FAEST round 2 update

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9/26/2025

Credit to Carsten, Lance, and Lennart for some of the slides

Talk outline

High level overview of FAEST

Round 2 changes:

1. Optimized vector commitments
2. Optimized AES proof strategy
3. Change keyspace for improved security proof

FAEST in one slide:

KeyGen: Sample a random AES/Rijndael key K,
Sample a random message x,
Encrypt $y = Enc_K(x)$, (ECB or Evan-Mansour)
Output s$k = K,\ pk = (x, y)$.

Sign: Generate a "VOLE-in-the-head" zero-knowledge proof of knowledge of K such that $Enc_K(x) = y$.

Verify: Check the zero-knowledge proof.

Security follows from the security of AES + security of ZK-proof.

Only standard symmetric-crypto security assumptions!

Round 2 sizes and performance

Scheme	Runtimes in ms, Mcyc.						Sizes in B		
	KeyGen		Sign		Verify		sk	pk	Signature
FAEST-EM-128s	0.002	0.005	2.766	9.403	2.176	7.398	32	32	3 906
FAEST-EM-128f	0.002	0.005	0.413	1.404	0.327	1.113	32	32	5 060
FAEST-EM-192s	0.003	0.009	11.553	39.282	10.659	36.239	48	48	9 340
FAEST-EM-192f	0.003	0.009	1.523	5.177	1.372	4.665	48	48	12 380
FAEST-EM-256s	0.004	0.013	18.372	62.465	17.570	59.738	64	64	17 984
FAEST-EM-256f	0.004	0.013	2.775	9.436	2.566	8.725	64	64	23 476

Reasonable performance and sizes (faster signing and smaller signatures than SLH-DSA), despite the very conservative security assumptions!

*Timings performed on a AMD Zen 3 Ryzen 9 5950X processor at 3.4 GHz

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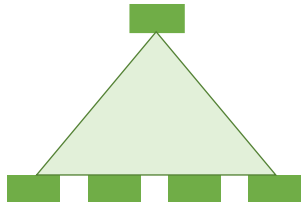
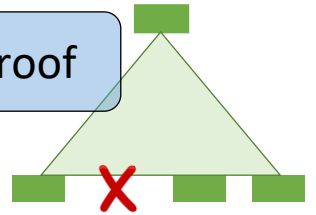
How to do VOLE-in-the-head?

