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Post-Quantum Cryptography for Engineers: Technical Overview

CHESS

Cyber-security Excellence Hub in Estonia and South Moravia

The Future Cryptography Conference

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[This presentation includes clickable links]

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Presentation Outline

1. **Introduction**
2. **Our Experience with PQC Implementation**
3. **How to Begin?**
    - Preparations, Technological Constraints, Implementation
4. **Where to Begin?**
    - PQ Algorithms, Cryptographic Libraries, Encodings, Hybrid modes
5. **Engineering Obstacles**
6. **Conclusions**

Introduction

- **Existing work:**
  - Timelines, "Migration Challenges", PQC Migration Handbook
- **The issue:**
  - How to actually migrate? Does a general security engineer have everything in their disposal for that?
- **Our work:**
  - Explore and support current FOSS state-of-the-art
  - Focus on engineering aspects of PQ implementations
  - Gather experience, problems, and remarks

Our Experience with PQC Implementation

- **e-Governance applications and frameworks**
  - Web-eID (Authentication)
  - CDOC2 (Encryption)
  - ASiC-E (Digital Signatures)
  - IVXV (e-Voting)
- **Supporting projects**
  - PQ library wrappers, extensions for crypto libraries
  - Lattice-based crypto development kit
  - PQ OCSP, TSA solutions

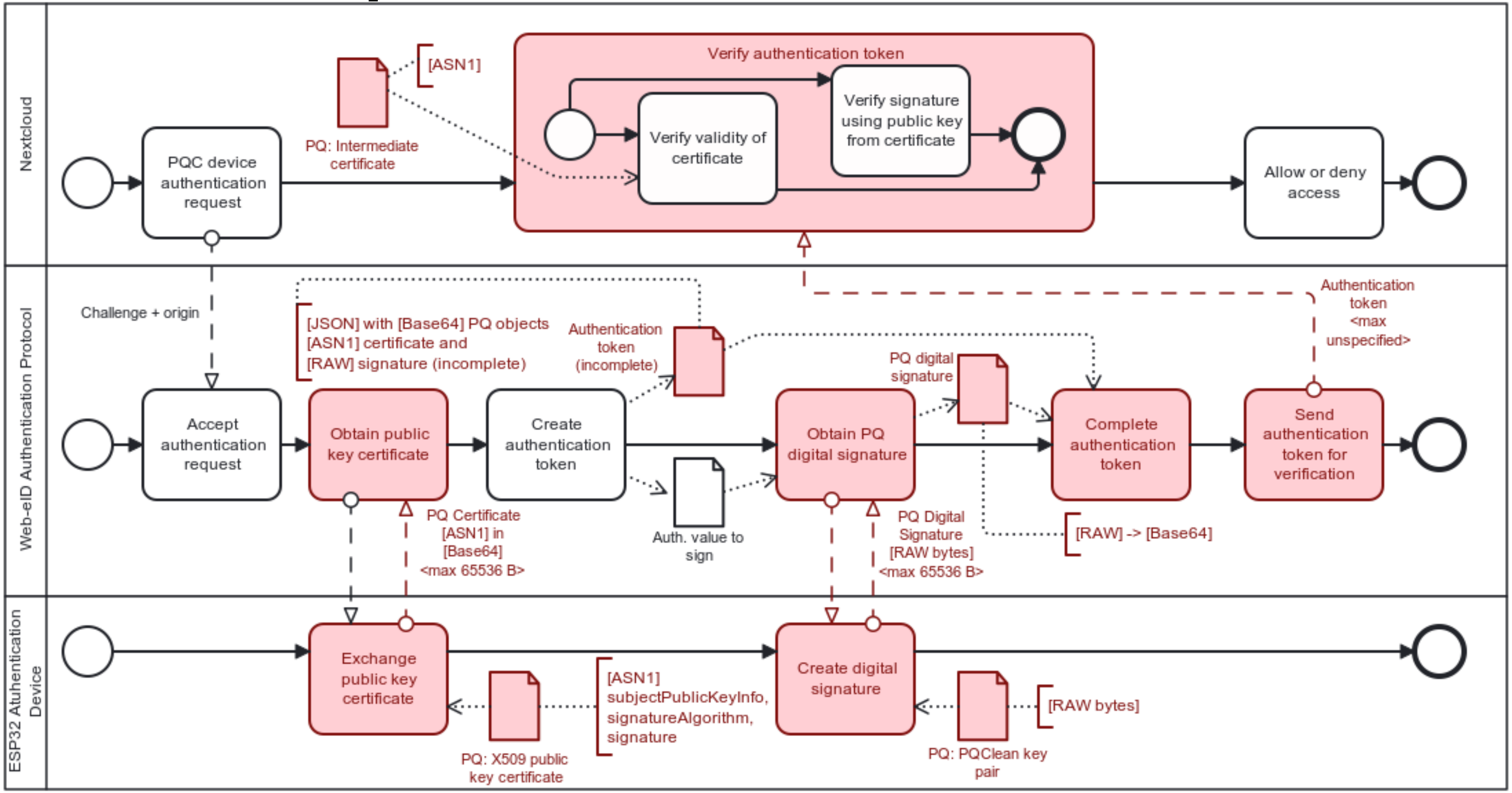
How to Begin?

