SHAKE modes of operation

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3rd NIST Workshop on Block Cipher Modes of Operation
Rockville, USA, October 3-4, 2023

Outline

(committing) authenticated encryption

- Authenticated encryption:
  - encryption (wrap) takes $(K, [N,], AD, P)$ and returns C (and tag T)
  - decryption (unwrap) takes $(K, [N,], AD, C[, T])$ and returns P or error $\perp$
- Ideally, C looks random for each input and unwrap of invalid ciphertext fails
- Some applications require collision-resistance of wrapping even if the key is known
- This is called *committing* AE
- In some cases a weaker property may be sufficient
- We propose committing AE schemes that have as tag the SHAKE hash of an injective encoding of $(K, [N,] AD, P)$

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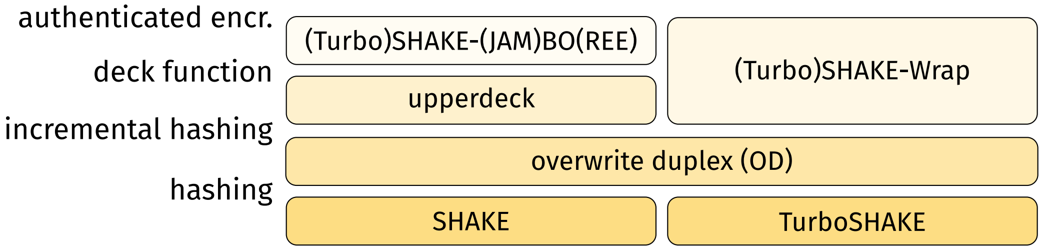
Committing authenticated encryption based on (Turbo)SHAKE



For the paper, see `https://eprint.iacr.org/2023/1494`

SHAKE and TurboSHAKE

SHAKE

- FIPS 202 specifies two XOFs: SHAKE128 and SHAKE256
- Based on KECCAK: sponge with KECCAK-$p[24 \text{ rounds}]$ [Bertoni et al., 2008]
- 15 years of public scrutiny $\Rightarrow$ 12 rounds give comfortable safety margin

TurboSHAKE

- Sponge with KECCAK-$p[12 \text{ rounds}]$ [Bertoni et al., ePrint 2023/342]
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Security:

- Unkeyed: flat sponge claim with security strength 128/256
- Keyed:
  - When input to (Turbo)SHAKE is prefixed with a secret key K
  - … it is hard to distinguish from a random oracle

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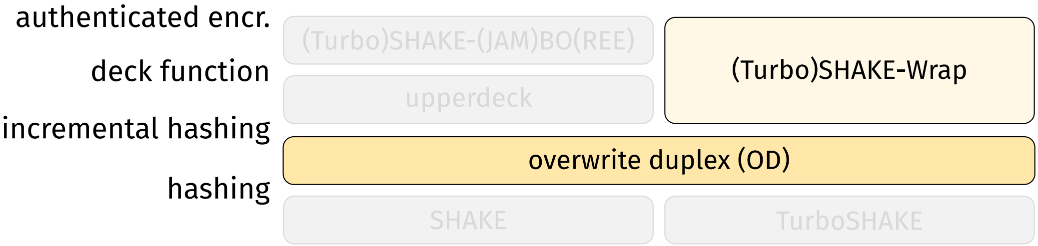
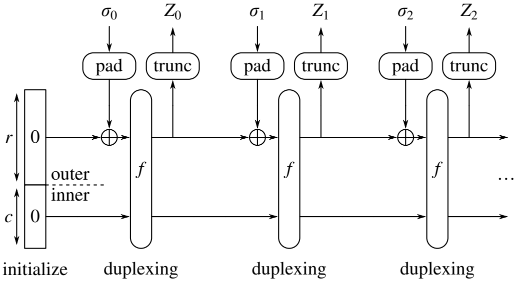
Outline

Duplex-based approach



Overwrite Duplex (OD)

Duplex [Bertoni et al., SAC 2011]:



- Security of duplex equivalent to sponge
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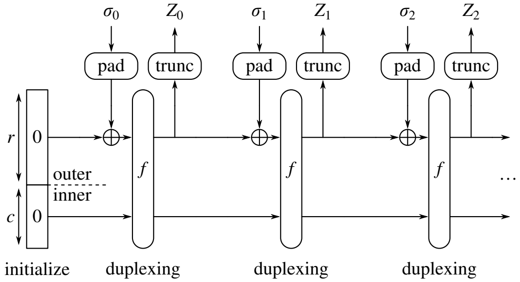

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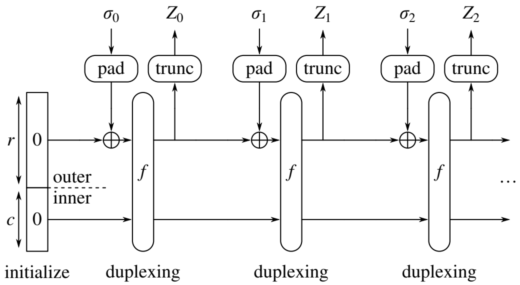

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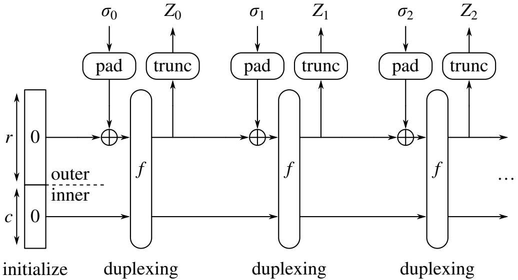

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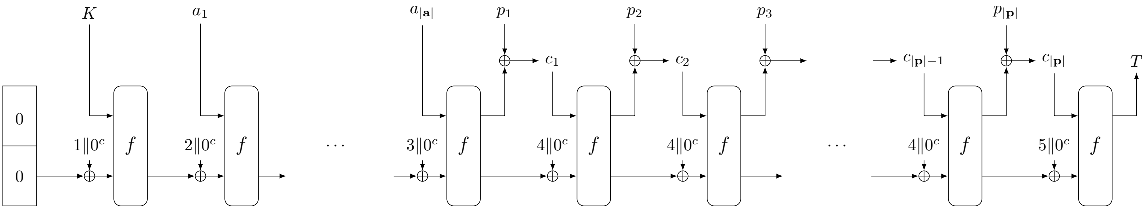
(Turbo)SHAKE-Wrap: nonce-based session AE

- Mode on top of ODWrap instantiated with one of the four SHAKEs
- Supports sessions: *online* AE through interm. tags and bidirectional messages



- Simple duplex-based AE with 1 domain separation byte per *f* call
- AE confidentiality and integrity follows from security of keyed SHAKE
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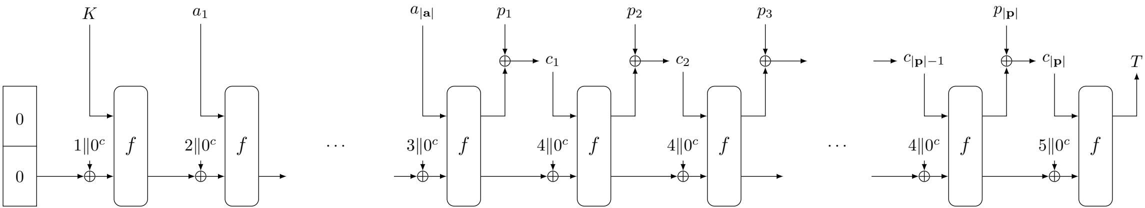

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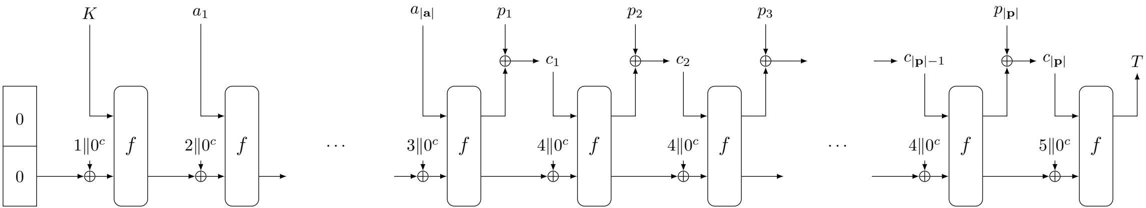

