SPHINCS$^+$

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Hash-based signatures

Boring crypto:

- Dates back to beginning of public key cryptography
- No fancy new mathematical assumption:
  Only requires a secure hash function
  („minimal security assumptions“)
- Stateful schemes already in standardization

SPHINCS

Joint work with Daniel J. Bernstein, Daira Hopwood, Tanja Lange, Ruben Niederhagen, Louiza Papachristodoulou, Michael Schneider, Peter Schwabe, and Zooko Wilcox-O'Hearn

Stateless hash-based signatures

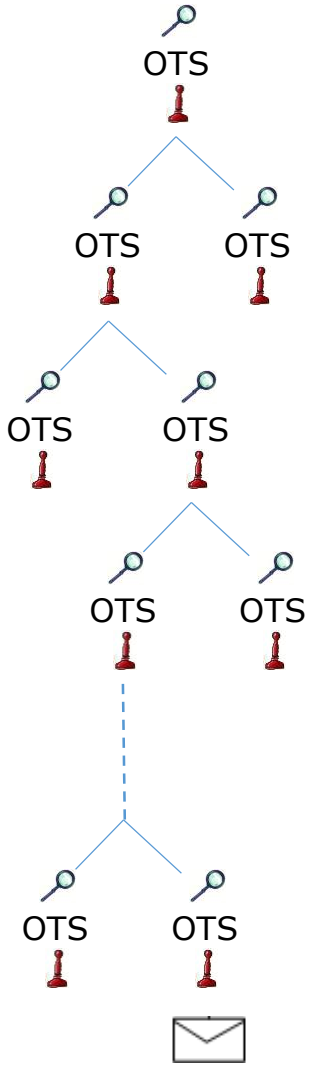
[NY89,Gol87,Gol04]

Goldreich's approach [Gol04]:

Security parameter $\lambda = 128$

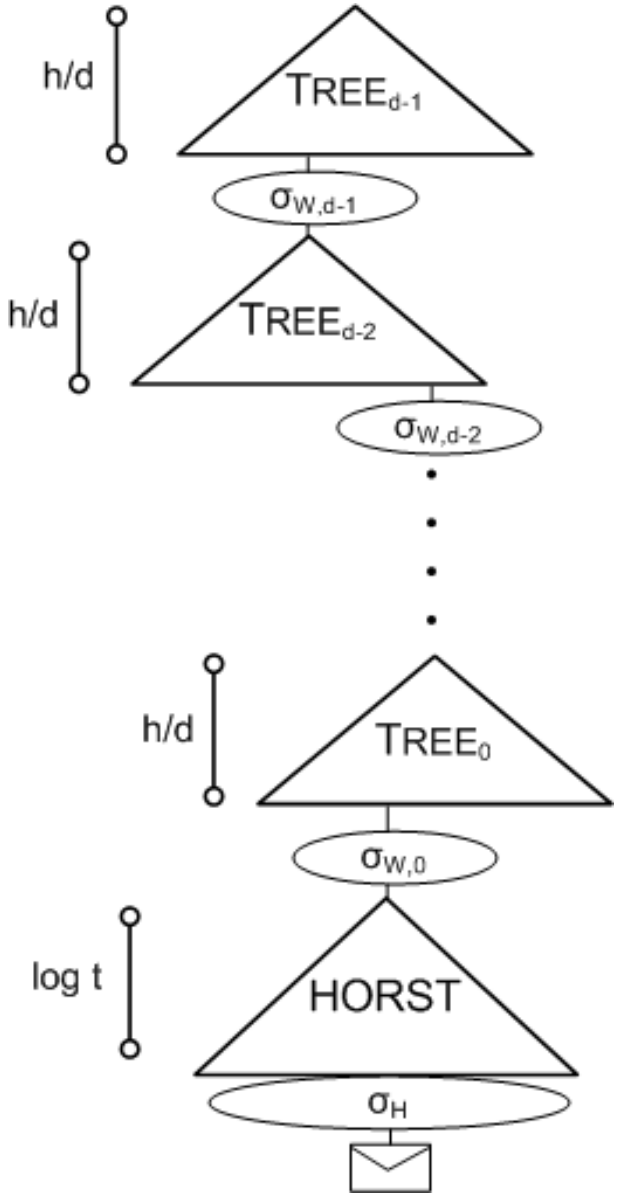
Use binary tree as in Merkle, but...

- …for security
  - pick index i at random;
  - requires huge tree to avoid index collisions (e.g., height $\mathrm{h} = 2\lambda = 256$).
- …for efficiency:
  - use binary certification tree of OTS key pairs (= Hypertree with $d = h$),
  - all OTS secret keys are generated pseudorandomly.



