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# Integrating Post-Quantum Algorithms In Practice

CHESS

Cyber-security Excellence Hub in Estonia and South Moravia

*Lasaris Lab*

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[This presentation includes clickable links]

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# Presentation outline

- **Introduction**
- **Our experience with PQC implementation**
- **Current state of PQC**
  - Libraries, ASN.1, JSON Web Algorithms, Hybrid modes
- **General remarks**
  - Preparations, technological constraints, implementation
- **Conclusions**

# Introduction

- **Quantum PC → ~~RSA, ECDSA, …~~ → PQC → new algorithms**
- **Standardization of PQC** (e.g. NIST)
- **Next step**:
  - PQ support in all system and architecture layers
  - Ensure functionality, compatibility, interoperability
- **My activities**:
  - Exploring current options and state-of-the-art
  - Focus on engineering aspects of PQ protocol implementations
  - Gather experience, remarks, and tips

# Post-Quantum Algorithms

- NIST standardization efforts (2016-now)
  - Round 4:
    - **Digital signatures:**
      - Dilithium, Falcon (lattice-based)
      - Sphincs+ (hash-based)
    - **Key Encapsulation Mechanisms:**
      - Kyber (lattice-based)
  - More algs.: TBA ("On ramp")
- other evaluation efforts (BSI, ENISA, ...) → possibly other algorithms

# Our experience with PQC implementation

PQ versions of Web-eID, CDOC2, ASICE, IVXV, TOPCOAT

# Project with direct implementation

- **PQ-Web-eID**
  - authentication framework for web applications
  - Estonian electronic ID cards + state web services
  - dig. signatures, ~~smart cards~~ → ESP32 programmable microcontroller
- **PQ-CDOC2**
  - Estonian standard for securing and exchanging data
  - KEMs, problems with TLS
- **PQ-ASiC-E**
  - (almost Estonian) standard for digitally signed container of data

# Project with problematic implementations

- **PQ-IVXV**
  - electronic voting system
  - preparation of infrastructure, PQ-OCSP, PQ-TSA
  - dig. signatures are OK, but vote encryption is problem
    - ~~elGamal~~ → completely new PQ protocol (lattice-based)
- **TOPCOAT**
  - threshold digital signature scheme
  - almost no existing implementations → completely new PQ protocol (lattice-based)

# Go-to libraries

- PQClean (C)
  - *Cleaned* aggregation of NIST-submitted algorithms
  - Source of source-code (i.e. not a library)
- libOQS (C)
  - + wrappers for C++, Python, Java, Go, .NET, and Rust
  - + applications built with libOQS (OpenSSL, OpenSSH, OpenVPN forks)
- BouncyCastle (Java), rustpq/pqcrypto (Rust), pqm4 (C, Cortex-M4), botan-pq (C++)
- custom wrappers

# PQ ASN.1 structures

- **No standards exist yet** → NIST requires raw bytes
- RFC drafts
  - private and public keys with alg. specific parameters
  - e.g. `DilithiumPrivateKey` (contains `nonce`, `tr`, `s1`, `s2`, `t0`, etc.)
- **PQ Object Identifiers (OIDs)**:
  - OQS defined their own (most commonly used so far)
  - BouncyCastle expanded with KEMs

# JSON Web Algorithms (RFC 7518)

- Usage: *JW Signature*
- Format: *(DIGSIG + HASH identification)*
- Example: *ES384 = ECDSA using P-384 curve and SHA-384*
- **No RFC drafts for PQ JWAs**
- RFC draft for **PQ JW Encodings**
  - *e.g. CRYDI5 = CRYSTALS-Dilithium parameter set 5*
  - *HASH? → SHA-512*
- RFC drafts for PQ JW Object Signing and Encryption (JOSE)
  - alg. specific parameters encoding

# Hybrid mode (PQ + classic crypto)

- Longevity of data confidentiality + protection against emerging threats in PQC
- **Concatenation, sequential** modes
  - *Ghinea et al.*
    - both have security issues
    - novel method to improve unforgeability of ECDSA+PQ signatures
- RFC Draft for hybrid **KEM in TLS1.3** follows **concatenation**
- **Cloudflare and Google Chrome** follow RFC draft using **concatenation** (X25519 + Kyber)

