
Cliff of Rsa
Forest of public key
River of ECC
Sea of classical cryptography
Curve 25519
N
The Realm of post-quantum


Sword of
Academia
Sword of
Industry
pgc
State
of
the
Art
pgc

Fraunhofer AISEC

zeroRISC

CHELPIS

Rivos

Migrating a Silicon Root of Trust to Post-Quantum Crypto

Amin Abdulrahman, Evan Apinis, Andrew 'bunnie' Huang, Matthias J. Kannwischer, Ruben Niederhagen, Felix Oberhansl,
Hoang Nguyen Hien Pham, Jade Philipoom, Dominic Rizzo, Robert Schilling, Peter Schwabe, Tobias Stelzer, Augustine Tang, Andreas Zankl

1. SPHINCS+ Secure Boot

1. SPHINCS+ Secure Boot
2. HW/SW Codesign for ML-KEM & ML-DSA

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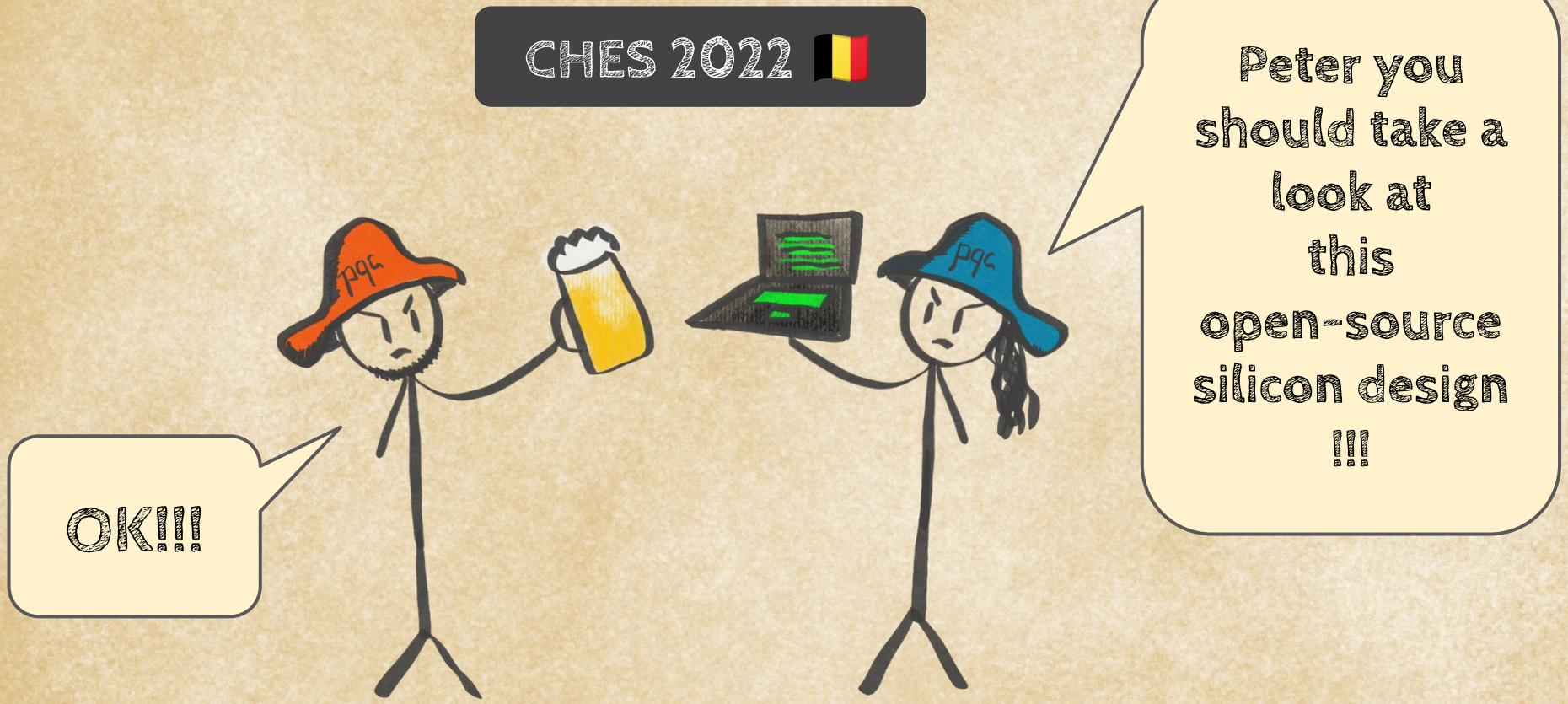
2. HW/SW Codesign for ML-KEM & ML-DSA
3. Ongoing Work & Lessons Learned

SPHINCS+

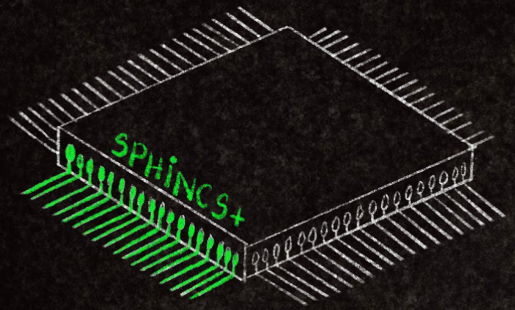
(aka SLH-DSA)


CHES 2022 🇧🇪
pqc
pqc
Peter you should take a look at this open-source silicon design !!!
OK!!!

29 hours later...

The first signature is VERIFIED

6 months later... SPHINCS+ secure boot!



3x faster than unmodified reference implementation

- shake-128s-simple: **< 13 ms @100MHz**
- sha3-128s-simple: **~ 9.3 ms @100MHz**

← Blog post: Landing SPHINCS+ on OpenTitan

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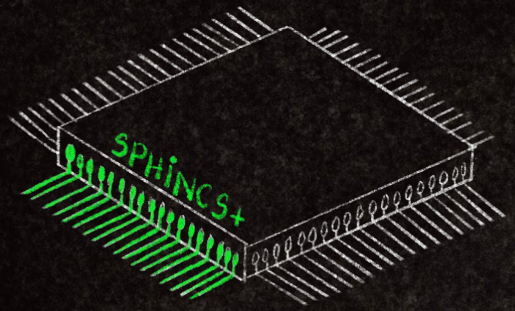

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6x slower than RSA-3072

3x slower than ECDSA-P256

- one-time programmable (OTP) memory configuration to enable

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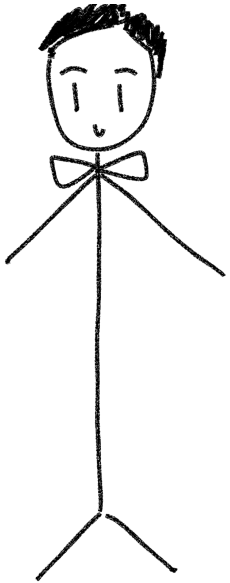
HW/SW Codesign for ML-KEM & ML-DSA

