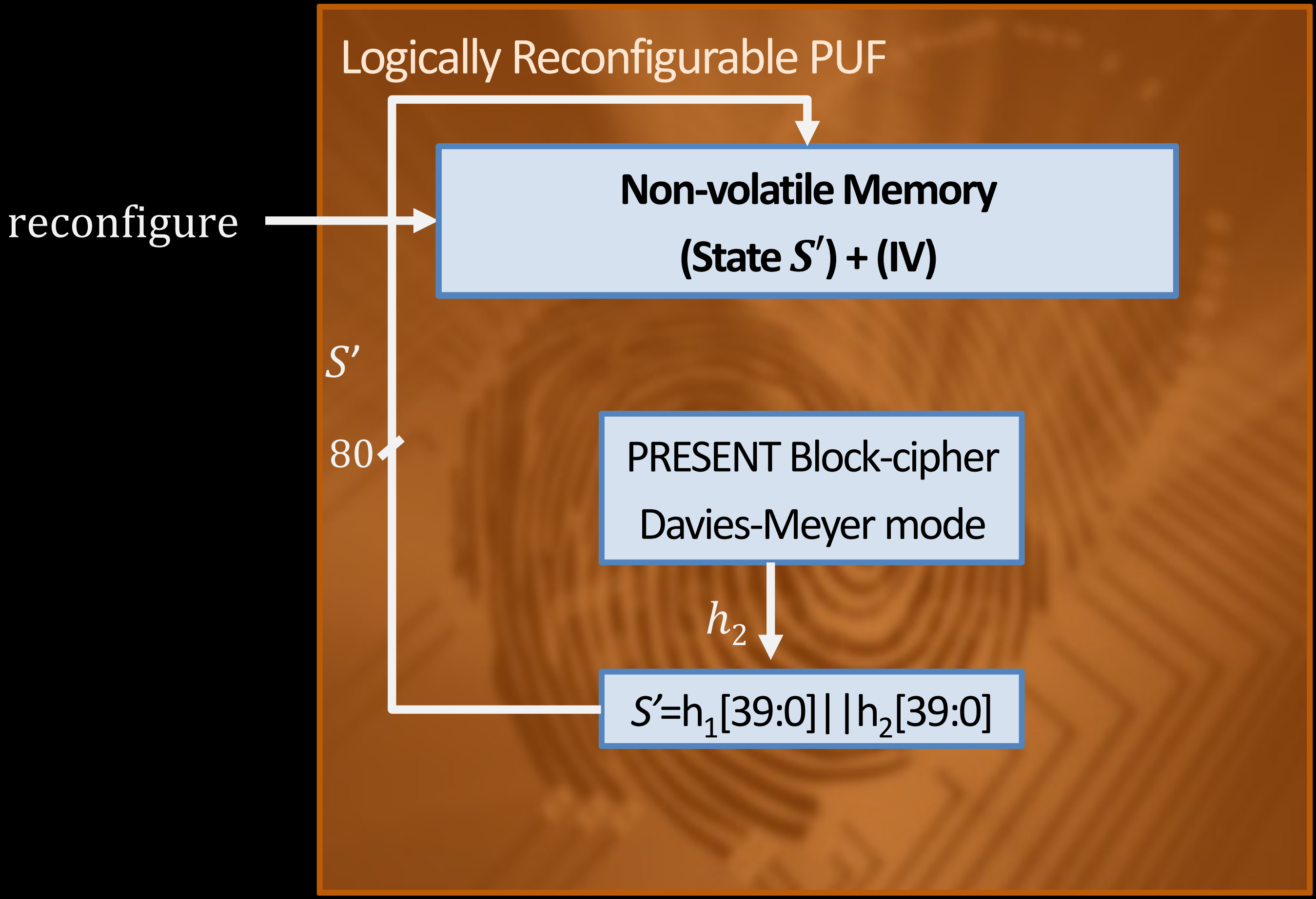
$h_2 \leftarrow E_{SK}(h_1)$

IV : Initialization vector – 64-bit

h_1 : hash-1 – 64-bit

h_2 : hash-2 – 64-bit

Speed-Optimized Implementation



$S' \leftarrow \mathrm{Hash}(S)$

$h_1 \leftarrow E_S(IV)$

$h_2 \leftarrow E_{SK}(h_1)$

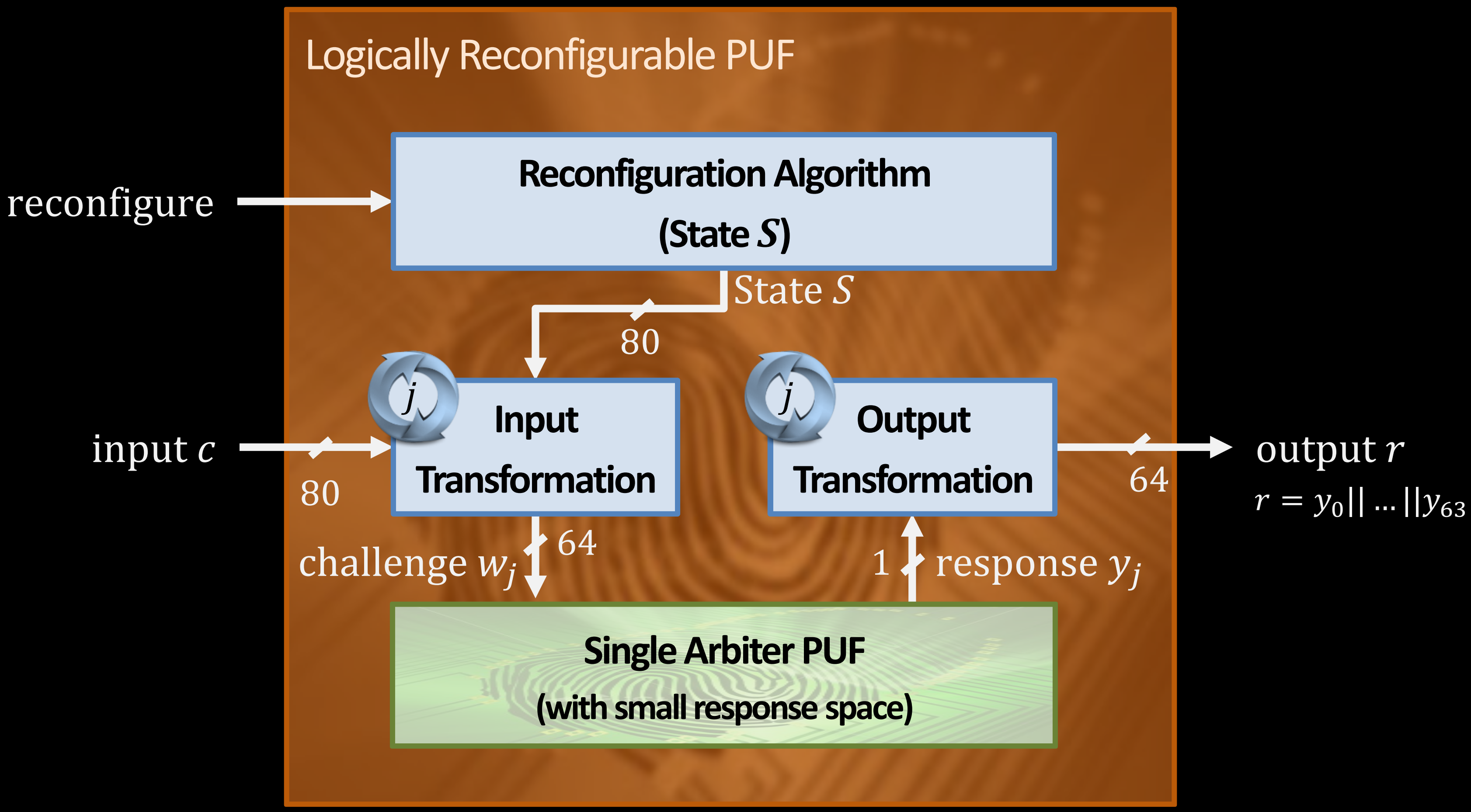
$S' \leftarrow h_1[39:0] || h_2[39:0]$

IV : Initialization vector – 64-bit

h_1 : hash-1 – 64-bit

h_2 : hash-2 – 64-bit

Area-Optimized Construction



Performance Results

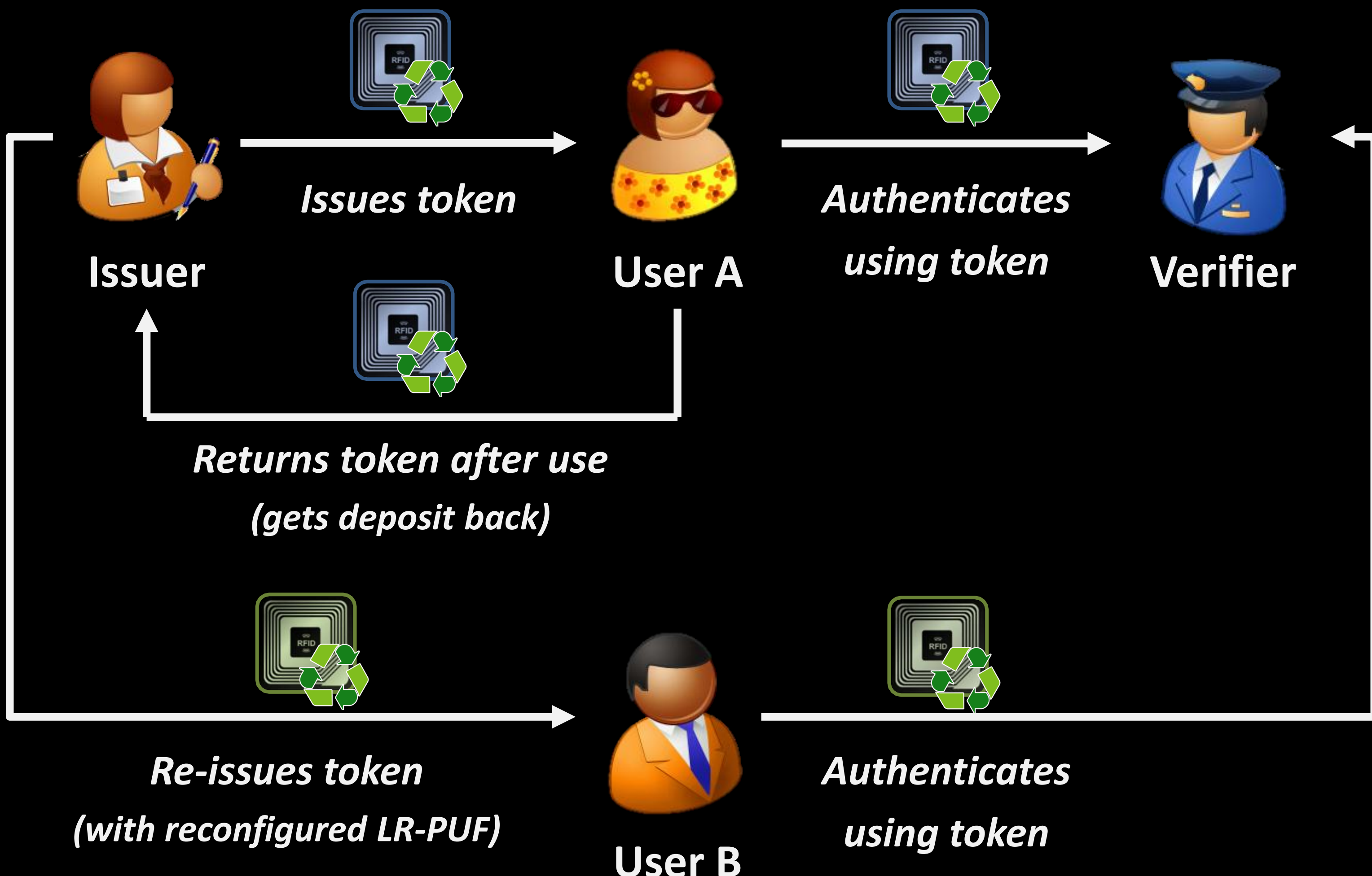
Implementation on Xilinx Spartan 6 FPGA

- Based on Arbiter PUFs (take 64 bit challenge, generate 1 bit response each)
- Hash function: PRESENT in Davies-Meyer Mode

Optimization	Response time in clock cycles	Area consumption in slices (gate equivalents)		
		Control logic	PUF	Total
Speed	1,069	166 (1,162 GE)	4,288 (29,056 GE)	4,454 (30,218 GE)
Area	64,165	358 (2,506 GE)	67 (454 GE)	425 (2,960 GE)