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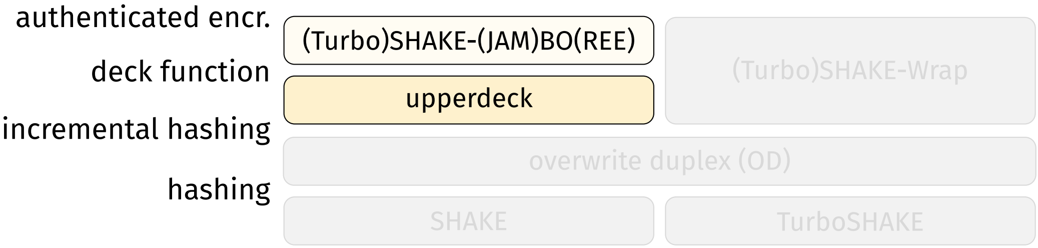
Deck-based approach



Definition of a deck function

A deck function F_K

$$Z = 0^n + F_K\left(X^{(1)}; \ldots; X^{(m)}\right) \ll q$$

doubly extendable cryptographic keyed function

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Definition of a deck function

A deck function F_K

$$Z = 0^n + F_K\left(X^{(1)}; \ldots ; X^{(m)}\right) \ll q$$

- Input: sequence of strings $X^{(1)}; \ldots ; X^{(m)}$
- Output: arbitrary length
  - **pseudo-random function of the input**
  - taking n bits starting from offset q
- Security model: shall be hard to distinguish from a random oracle

Definition of a deck function

A deck function F_K

$$Z = 0^n + F_K\left(X^{(1)}; \ldots ; X^{(m)}\right) \ll q$$

Efficient incrementality

- Extendable input
  1. Compute $F_K(X)$
  2. Compute $F_K(X; Y)$: cost independent of X

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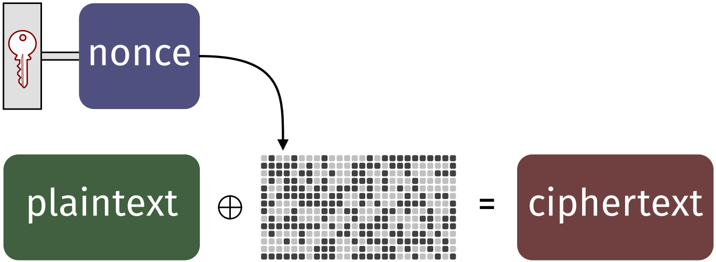
Efficient incrementality

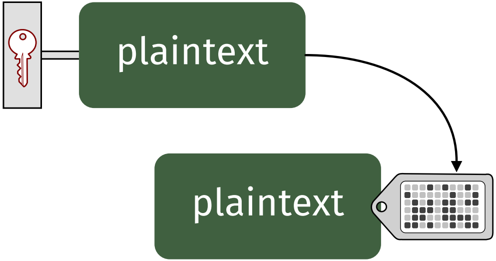
- Extendable input
  1. Compute $F_K(X)$
  2. Compute $F_K(X;Y)$: cost independent of X
- Extendable output
  1. Request n_1 bits from offset 0
  2. Request n_2 bits from offset n_1: cost independent of n_1

Stream encryption: short input, long output



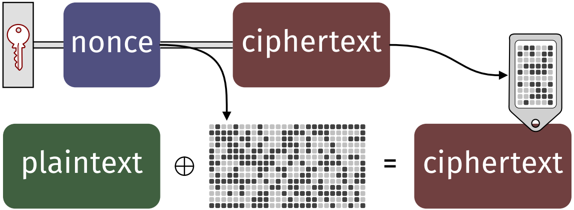
$$C \leftarrow P + F_K(N)$$

MAC computation: long input, short output



$$T \leftarrow 0^t + F_K(P)$$

Authenticated encryption



Wrap:

$$C \leftarrow P + F_K(\text{nonce})$$
$$T \leftarrow 0^t + F_K(\text{nonce}; C)$$

Unwrap:

$$T \stackrel{?}{=} 0^t + F_K(\text{nonce}; C)$$
$$P \leftarrow C + F_K(\text{nonce})$$

