On FHEMPCZK-friendly symmetric crypto

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A Zoo of FHEMPCZK-friendly concretely-efficient symmetric crypto: How many designs?

2013: -

2014: -

2015: 1

2016: 4

2017: -

2018: 3

2019: 5

2020: 5

2021: 8

2022: 10

2023: 4 until April

source: mostly IACR eprint, plus selection from IEEE Access, ToSC, arxiv

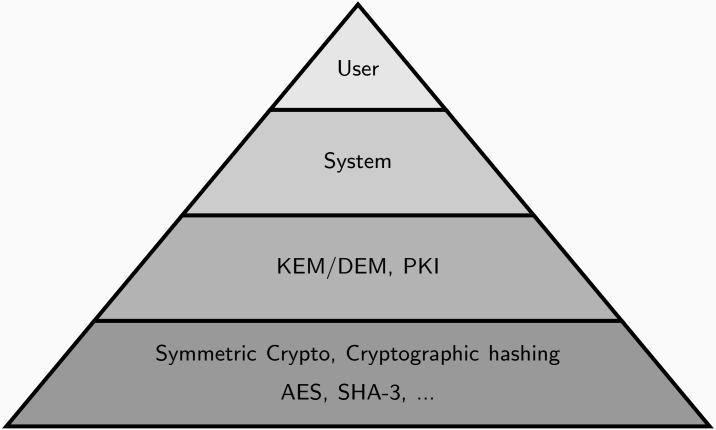
How did we get here?

Implementation environments for symmetric cryptography

Efficiently provide confidentiality, authenticity, integrity

- until 1980s: dedicated machines, hardware implementing DES, LFSR-based approaches
- since 1990s: software implementations become more relevant in addition to hardware, see e.g. AES
- since 2010s: another boost for software-environments due to virtualization

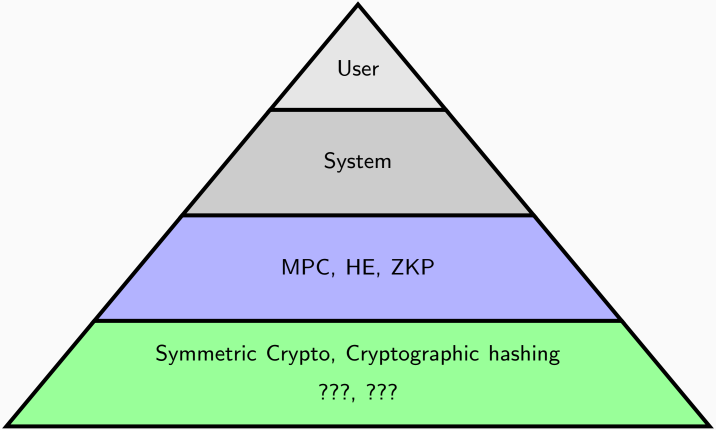
Role of symmetric-key crypto and hashing in systems



New cryptographic functionalities are new applications of symmetric cryptography

- FHE: Reducing ciphertext expansion, OPRFs, ...
- MPC: Distributed databases, private set intersection, data analytics, but also new public-key signature schemes
- ZKP: Use-cases of zero-knowledge proofs:
    - Set Membership Proofs ("I know a private key of one of the public keys of this Merkle tree")
    - Data Commitments ("Here is the Merkle tree of the execution trace of my program, I can open it at any point").

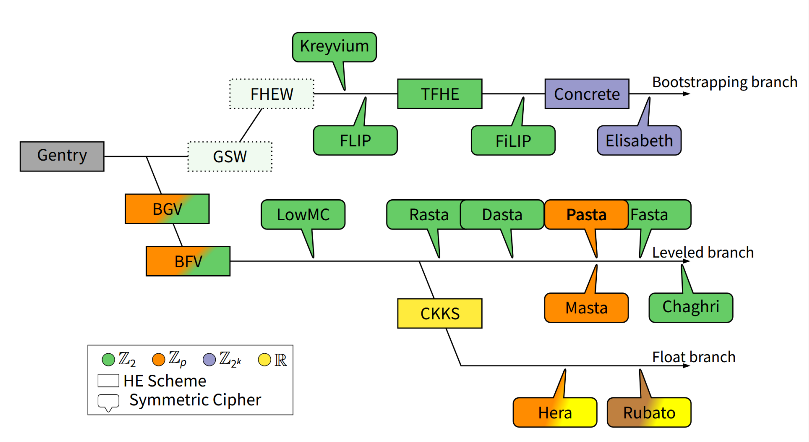
Role of symmetric-key crypto and hashing in systems



