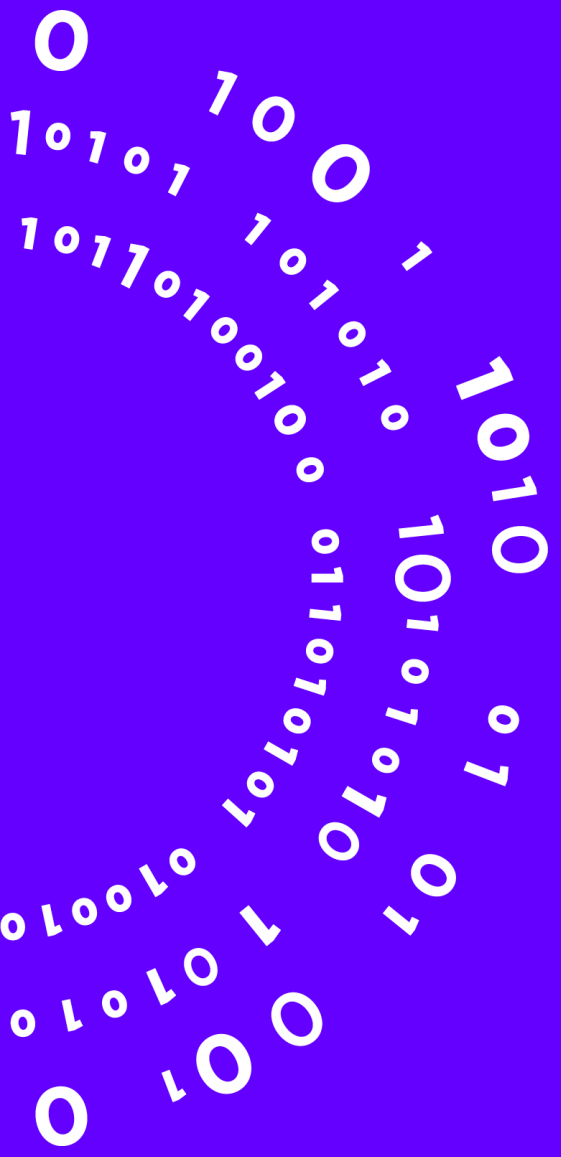

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Universal Hash Designs for an Accordion Mode

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Outline

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- Universal Hash Functions and Accordion Mode Candidates
- Reconsidering the Design of Poly1305
- Considerations for a Universal Hash in an Accordion Mode
- Summary and Ongoing Work

Universal Hash Functions and Accordion Mode Candidates

Δ-Universal Hash Functions

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- Syntax: $H: \mathcal{R} \times \mathcal{M} \rightarrow \mathcal{D}$
- Δ-Universality: For all $Z \in \mathcal{D}$ and $M \neq M' \in \mathcal{M}$ it holds that:

$$Pr_{r \leftarrow \mathcal{R}}[H_r(M) - H_r(M') = Z] \leq \epsilon$$

- Typical constructions are based on evaluating a polynomial over a finite field: $GF(2^n)$ or $GF(p)$.
- For polynomial hash functions, ϵ is typically an increasing function of the maximal message length in the message space.