Amin's Master Thesis: Dilithium on OpenTitan (2023)



8 bits	8 bits	8 bits	8 bits	8 bits	8 bits	8 bits	8 bits

Proposed vector instructions for OpenTitan Big-Number Accelerator (OTBN):

Thesis

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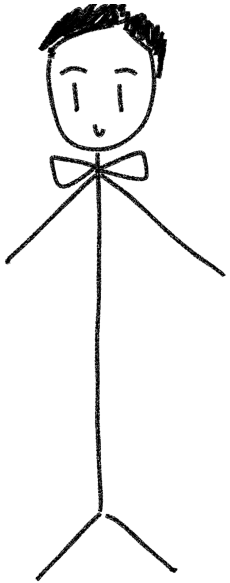

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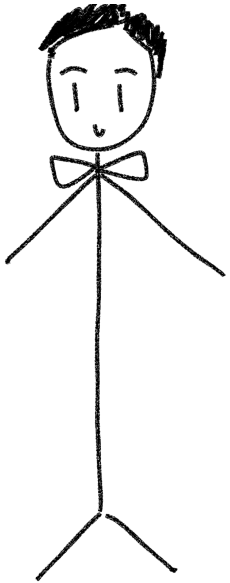

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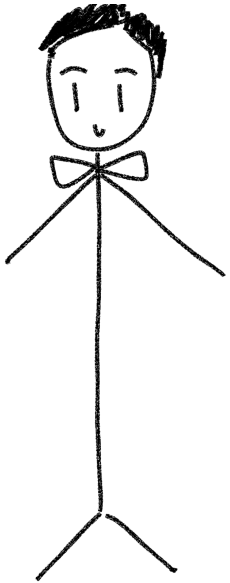

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  -> hardware multiplier

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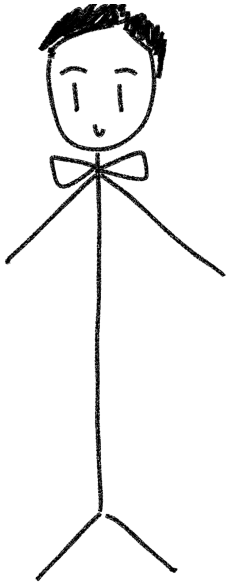

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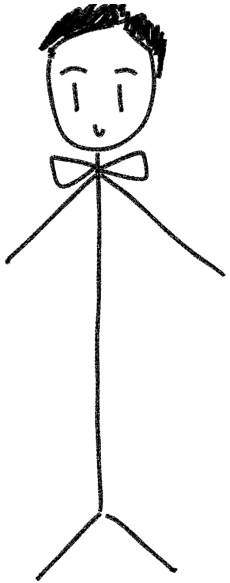

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Idea for SHA3/SHAKE connection to OTBN

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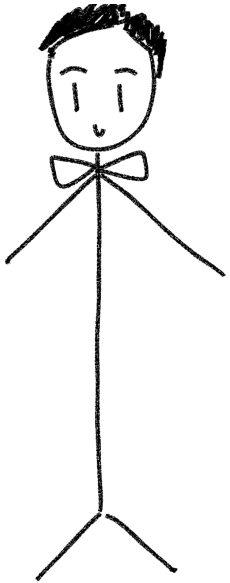

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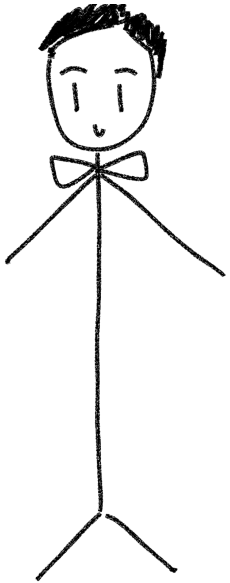

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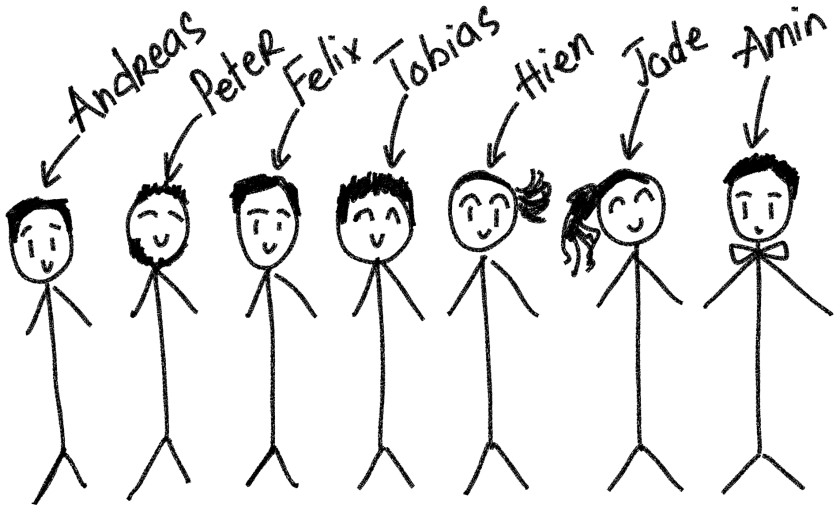
Increased IMEM from 8 to 32KB and DMEM from 4 to 128KB

Thesis

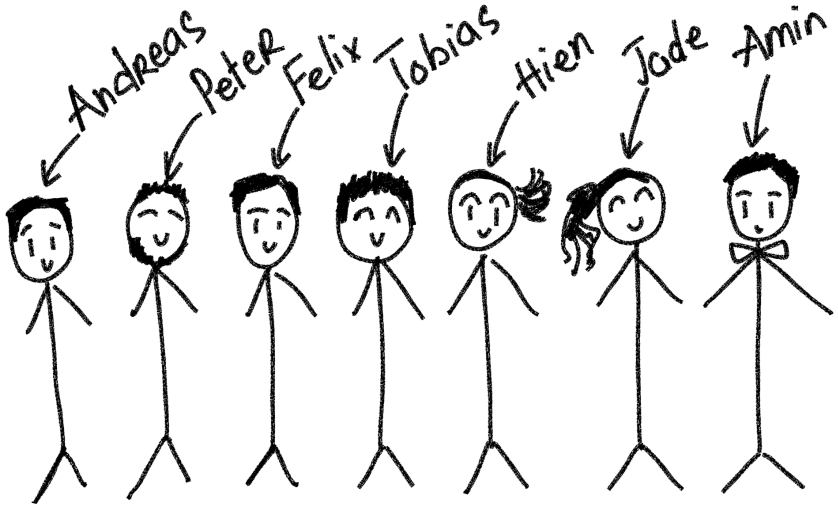

Let's collaborate again



Vector instructions for OTBN:

- bn.{add,sub,mul}v(m)
- bn.shv

Paper Code



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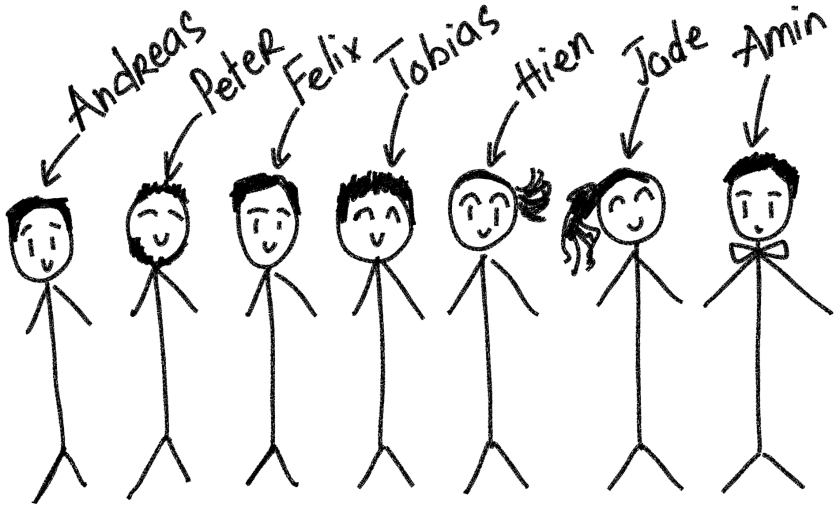

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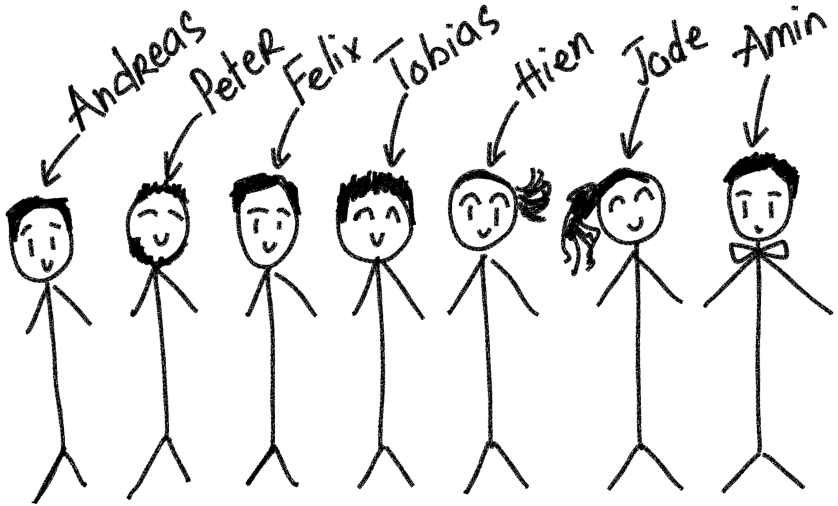

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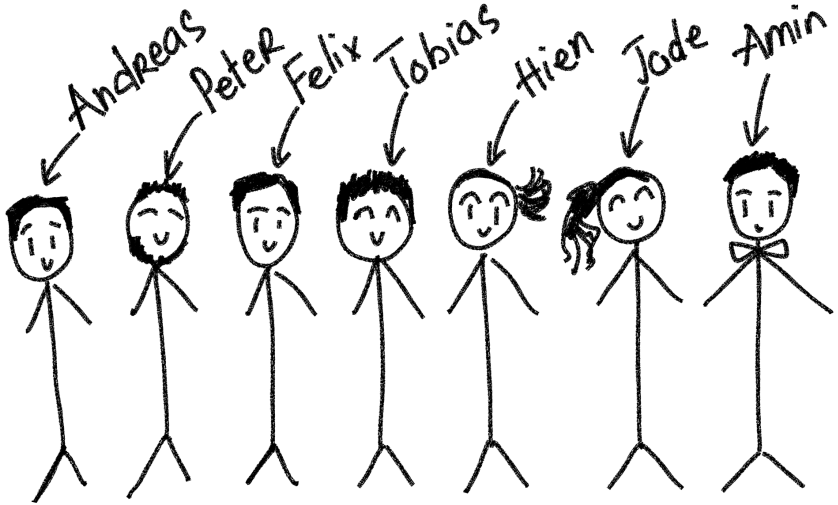
Hardware implementations of the proposed instructions

New SHA3/SHAKE hardware connection

Paper Code

Towards ML-KEM and ML-DSA on OpenTitan (IEEE S&P 2025)



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Paper Code

Result at target frequency

← Blog post:
Accelerating Post-Quantum Cryptography on OpenTitan-based Designs: Flexible Hardware for a Secure Future

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- Cell-count increase of **less than 17% for OTBN** and **less than 3% for OpenTitan's Top Earlgrey (without memory)**

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But...We can still do better

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- bn.mulvm takes 12 cycles and bn.mulv takes 4 cycles

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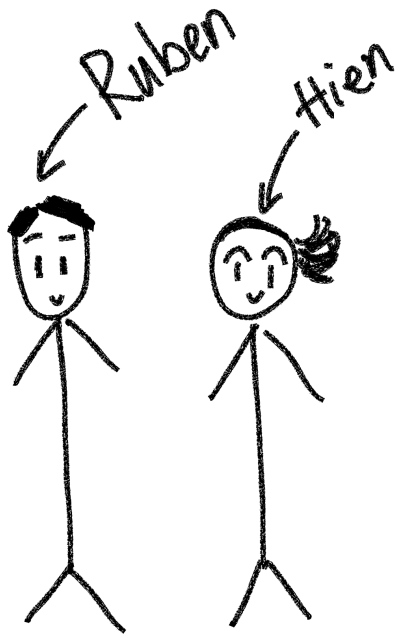
- Sequential vector adder design leads to reduced maximum frequency



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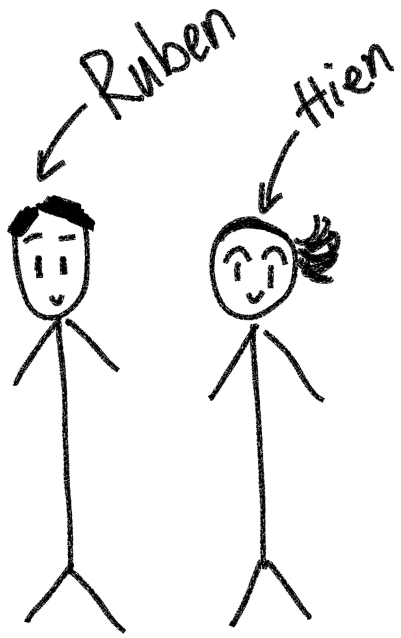

Shift modular multiplication back to SW:

- ~~bn.mulv(m)~~ bn.mulv{.lo,.hi}{.even,.odd} -> V{1,2,3}

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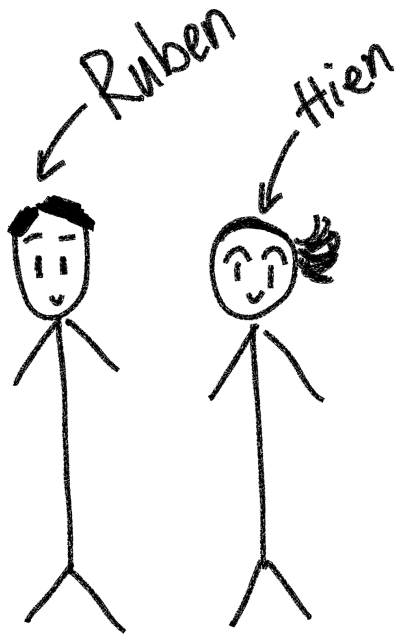

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  - 32-bit: ~~12 cycles~~ 7 cycles

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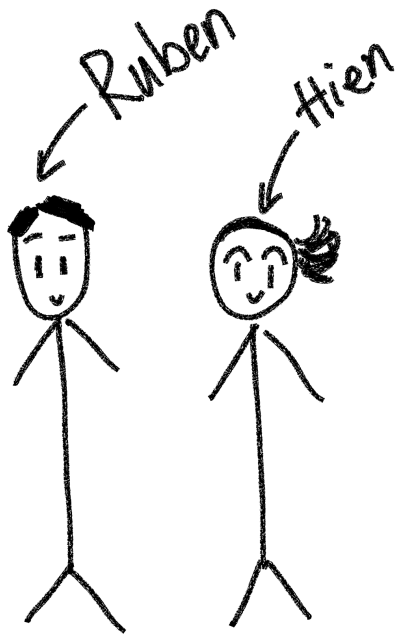

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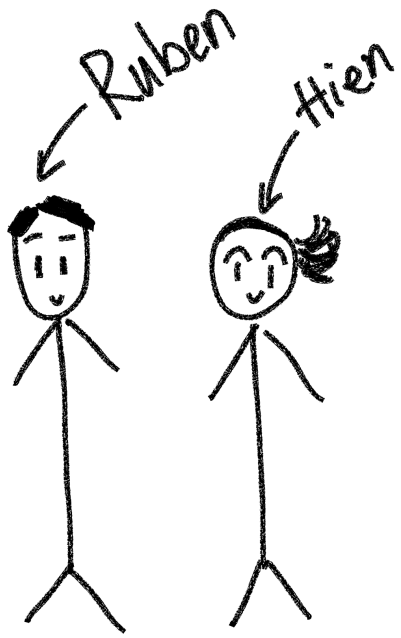

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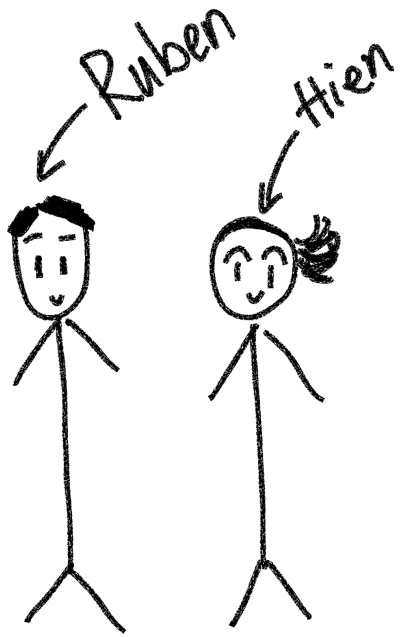

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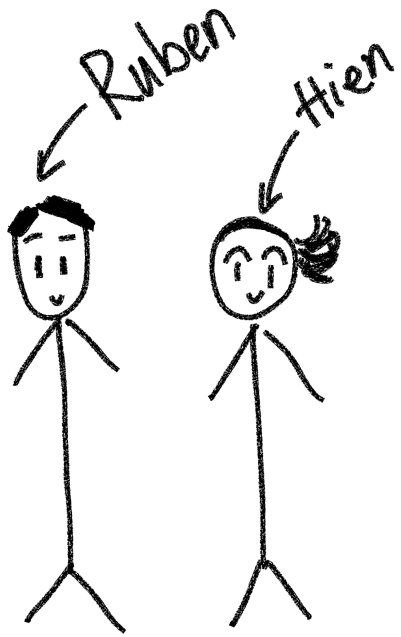

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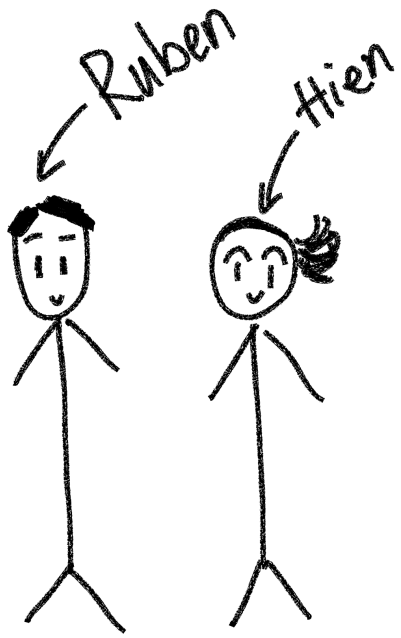

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Improved vector adder designs (tailored for target platform ASIC/FPGA)

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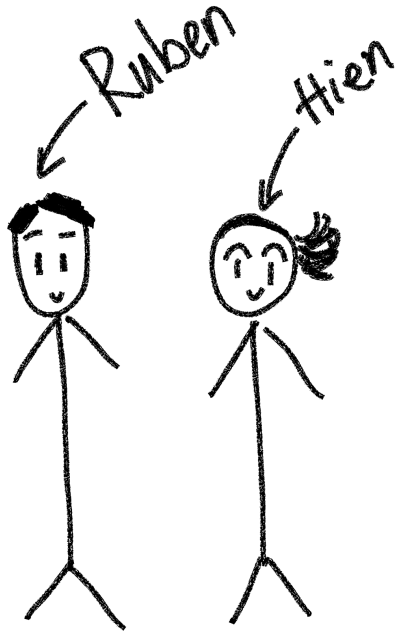
Improving ML-KEM and ML-DSA on OpenTitan (CHES 2026)