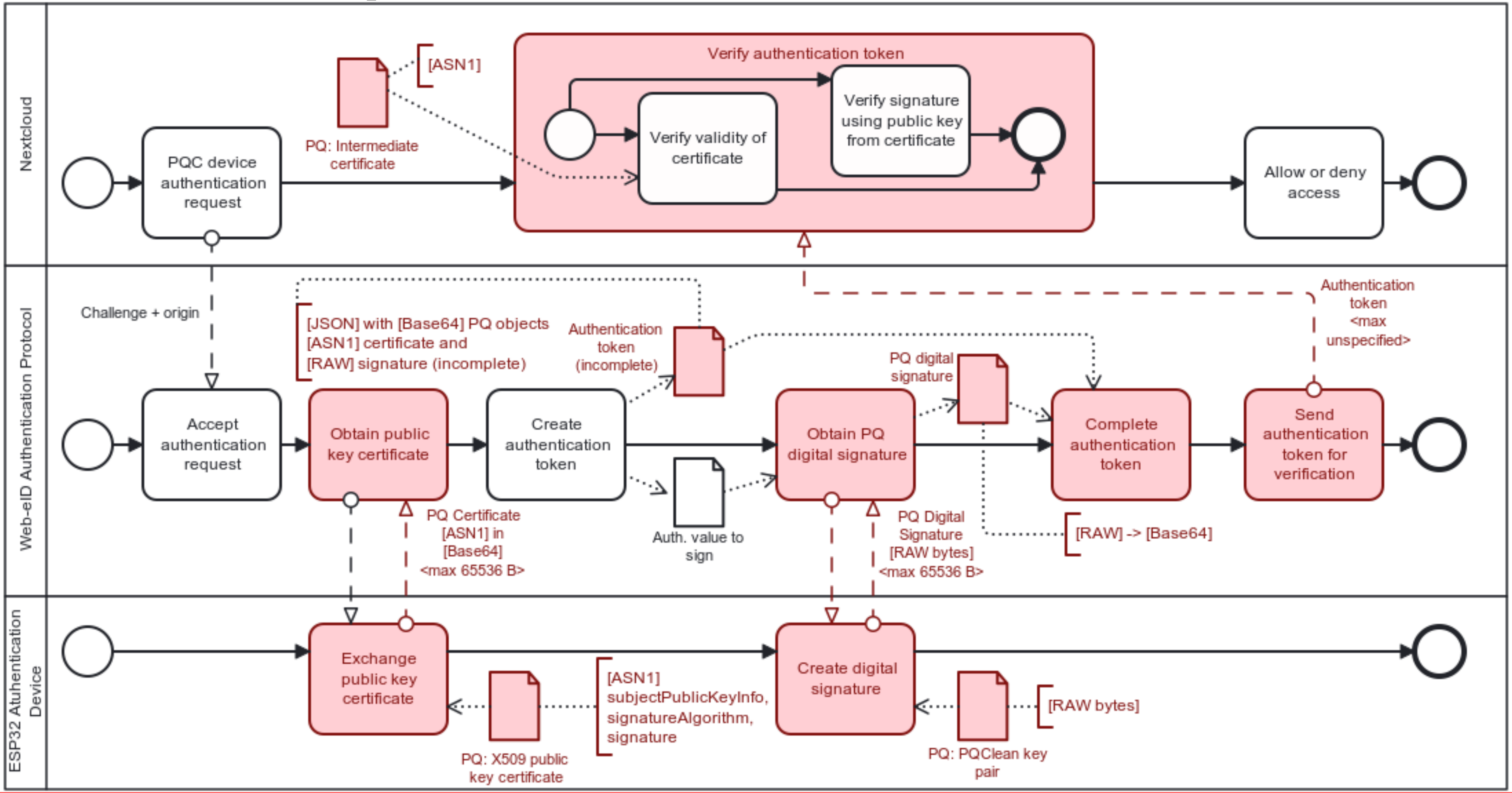
# General remarks

Preparations, technological constraints, implementation

# Identifying relevant locations

- **Identify all PKI objects through their lifetime**
- **Beware of MTUs**
  - bigger objects, variable sizes (Falcon)
- **Beware of changing data formats**
  - ASN1, Base64, PEM, JOSE, other...