Applications of Δ-Universal Hash Functions

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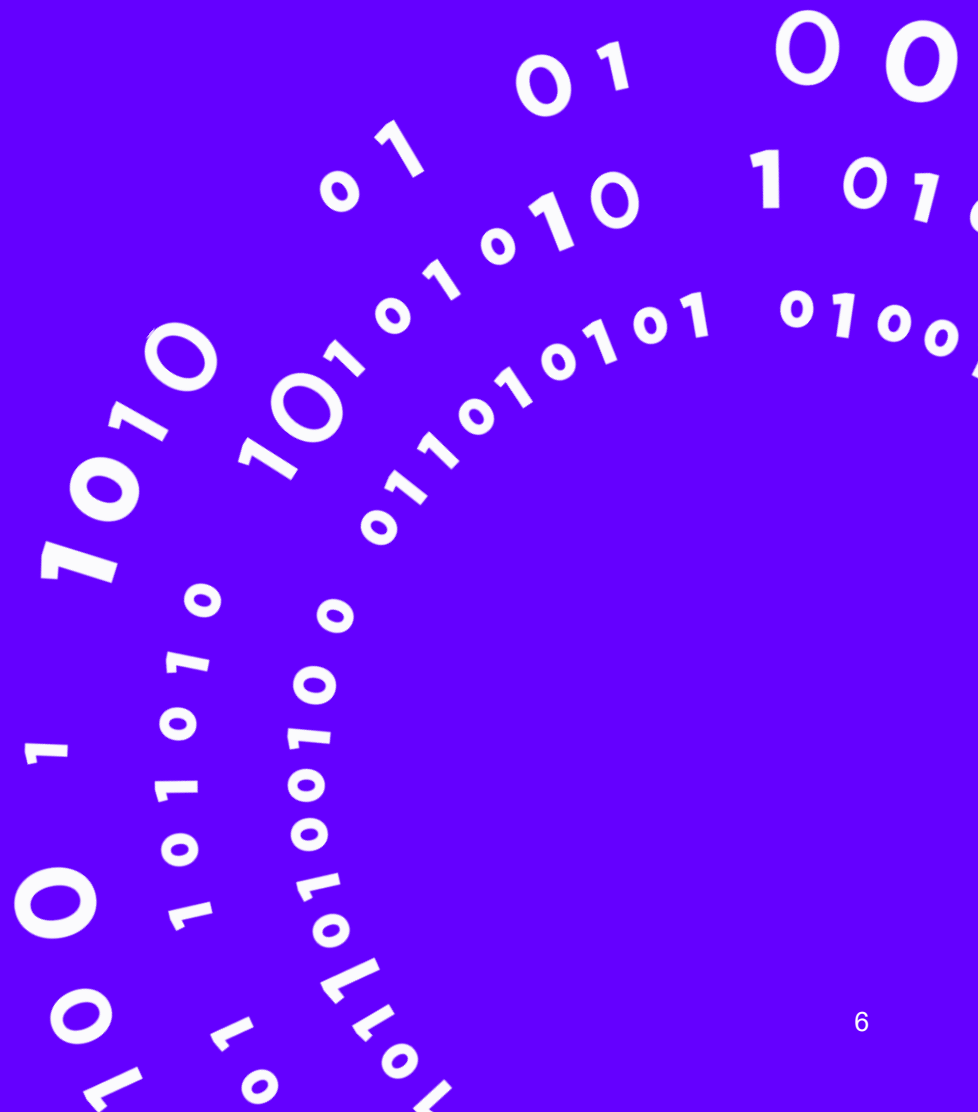
- Carter-Wegman MACs and AEAD: GMAC, Poly1305-AES, GCM, ChaCha-Poly1305, AES-GCM-SIV.
- Transforming a Blockcipher into a Tweakable Blockcipher: LRW2 construction.
- Various Blockcipher-based Accordion constructions: XCB, HCTR, HCTR2, TET, PIV (TCT1), AES-based Docked Double Decker, FAST, and more...
- E.g. HCTR uses **one instance of CTR and two hash instances**. Thus, a good choice of a hash function is (arguably) twice as important here.

Reconsidering the Design of Poly1305



Poly1305 and its Popularity

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- GHASH/POLYVAL and Poly1305 are the two dominant designs in practice.
- ChaCha-Poly1305 saw rapid adoption after RFC7539 (2015) and it is the **second most popular AEAD** scheme in use on the Internet today.
- It is known to outperform GCM on CPUs which **do not support** AES and Carry-Less-Multiplication instructions.
- It is used in TLS and is the default choice in **Wireguard**, **OpenSSH**, **OTRv4**, and the **Bitcoin Lightning Network**.

Another Look at Poly1305

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- It was designed by Bernstein in 2005 **for use with AES** as a CW MAC.
- Its design was intended for 32-bit architectures and specifically intended to **benefit from** the (then) superior performance of **FPUs**.
- However, all modern implementations employ **integer arithmetic** instead.
- Openssl poly1305-x86.pl:

"Besides SSE2 there are floating-point and AVX options; FP is deemed unnecessary, because pre-SSE2 processors are too old to care about, while it is not the fastest option on SSE capable ones."

What is Wrong with Poly1305?

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- To enable FPU implementations, 22 bits in the key are ‘clamped’ to zero, resulting in a **loss of 22 bits of security** (without a performance benefit).