SPHINCS [BHH+15]

- Select index pseudorandomly
- Use a few-time signature key-pair on leaves to sign messages
  - Few index collisions allowed
  - Allows to reduce tree height
- Use hypertree: Use d << h.



SPHINCS$^+$ in 1st Round

Joint work with Daniel J. Bernstein, Christoph Dobraunig, Maria Eichlseder, Scott Fluhrer, Stefan-Lukas Gazdag, Panos Kampanakis, Stefan Kölbl, Tanja Lange, Martin M. Lauridsen, Florian Mendel, Ruben Niederhagen, Christian Rechberger, Joost Rijneveld, Peter Schwabe

SPHINCS$^+$ vs SPHINCS

- Allow for 2^{64} instead of 2^{50} signatures per key pair
- Add multi-target attack mitigation (Tweakable hash functions)
- New few-time signature scheme FORS
- Verifiable index selection
- Optional non-deterministic signatures

SPHINCS$^+$ in 2nd Round

Joint work with Jean-Philippe Aumasson, Daniel J. Bernstein, Christoph Dobraunig, Maria Eichlseder, Scott Fluhrer, Stefan-Lukas Gazdag, Panos Kampanakis, Stefan Kölbl, Tanja Lange, Martin M. Lauridsen, Florian Mendel, Ruben Niederhagen, Christian Rechberger, Joost Rijneveld, Peter Schwabe

2nd Round changes

- One new team member: 1/2 Gravity-SPHINCS (J.-P. Aumasson)
- “Simple”-instantiations (of tweakable hash functions)
- Performance optimization for SHA-256 instantiations
- Fixed tight security reduction

Instantiations

- SPHINCS$^+$-SHAKE256-robust
- SPHINCS$^+$-SHAKE256-simple NEW!
- SPHINCS$^+$-SHA-256-robust
- SPHINCS$^+$-SHA-256-simple NEW!
- SPHINCS$^+$-Haraka-robust
- SPHINCS$^+$-Haraka-simple NEW!

Simple instantiations inspired by LMS: All security reasoning in (Q)ROM

Instantiations (cycles for SHA2)

Scheme		Cycles			Bytes		
	sec	keypair	sign	verify	sig	pk	sk
SPHINCS$^+$-SHA-256-128s-simple	L1	49 078 104	835 272 076	2 348 916	8 080	32	64
SPHINCS$^+$-SHA-256-128s-robust	L1	94 988 100	1 624 566 118	4 700 588	8 080	32	64
SPHINCS$^+$-SHA-256-128f-simple	L1	1 602 368	51 805 308	5 676 578	16 976	32	64
SPHINCS$^+$-SHA-256-128f-robust	L1	2 978 018	96 974 576	11 401 188	16 976	32	64
SPHINCS$^+$-SHA-256-192s-simple	L3	69 860 954	1 737 629 602	3 662 790	17 064	48	96
SPHINCS$^+$-SHA-256-192s-robust	L3	134 664 612	3 024 929 742	7 784 118	17 064	48	96
SPHINCS$^+$-SHA-256-192f-simple	L3	2 116 010	66 380 214	9 611 814	35 664	48	96
SPHINCS$^+$-SHA-256-192f-robust	L3	4 390 738	133 192 018	19 219 918	35 664	48	96
SPHINCS$^+$-SHA-256-256s-simple	L5	85 946 882	1 121 074 298	4 903 926	29 792	64	128
SPHINCS$^+$-SHA-256-256s-robust	L5	350 260 762	4 064 645 574	13 790 402	29 792	64	128
SPHINCS$^+$-SHA-256-256f-simple	L5	5 298 662	133 374 038	9 408 596	49 216	64	128
SPHINCS$^+$-SHA-256-256f-robust	L5	21 672 826	495 051 104	26 825 462	49 216	64	128

SHA-256 optimization

$$\mathrm{F}(\mathrm{PK}.seed, \mathrm{ADRS}, M_1)$$
$$= \mathrm{SHA\text{-}256}(\mathrm{PK}.seed \,||\, \mathrm{toByte}(0, 64-n) \,||\, \mathrm{ADRS}^c \,||\, M_1^{\oplus})$$

Ensure that key dependent input fills first block (precompute & reuse state)

Compress ADRS to fit padding in second block

Only 1 compression function call per F call!

Table 2: Performance comparison of different symmetric-crypto-based signature schemes on the Intel Haswell microarchitecture. All software is optimized using architecture-specific optimizations such as AESNI or AVX2 instructions.