All-but-one
vector commitment



Commit to n random strings

Run VOLE-ZK proof



Challenge Δ

Open $n-1$

Convert to VOLE

$\vec{u}, \vec{v}$

$\vec{q} = \vec{u}\Delta + \vec{v}$

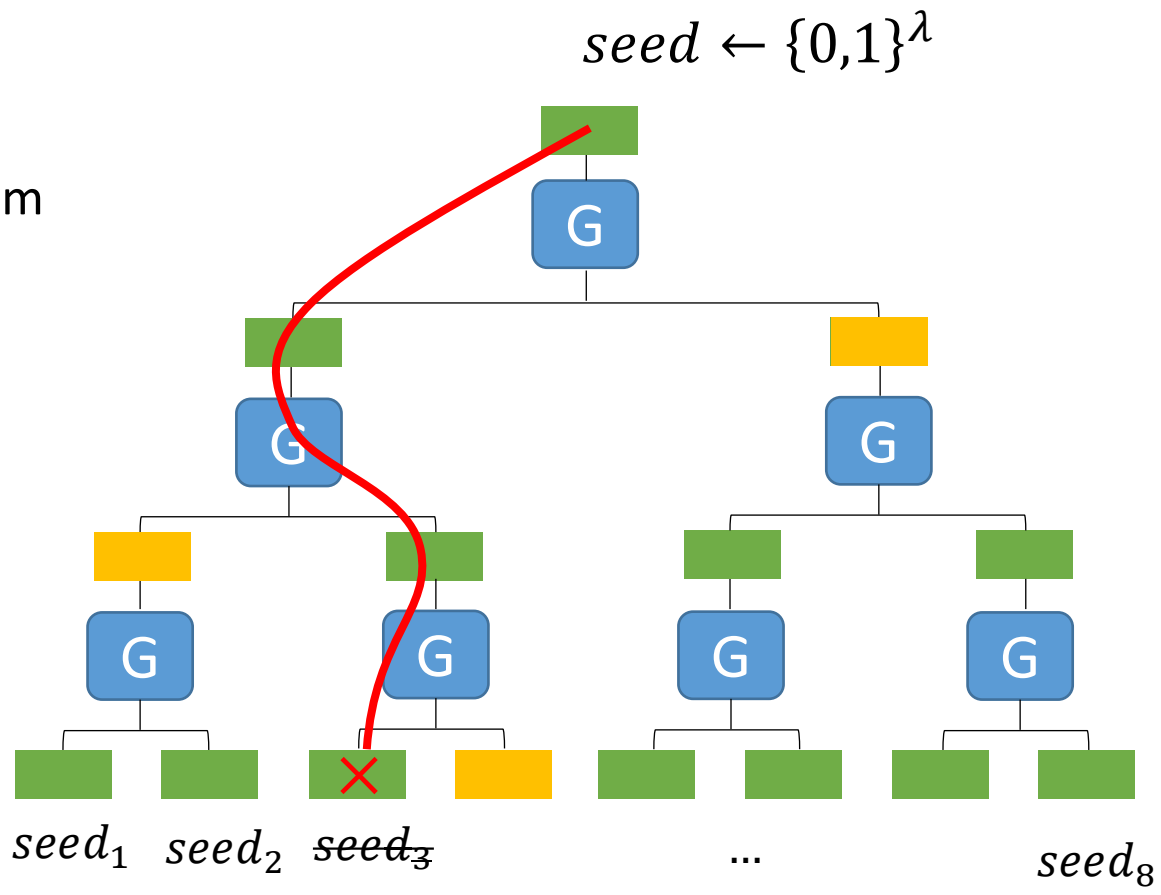
All-but-one commitments

Let G be a length-doubling PRG

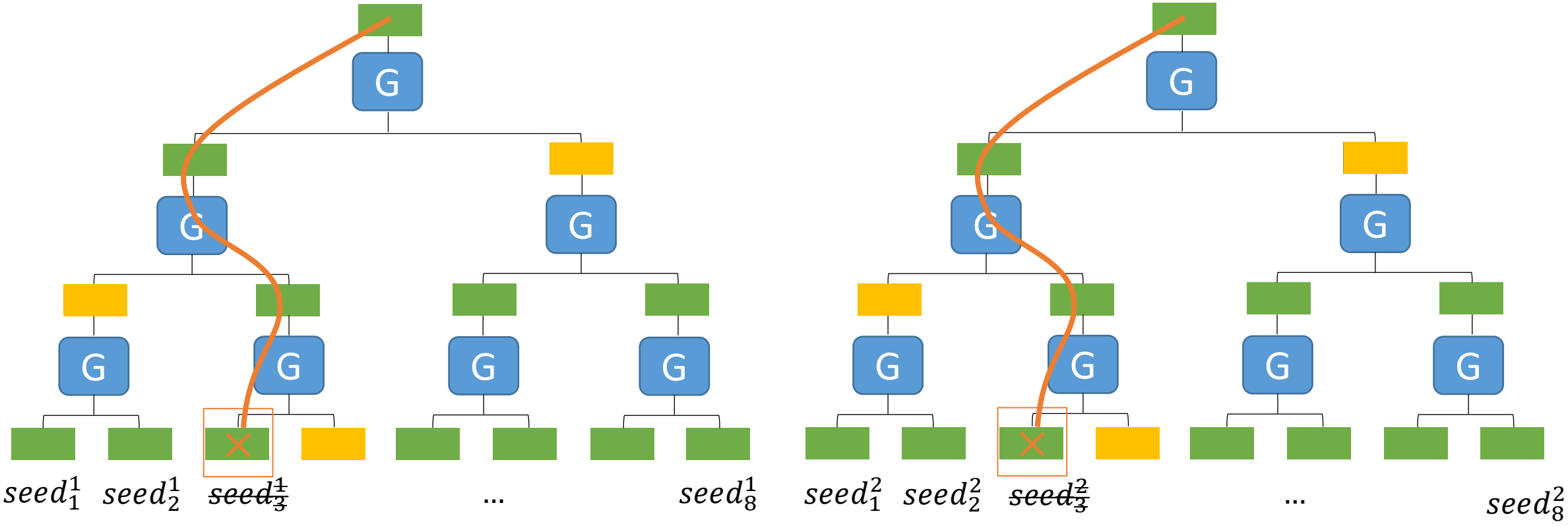
Derive all nodes and leaves recursively from root via G