- The choice of prime $(2^{130} - 5)$ is very wasteful on 64-bit architectures, resulting in a **lot of unused space** and **extra computation** when translating field elements into 64-bit limbs.

- Poly1305 and ChaCha were **designed independently** and only combined into an AEAD around a decade later by Langley.

- As such they have wildly **mismatching security levels** where the multiuser security of ChaCha-Poly1305 is not as strong as one would expect.

New Polynomial Hashes Over Prime Fields

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- We aimed to identify new hash designs, that **retain the benefits** offered by Poly1305, but attain **better security** and **performance** that suit today's applications and technology.

- The design space is surprisingly broad, with several complex interactions between **design** and **implementation** choices.

- To explore this space systematically, we built a **framework** through which we could **configure design** and **implementation parameters** and generate a C implementation of that hash.

New Designs

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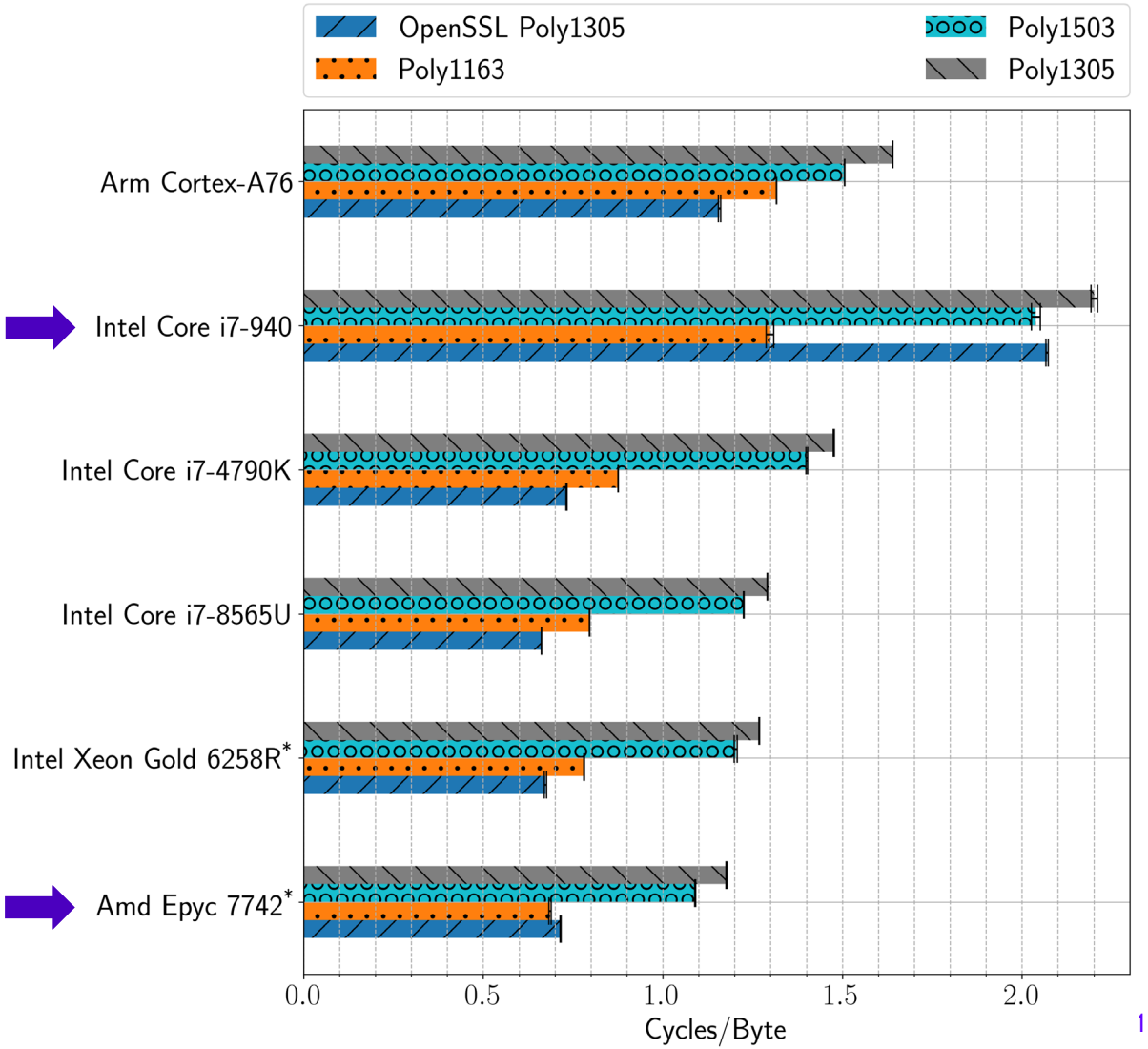
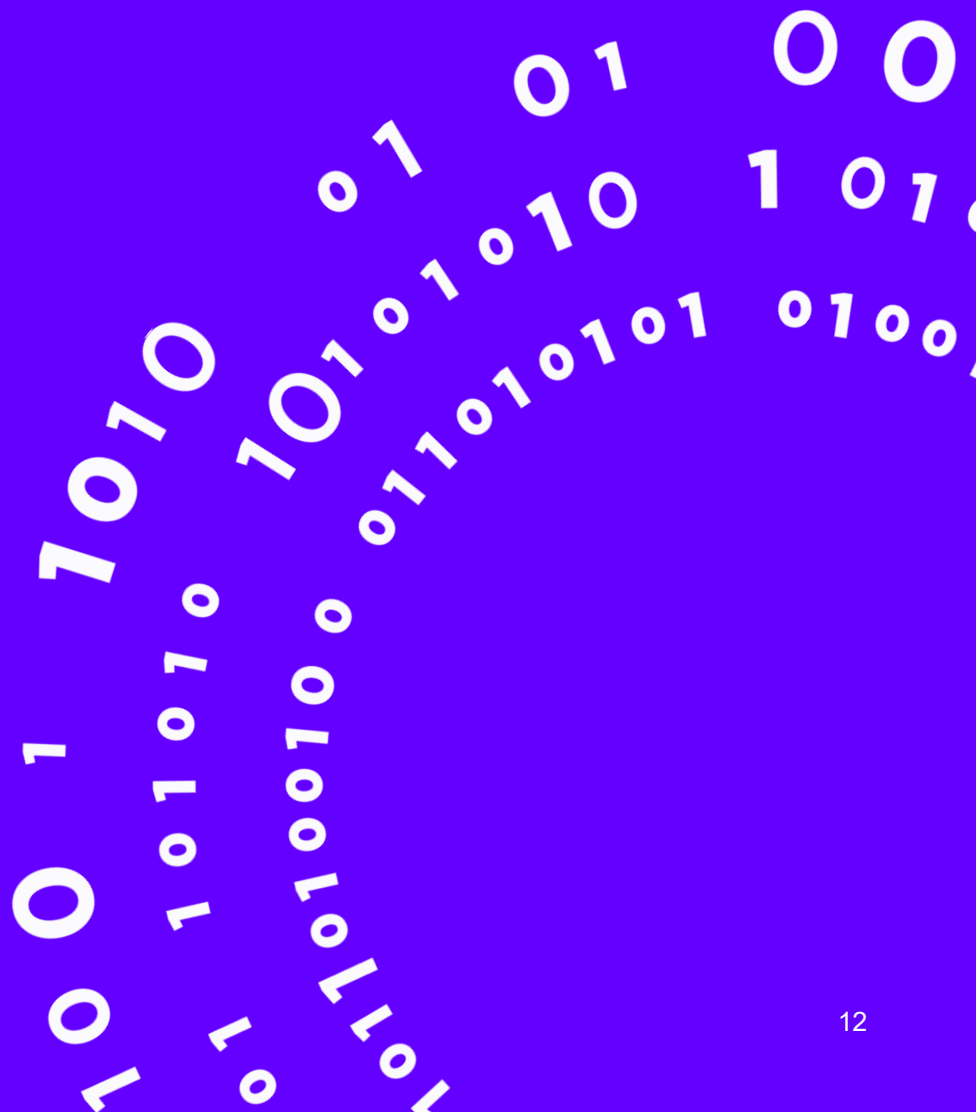
Name	Prime	Message Block, Key & Tag Size	Security Level
Poly1305	$2^{130} - 5$	16 Byte	103
Poly2663	$2^{266} - 3$	32 Byte	245
Poly1743	$2^{174} - 3$	21 Byte	161
Poly1503	$2^{150} - 3$	18 Byte	137
Poly1223	$2^{122} - 3$	15 Byte	117
Poly1163	$2^{116} - 3$	14 Byte	107

- Our modular implementations achieve high performance without vectorization.
- We expect significant speedup with vectorization.