Scheme	Cycles			Bytes		
	keypair	sign	verify	sig	pk	sk
Comparison to SPHINCS-256						
SPHINCS-256 [8]	2 868 464[a]	50 462 856[a]	1 672 652[a]	41 000	1 056	1 088
SPHINCS$^+$ (Haraka, robust) ($n = 192, h = 51, d = 17, b = 7, k = 45, w = 16$)	1 254 968[b]	29 015 002[b]	2 739 770[b]	30 696	48	96
Comparison to Gravity-SPHINCS						
Gravity-SPHINCS [5] (parameter-set L)	30 729 044 392[a]	32 564 796[a]	625 752[a]	max: 35 168 avg: ?[c]	32	1 048 608
SPHINCS$^+$ (Haraka, robust) ($n = 192, h = 66, d = 22, b = 8, k = 33, w = 16$)	1 257 826[b]	38 840 268[b]	3 467 192[b]	35 664	48	96
SPHINCS$^+$ (Haraka, simple) ($n = 192, h = 64, d = 16, b = 7, k = 49, w = 16$)	1 892 462[b]	35 029 380[b]	1 460 204[b]	30 552	48	96
Comparison to Picnic						
Picnic2-L5-FS [16]	18 244[c]	904 189 188[c]	268 485 212[c]	max: 54 732 avg: 46 282	65	97
SPHINCS$^+$ (SHA-256, simple) ($n = 256, h = 63, d = 9, b = 12, k = 29, w = 16$)	43 317 320[b]	527 413 100[b]	5 463 884[b]	33 408	64	128

[a] As reported by SUPERCOP [10] from 3.5GHz Intel Xeon E3-1275 V3 (Haswell)
[b] Median of 100 runs on 3.5GHz Intel Xeon E3-1275 V3 (Haswell), compiled with `gcc-5.4 -O3 -march=native -fomit-frame-pointer -flto`
[c] As reported by SUPERCOP [10] from 3.1GHz Intel Xeon E3-1220 V3 (Haswell)
[d] Neither [5] nor [6] report the average size of signatures; the analysis in [4] suggests that it is about 1KB smaller than the worst-case size.

Tight security reduction

“2. This claim is incorrect, because the theorem apparently does not apply to the proposed instantiations: it requires the component function F to have a structural property that it almost certainly does not have. (Indeed, it seems hard to find *any* suitable instantiation having the property.)”

Chris Peikert, May 24, 2018

Ugly fixes:

a) Rely on loose security reduction

b) Build artificial hash with property

$$F = \text{SHA2-256}(K, \text{SHA2-256}(K, M)_{0\ldots248})$$

Cost of factor 2 speed penalty and slightly decreased security

More elegant fix

Replace statistical property by new computational assumption:

Decisional second-preimage resistance (DSPR) [BH19]

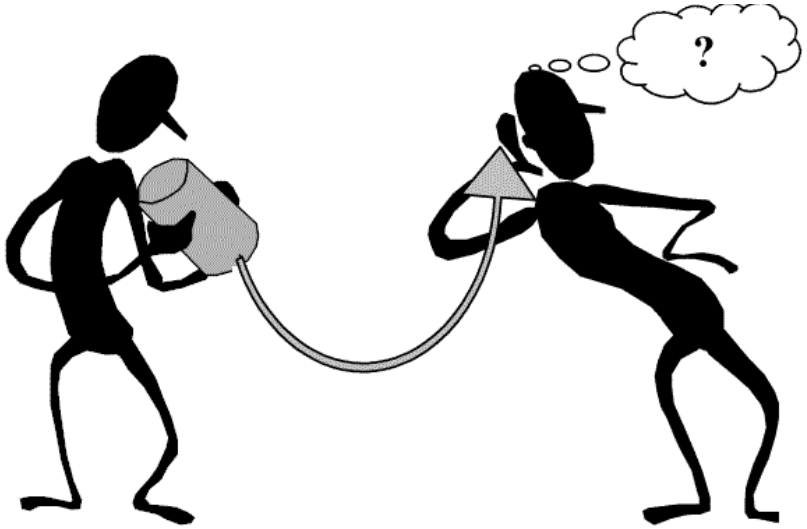
Intuition:

Given domain element it is hard to decide if second-preimage exists (with probability better than guessing)

Conclusion

- SPHINCS$^+$ beats performance of other symmetric crypto based signatures for comparable parameters.
- Possible synergies with standardizing stateful hash-based signatures
- New *simple* instantiations integrate well with an LMS-like stateful scheme.
- Re-established tight security proof.
- *The* most conservative submission in the competition.

Thank you!
Questions?



Structural property

- “Every n bit string has at least one colliding n bit string under F_K“

Use in proof:

We can turn preimage finder A for F_K into second-preimage finder B for F_K.

- $B(x)$: On input x return $A(F_K(x))$
- If property holds,

$$\Pr\left[A\left(F_K(x)\right) \neq x\right] \geq \frac{1}{2}$$