Open $n-1$ leaves (seeds):

- Send $O(\log n)$ PRG seeds

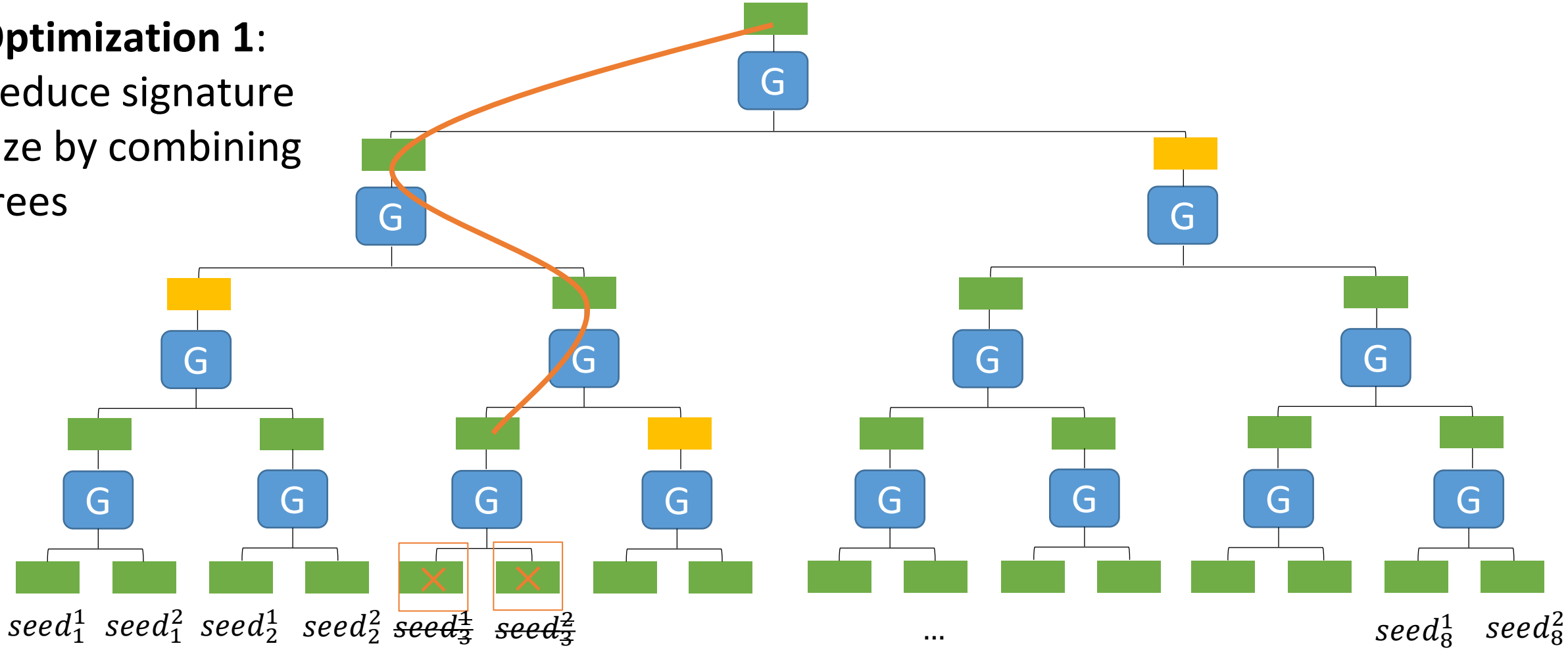


FAESTv1: Multiple GGM trees in parallel



FAEST version 2: One-tree optimization [BBM+24]