# BPMN example



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# Technological constraints

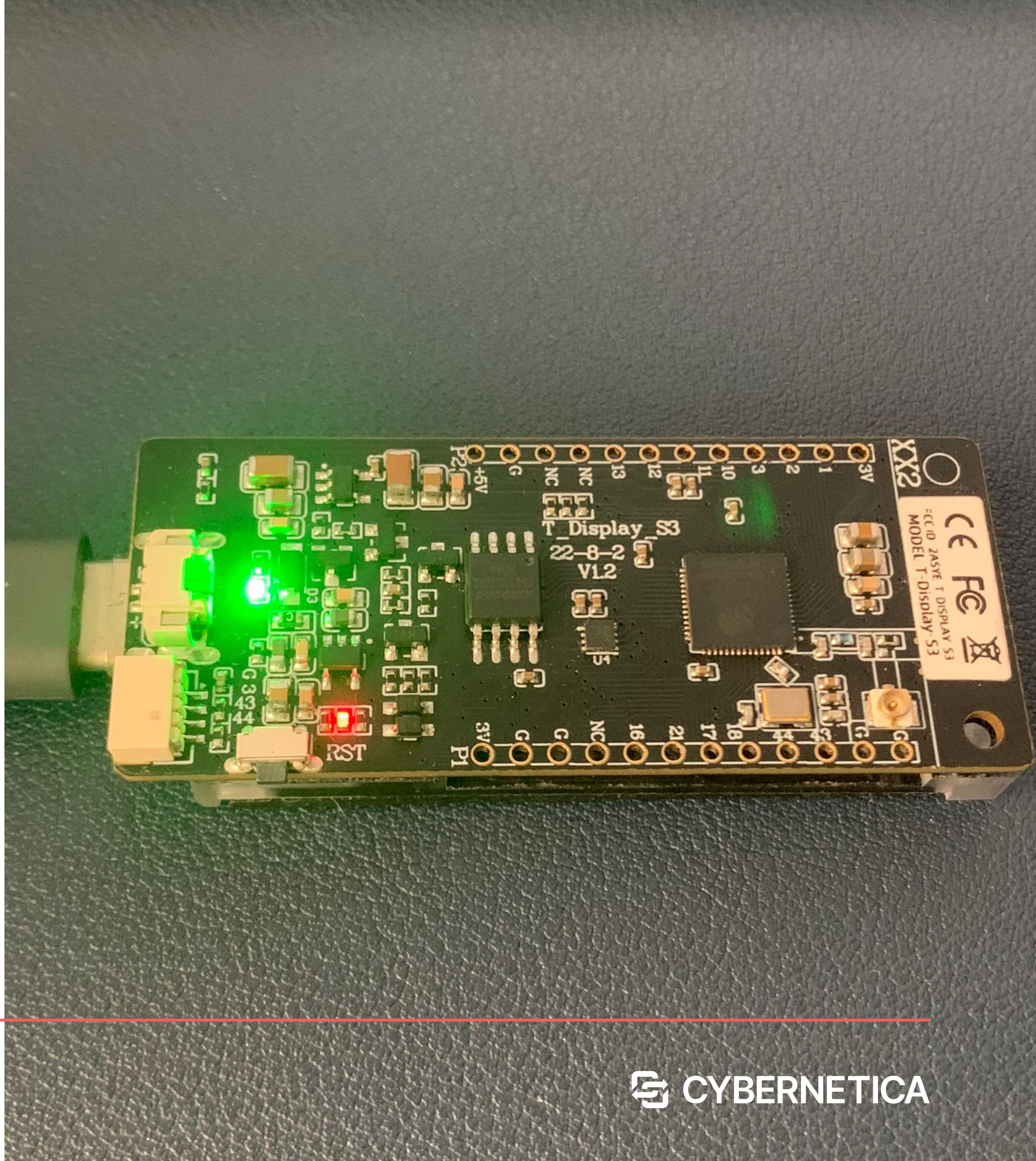
- Assess current boundaries of the system
  - Increased **performance**, **memory**, and **storage overhead**
  - Limited devices and slow networks
- **Protocol adjustments**:
  - streaming public keys and signatures into memory
  - key encapsulation instead of digital signatures (credit cards)
  - allocate all objects in heap instead of limited stack memory (our case)