Considerations for a Universal Hash in an Accordion Mode



Performance Considerations

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- One aspect contributing to GCM's high performance is the fact that GHASH can be evaluated in **parallel** with AES on CPUs with native **AES** and **CMUL** instructions.
- **Accordion mode** designs can also (partially) exploit this. Moreover, this holds even if we use a **universal hash over a prime field**.
- Such a combination would **exploit AES-NI** when available, but also attain **better performance** when AES and CMUL instructions are **not supported**.
- Our benchmarks indicate that Poly1163 achieves **comparable performance** to GHASH even on CPUs with CMUL.

Performance Considerations

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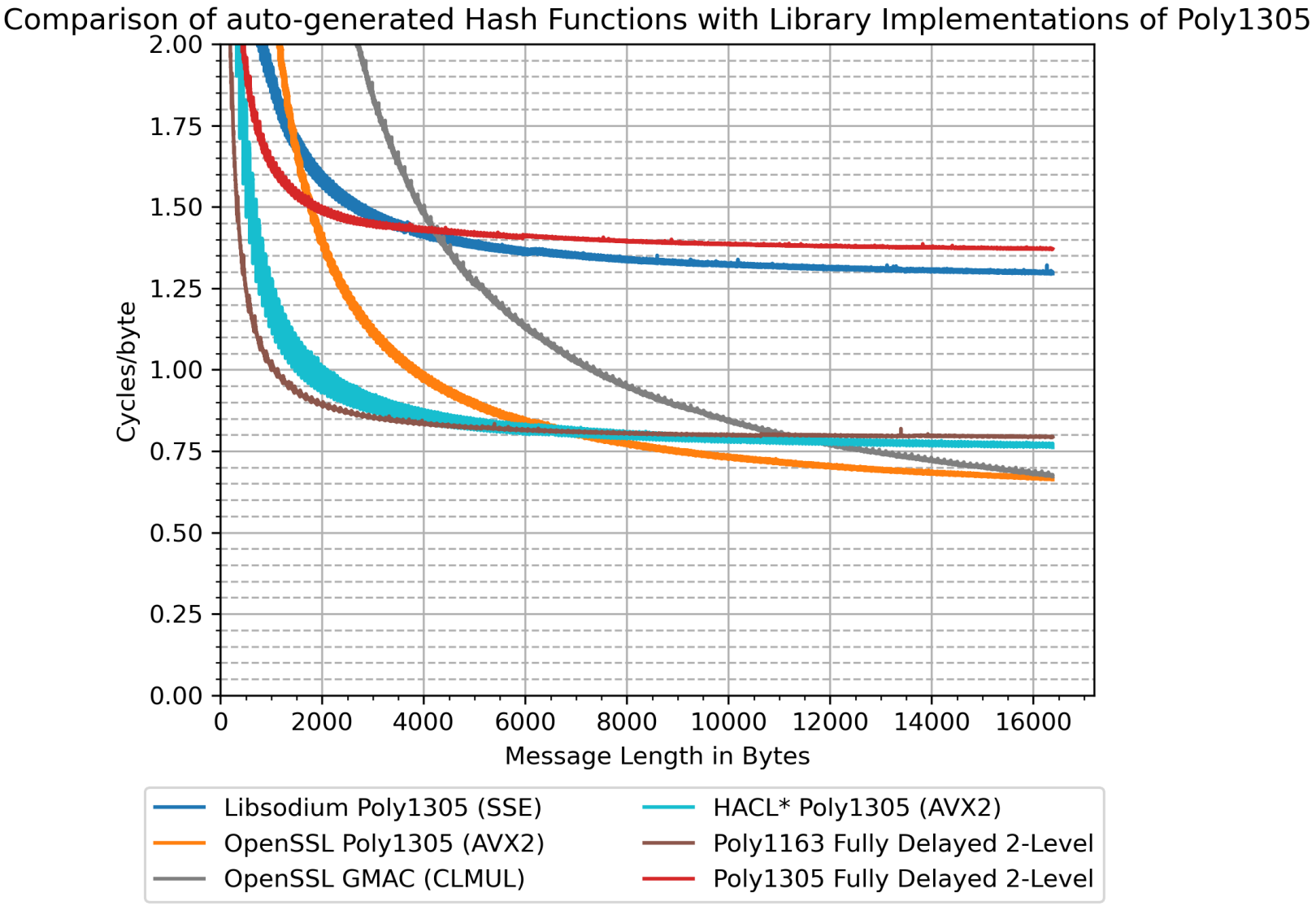