Optimization 1:
Reduce signature size by combining trees



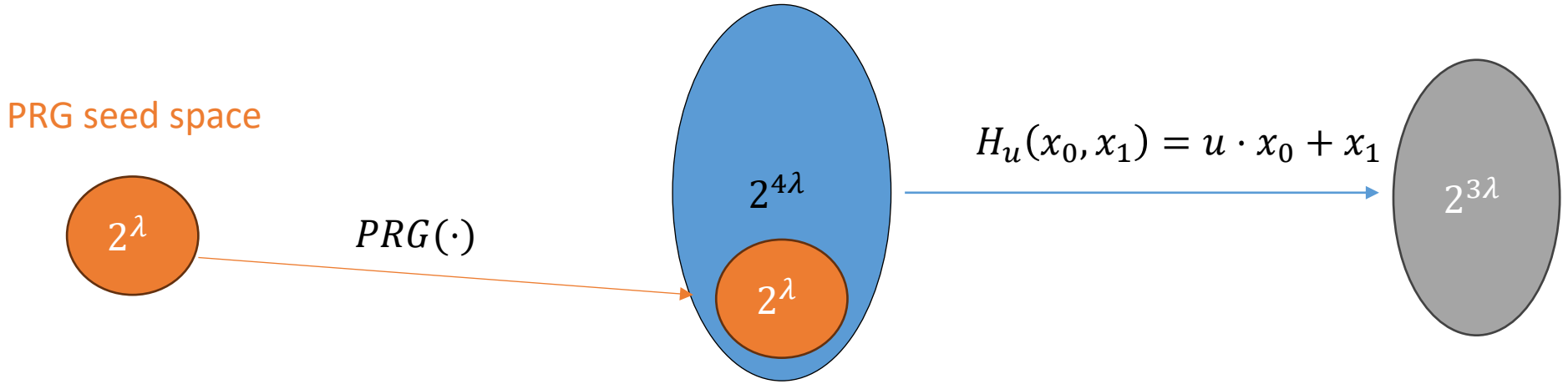
More optimizations!

Computing these is expensive!

Current state

Prover sends $\mathrm{h} = H(com(seed_1)| \cdots |com(seed_n))$

New idea: compute $com(seed_i) = H'(PRG(seed_i))$ where H' is UHF



More optimizations!

Computing these is expensive!

Current state

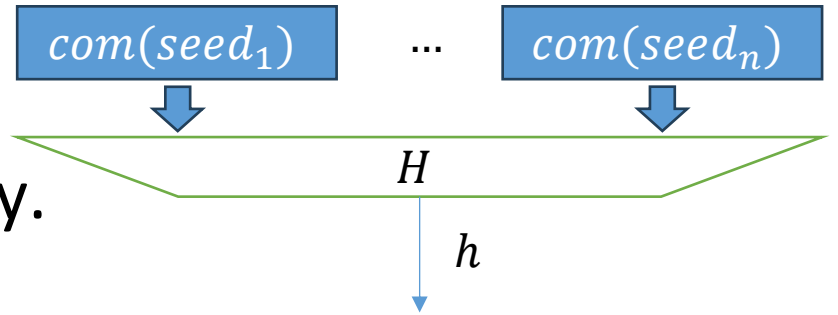
Prover sends $\mathrm{h} = H(com(seed_1)| \cdots |com(seed_n))$

New idea: compute $com(seed_i) = H'(PRG(seed_i))$ where H' is UHF

Problem: Breaks security proof.