# Implementation

- Start at the **beginning of the data lifecycle**
- Implement PQC **one step at a time**
- Implementation is still **not straight-forward**
- **Extensions, adjustments, adaptations** of crypto libraries
- **Create your own wrappers** using SWIG
- Expect future changes - standardization is not over!

# Embedded devices

- Smart cards are not suitable → LilyGO T-Display-S3
- Problematic memory management:
  - Limited to 8 KB of stack RAM
  - *PQClean* allocates to a stack a lot
- Solved by adjusting *PQClean* code by using:
  - `malloc` and `free` functions
  - `std::unique_ptr` (C++ v11)



# libOQS extensions

- Available wrappers for C++, Python, Java, Go, .NET, and Rust
  - ~~PHP~~? → SWIG wrapper generator!
- C/C++ interface definition required
  - → *liboqs-php*, *liboqs-python*, *liboqs-go*
- Some remapping was required:
  - PHP `string` ↔ C++ `uint8_t*`
  - Python `bytes` ↔ C++ `uint8_t*`

# PQ in PHP

- **OpenSSL usage → OQS-OpenSSL**
  - (v1 forks discontinued)
  - v3 extension provider:
    - extends regular OpenSSL@3
    - PHP algorithms IDs hardcoded for DSA, DH, RSA, and EC
      - some built-in functions do not require algID (e.g. `openssl_verify()`)
  - my notes on OQS-OpenSSL in PHP
- **PHPSecLib → new PQC-PHPSecLib fork**
  - *OQS-OpenSSL* or *liboqs-php* (based on availability)



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# PQ in BouncyCastle (v1.74+)

- Not well documented
  - bc-java / core / src / main / java / org / bouncycastle / asn1 / bc / BCObjectIdentifiers.java
  - `org.bouncycastle.pqc.*` packages
- Works with actual algorithm parameters from ASN1 drafts
  - vs raw bytes in libOQS
  - e.g. `KyberPublicKeyParameters` has `t` and `rho`