Transitions of use-cases in (symmetric) cryptography

- in the 1980s and 90s, there was a transition from hardware to software.
  - Hardware grew, but software grew much more.
- since the mid 2010s: we seem to be in a transition phase from direct implementations to indirect implementations within protocols aiming for "high functionality cryptography"
  - direct hardware and software implementations of course remain relevant, but the area of indirect implementations is growing fast.
  - new "virtual machines", new "metrics", co-developments of symmetric crypto with "higher/more functional" crypto layers

A Zoo of Ciphers for Hybrid Homomorphic Encryption, a.k.a. Transciphering



The ZK-friendly Hash Function Zoo

Type 1

"low degree only"

- Low-degree

$$y = x^d$$

- Fast in Plain
- Many rounds
- Often more constraints
- MiMC(16), GMiMC(19), Poseidon(19), Neptune (21), Poseidon2 (23)

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Type 2

"non-procedural", \ uid"

- Low-degree equivalence

$y = x^{1/d}$) $x = y^d$

- Slow in Plain
- Fewer rounds
- Fewer constraints
- Friday(18), Vision (19), *Rescue*(19), Grendel(21), Griffin (22), Anemoi (22), Arion(23)

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Type 3

"lookups"

- Lookup tables

$$y = T[x]$$

- Very fast in Plain
- Even fewer rounds
- Constraints depend on proof system
- `Reinforced Concrete` (21), Tip5 (23), Tip4 (23), RC_p(23)

The MPC/Sharing-friendly Symmetric Crypto Zoo

2015: LowMC

2016: MiMC, LegendrePRF

2018: CryptoDarkMatter

2019: GMiMC

2020: HadesMiMC

2021: Ciminion, "CryptoDarkMatter++"

2022: Rain, AIM

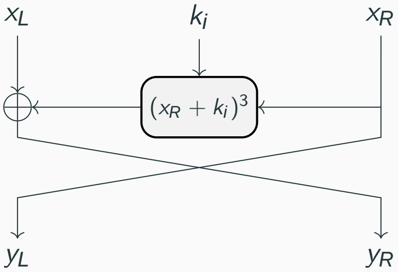
2023: Hydra

Open-sourcing implementations: `zoos.iaik.tugraz.at`

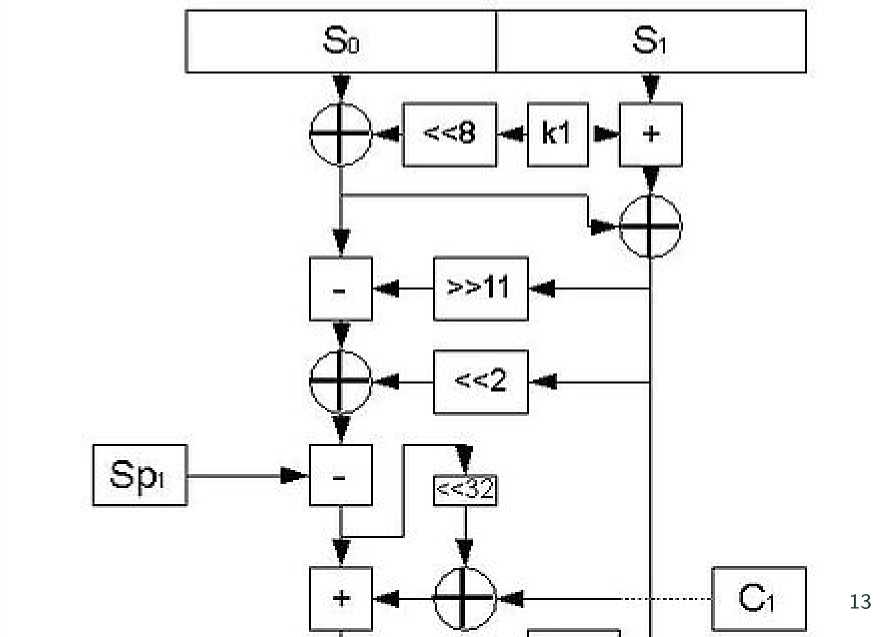
- Hybrid HE Use-Case:
  - Extensive benchmarks in different HE libraries including use-cases
  - 16 implementations (various ciphers for various HE libraries), before the count was 1.
- MPC Use-Cases:
  - Implementations of MiMC, GMiMC, HadesMiMC, Rescue, Ciminion, Hydra
  - More elaborate framework allowing for various libraries, access structures, still to come
- Zero-Knowledge Use-Cases:
  - Zoo of plain implementations (8)
  - Proof knowledge of preimages of hash functions (6)
  - Proof membership witness in Merkle tree accumulators (6)