Solution: Painful new security proof.

Result: Up to 2x speedup for sign and verify.



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How to prove an AES encryption using VOLE-in-the-Head

VOLE-in-the-Head allows to prove any low-degree polynomial constraints of the witness. Cost of the proof is $O(\ |witness|\ + deg\ )$

Problem: $Enc_K(x) - y$ has a huge degree
(as a polynomial in bits of witness K)

Solution: Extend the witness with state after every AES round R

$w\ = (K, x_1, x_2, \dots, x_9\ )$. Prove $R(x_i) - x_{i+1}\ = 0$ for $i \in \{0, \dots, 9\}$

$$x = x_0 \ \xrightarrow{R}\ x_1 \ \xrightarrow{R}\ x_2 \ \xrightarrow{R}\ \dots \ \xrightarrow{R}\ x_9 \ \xrightarrow{R}\ x_{10} = y$$

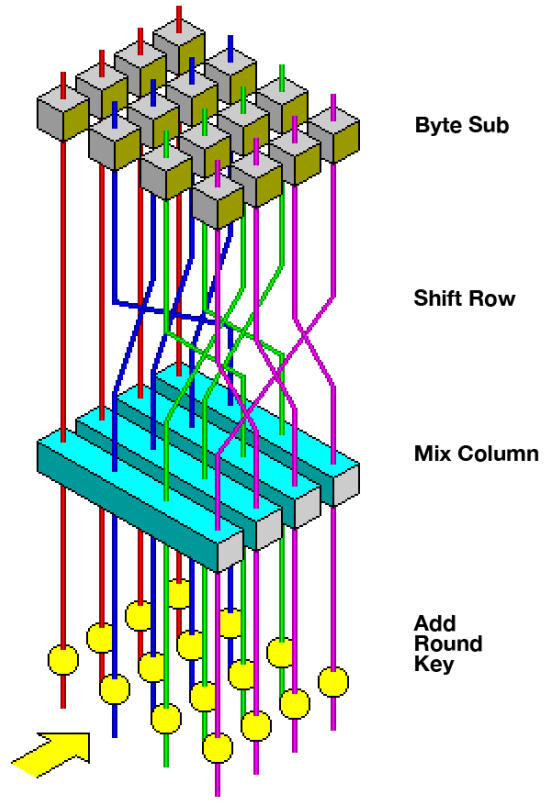
Proving a single AES round (Round 1 version)

Naively $R(x)$ has degree 7. But we did better.

The only nonlinear operation is the S-box

AES S-box is $\mathrm{a} \mapsto \begin{cases} \frac{1}{a} & a \neq 0 \\ 0 & a = 0 \end{cases}$

Instead of proving that $b = S(a)$, (degree 7)
we just prove $ab = 1$ (degree 2)



We make sure that no s-box has a zero input during KeyGen!

Proving two consecutive AES rounds together

Witness $= (K, x_2, \ldots, x_8)$. Prove $R(x_i) = R^{-1}(x_{i+2})$ for $i \in \{0, \ldots, 8\}$

$$x = x_0 \xrightarrow{R^2} x_2 \xrightarrow{R^2} \ldots \xrightarrow{R^2} x_8 \xrightarrow{R^2} x_{10} = y$$