Preparation, Technological Constraints, Implementation

Preparation

- **Identify all PKI objects and their lifetime in the system**
  - understand the extent of required changes
  - dig. signatures, key agreements, ...
- **Beware of MTUs**
  - PQ = bigger object sizes, sometimes even variable size (Falcon)
- **Beware of changing data formats**
  - ASN1, Base64, PEM, JOSE, other...

BPMN Example



Technological Constraints

- Assess current boundaries of the system
  - Increased **performance**, **memory**, and **storage overhead**
  - Limited devices and slow networks
- Possible **protocol adjustments**:
  - streaming public keys and signatures into memory
  - key encapsulation instead of digital signatures (credit cards)
  - objects allocations on embedded devices (stack → heap)

Implementation

- Start at the beginning of the data lifecycle → step-by-step
- **Extensions, adjustments, adaptations** of crypto libraries
- Expect future changes - standardization is not over!
  - → Crypto agility
- Rest of this presentation

Where to Begin?

PQ Algorithms, Cryptographic Libraries, Encodings,
Hybrid modes

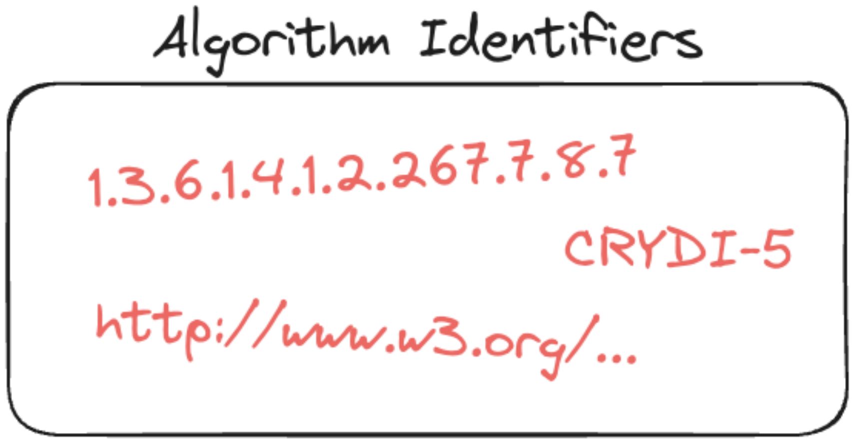
Post-Quantum Algorithms

- NIST standardization process (2016-now)
  - **Key Encapsulation Mechanisms:**
    1. ~~Kyber~~ → **ML-KEM** (FIPS 203)
    2. + round 4 (soon)
  - **Digital signatures:**
    1. ~~Dilithium~~ → **ML-DSA** (FIPS 204)
    2. ~~Sphincs+~~ → **SLH-DSA** (FIPS 205)
    3. Falcon → ~~FN-DSA~~ (TBD Q3 2024)
    4. + "on-ramp" round 1 (not before 2027)
- other evaluation efforts (BSI, ENISA, ...) → possibly more algorithms

