Design Automation and Test in Europe 2014

PUFs at a Glance

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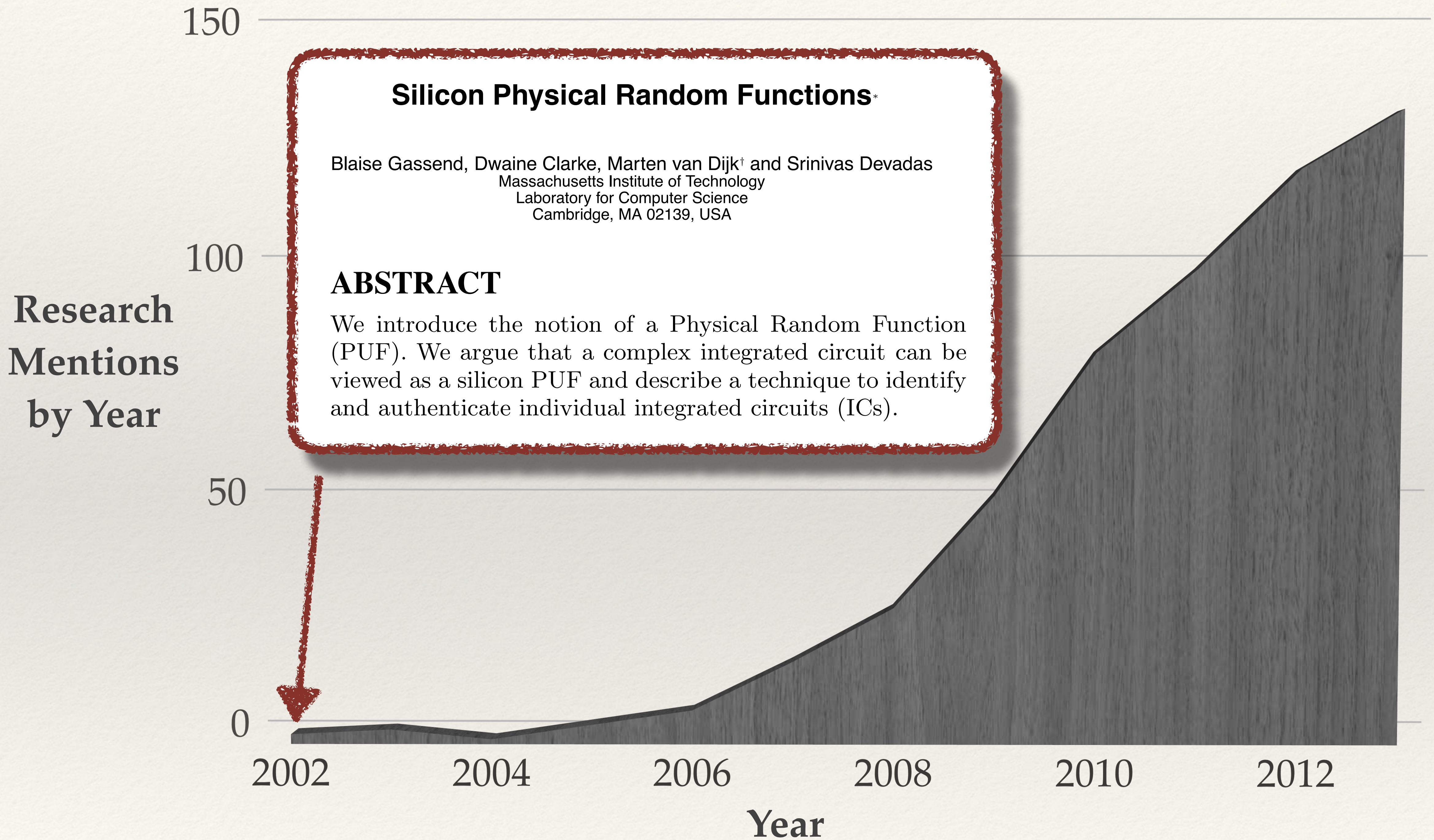
Physical Unclonable Functions



Overview

Context and motivation for remainder of session

1. **Brief introduction to PUFs**
2. Weak PUFs and applications
3. Strong PUFs and applications
4. Conclusions

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  - Map challenges to responses

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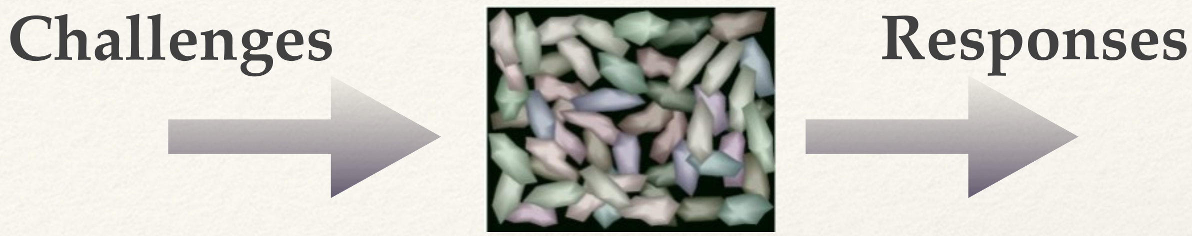

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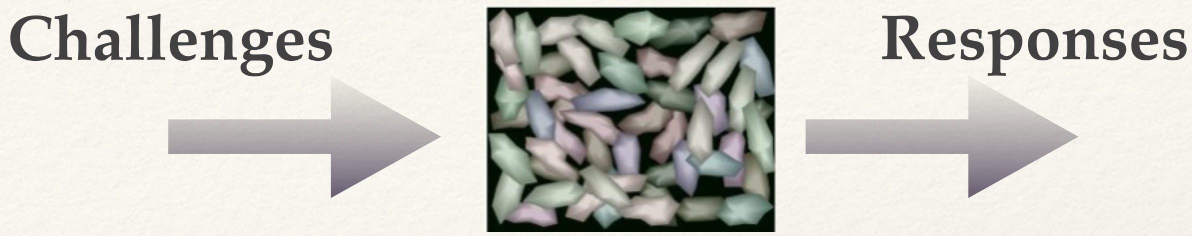
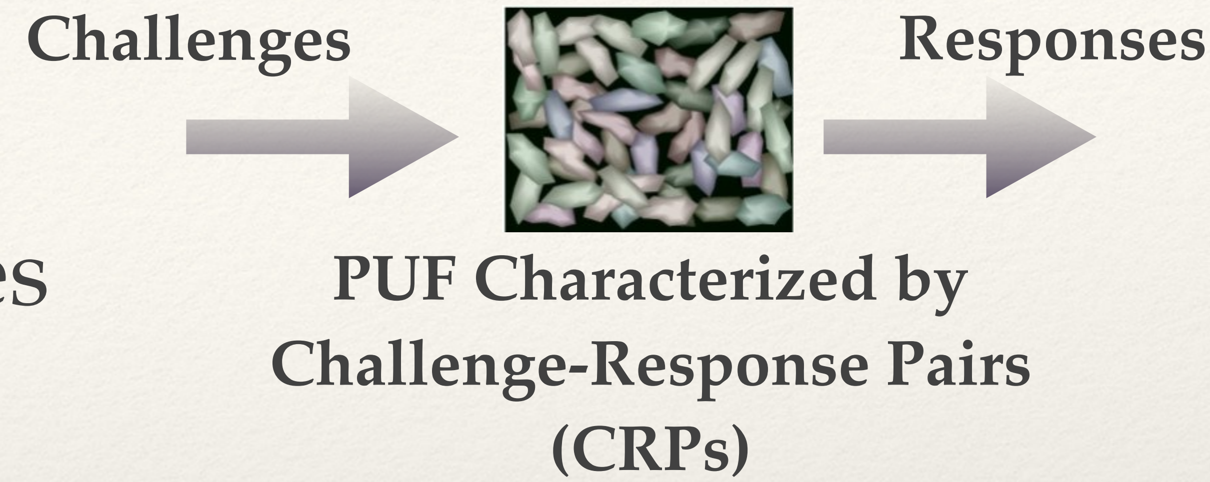


PUF Characterized by Challenge-Response Pairs (CRPs)

Physical Unclonable Functions



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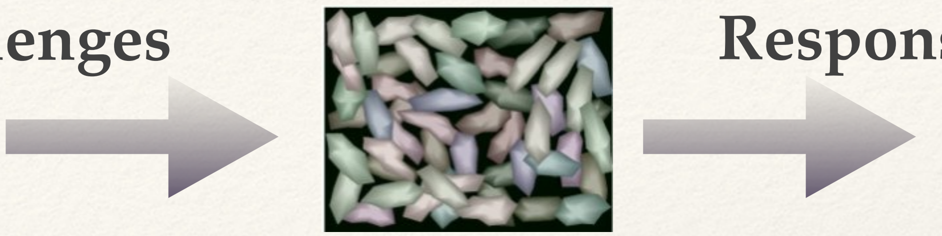

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  - Or, responses kept secret

Design Considerations for Silicon PUFs

- Outputs determined by uncorrelated variation
  - Random dopant fluctuations and small devices
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4th talk of session

Weak vs Strong PUFs

Weak PUFs

Strong PUFs

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- Use cases: New cryptographic primitive

Weak vs Strong PUFs

Weak PUFs

Strong PUFs

- Weak and strong are two PUF subclasses among many
  - Controlled PUFs
  - Public PUFs
  - SIMPL, etc

Overview

1. Brief introduction to PUFs
2. **Weak PUFs and applications**
3. Strong PUFs and applications
4. Conclusions

Examples of Weak PUFs

- Using custom circuits
  - Drain currents [Lofstrom et al. '02]
  - Capacitive coating PUF [Tuyls et al. '06]
  - Cross-coupled devices [Su et al. '07]
  - Sense amps [Bhargava et al. '10]
- Using existing circuits
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  - Power-up SRAM state [Guajardo et al. '07, Holcomb et al. '07]

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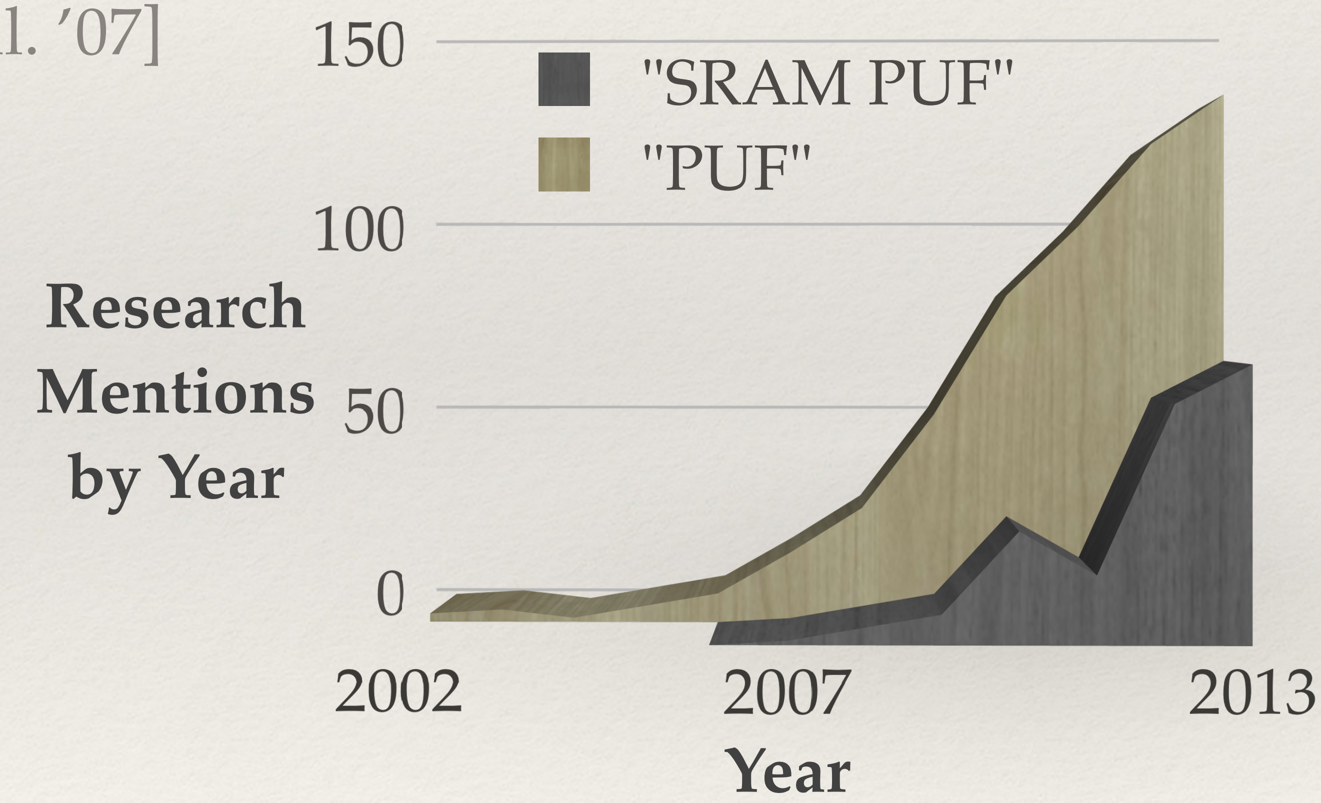

Applications of Weak PUFs

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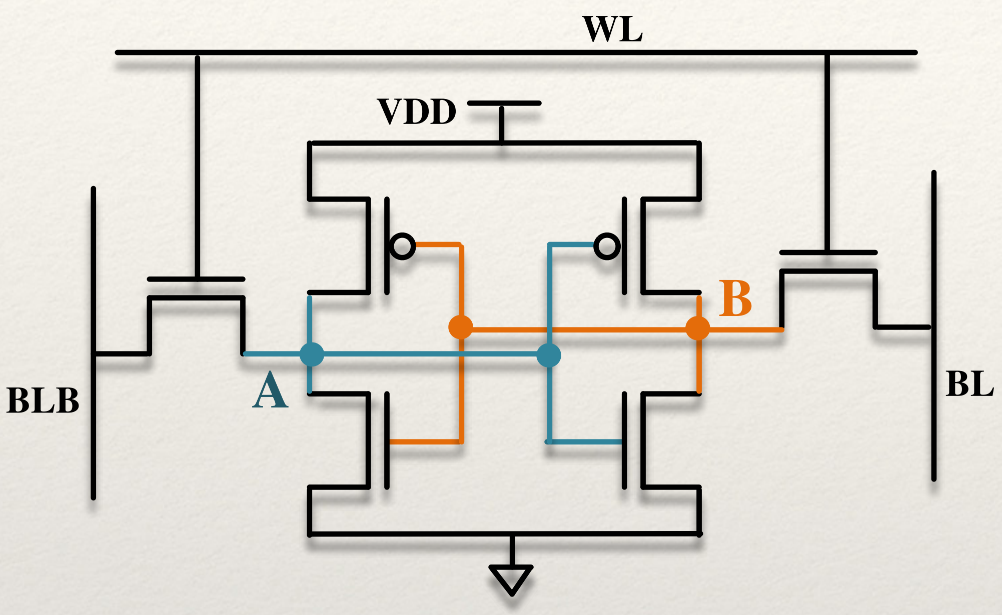
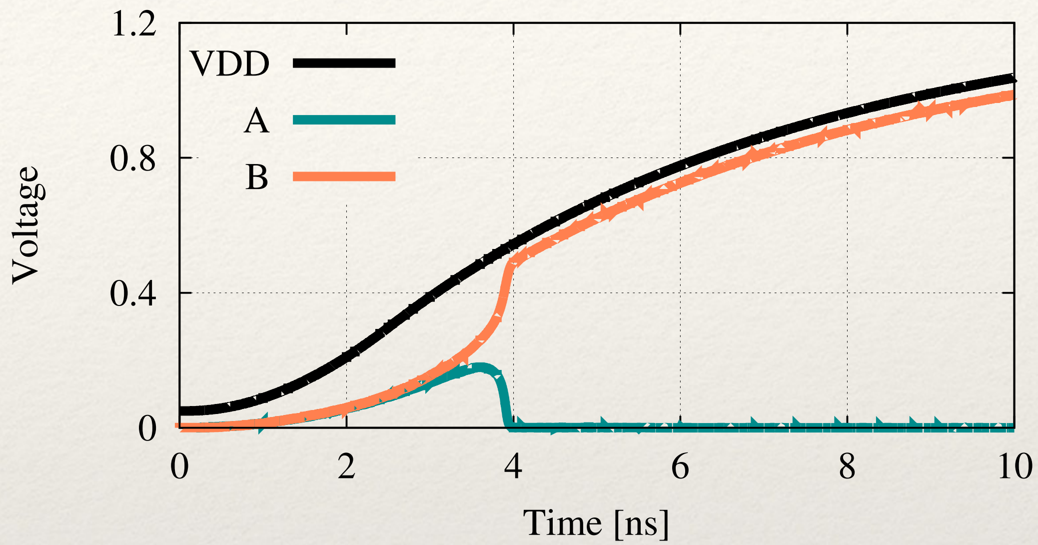
SRAM Power-up State