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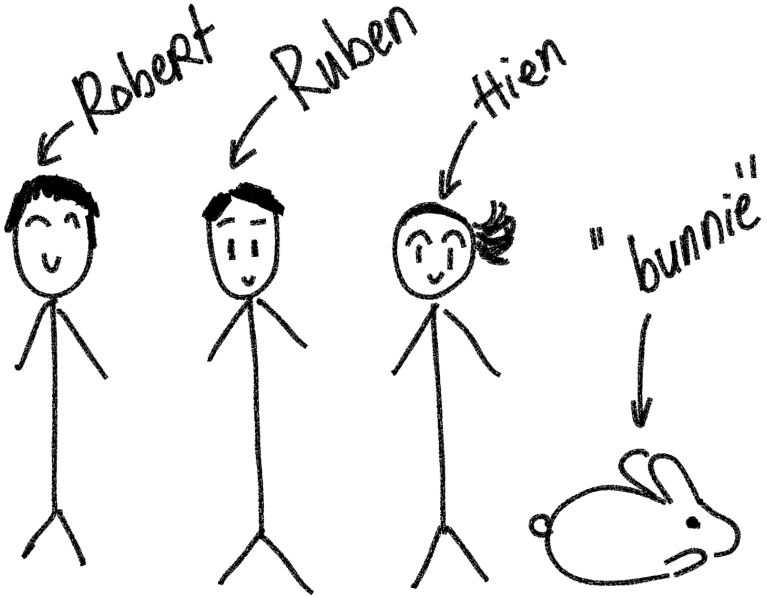

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Improved vector adder designs (tailored for target platform ASIC/FPGA)

ASIC synthesis on other technology nodes and confirmed that the results are consistent with what we had using Cadence and OpenROAD

Results

- Up to 17% speedup in cycle count and 16% increase in code size for ML-KEM and ML-DSA compared to previous paper on OTBNV2

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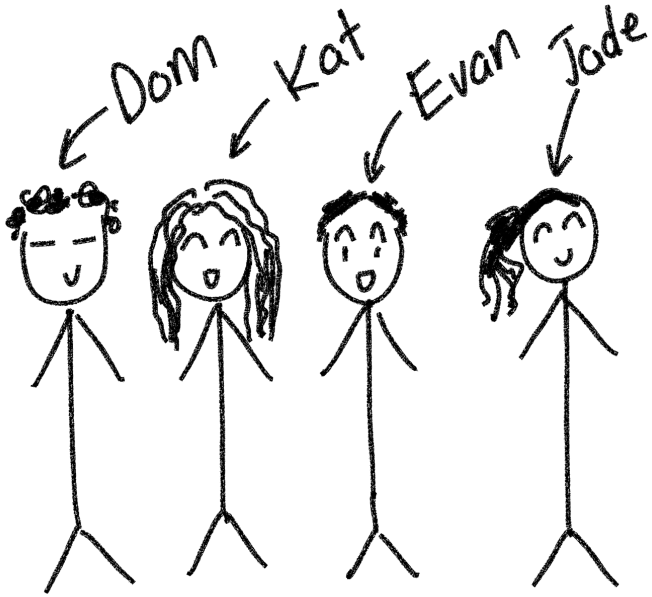
- Up to 17% speedup in cycle count and 16% increase in code size for ML-KEM and ML-DSA compared to previous paper on OTBNV2
- Similar area while improving maximum frequency of the whole OTBN

Ahem...but we can still do better!!!

Here comes the ZeroRISC refinement squad...



← Blog post: From Artifact to Production: Integrating and Refining Lattice Cryptography Acceleration

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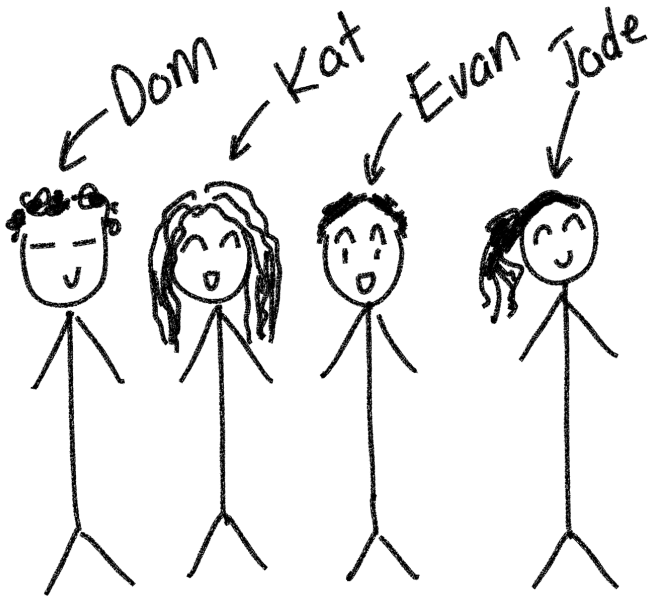

Stack optimized ML-DSA

- 121kB -> 11kB (91% reduction) for ML-DSA-87 signing
- Tradeoff: 80%-140% slowdown for sign (negligible for other ops)

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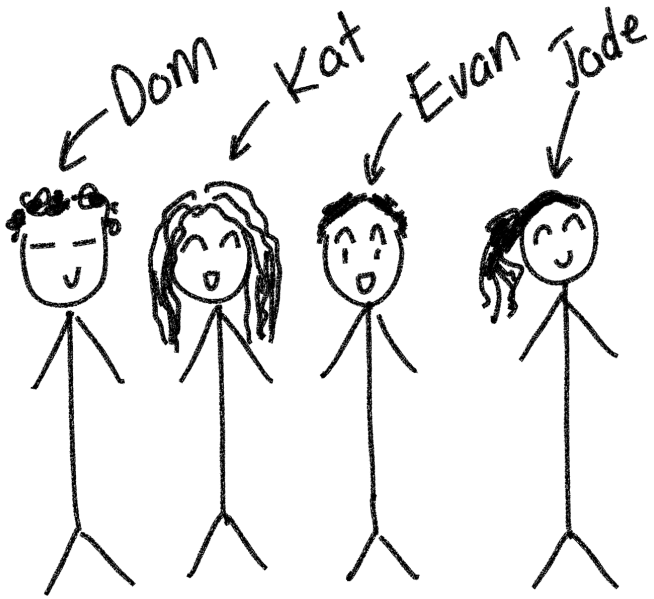

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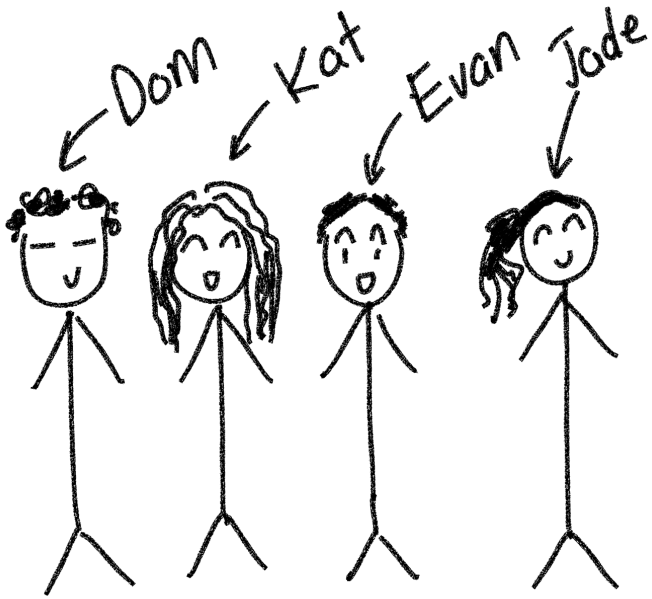

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Redesigned SHA3/SHAKE interface
- ~6% speedup (all ops)

Integration with Design Verification tools

← Blog post: From Artifact to Production: Integrating and Refining Lattice Cryptography Acceleration

Beyond bignums...