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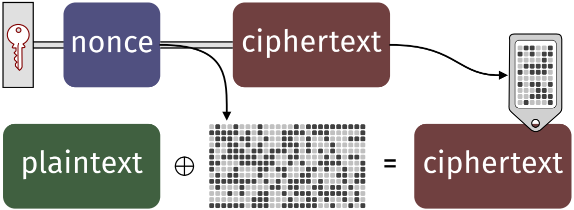

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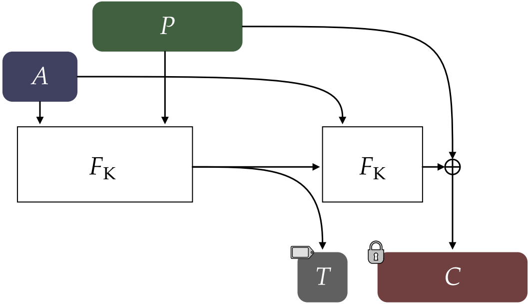
(SIV)-type authenticated encryption



wrap:

$T \leftarrow 0^t + F_K(\mathrm{AD}; P||0)$

$C \leftarrow P + F_K(\mathrm{AD}; T||1)$

return $C||T$

unwrap:

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$T \stackrel{?}{=} 0^t + F_K(\mathrm{AD}; P||0)$

return P (or $\perp$)

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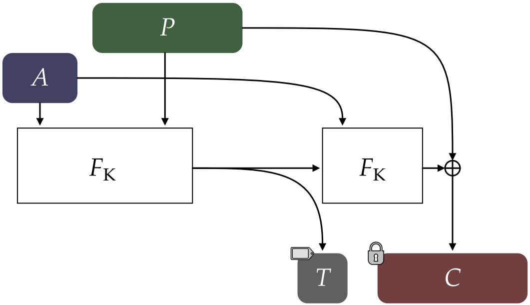

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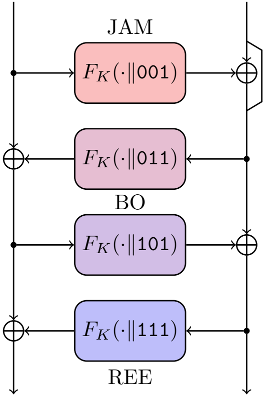
Deck-[JAM]BO[REE]: Feistel network



Norica Băcuieți, Joan Daemen, Seth Hoffert, Gilles Van Assche, Ronny Van Keer, Jammin' on the deck , Asiacrypt 2022, `https://eprint.iacr.org/2022/531`

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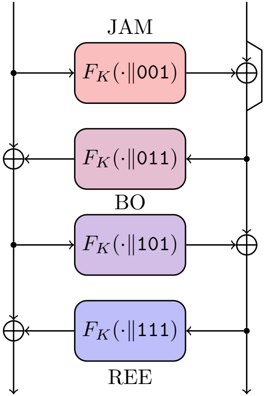

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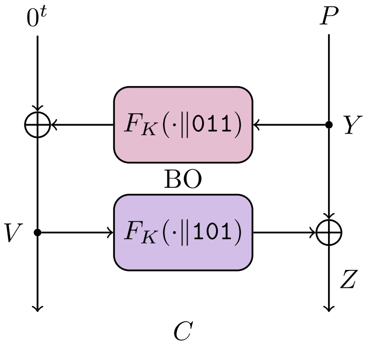
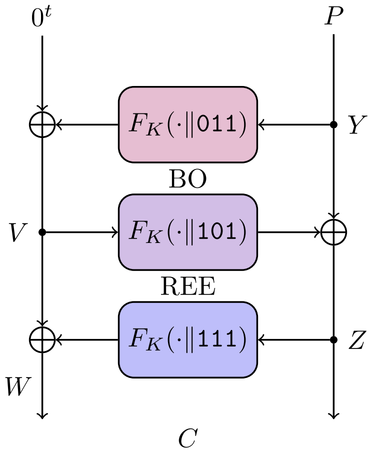