Utilize inherent power-up bias of each SRAM cell





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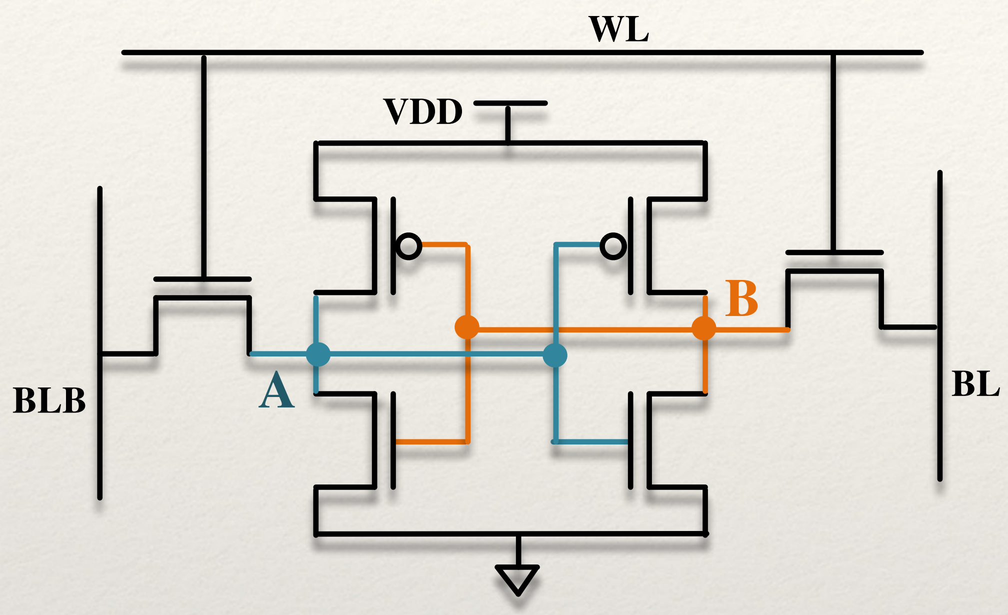

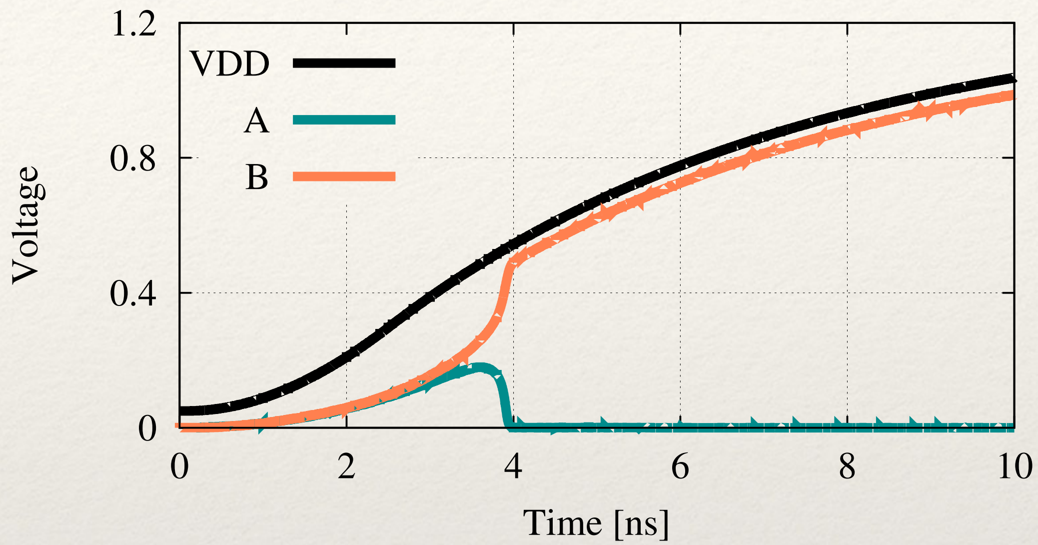

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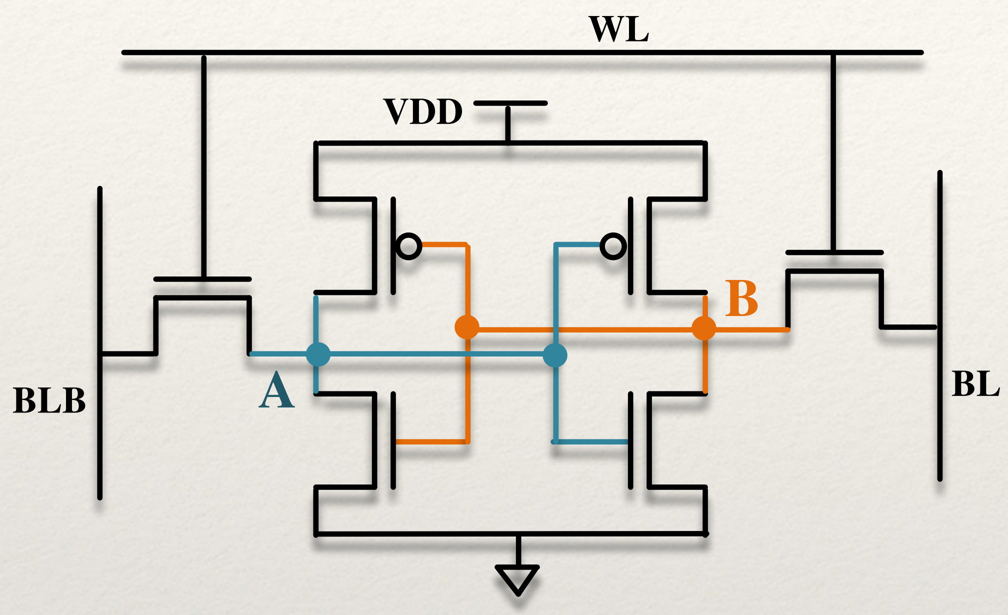

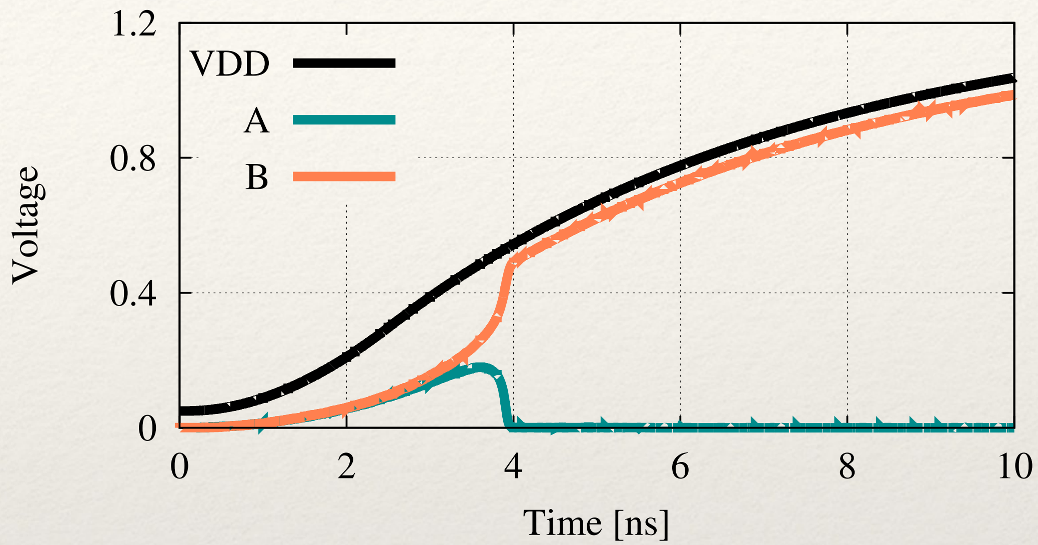

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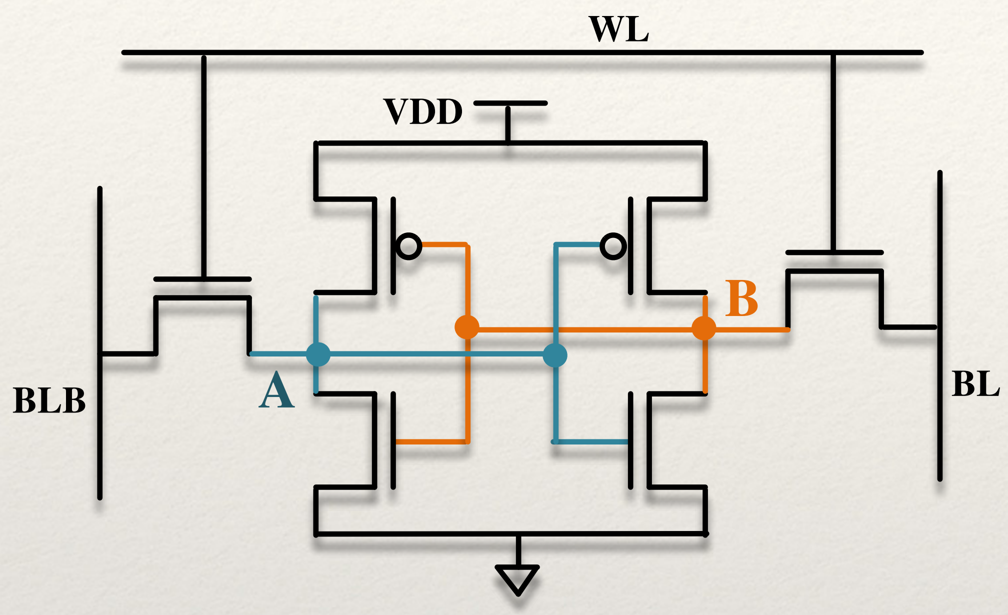

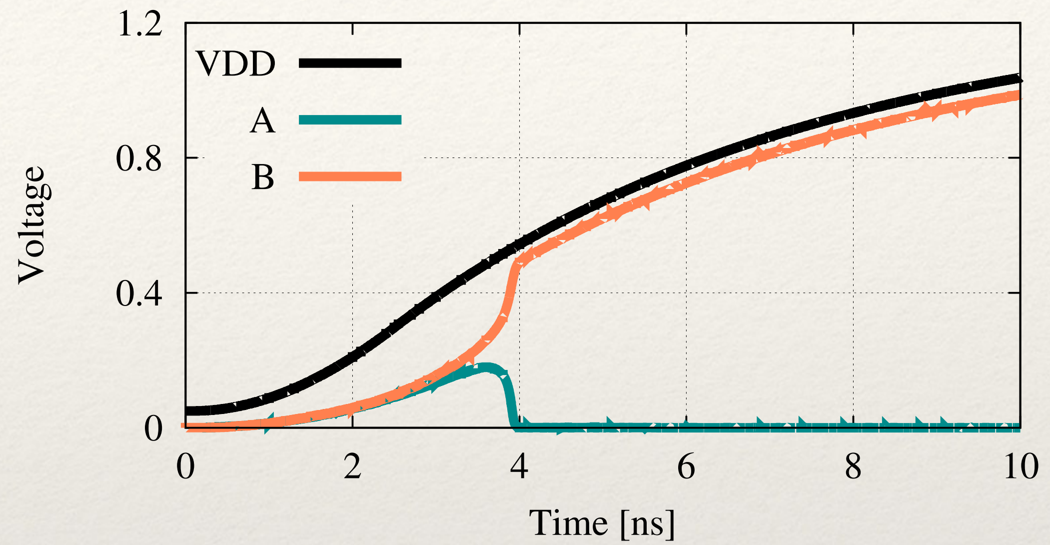

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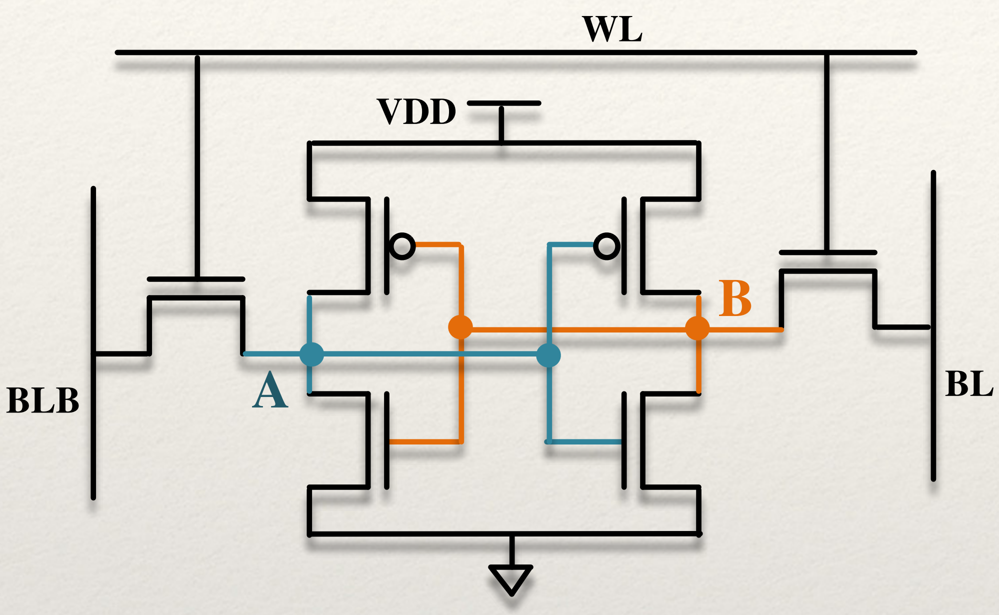

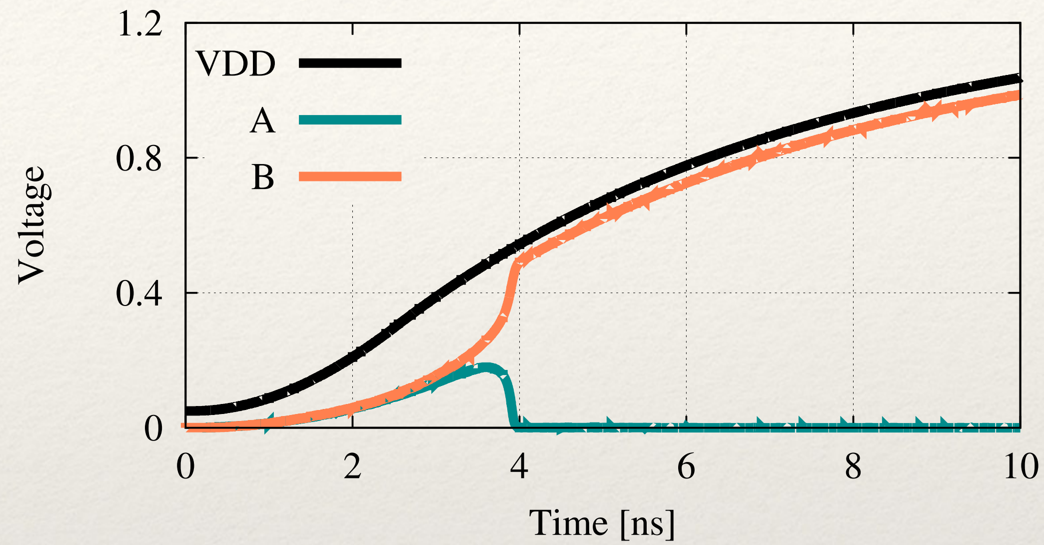

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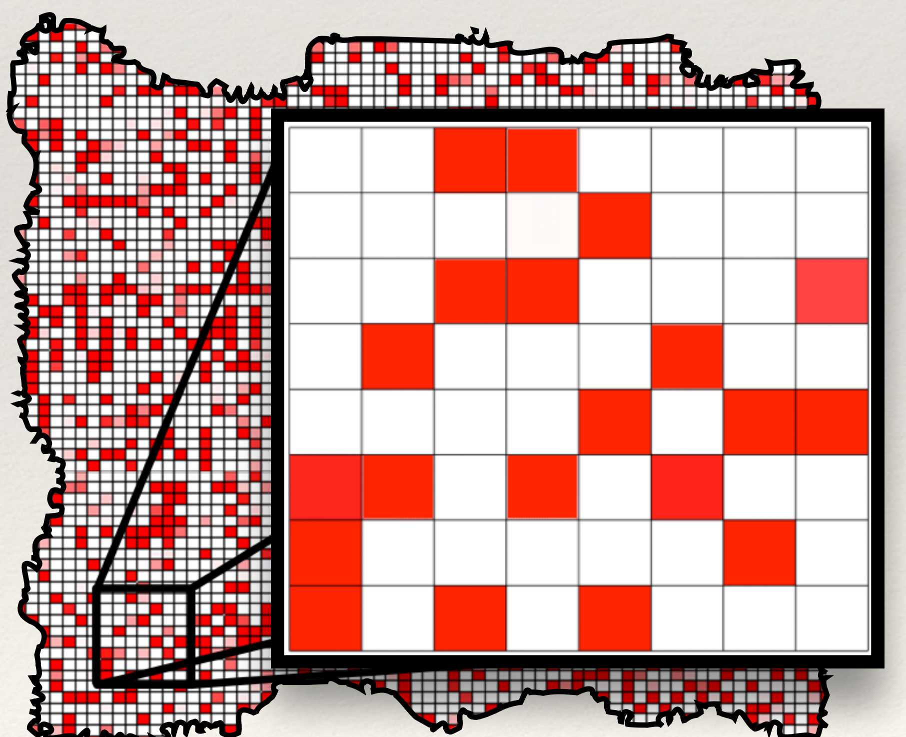
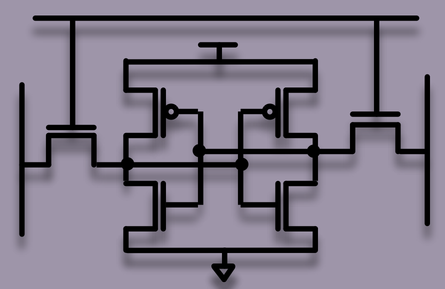