OTBN + ML-DSA + ML-KEM = ACC

Asymmetric
Cryptography
Coprocessor

Beyond bignums...

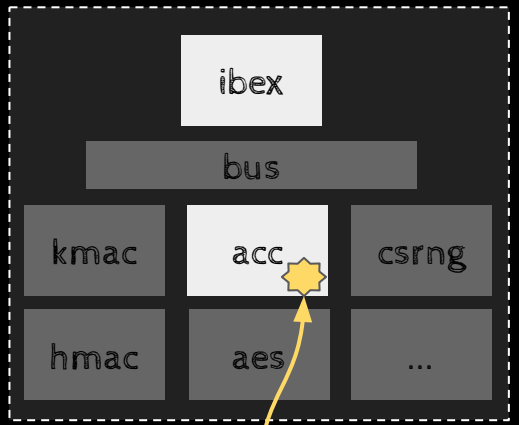
OTBN + ML-DSA + ML-KEM = ACC

Asymmetric
Cryptography
Coprocessor

ML-KEM-768 decapsulation: 0.7ms at 100MHz
ML-DSA-65 signing (median): 6.5ms at 100MHz
Memory: 32KB IMEM, 32KB DMEM

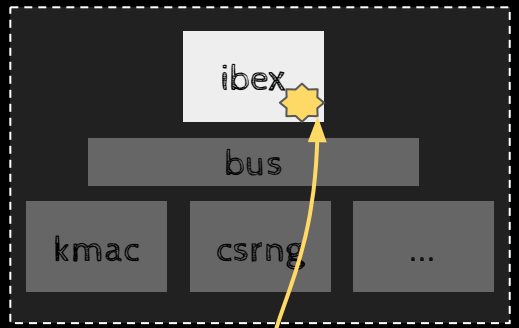
Multiple integration options for flexibility

Ibex + ACC

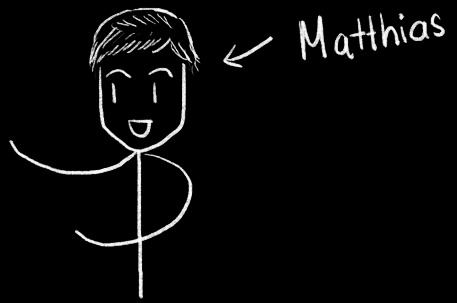


fast ML-KEM and ML-DSA on ACC

Ibex only

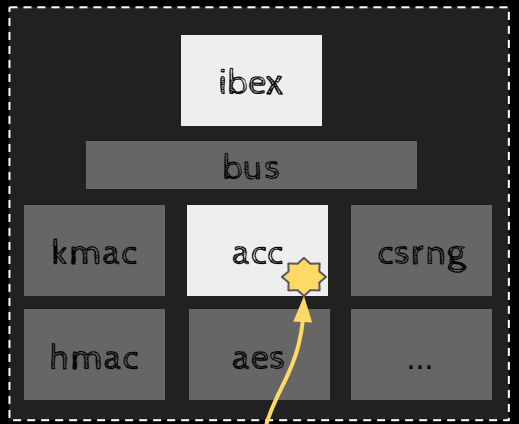


mlkem-native and mldsa-native on Ibex



Multiple integration options for flexibility

Ibex + ACC



fast ML-KEM and ML-DSA on ACC

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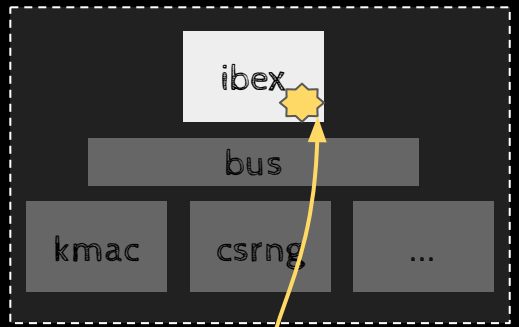
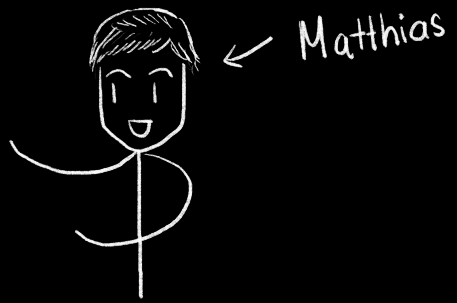


mlkem-native and mldsa-native on Ibex

Lower area, but slower asymmetric cryptography:

- ~10x for ML-KEM, ML-DSA
- ~20x for RSA



Ongoing Work, Lessons Learned


ACC

Preparing for
industry and
research tapeouts

Preparing for
industry and
research tapeouts

ISE for
UOV/Mayo,
FN-DSA

Preparing for industry and research tapeouts

Iasmin support for ACC

ISE for UOV/Mayo, FN-DSA

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SLOTHY for automatic leakage mitigation

ISE for UOV/Mayo, FN-DSA

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Side-channel attacks & evaluation

Preparing for industry and research tapeouts

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SLOTHY for automatic leakage mitigation

ISE for UOV/Mayo, FN-DSA

Side-channel attacks & evaluation

Masking for ML-KEM & ML-DSA (Hien's internship)

