Hardware Security Modules Unpacking a Black Box

Christian Colombo

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Imagine there were No Adversaries…

You could…

…trust everyone to be who they say they are

…just store your data

…communicate freely

…provide services

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Sadly cannot be further from the truth!

Imagine we could avoid interacting…

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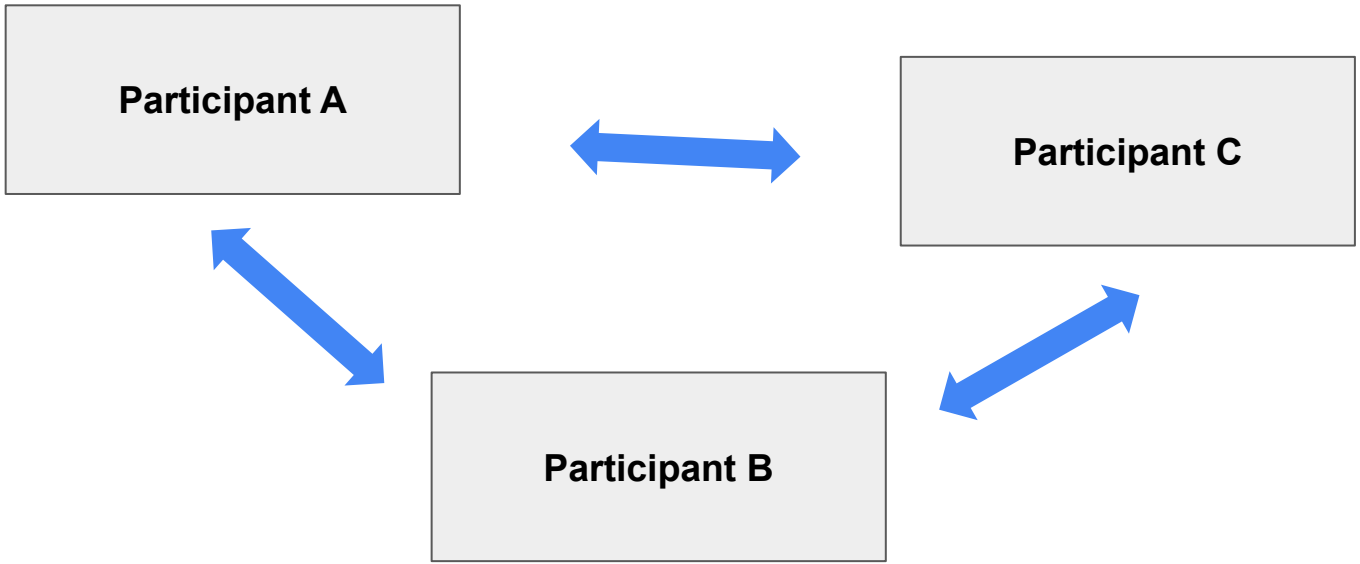
… but we do need to interact!
(in the presence of adversaries)