[Holcomb et al., '07]

Weak PUF as Secret Key

Enroll PUF

Weak PUF



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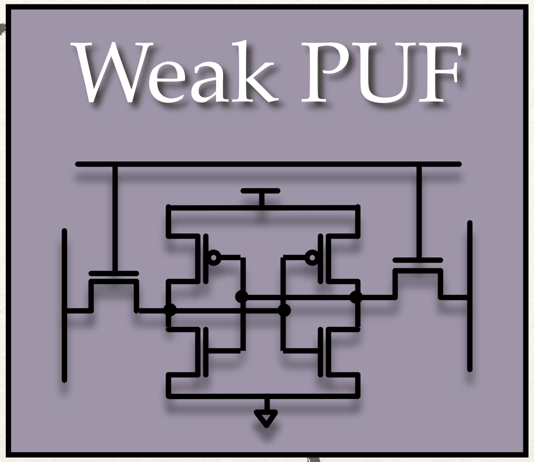

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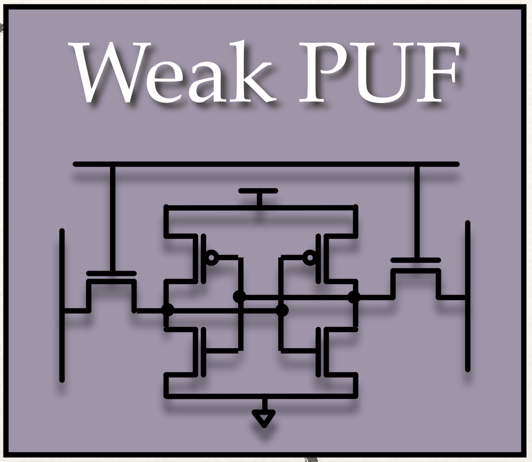

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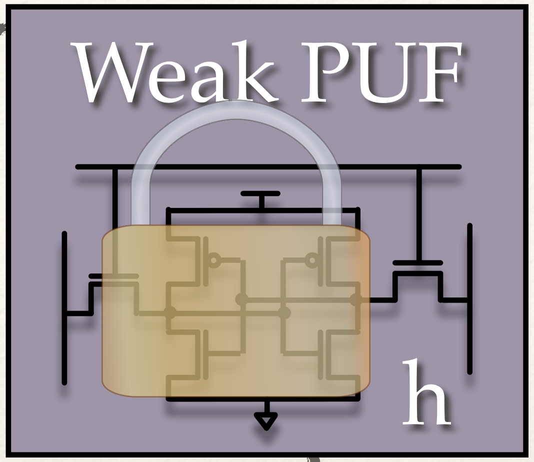

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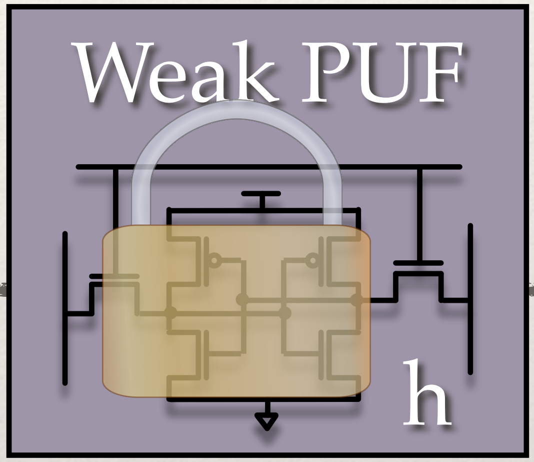
Generate Key in Field



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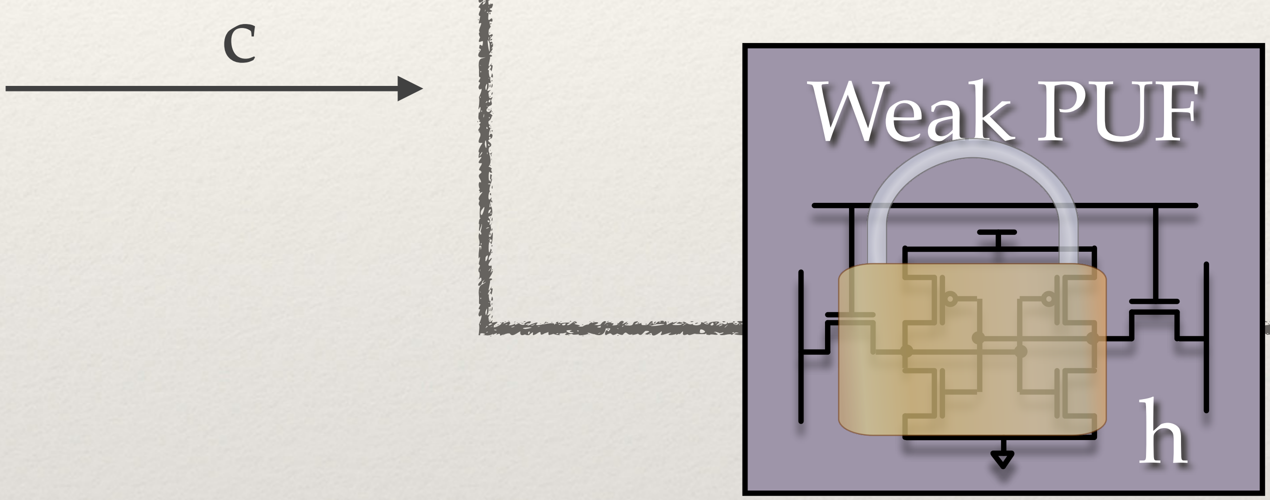

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- Apply c, obtain r′ ⊕ h
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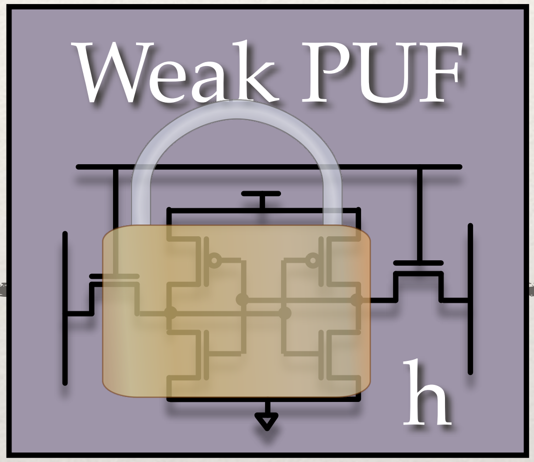

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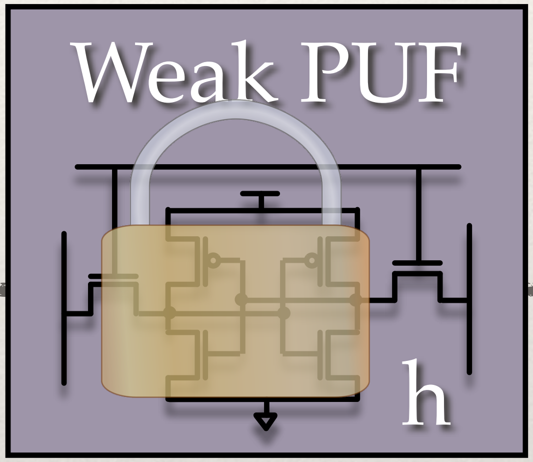

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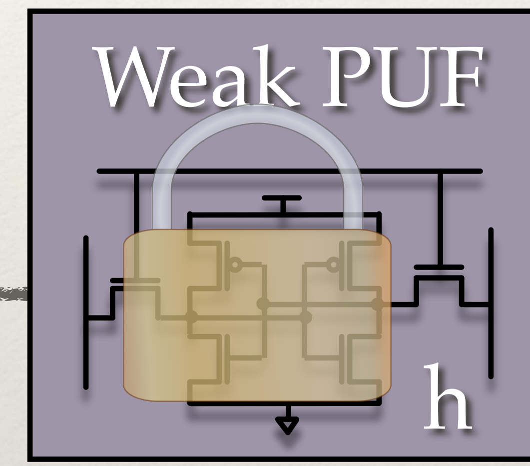

- Reliable unclonable key for crypto
- Assumes that r cannot be read in field

Overview

1. Brief introduction to PUFs
2. Weak PUFs and applications
3. **Strong PUFs and applications**
4. Conclusions

Examples of Strong PUFs

- Optical PUF [Pappu et al. ’02]
- Arbiter PUF [Gassend et al. ’02, Lim et al. ’05]
- Bistable Ring PUF [Chen et al. ’11]
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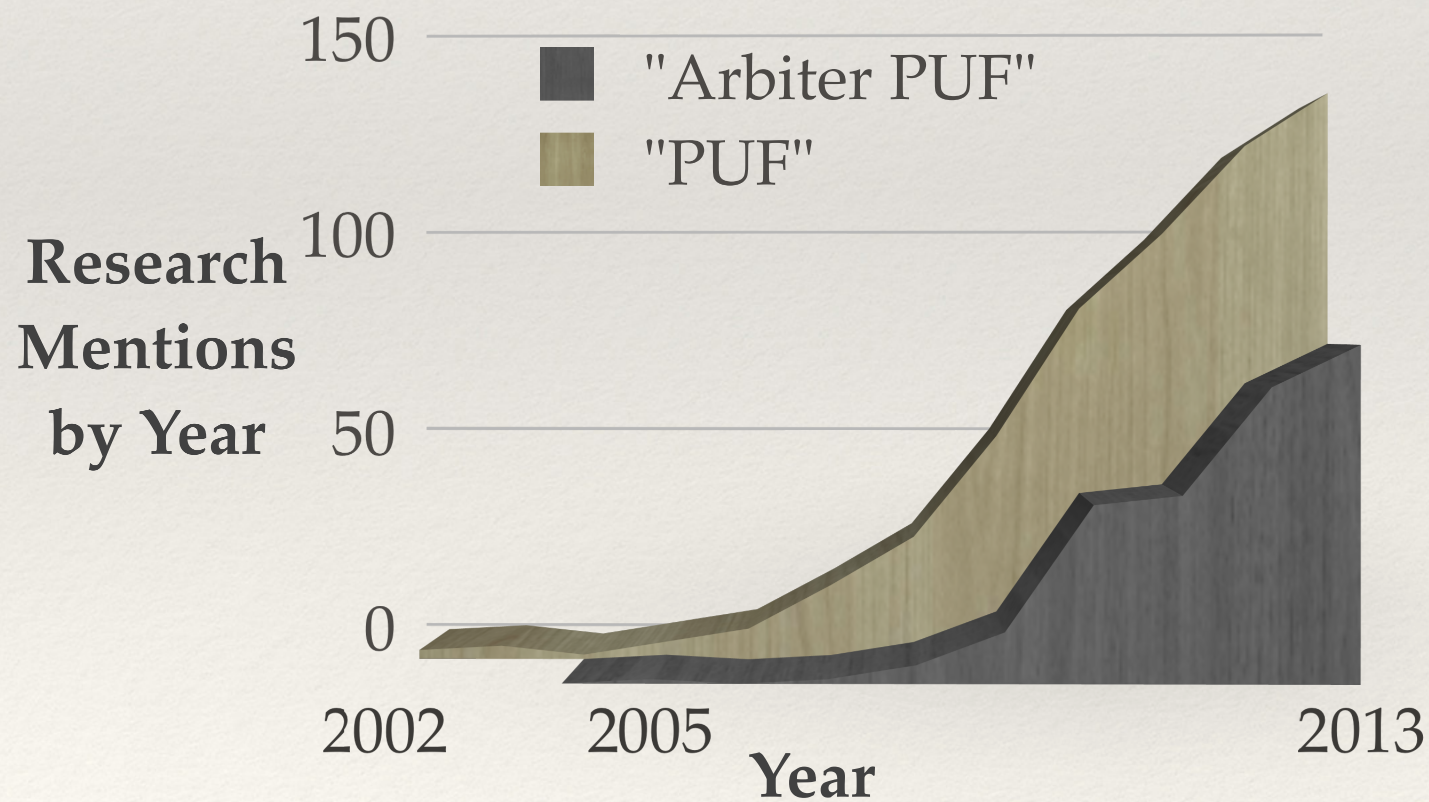

Strong PUF Protocols

- Identification/Authentication (1)
- Key Exchange (2,3)
- Oblivious transfer (4,3,5,6) — enables secure two-party computation
- Bit commitment (3,5,6,7,8) — enables zero-knowledge proofs
- Combined key exchange and authentication (9)

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Arbiter PUF

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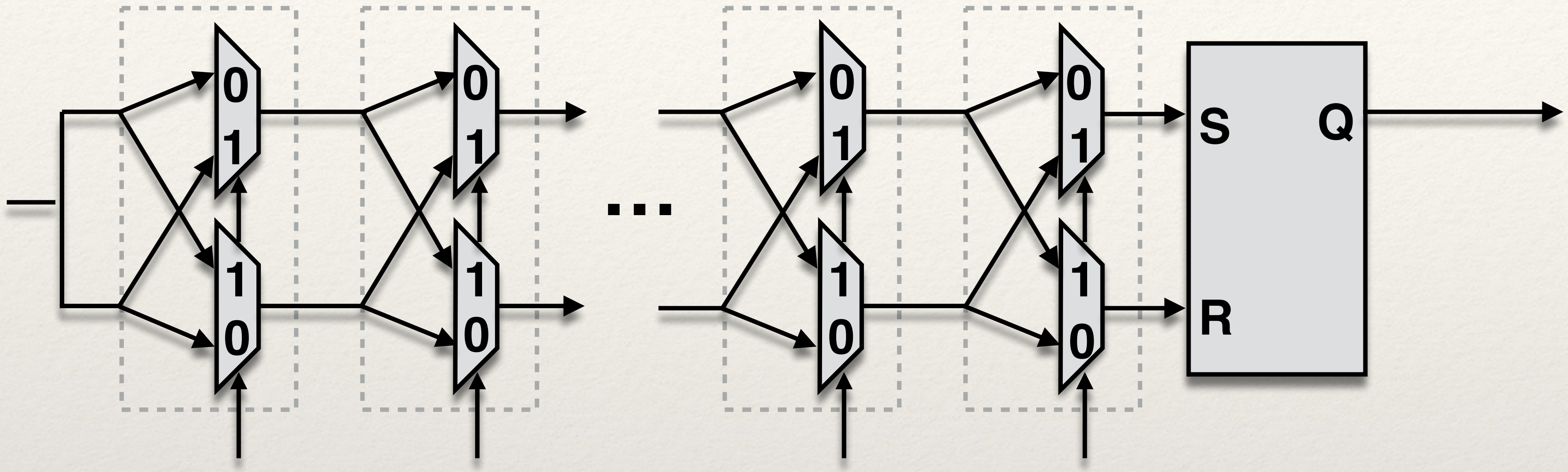