Prior art for (Feistel) MiMC

- $\mathcal{PURE}$ cipher [JK97] based on the $\mathcal{KN}$ Feistel cipher [NK95]



More prior art, for F(p) ciphers (1/2)



More prior art, for F(p) ciphers (2/2)

Richard Schroeppel: "The Hasty Pudding Cipher", submission to the NIST AES Competition, 1998.

First(?) F(p) cipher.

First tweakable block cipher

Flexible parameterization (blocksize, keysize), maybe a first too?

Ok. Where do we go from here?

On the ”stability” of symmetric crypto and hashing

- MPC-friendly: Seems the most stable. Focus cryptanalysis efforts in standardization process/competition?
- HE-friendly: 4-5 underlying HE schemes are under standardization at ISO. Most, but not all schemes have a matching transciphering proposal.
- ZK-friendly: Most dynamic development at the moment, almost most immediate use in industry.

In general, more cryptanalysis is definitely usefull and needed.

Underexplored directions?

- MPC-friendly hashing? Brought up by Luis Brandao in recent NIST call.
- FHE-friendly PRFs.
- Hardware-friendly Sharing-friendly F(p) ciphers.
  Also relevant for cheap side-channel countermeasures.
  - Mathias Oberhuber(2021): MiMC+ECC synergies in e.g. hash+sign HW implementations. Both use same-sized multiplier in $GF(2^n)$ or GF(p).
  - FX Standaert et al. (2023): AES-like F(p) ciphers

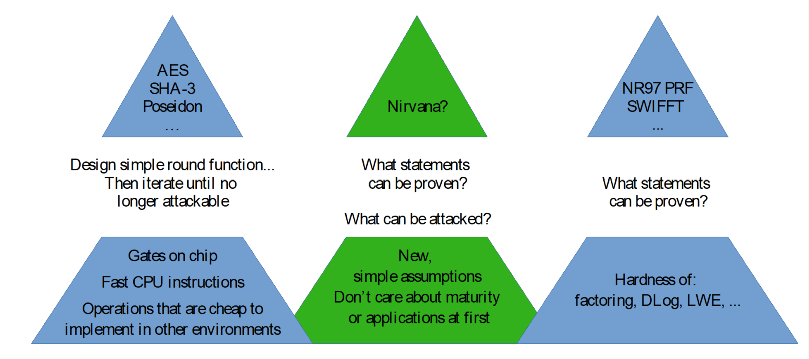
Classes of open problems

- How far can we go with signature schemes based symmetric crypto *only*? Signature size, computation effort?
- How far can we go with reducing computational overhead of hybrid homomorphic encryption?
- Holy grail in ZK-friendly hash function design: *Simultaneously* good performance in both plain and ZK
- Cryptanalysis of various new schemes in this domain

Thoughts on "Theory" vs. "Practice"

- Provable Security?
  - Modes of operation: do proofs carry over from F_2 to F_p?
  - SPN vs. Partial-SPN: First positive results by Guo, Standaert, Wang, Wang, Yu (FSE 22)
    - Stronger model, like indifferentiability?
- "Asymptotic analysis" / "asymptotic designs".
  - Input: blocksize, security level
  - Output: concrete design with security claim
  - Some designs allow for it, e.g. HPC, LowMC, MiMC, Poseidon, ...
  - Pros: Flexibility.
  - Cons: Less focused cryptanalysis.

Thoughts on "Theory" vs. "Practice": A vision



Conclusions

- Lots of exciting new developments in "high functionality cryptography" - some are likely here to stay
- ... leading to lots of exciting research for design and analysis of symmetric crypto and hashing
- Industry interest is growing, demand for standards to support interoperability and increase trust

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