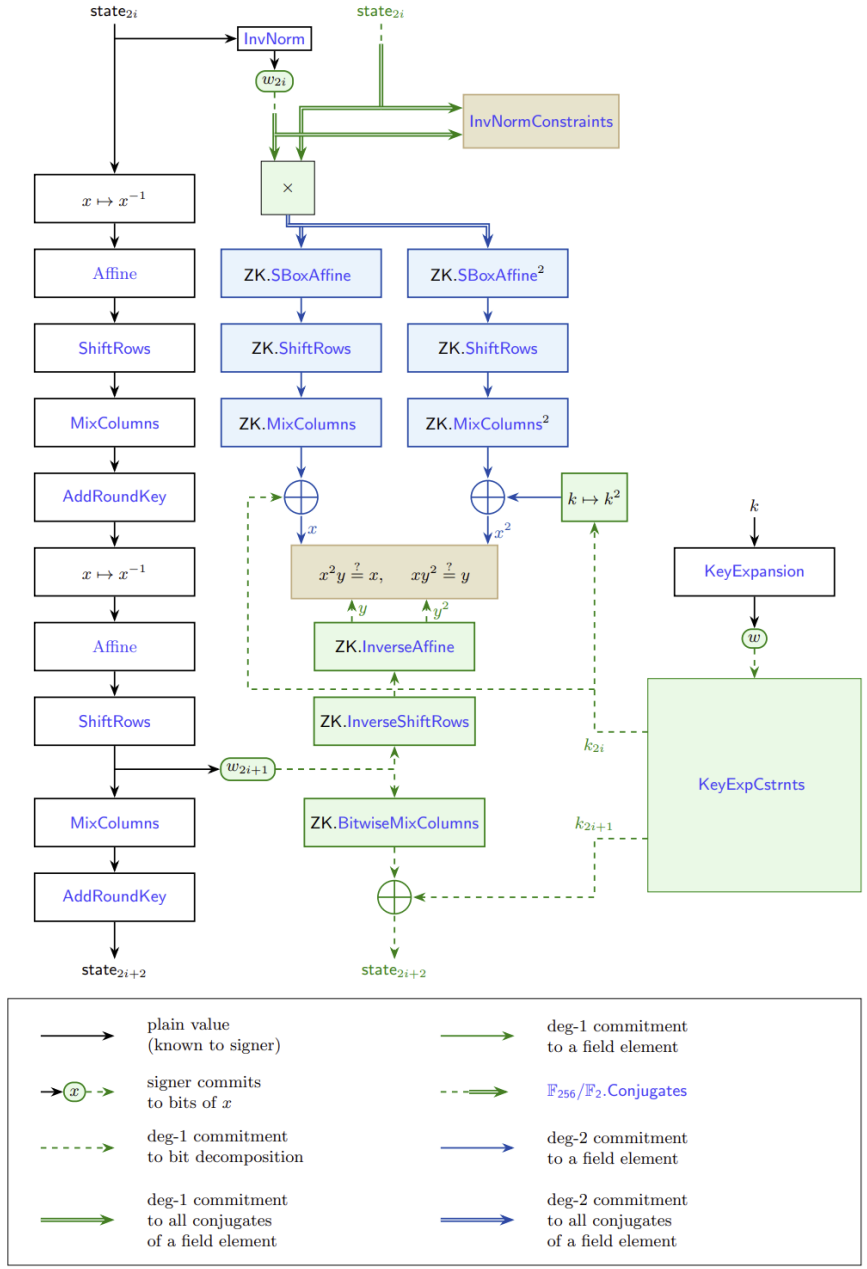
Reduce witness by 50%, but degree 7. Good, but we can do better!

Proving two consecutive rounds together. (Round 2)

We use a trick using the Field norm $N_{GF(256)/GF(16)}$ to have a witness size reduction of 25% and only use degree 3.

This gives roughly a 5% reduction in signature size.

Also, removes restriction that S-box inputs have to be non-zero.



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Security proof in the QROM

One key idea is to make the keys “lossy” i.e. make it so that many public keys don’t have a corresponding secret key.

Extra constraint: The first two bits of the key are not both 1.
This is a quadratic constraint $K_1 K_2 = 0$,
so we can prove it for free.

Proof of EUF-KO security: Replace public key $(x, y = Enc_K(x))$ by a random pair. With probability $\sim 1/4$ there does not exist a secret key. So we only need soundness, not knowledge soundness.

Conclusion

FAEST is a signature scheme with **reasonably good performance** and very **conservative security assumptions**

The Round 2 version is **faster and has smaller signatures** due to various optimizations, and has a **security proof in the QROM**

https://faest.info