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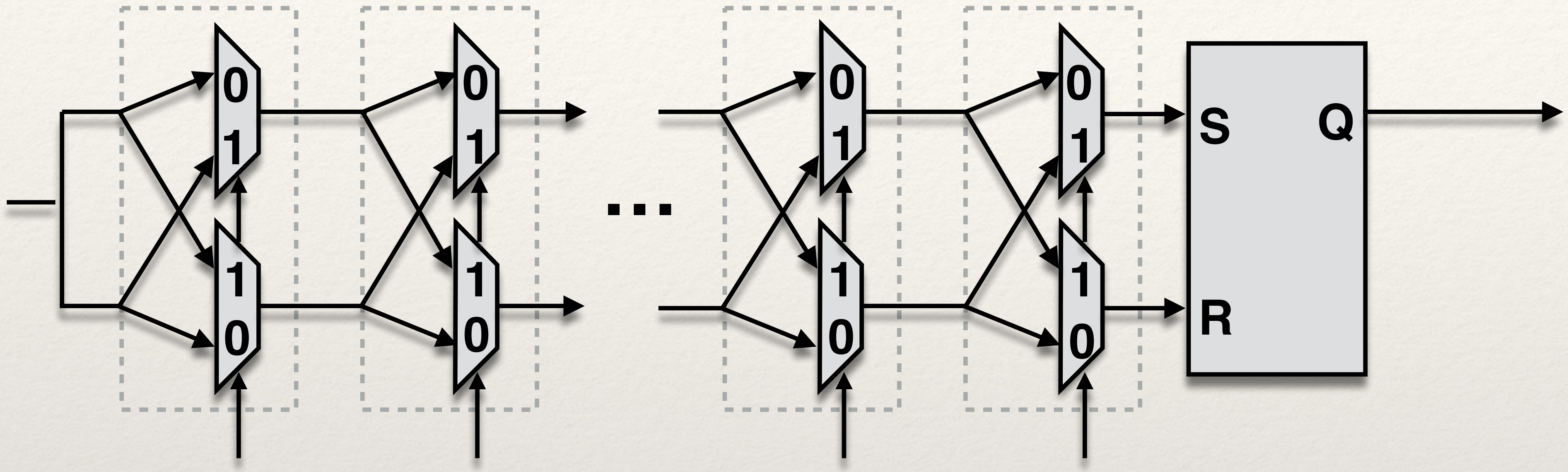

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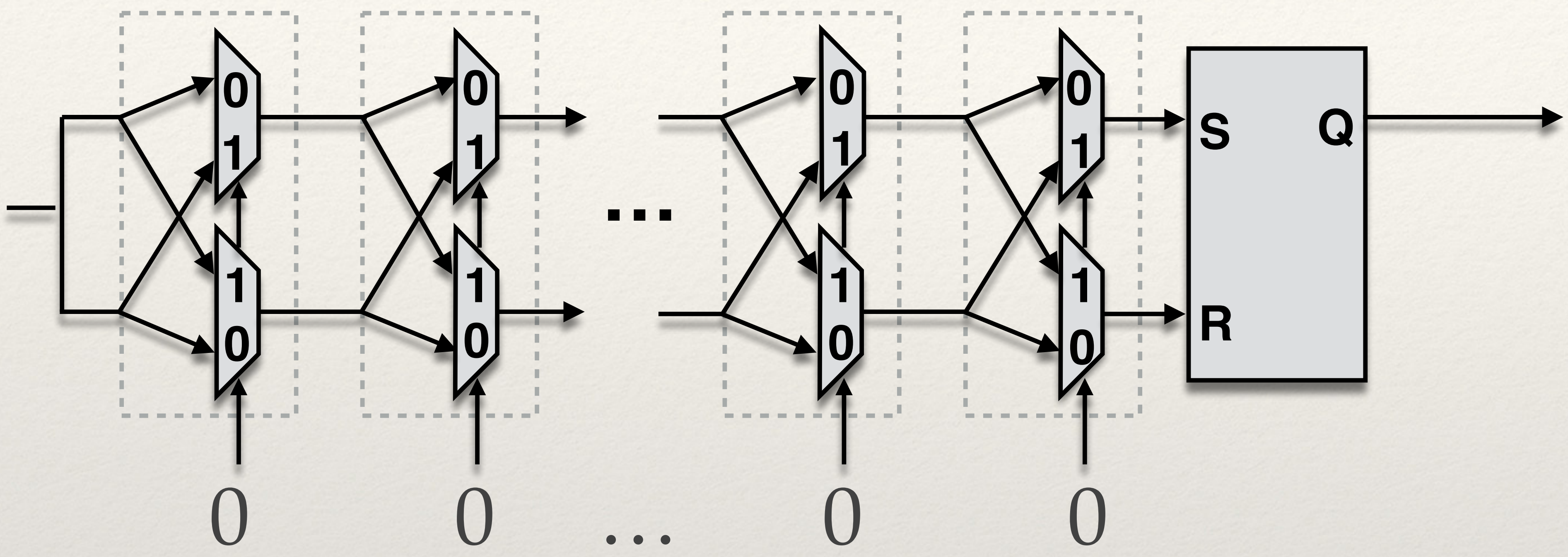

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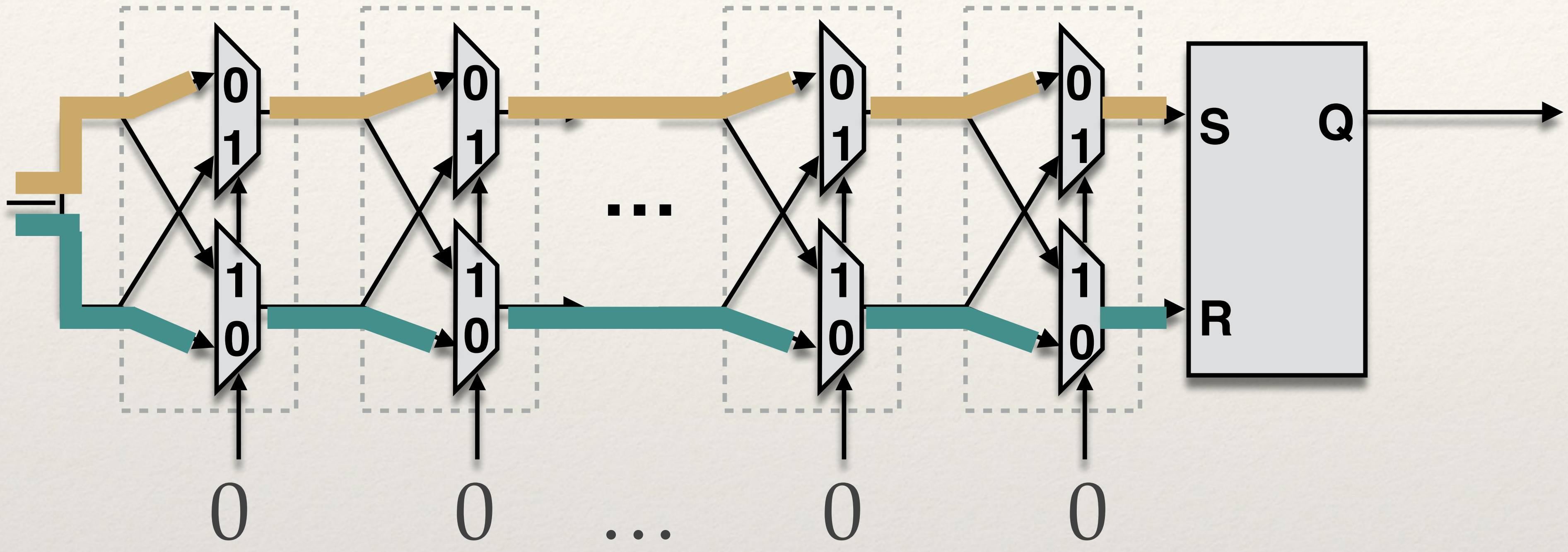

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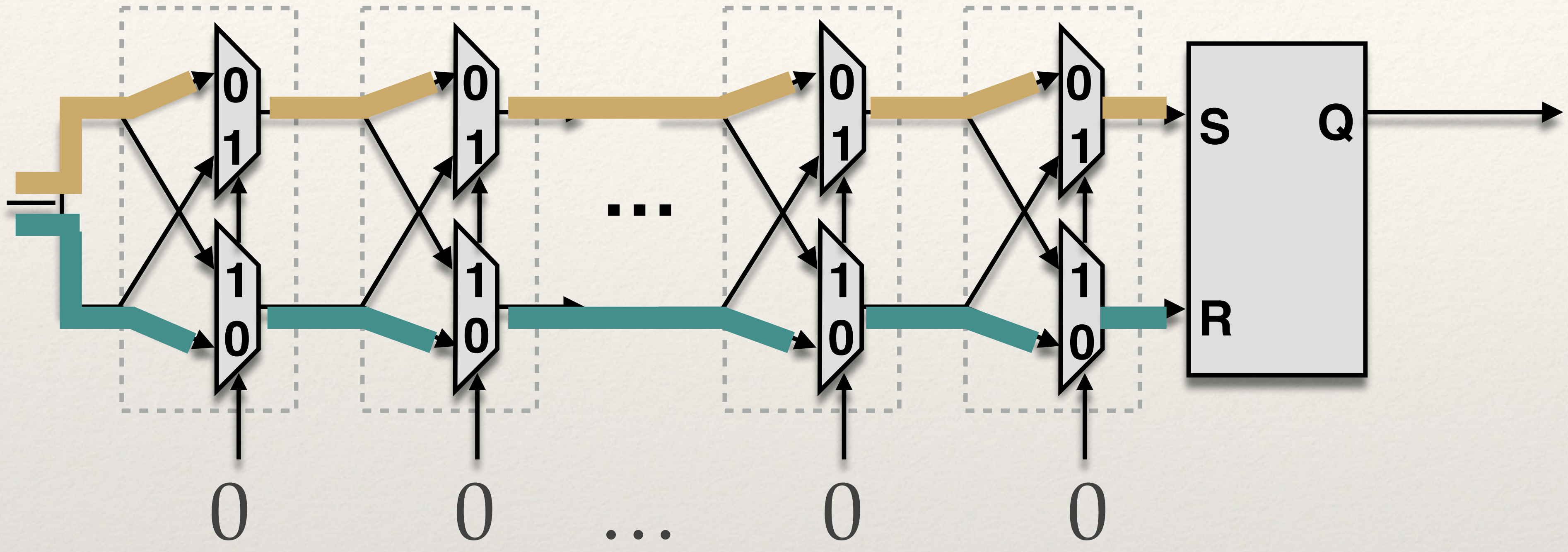

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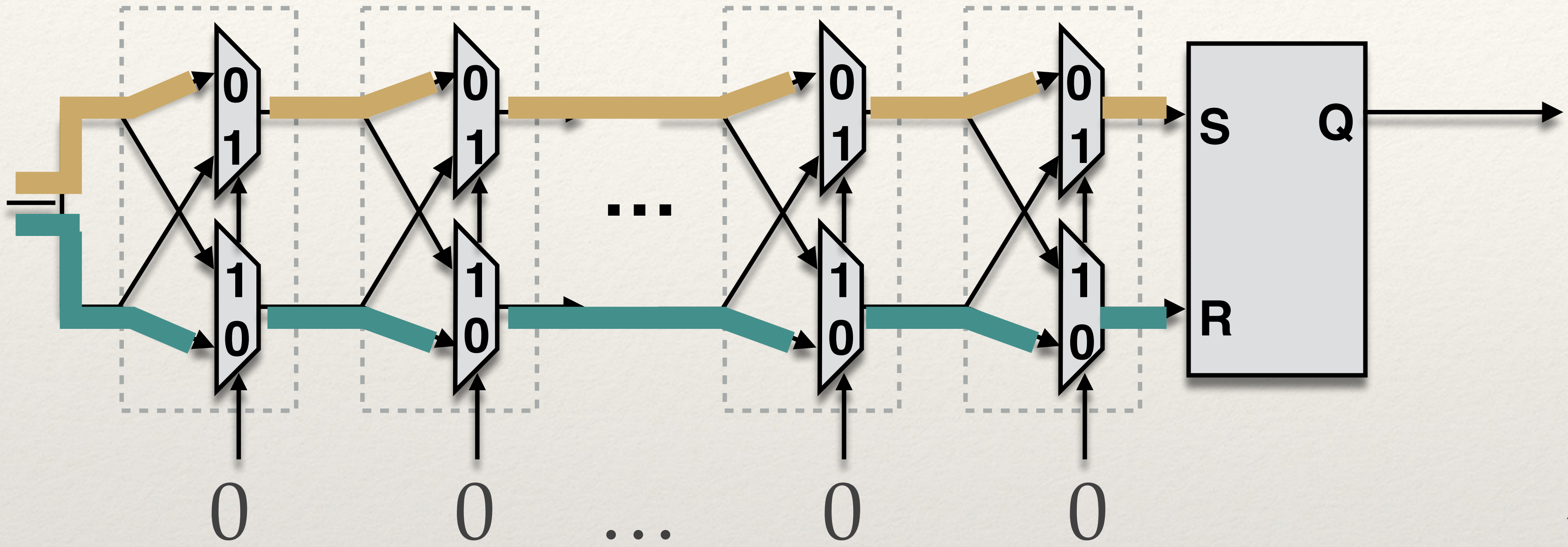

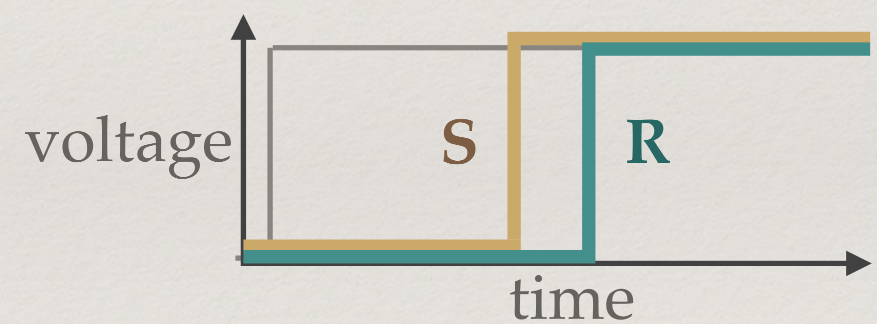

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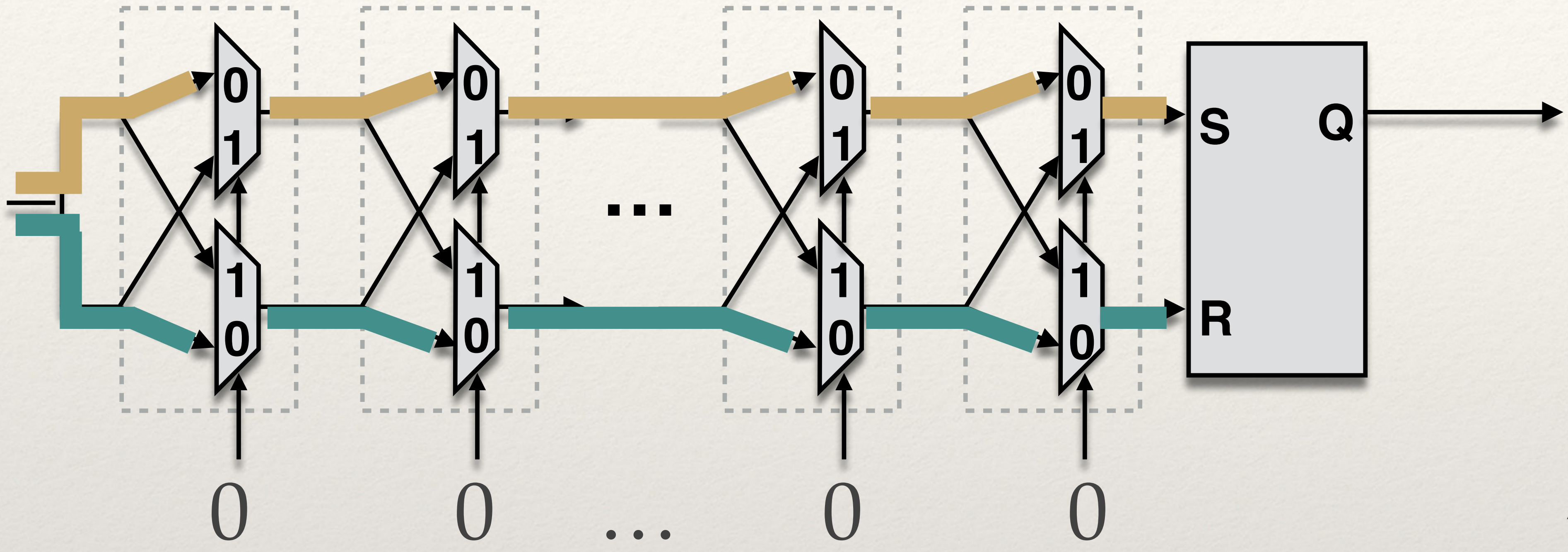