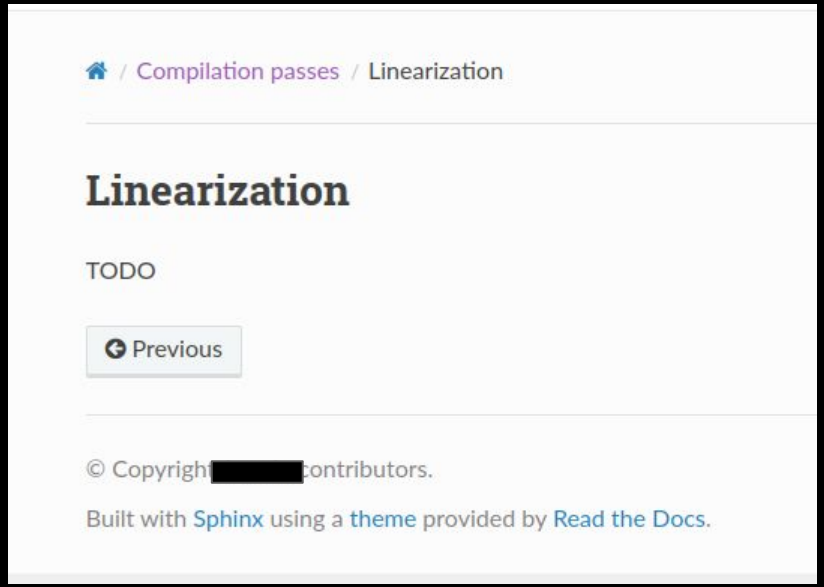
Lesson 1

Open-source removes friction

Lesson 2

Documentation saves ...lives

Official Documentation



“Official” Documentation

Hi Santiago,

Hi Santiago,

Hi Santiago,

Hellu Santiago,

Hi Santiago (again),

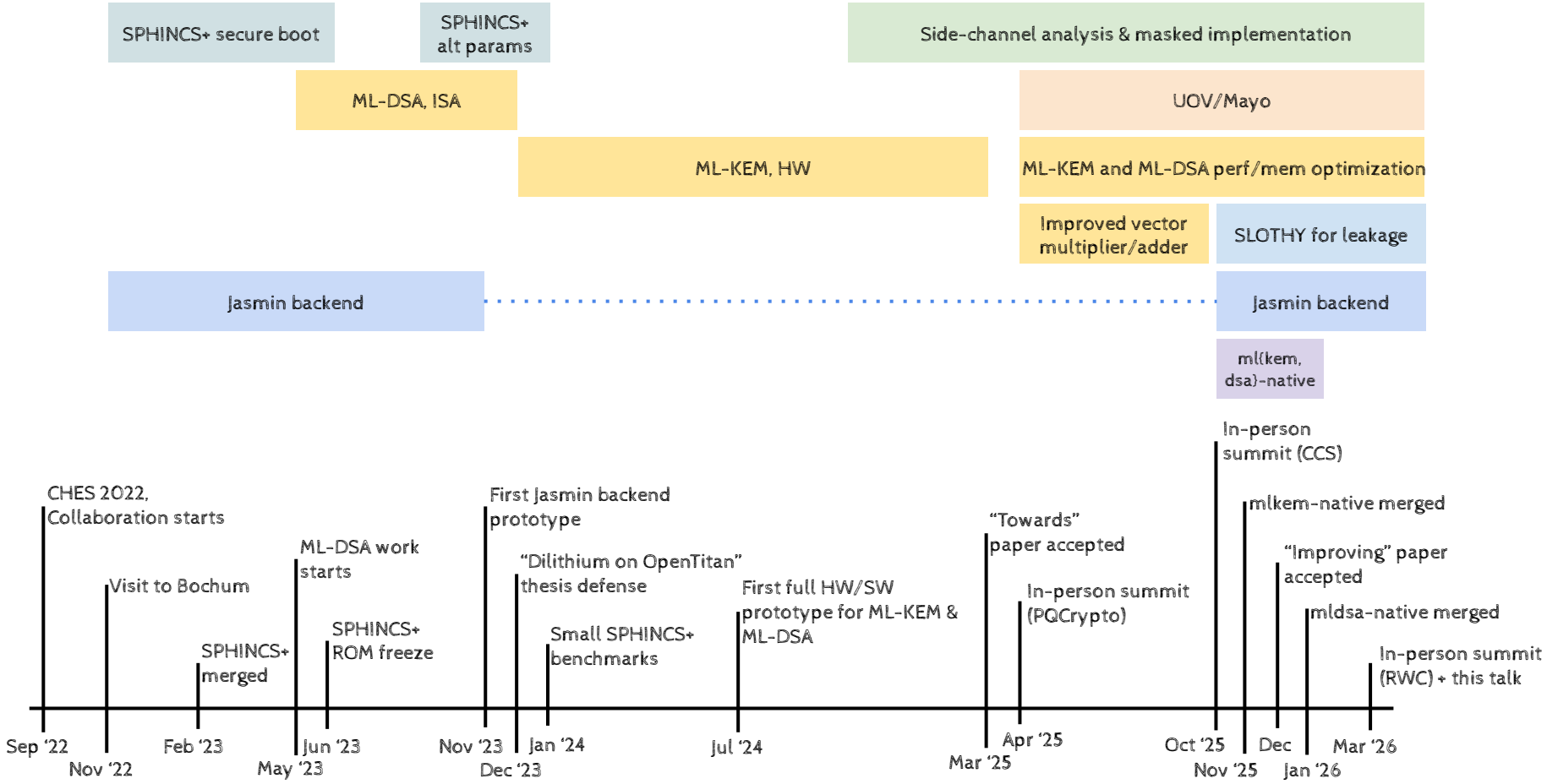
AskSantiago Premium™ 🤓

Lesson 3

Research sparks, industry scales

Lesson 4

Meeting in person MATTERS!!!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ML-DSA, ISA
UOV/Mayo
ML-KEM, HW
ML-KEM and ML-DSA perf/mem optimization
Improved vector multiplier/adder
SLOTHY for leakage
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ml(kem, dsa)-native
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In-person summit (RWC) + this talk
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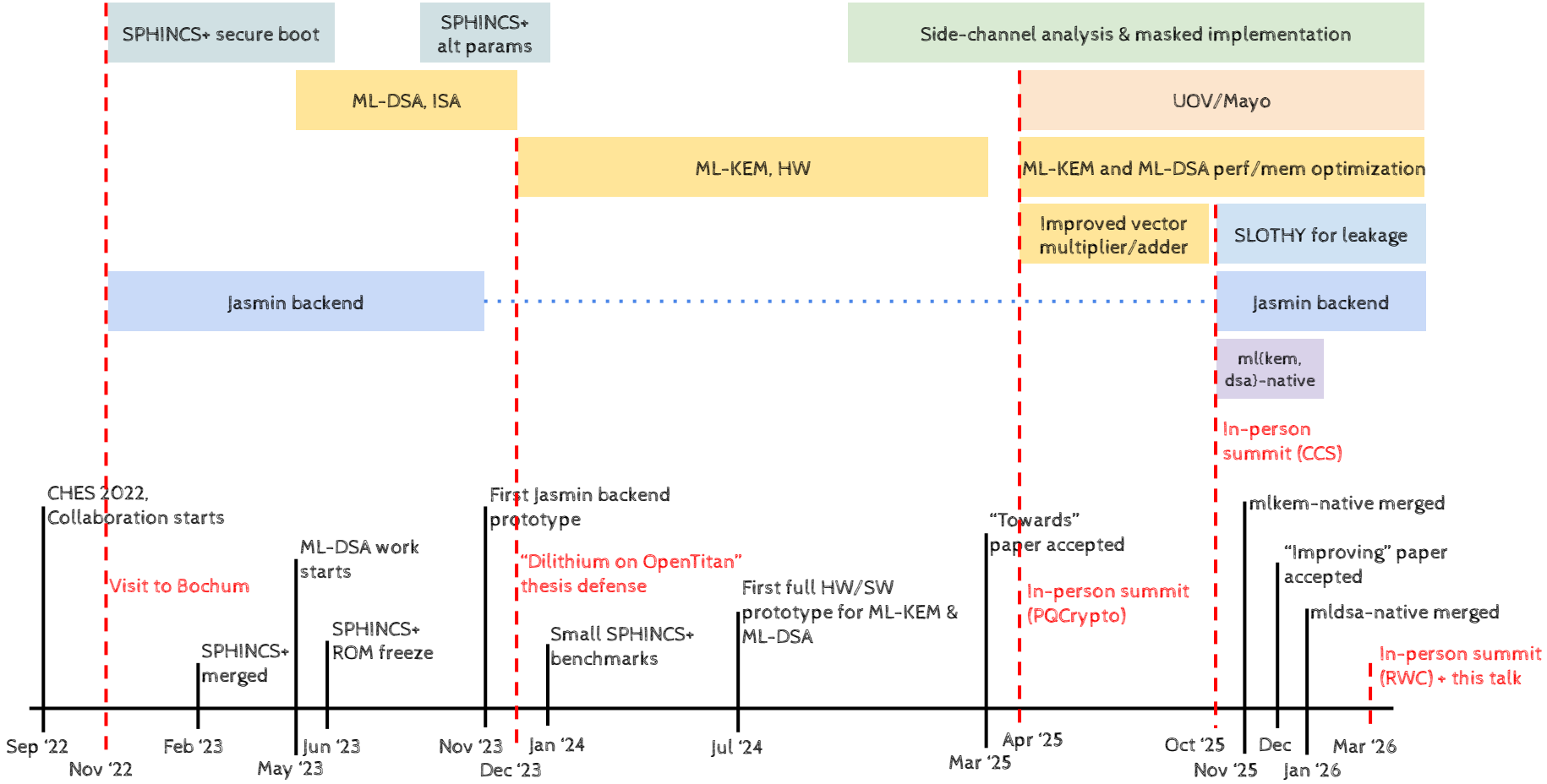
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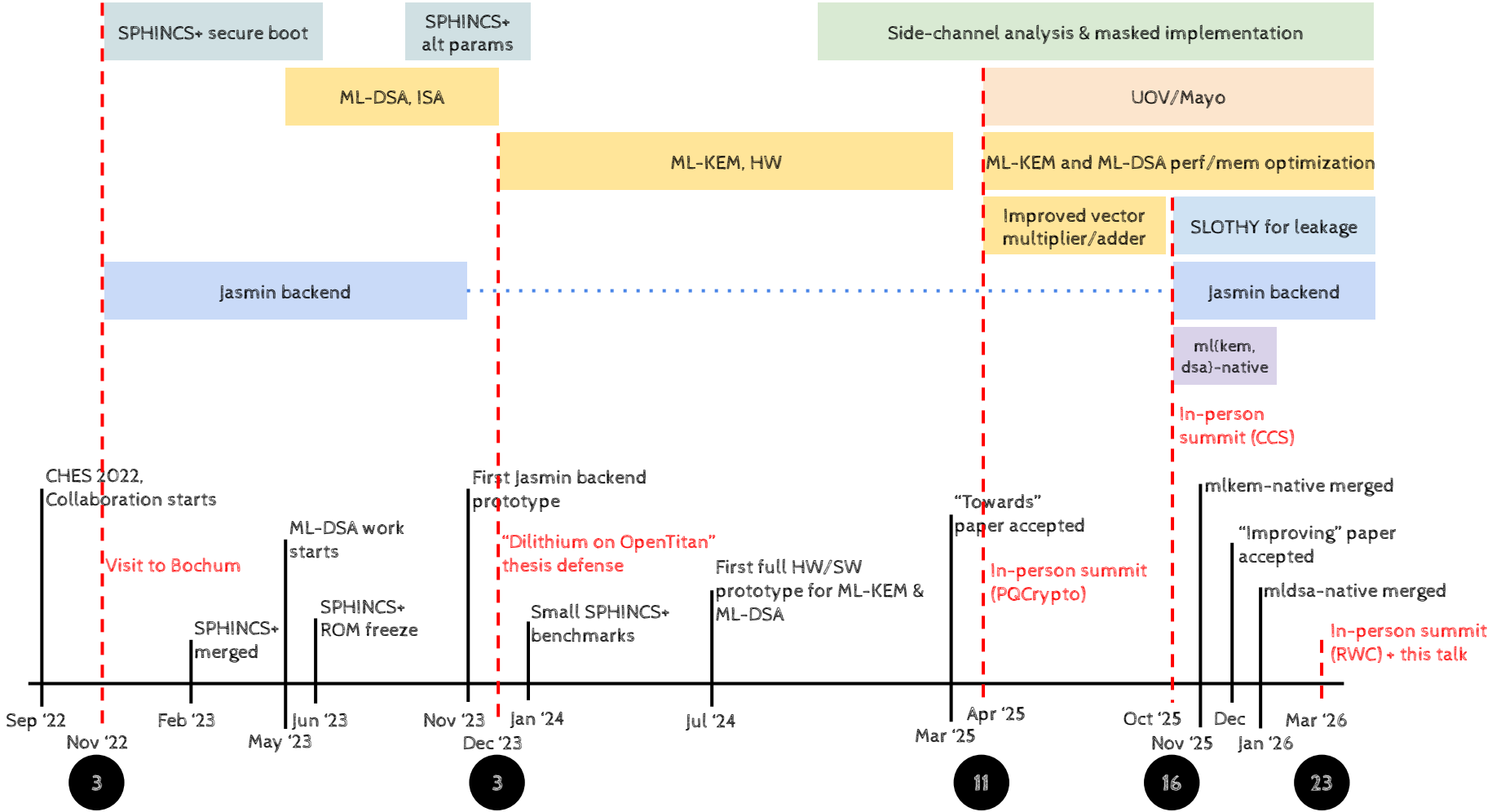
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Oct '25
Nov '25
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Jan '26
Mar '26
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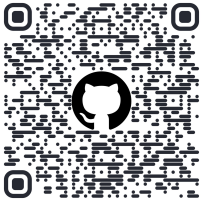
饒河街觀光夜市
Raohe St. Night Market
Welcome Open-source Silicon Collaborators
哈囉海鮮鍋燒
粥。意麵。雞絲。烏龍
申龍帆布
2596-2406
"bunnie"
Hanno
Lejla
Santiago
Benjamin
Inez
Kat
Mathias
Jade
Ruben
Peter
Evan
Francisca
Dom
Pierre-Yves
Amin
Hiier
Julius
Augustine
Robert
Richard
Azade
Parisa

Thank you for your attention

Towards ML-KEM & ML-DSA on OpenTitan (IEEE S&P 2025)

ZeroRISC's OpenTitan fork


Improving ML-KEM & ML-DSA on OpenTitan (CHES 2026)

ZeroRISC's Blog

Max Planck Institute for Security and Privacy (MPI-SP) Blog

Presentation art: Hoang Nguyen Hien Pham

Contact us:

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- Jade: jade@semiprecious.net
- MPI-SP: office@csp.mpg.de
- ZeroRISC: info@zerorisc.com