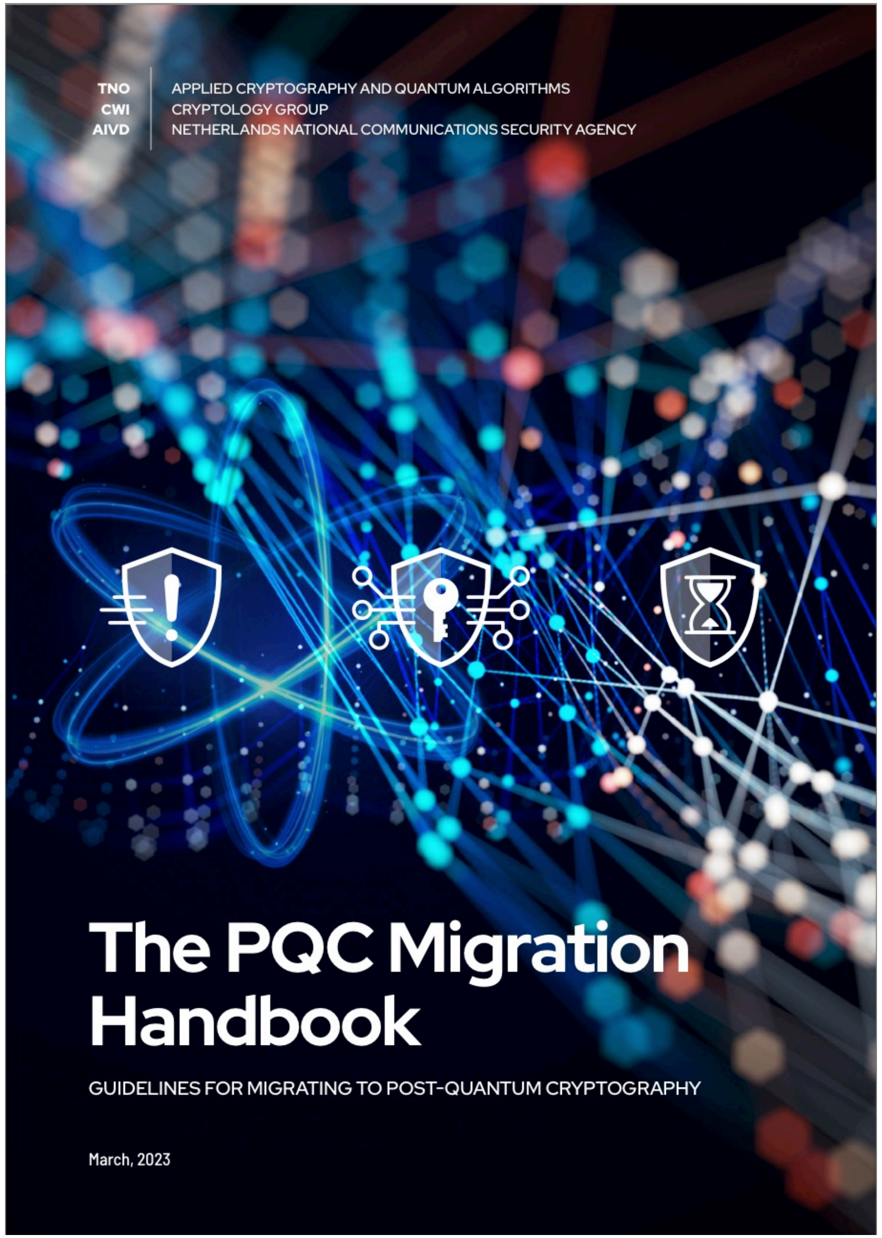
# PQ Java Keytool

- keytool = command for managing a keystore of cryptographic objects
- PQ BouncyCastle → PQ Java Keytool
- e.g. to generate .p12 with Dilithium keypair and self-signed certificate:

```
keytool \
    -providerpath bcprov-jdk18on-175.jar \
    -provider org.bouncycastle.pqc.jcajce.provider.BouncyCastlePQCProvider \
    -genkeypair \
    -keyalg Dilithium5 \
    -alias cdoc20-client-pqc-CA \
    -keystore cdoc20clientpqcCA.p12 \
    -storepass passwd \
    -sigalg Dilithium5 \
    -dname "CN=cdoc20-client-pqc-CA,OU=ISRI,O=CyberneticaAS,L=Brno,S=Czechia,C=CZ"
```

# This week's news

- **Post-Quantum Cryptography conference 2023** by PKI Consortium
  - Recording on YT
  - PQC Migration Handbook
  - Experiments on embedded devices are unrealistic
  - FIDO2 tokens are highly limited
  - PQC on mobile phones might require new HW co-processors
  - banking is XY years behind



# Conclusions

- **Implementing PQC today is...**
  - **...complicated**:
    - different libraries → different approaches and documentation level
    - computational constraints, adaptation and tweaking
    - standardization is not finished (and complete - MPC, ZKP, etc..)
  - **...doable:**
    - authentication framework, crypto systems for encryption, signing containers, etc.
  - **...worth it:**
    - long-term data protection, experience
  - **...helpful:**
    - big space for open-source PQ contributions, reduce confusion

# Thank you for listening!

**References:**

- links in presentation
- PQ authentication framework
- Notes on PQC in PHP
- write me an email!

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