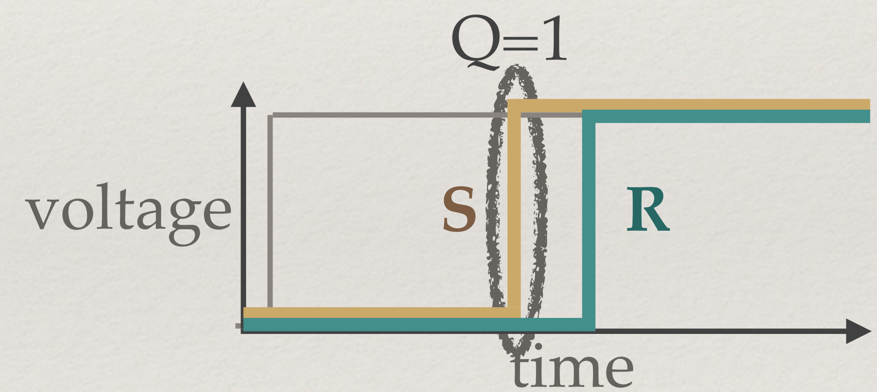

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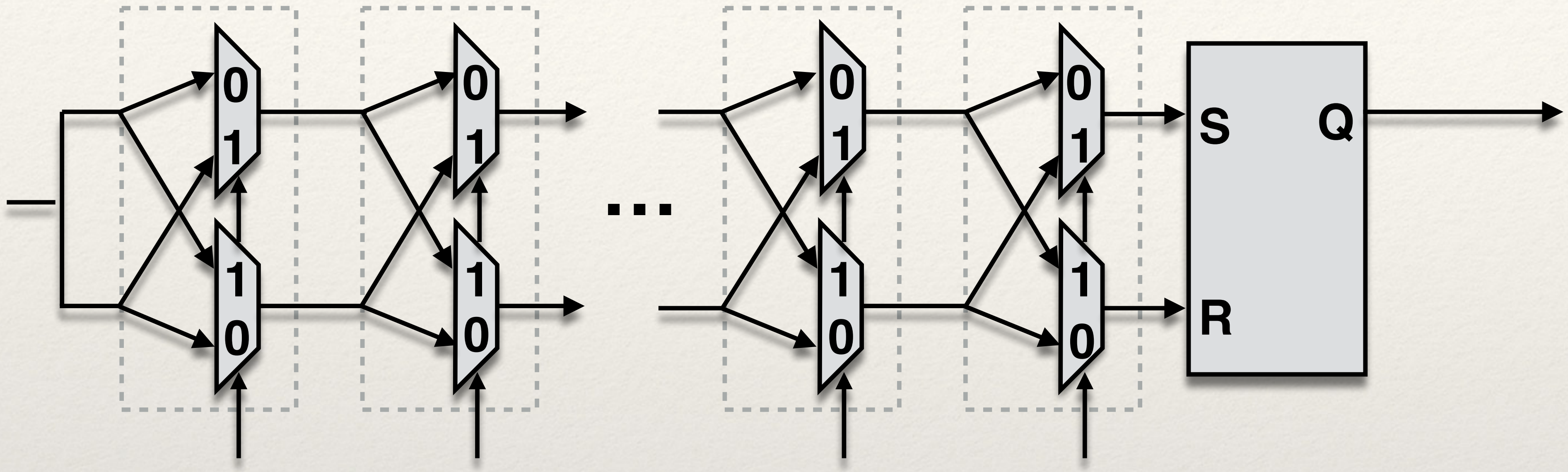

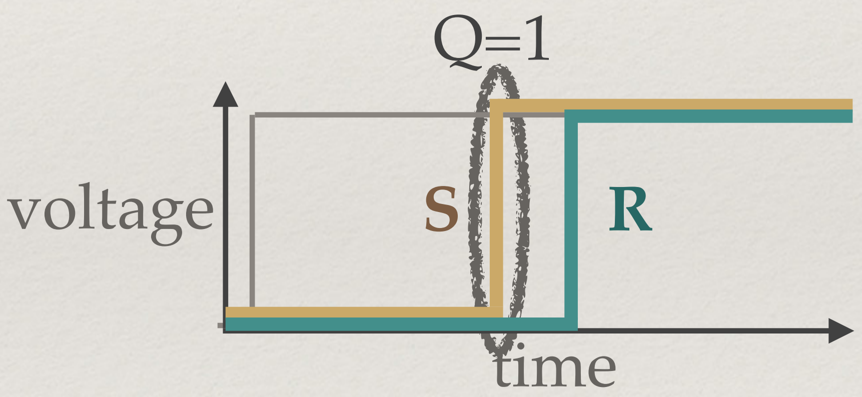

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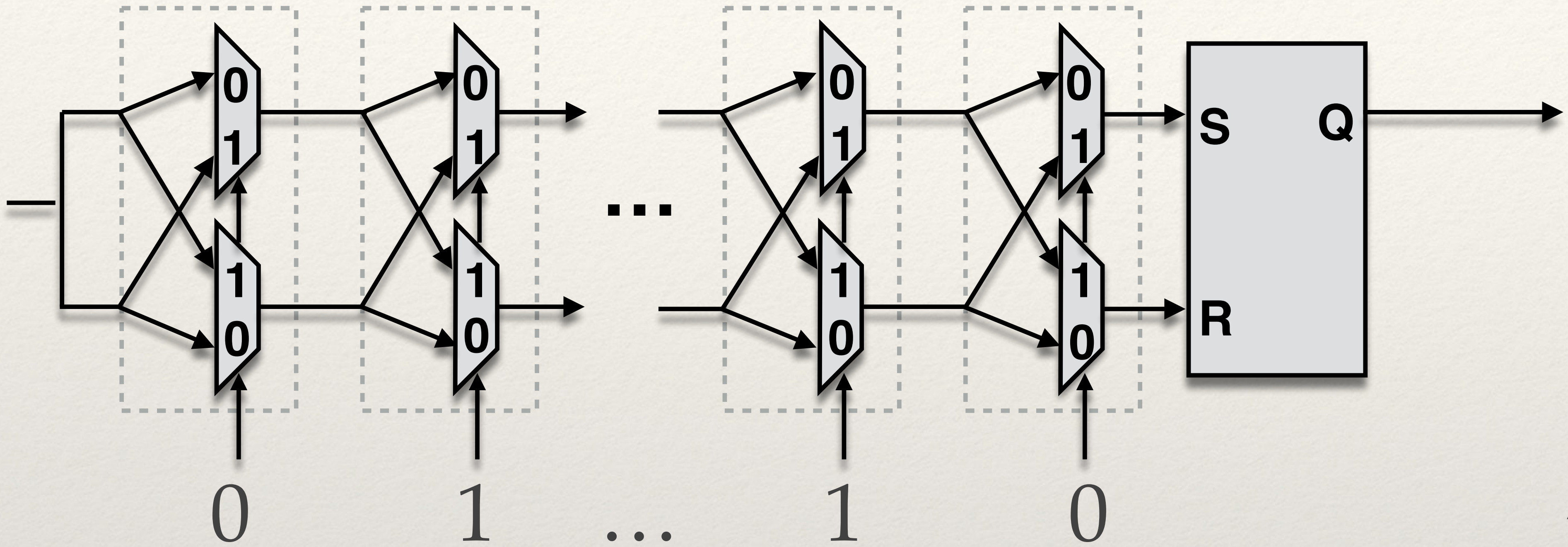

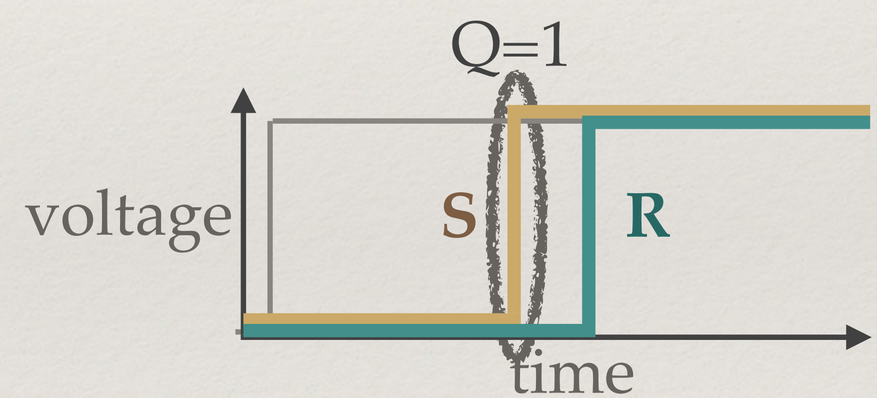

- Challenges: $c_i \in 2^m$ (m= num stages)
- Responses: $r_i \in 2^n$ (n=1 shown)

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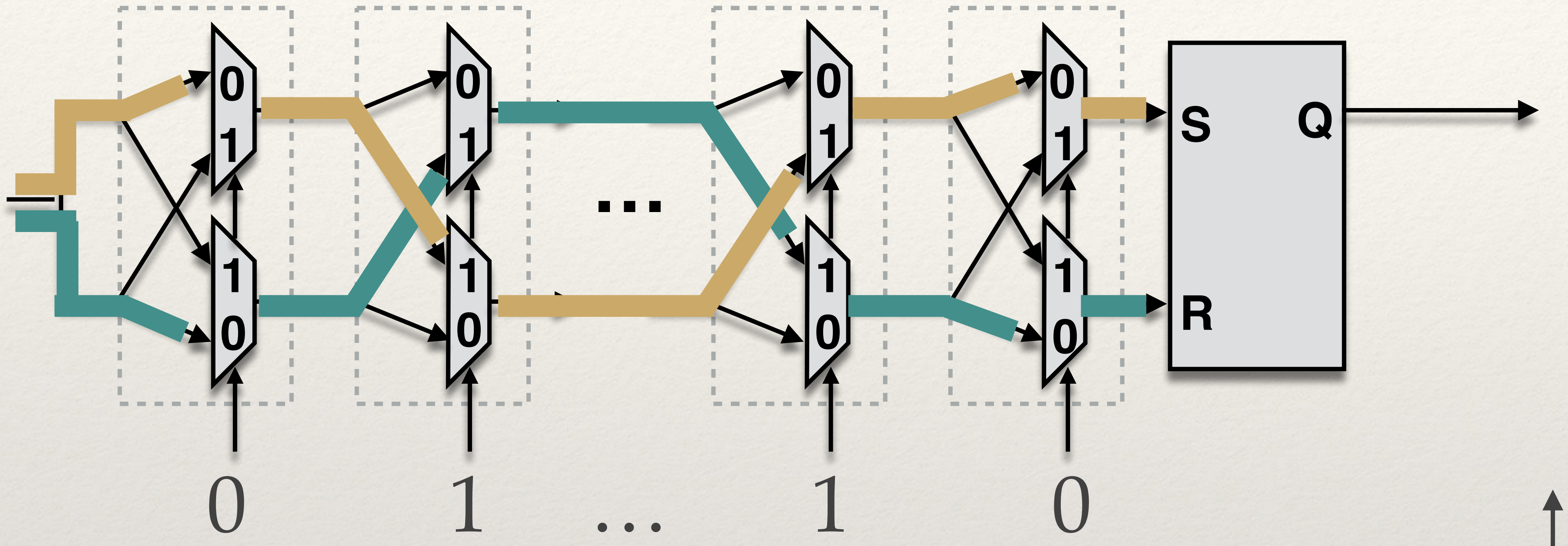

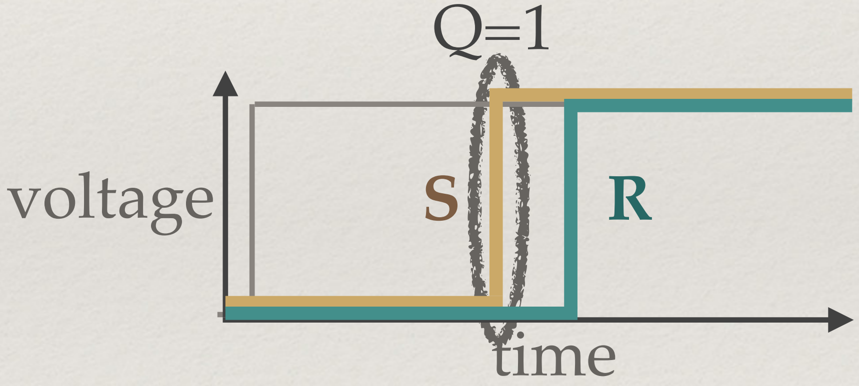

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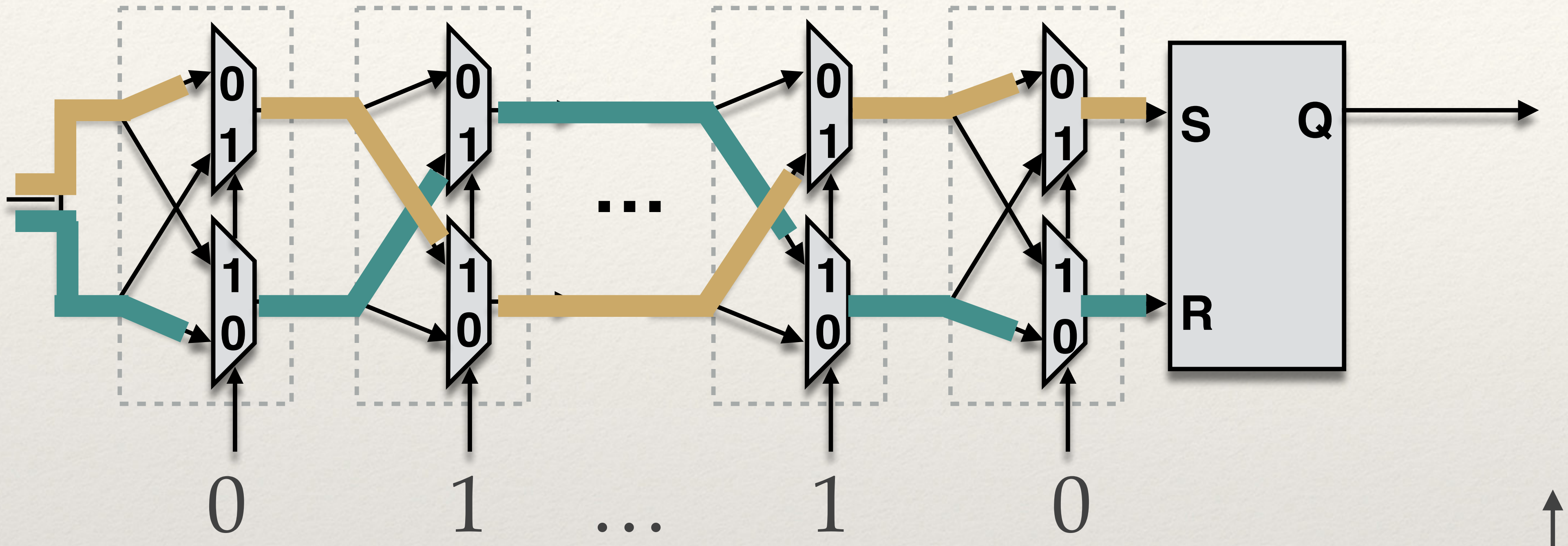

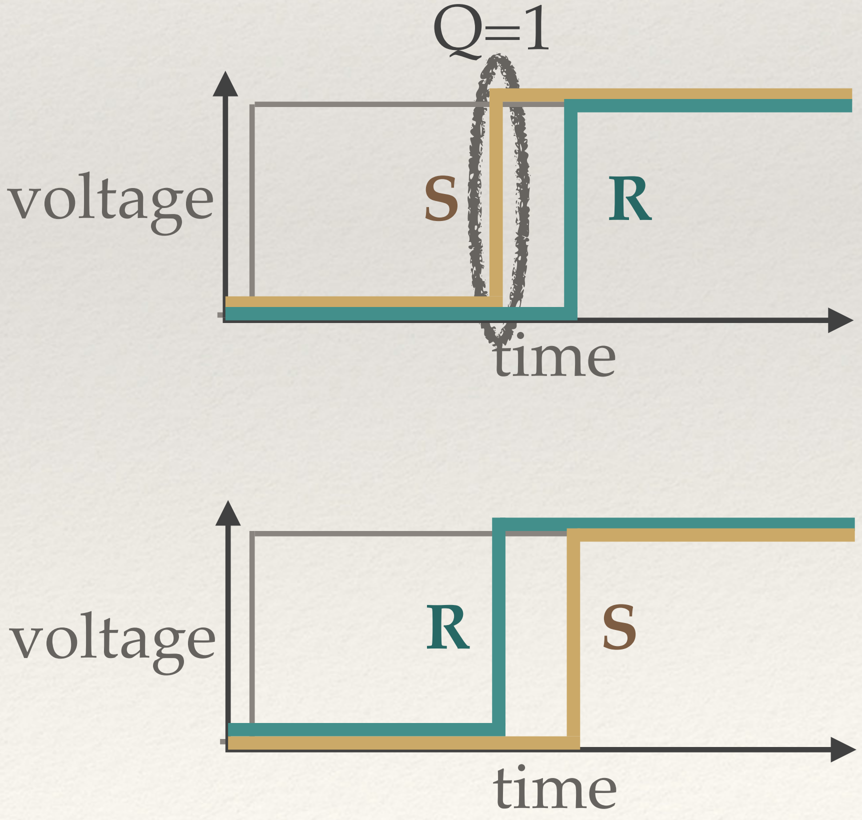

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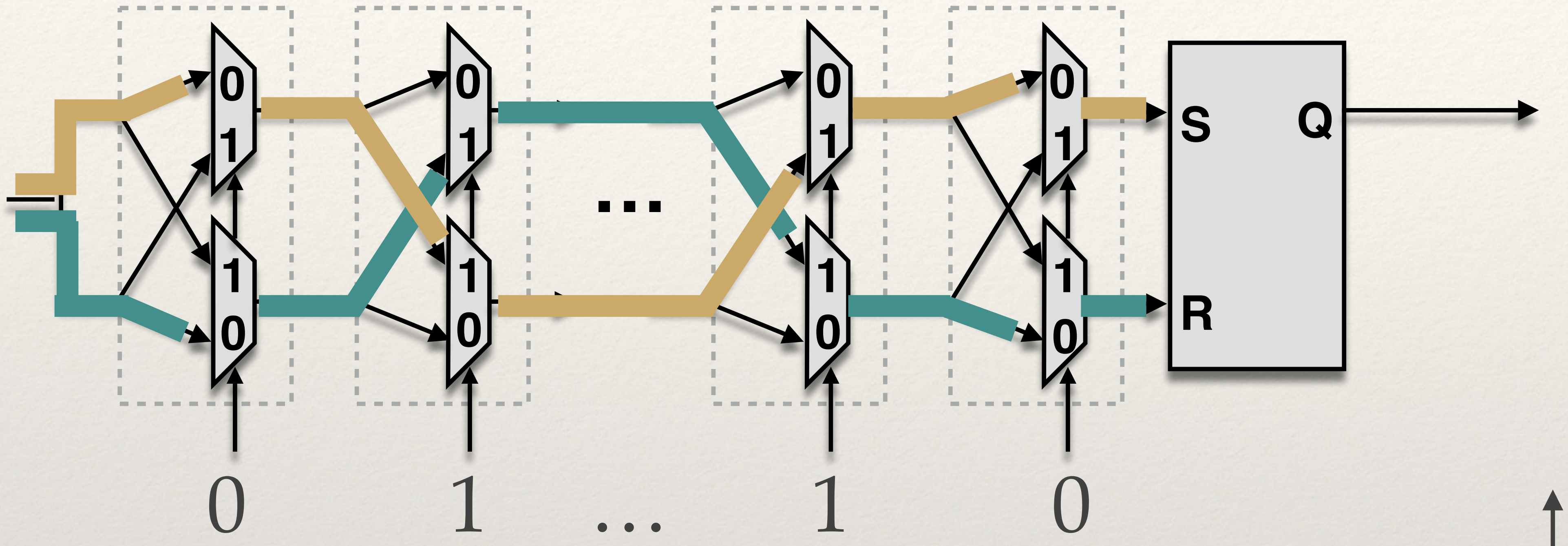