Speed-optimized variant is 63 times faster but 10 times bigger than area-optimized variant

Use Case: Recyclable Access Tokens



B should not be able to use A's access rights

Recyclable Access Tokens

Save money

No new tokens needed

Can increase security and privacy

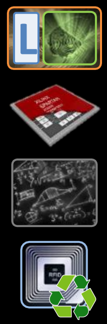
Use and re-use small number of advanced tokens instead of a large number of low-cost and constrained one-time tokens

Reduce electronic Waste

Besides obvious ecologic aspects, economic aspect: Governments make vendors of electronic equipment responsible for disposal of their products

System Security Lab Fraunhofer SIT TECHNISCHE UNIVERSITÄT DARMSTADT CASED

Conclusion and Future Work



We presented

- Concept of Logically Reconfigurable PUFs (LR-PUFs)
- Formal security model (backward and forward unpredictability)
- LR-PUF constructions (optimized for speed and area consumption)
- Discussed potential applications

Current and Future work

- Improved LR-PUF constructions allowing for more efficient verification
- Concrete protocols for LR-PUF-based access tokens

Thank you!

Ünal Kocabaş
unal.kocabas@trust.cased.de
TU Darmstadt (CASED), Germany

Back up slide: Controlled PUFs vs. LR-PUFs

Controlled PUFs

- Objective: Prevent model building attacks that allow emulating the PUF
- Approach: Hide responses of underlying PUF (e.g., by hashing the PUF response)

Logically Reconfigurable PUFs

- Objective: Change challenge/response behavior of underlying PUF after deployment
- Approach: Entangle challenges/responses of underlying PUF with some random state (e.g., by hashing the PUF challenge together with some state)

Although specific instantiations of controlled and logically reconfigurable PUFs look similar, they represent different concepts with different objectives!