Cryptographic Libraries

- PQClean (C)
  - *Cleaned* aggregation of NIST-submitted algorithms (latest + last round)
  - 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)
- custom wrappers of libOQS

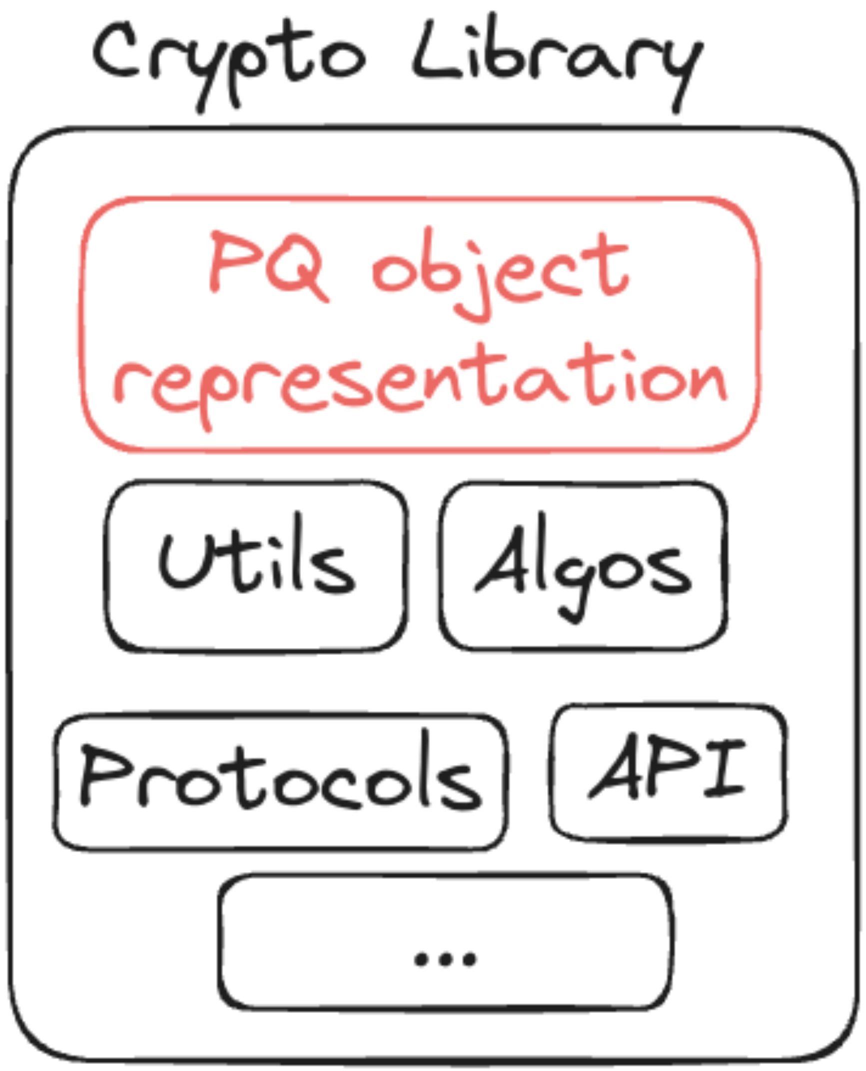
Algorithm Identifiers



- **ASN.1 Object Identifiers**
  - OQS, IETF Hackathon OID lists
- **JSON Web Algorithms**
  - RFC, but only for KEMs
- **XML Signature Syntax Algorithms**
  - ...
- **Other identifiers**

Object Encoding

- **Raw bytes**
  - originally NIST submission rule, now in libOQS
  - output from one function = input for second function
- **PQ ASN.1 structures**
  - IETF Hackathon - PQC certificates
    - tries to solve compatibility issues and unify structures
  - BouncyCastle maps to classes