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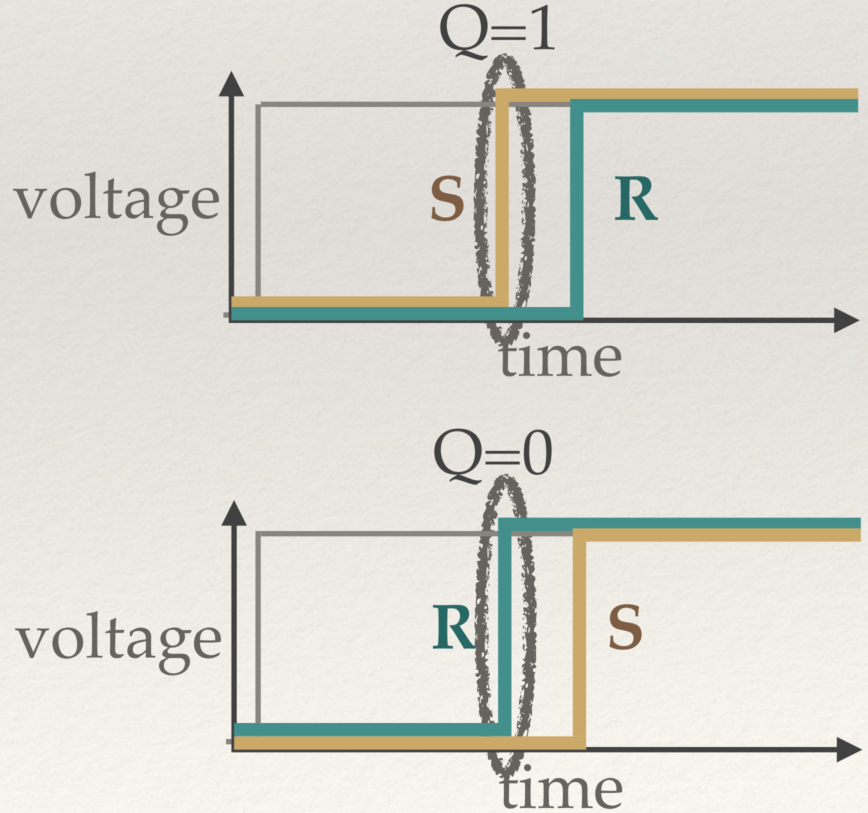

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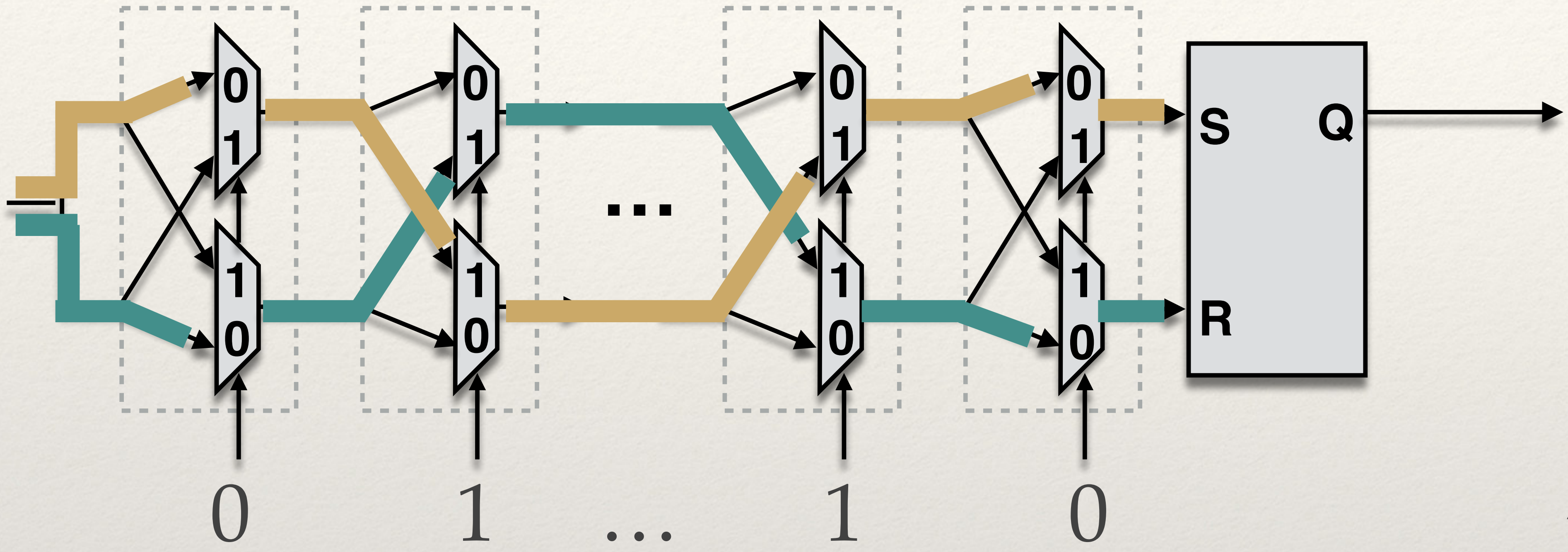

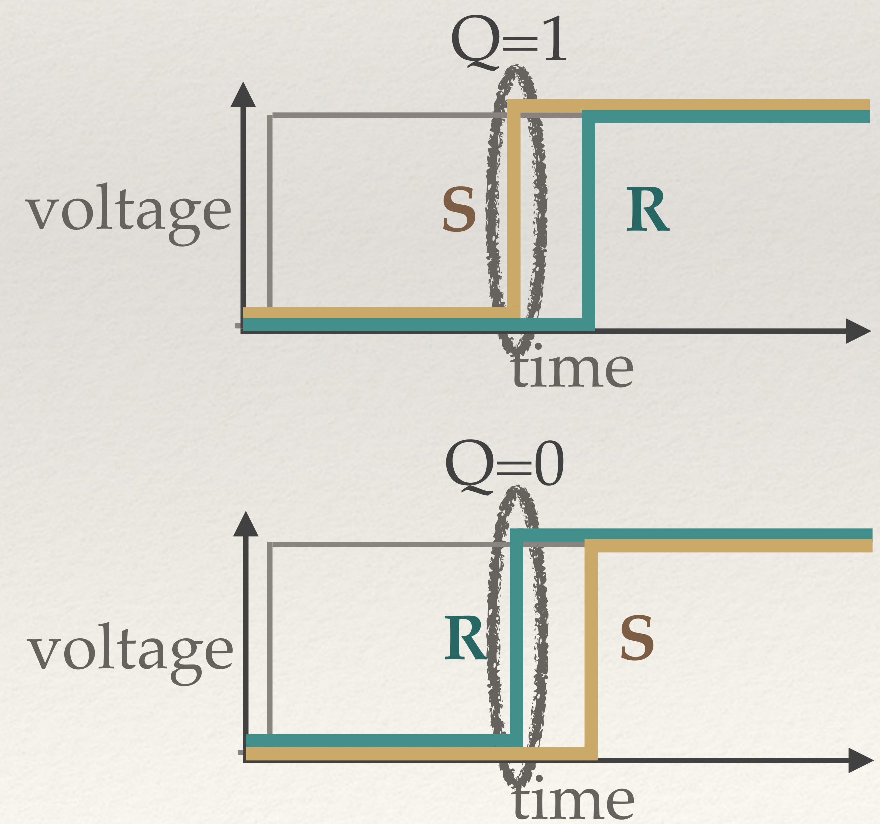

- Challenges: $c_i \in 2^m$ (m= num stages)
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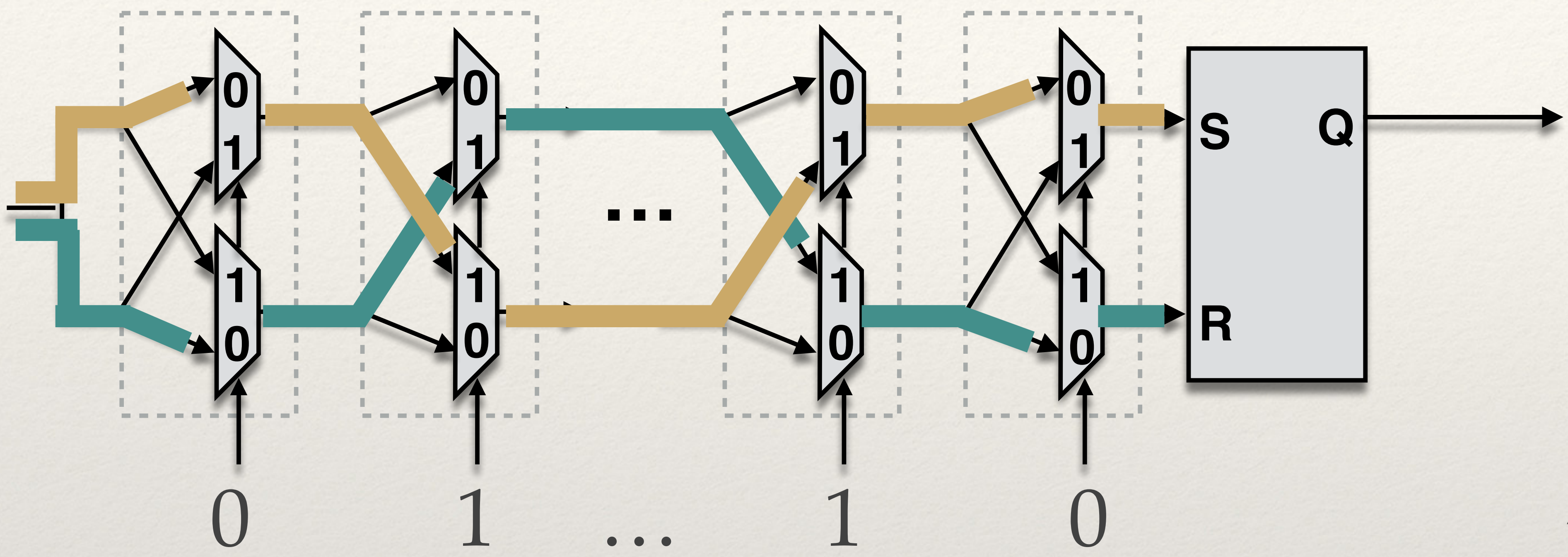
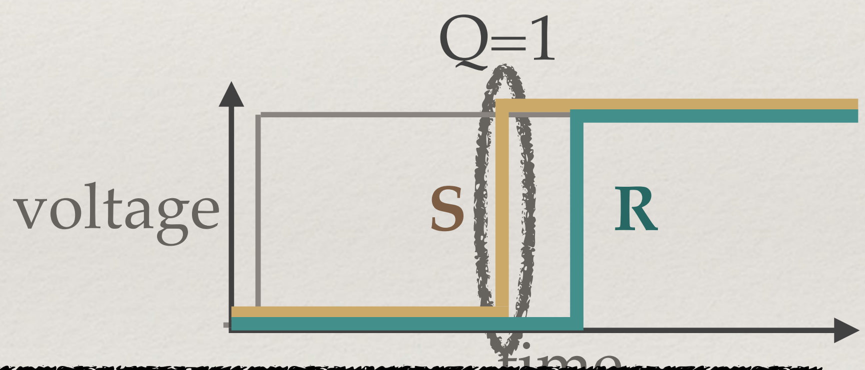
- Disorder / randomness: Delays in the subcomponents

Arbiter PUF

[D. Lim et al., ’05]





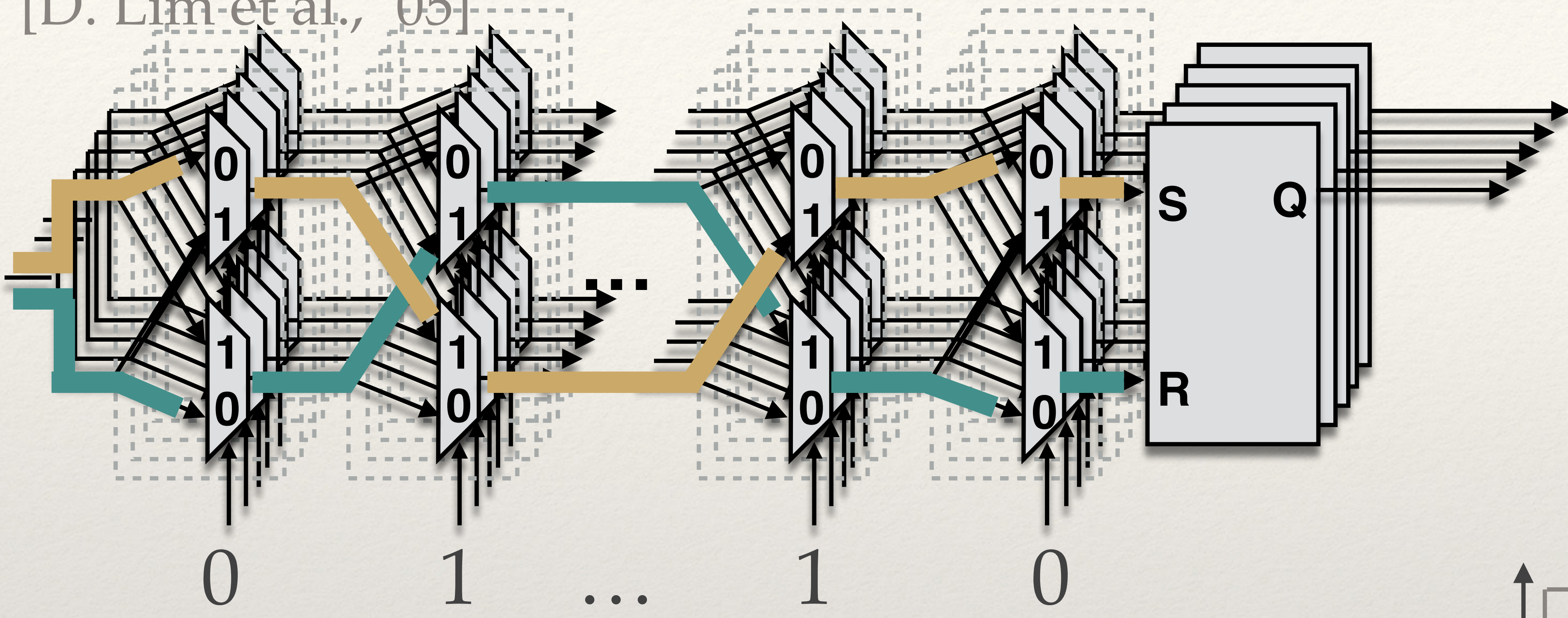
- Challenges: $c_i \in 2^m$ (m= num stages)