Performance Considerations

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- Note that the **openssl implementation of GHASH** attains its **top speed** well beyond a message size of 16kB—the **maximum packet size in TLS**!
- In the case of an Accordion mode to be used for **disk encryption**, the typical disk sector size is around 4kB.
- The **asymptotic performance** (often quoted in the literature) is **misleading** for an Accordion mode. Benchmarks should be quoted for the range relevant for the intended applications.
- Currently the list of requirements **does not specify** the intended range of message lengths at which performance should benchmarked.

Security Considerations

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- A good choice of hash function should **match the security** of the constructions rather than limit it (unlike ChaCha-Poly1305)
- The current requirements specify a **security strength of 256 bits**—which seems to suggest a digest size of 256 bits?
- For Accordion modes using a blockcipher with a **block size of 256 bits**, what is a good choice of universal hash? Is **concatenation** a good option?
- Our new designs and benchmarks address this issue.

Security Considerations

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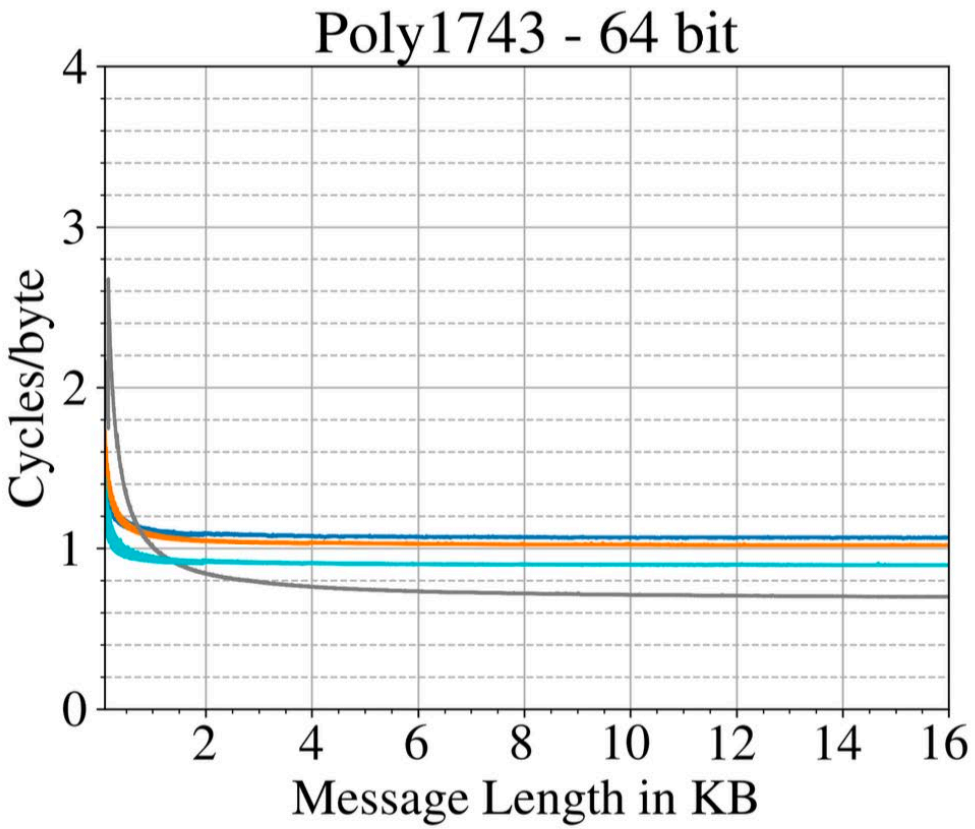