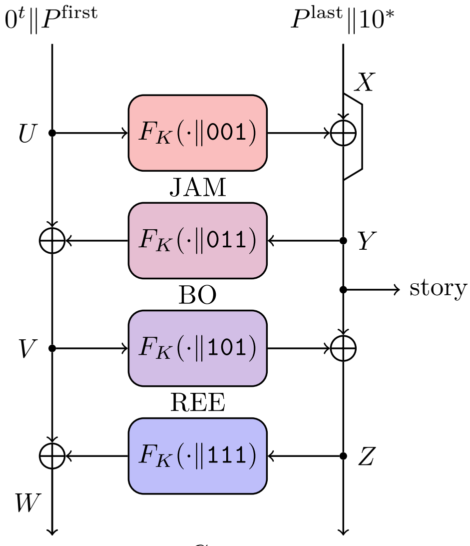
SIV [Rogaway and Shrimpton, EC 2006] + support for AD and sessions

Deck-BOREE



RIV [Abed et al., FSE 2016] + session support

Deck-JAMBOREE



Robust AE [Hoang, Krovetz and Rogaway, EC 2015] + session support

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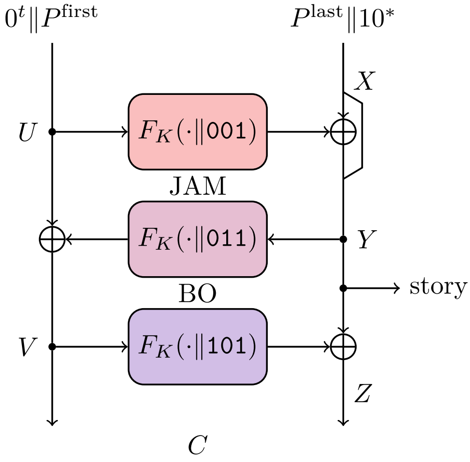
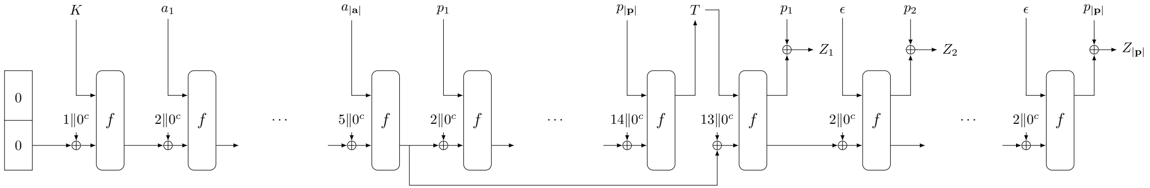


SIV with optimal redundancy
(but not RUP resistance)

(Turbo)SHAKE-BO: SIV AE with support for sessions

- Upperdeck: deck function on top of OD
- (Turbo)SHAKE-BO: Deck-BO on top of upperdeck instantiated with (Turbo)SHAKE



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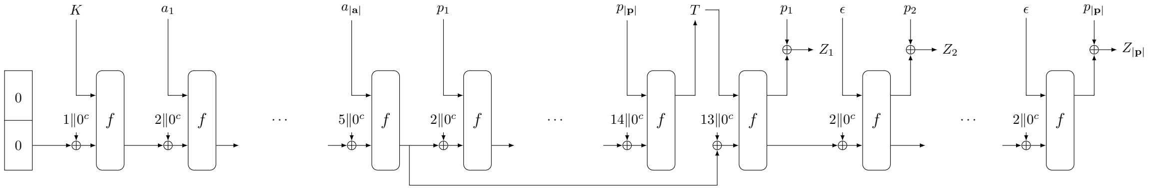

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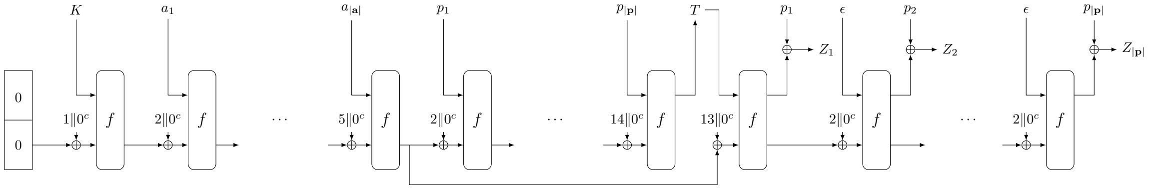

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Conclusions

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- robustness and flexibility of deck-based modes
  - See also nonce-encrypting modes [Hoffert, ePrint 2022/1711]

And simplicity of the modes once the layers are merged

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