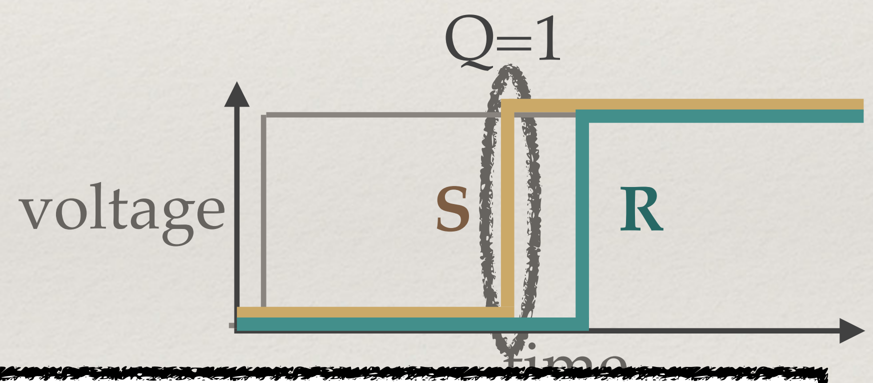
- Assumes that model cannot be created by observing CRPs
- But basic arbiter PUF susceptible to additive delay model

time

Arbiter PUF

[D. Lim et al., '05]





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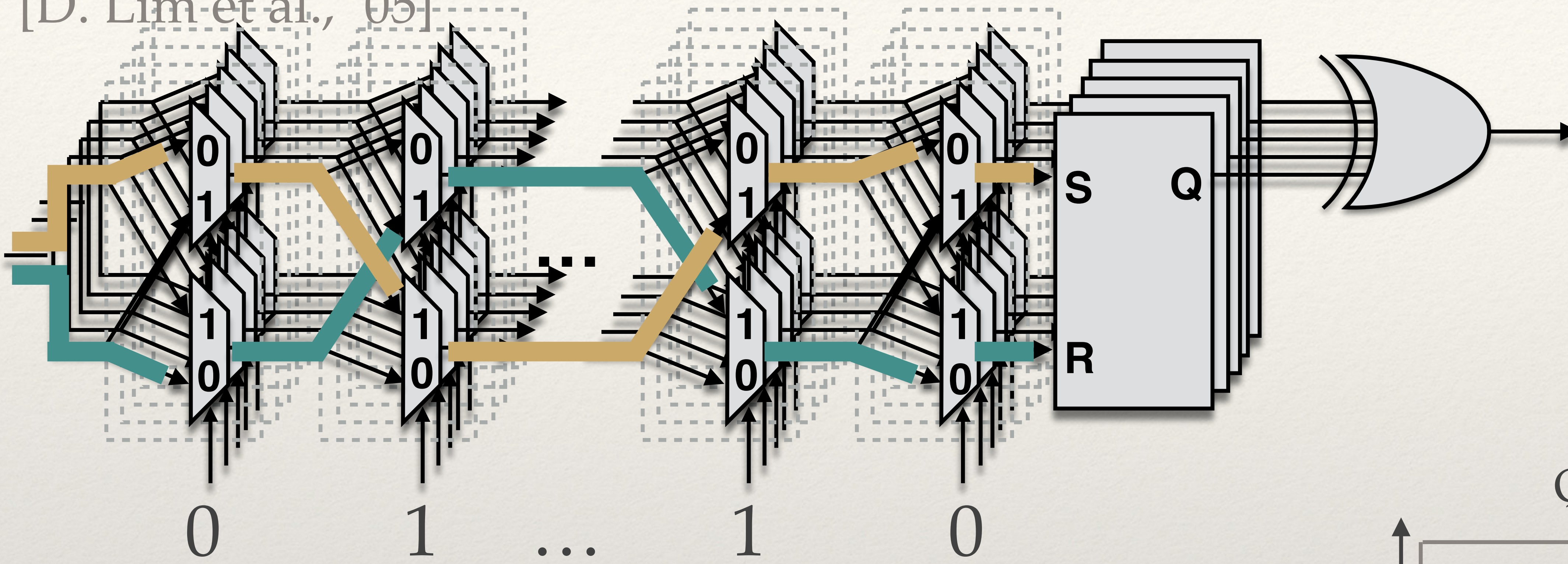

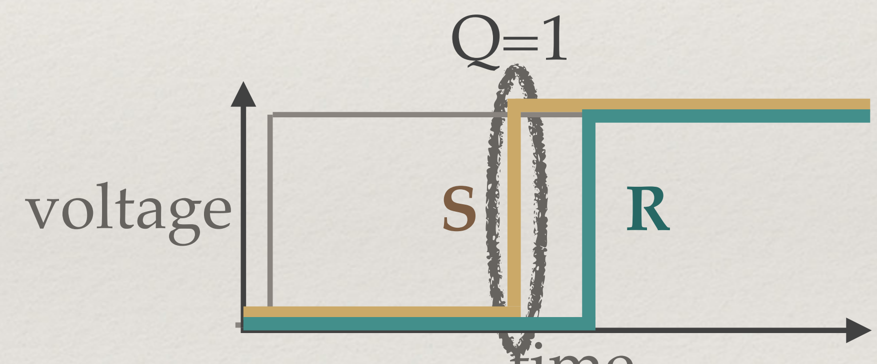

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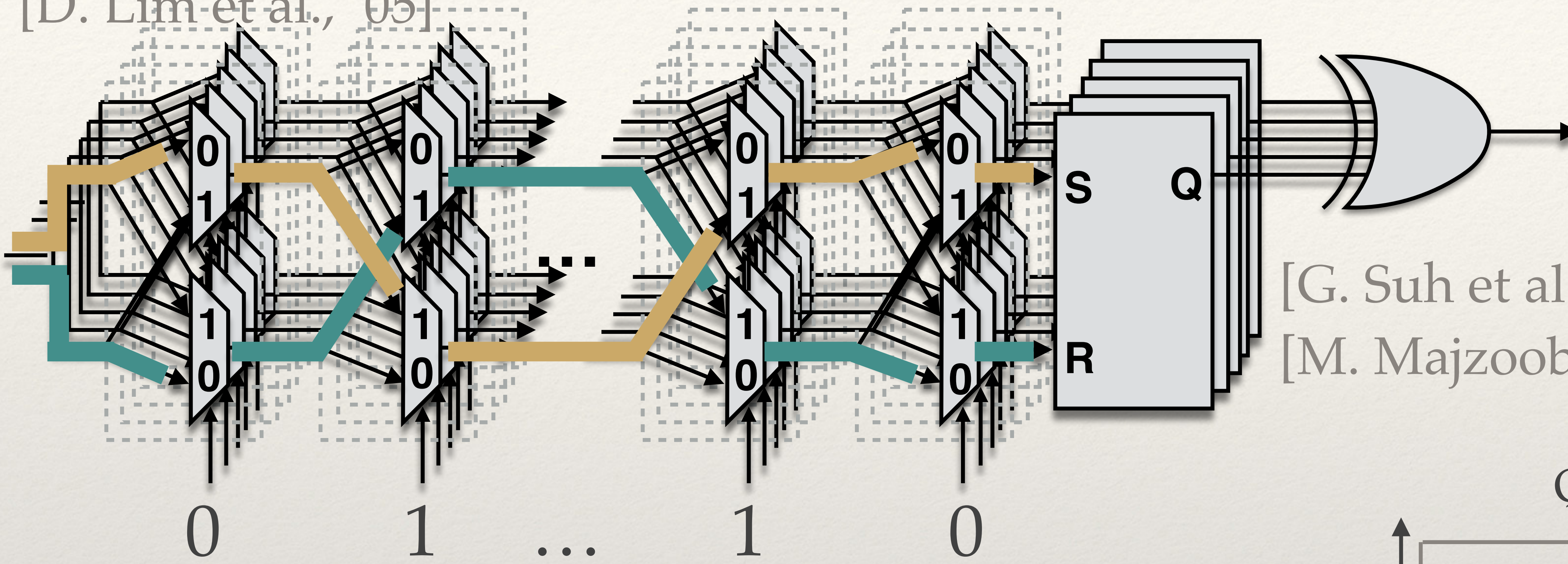
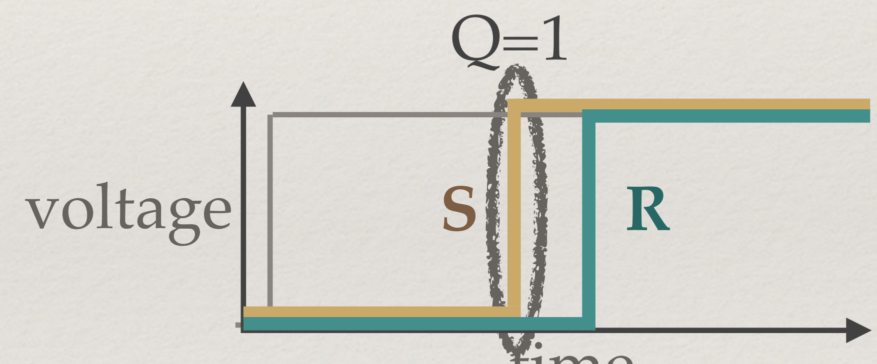


[G. Suh et al., '07]
[M. Majzoobi et al., '08]



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Arbiter PUF

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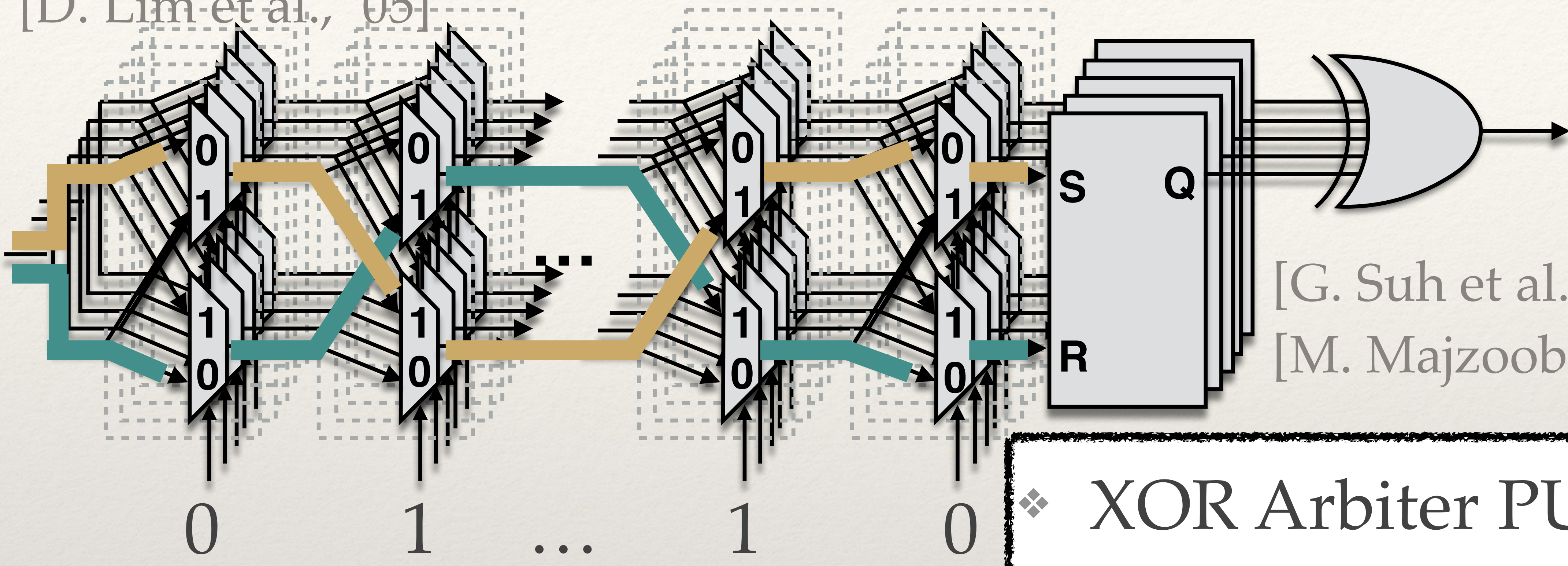

[G. Suh et al., ’07]
[M. Majzoobi et al., ’08]

- XOR Arbiter PUF resists additive model

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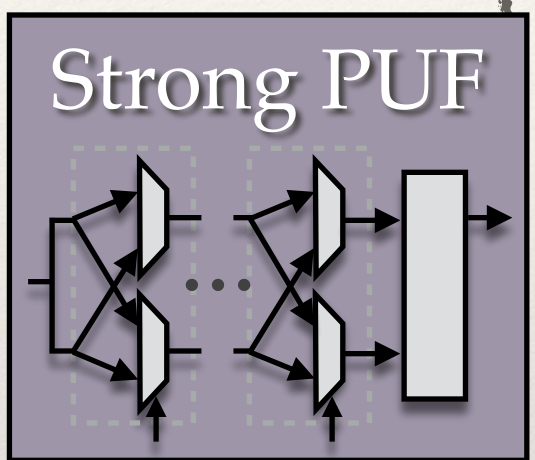
Authentication using Strong PUF

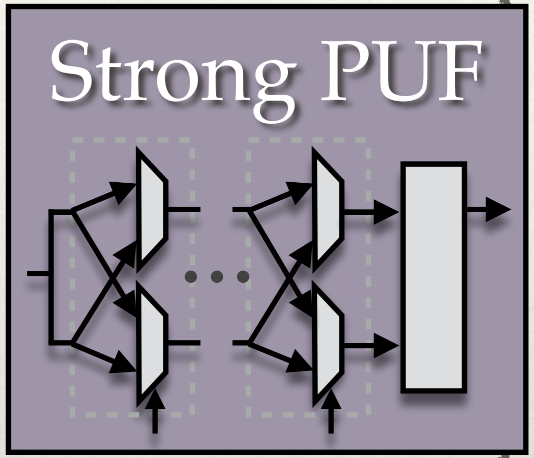
Enroll PUF



Authentication using Strong PUF

Enroll PUF

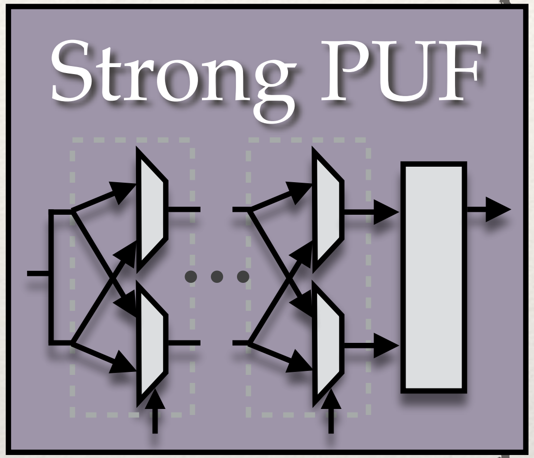
- Choose random challenges



Authentication using Strong PUF

Enroll PUF

- Choose random challenges
- Apply and store private CRPs



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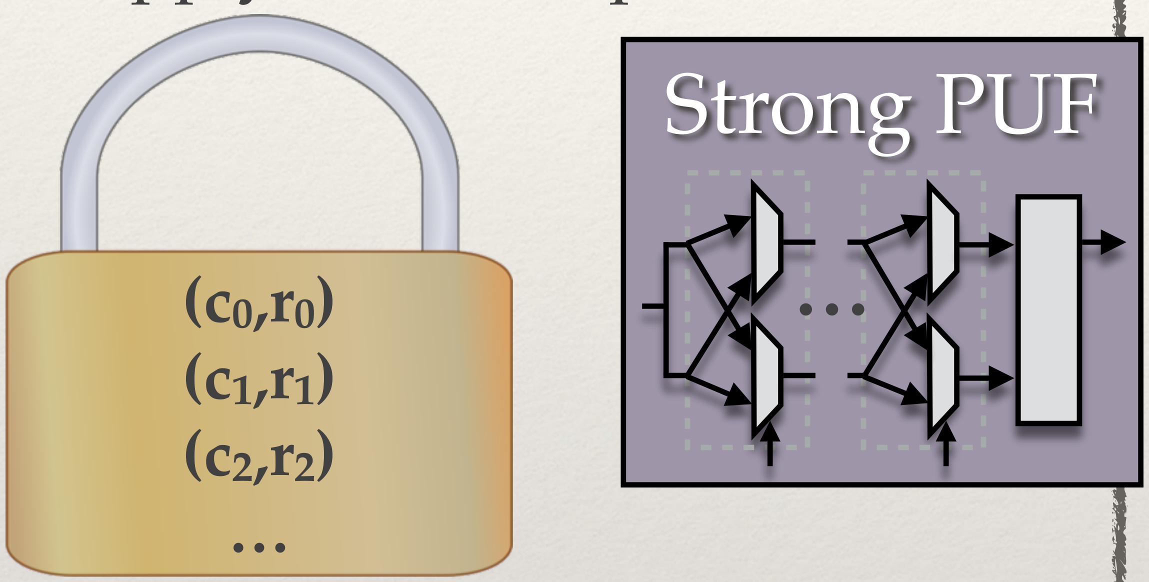