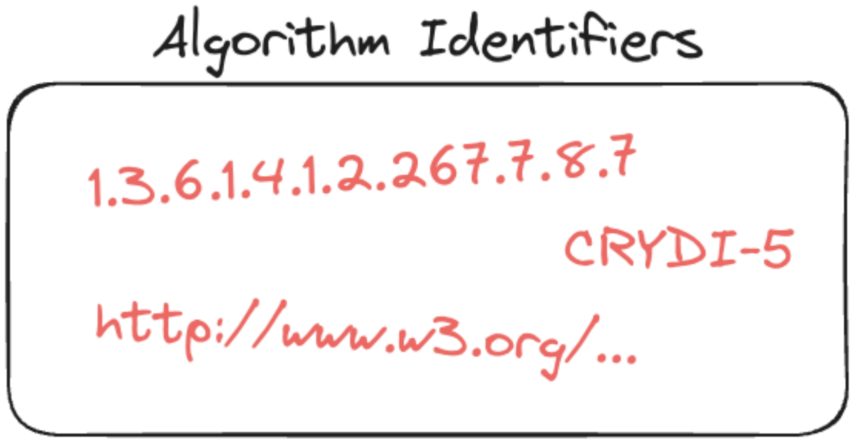
Hybrid mode (PQ + classic crypto)

- **Post-quantum cryptography:**
  - ensures the longevity of data protection
- **Classical cryptography:**
  - protects against emerging threats on unexplored PQC
- **Most common modes: concatenation or sequential**
  - both can have their issues → nothing concrete yet
  - RFC Draft for hybrid **KEM in TLS1.3** uses **concatenation**
  - **Cloudflare and Google Chrome** follow RFC draft using **concatenation** (X25519 + Kyber-768)

Engineering Obstacles

PQC Implementation is far from straight-forward

Algorithm Identifiers



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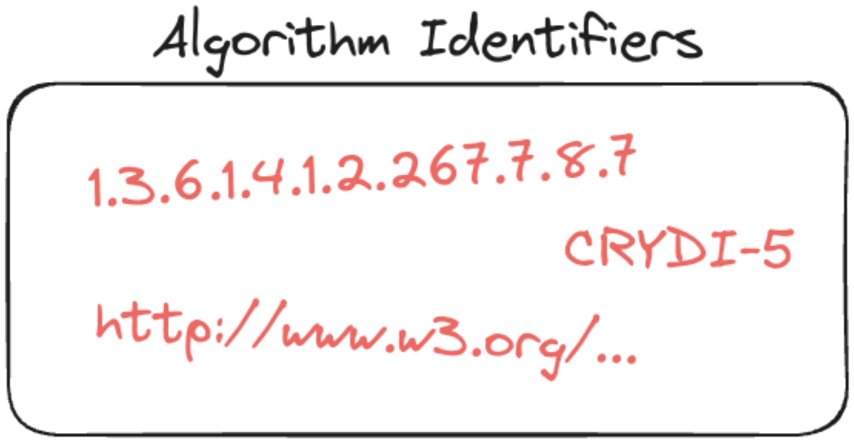
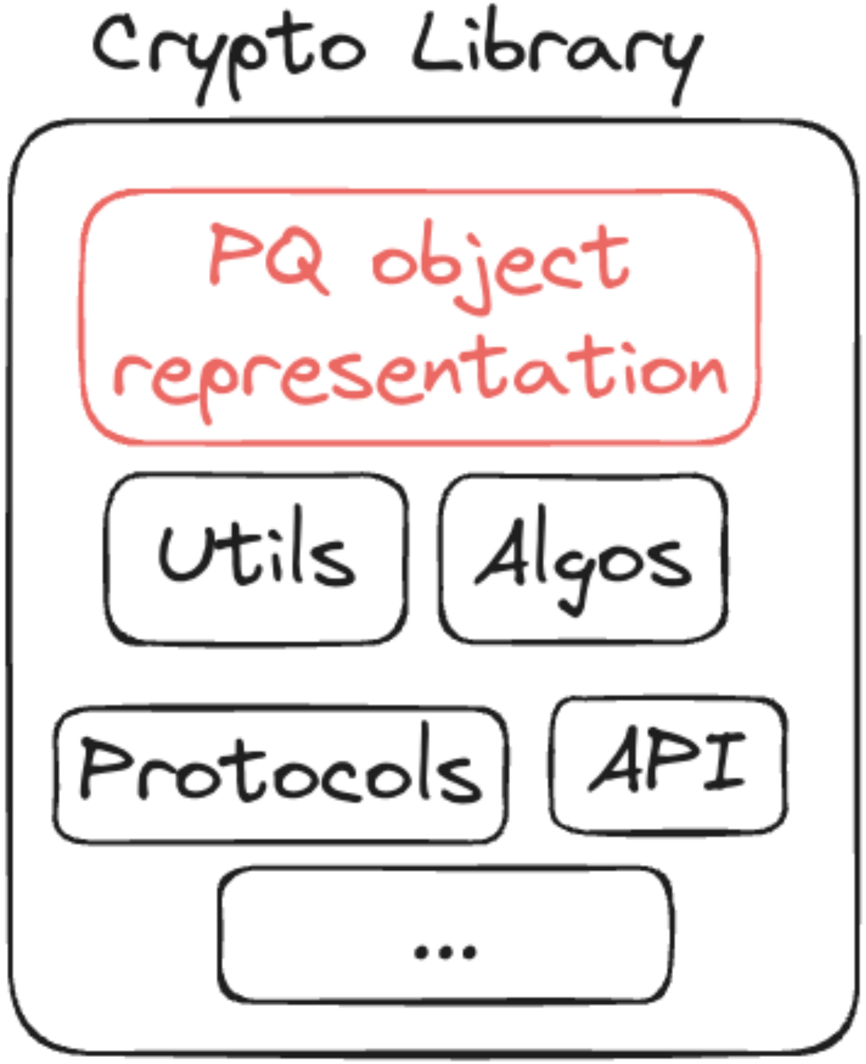