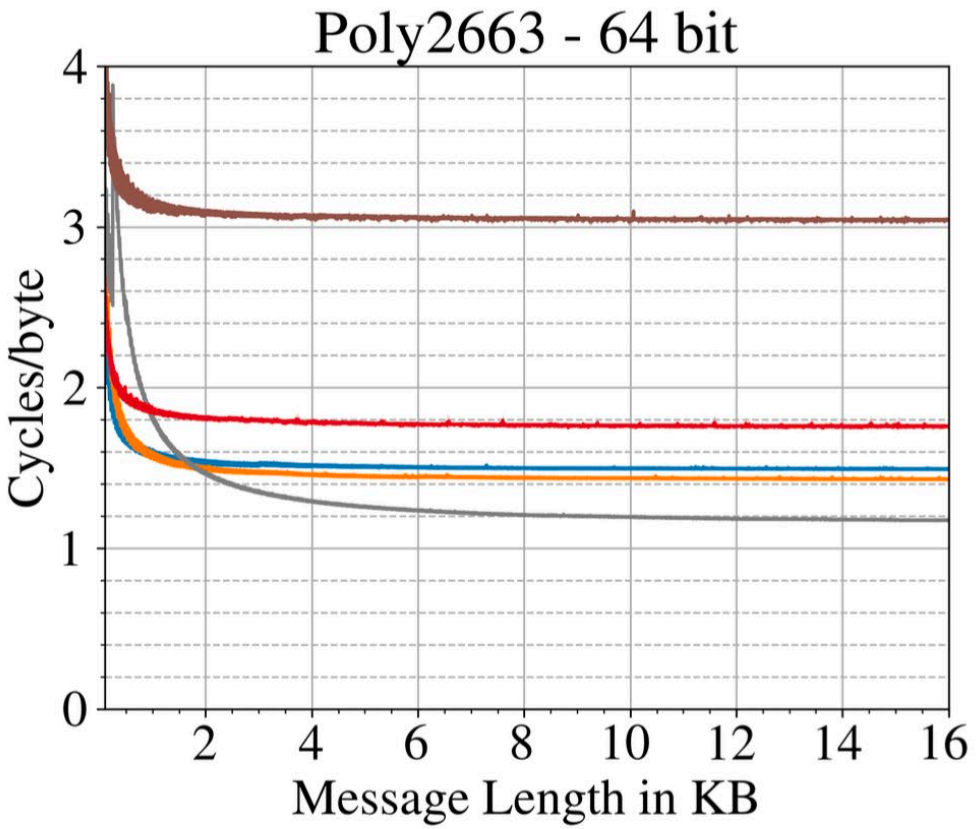

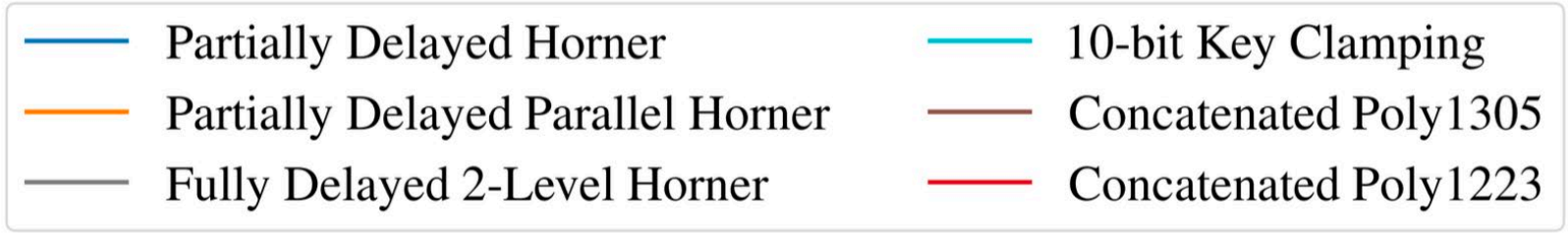

Summary and Ongoing Work

Summary and Ongoing Work

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- Combining AES with a universal hash over a prime field can be beneficial.
- We need **universal hash functions with larger parameters** to match a 256-bit-block blockcipher.
- We need universal hash functions that are **simple to implement** and attain good **performance** over the **intended range of message lengths**.
- Besides the new designs we recently proposed, we are **currently exploring** other hash designs both over $GF(p)$ and $GF(2^n)$.

The End