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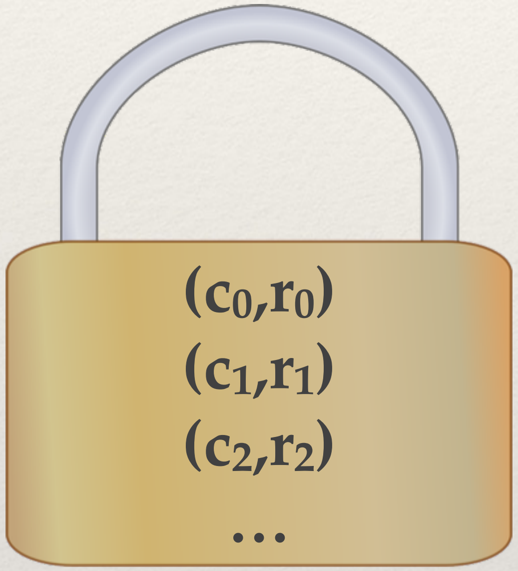

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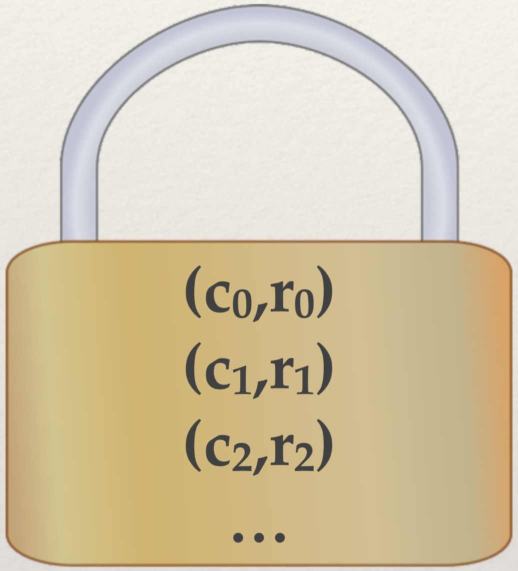

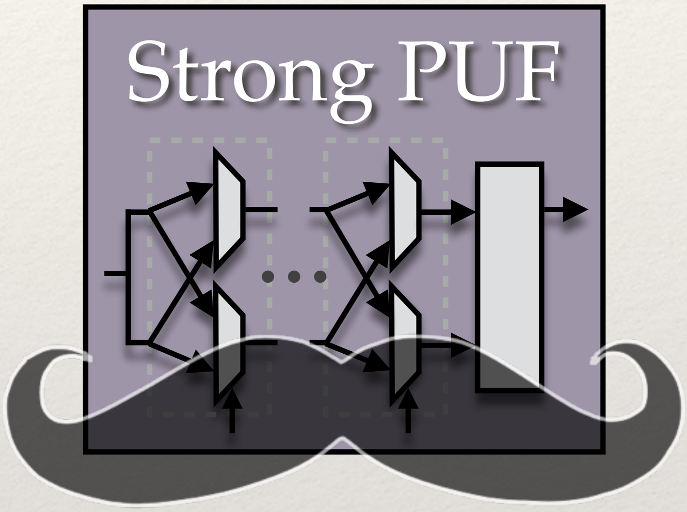

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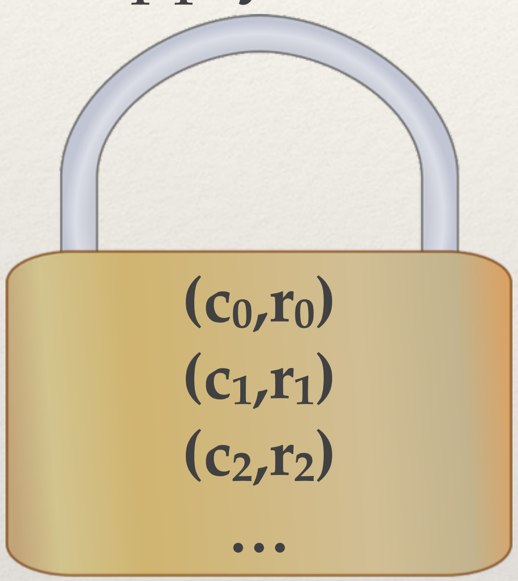
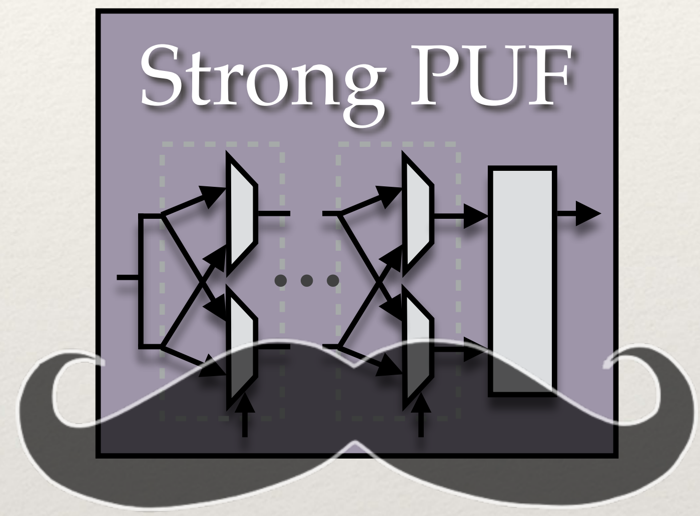


c_0



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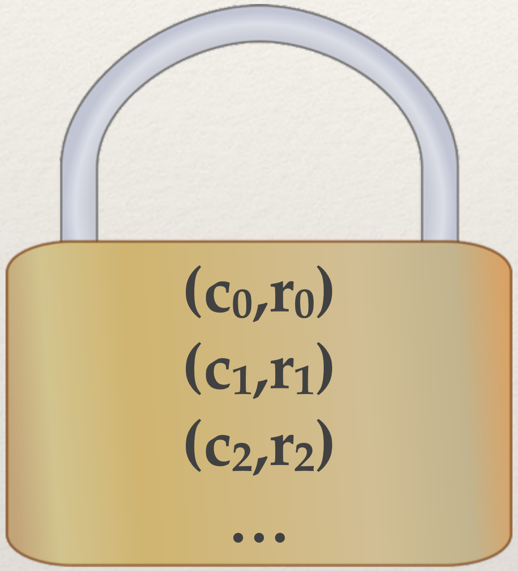

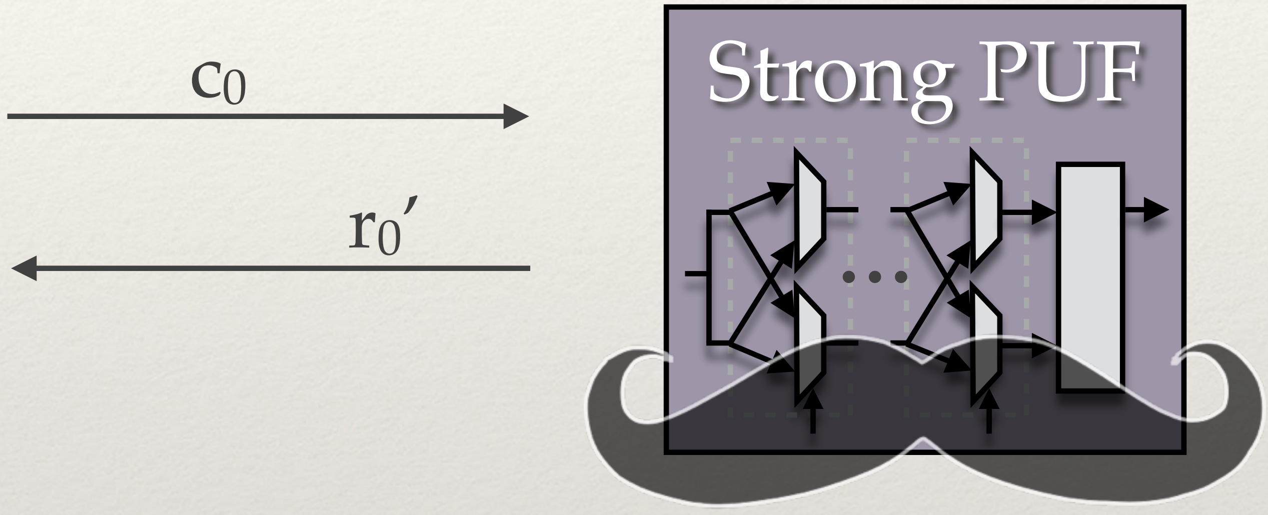

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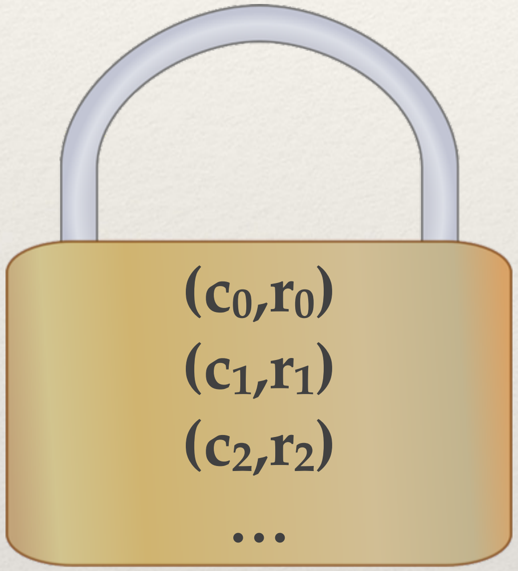
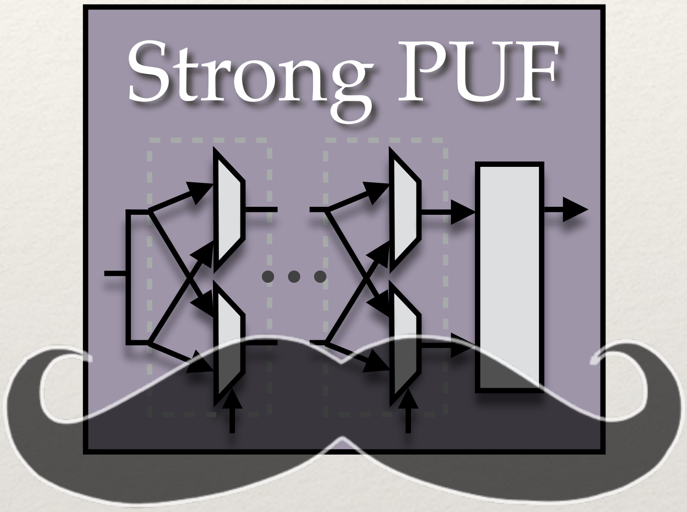


Authenticate

$r_0 \approx r_0'$?

c_0 →

← r_0'



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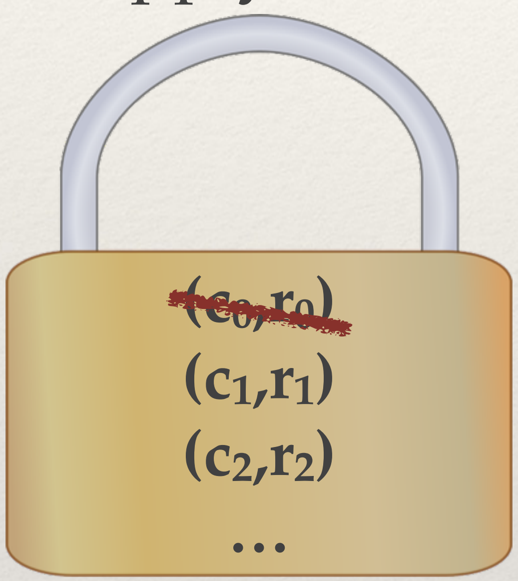

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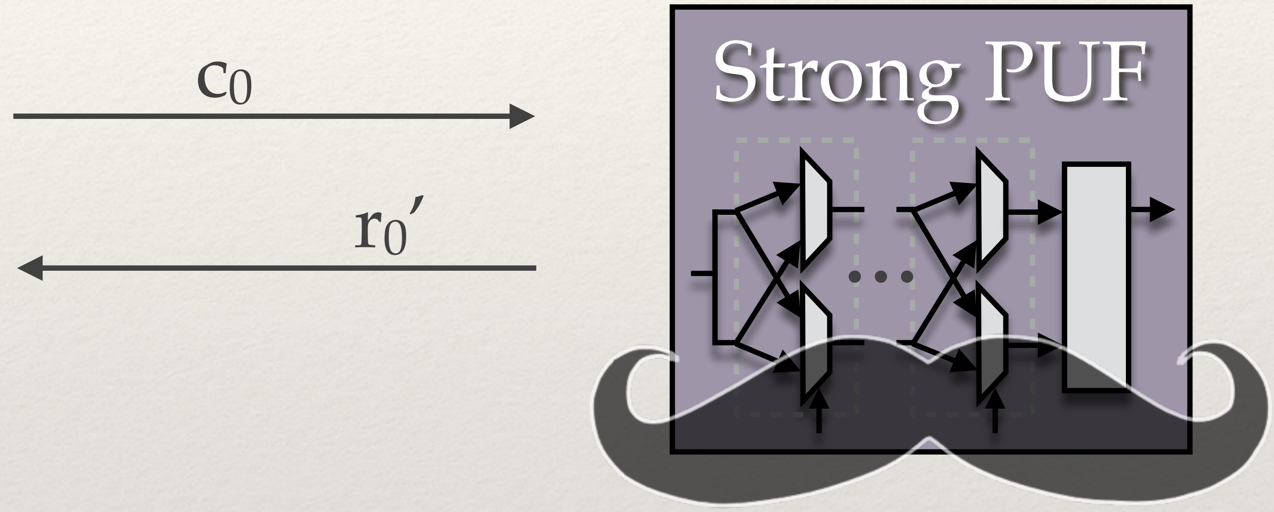

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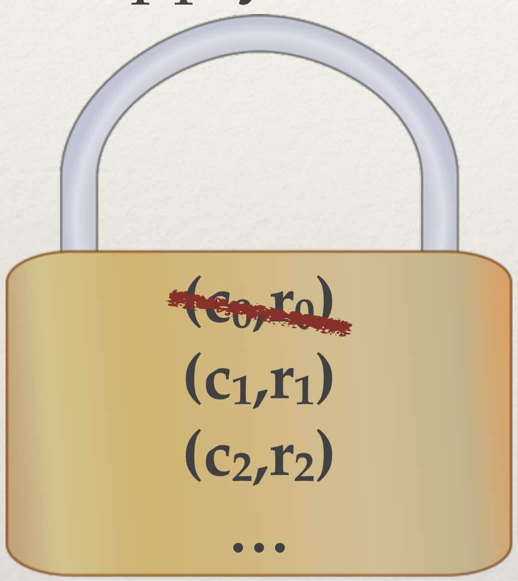

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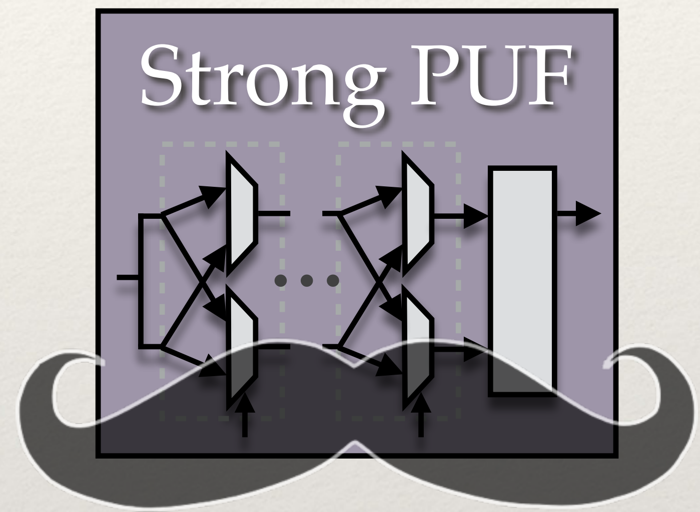

- No need to hide responses if PUF cannot be modeled

Overview

1. Brief introduction to PUFs
2. Weak PUFs and applications
3. Strong PUFs and applications
4. **Conclusions**

Review

- PUFs are exciting new security primitive based on physical disorder
  - Desirable properties but also limitations
  - Arms race between designing and breaking

PReview

- PUFs are exciting new security primitive based on physical disorder

1. ~~PUFs at a Glance~~
2. Modeling attacks
3. Modeling attacks using side-channel information
4. Invasive attacks
5. Requirements for secure PUF protocols
6. Forward-looking trends and challenges