- **ASN.1 Object Identifiers**
  - Wild West
  - OQS → BouncyCastle → OQS → IETF Hackathon → ???
  - ML-KEM vs CRYSTALS-Kyber?
- **JSON Web Algorithms**
  - PQ alternative to *ES256*?
  - Recent RFC, but only for KEMs
- **XML Signature Syntax Algorithms**
  - PQ alternative to http://www.w3.org/2001/04/xmldsig-more#rsa-sha256?

Object Encoding

- Most crypto libraries have classical algorithms **hard-coded**
  - PHP extension for OpenSSL, PHPSecLib
  - cryptography, asn1crypto (Python)
  - crypto (Go)
- **Two options**:
  - **Extend** vs **circumvent**



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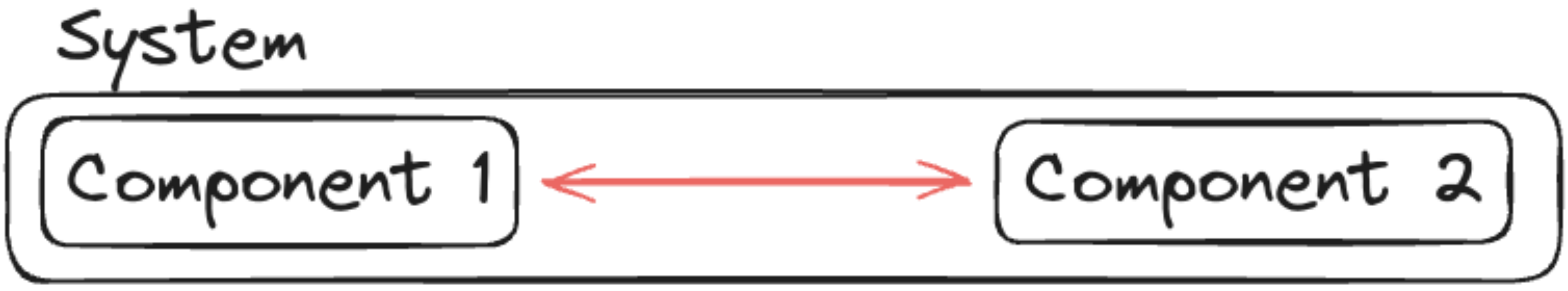
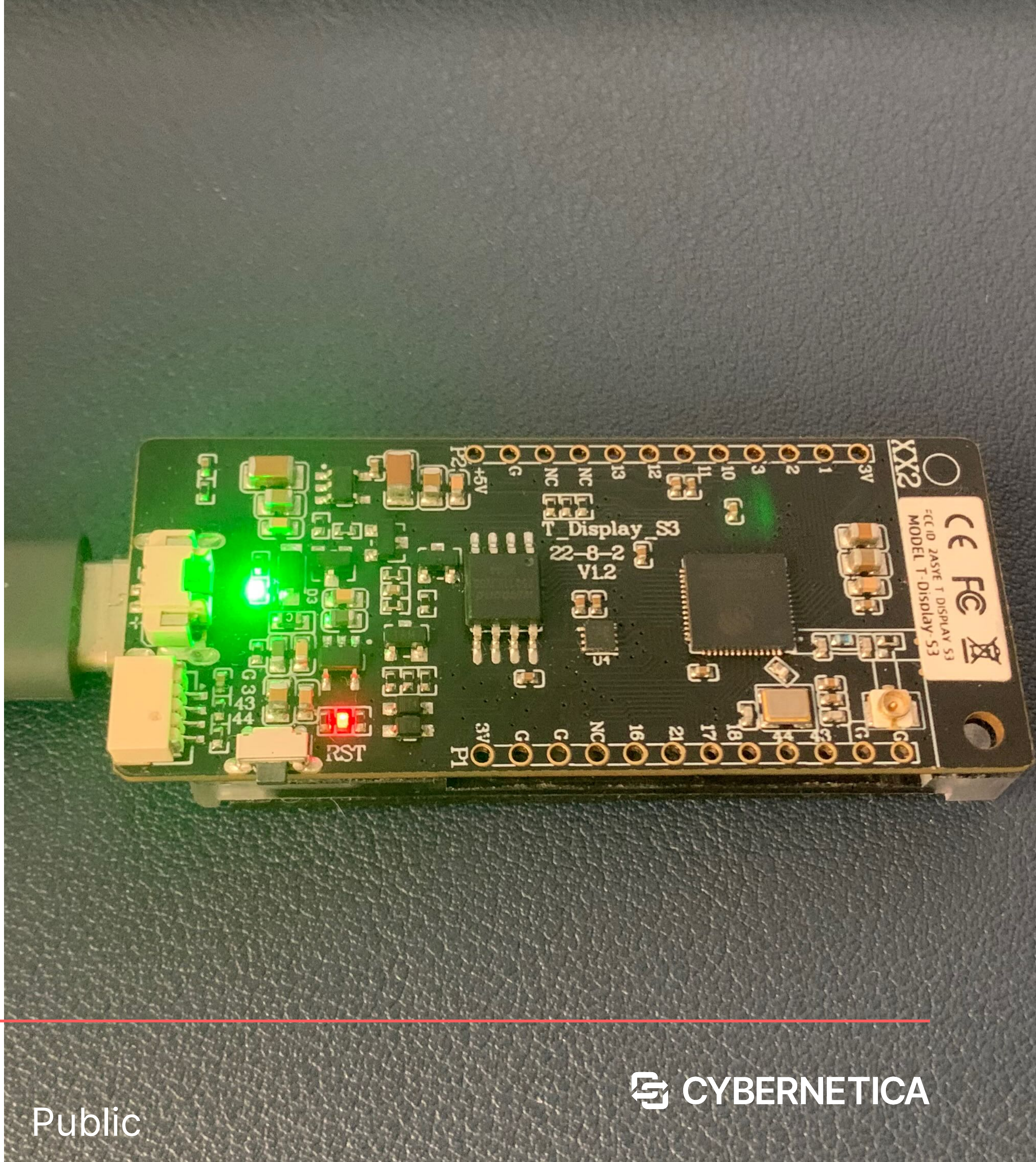
Interoperability Awareness

- Growing with system complexity
- **Active thinking** about all components
  - Identifiers, encoding, MTU, processing



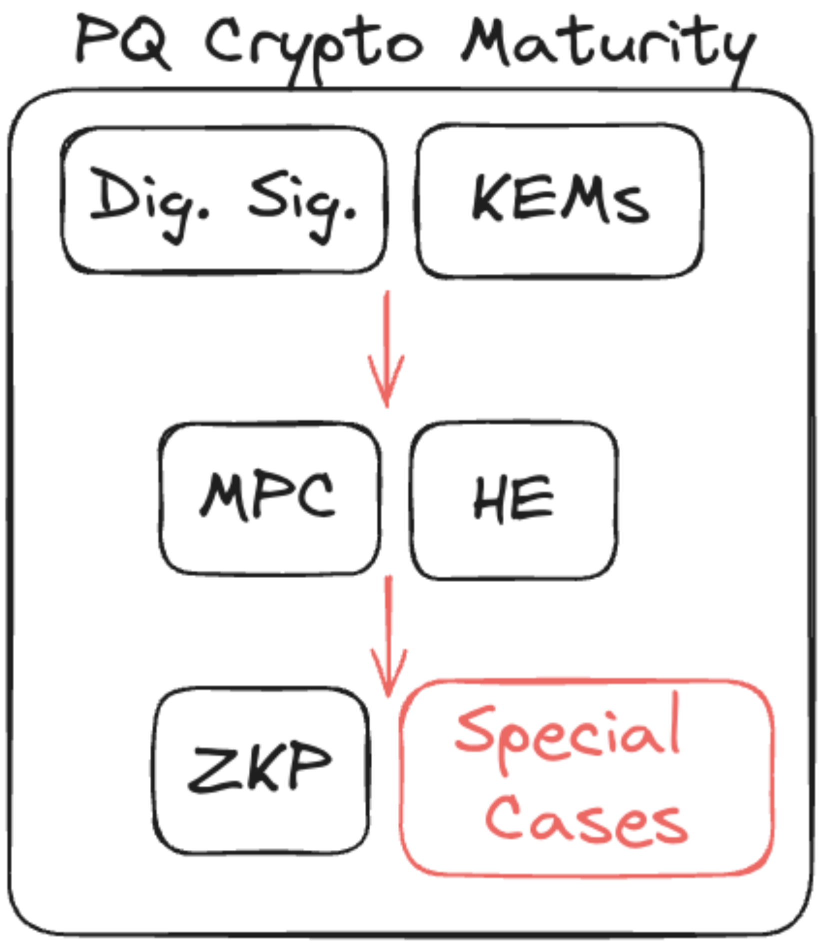
Cryptographic Tokens

- ~~Smart cards~~
- Chip manufacturers?
- Embedded devices for local testing purposes
  - Performance OK (ESP32-S3)
  - Memory OK, but complicated
  - Safety not OK (no HSM, TPM, not certifiable)
- Protocol adjustments might be required (~~stack~~ → heap, streaming)



Maturity of PQ Custom Crypto

- What if application requires:
  - **Multi Party Computation**?
  - **Homomorphic Encryption**?
  - **Special features**?
    - e.g. *ElGamal* in vote encryption - special decryption without private key
- Still lot of **R&D to be done**



Miscellaneous PQ Engineering Efforts

- **All the little things**
  - (OQS-)OpenSSL encodes private keys as:
    - *0×04 or 0×03 || length || private_key || public_key*
  - Custom wrappers → data type conversions
  - Adding single lines into dependencies' files to support PQ
  - Build issues, insufficient or confusing documentation

Conclusions

- **Implementing PQC today is...**
  - **...complicated**
    - not straight-forward
    - different libraries → different approaches and documentation level
    - computational constraints, adaptation and tweaking
  - **...doable**
  - **...worth it**
    - long-term data protection, experience, possibility to set good practices
  - **...helpful**
    - big space for open-source PQ contributions, reduce confusion, helps shaping the industry

Thank you for listening!

References:

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

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