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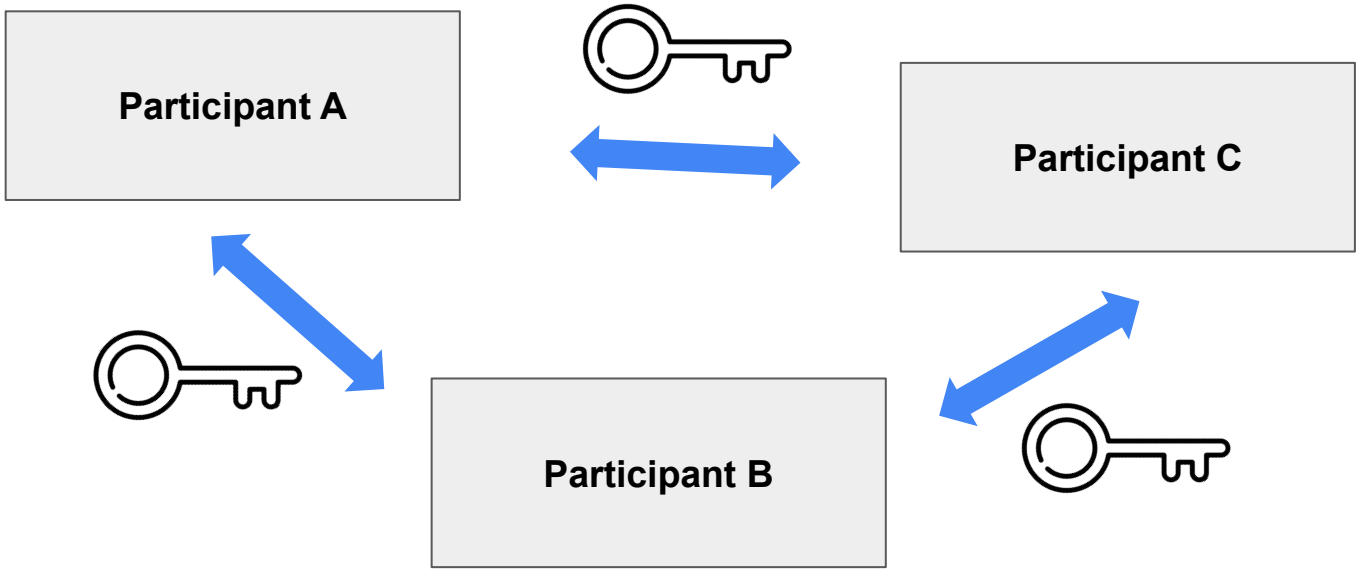
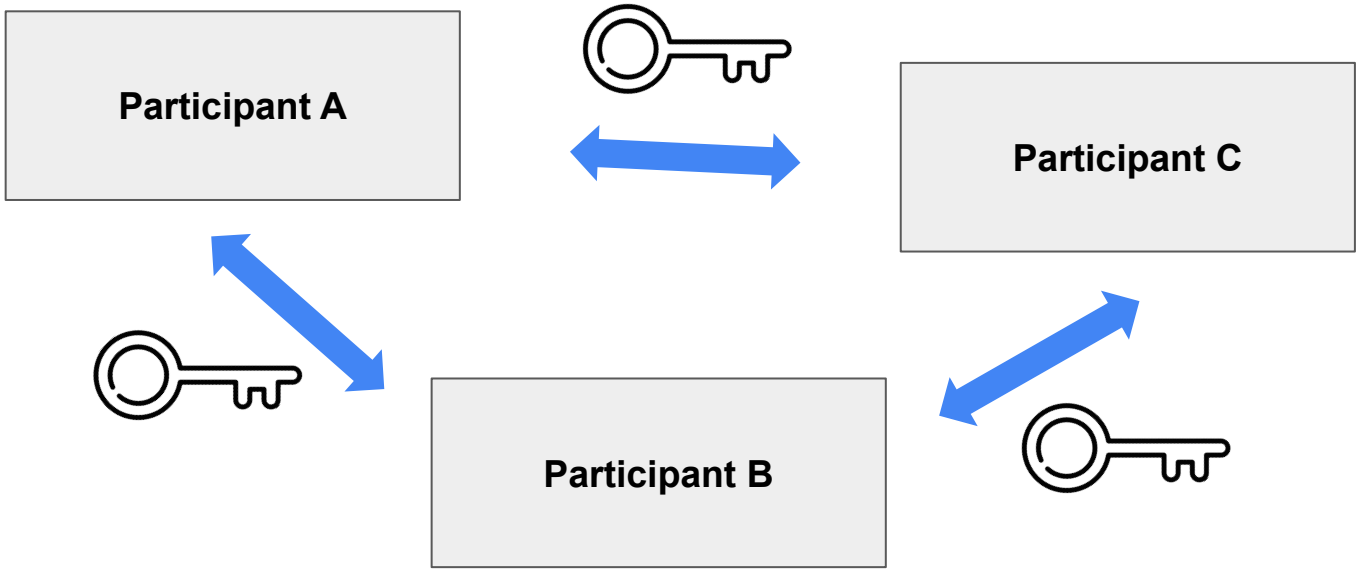
This is why we need cryptography!!



Keys keep our data secure BUT…



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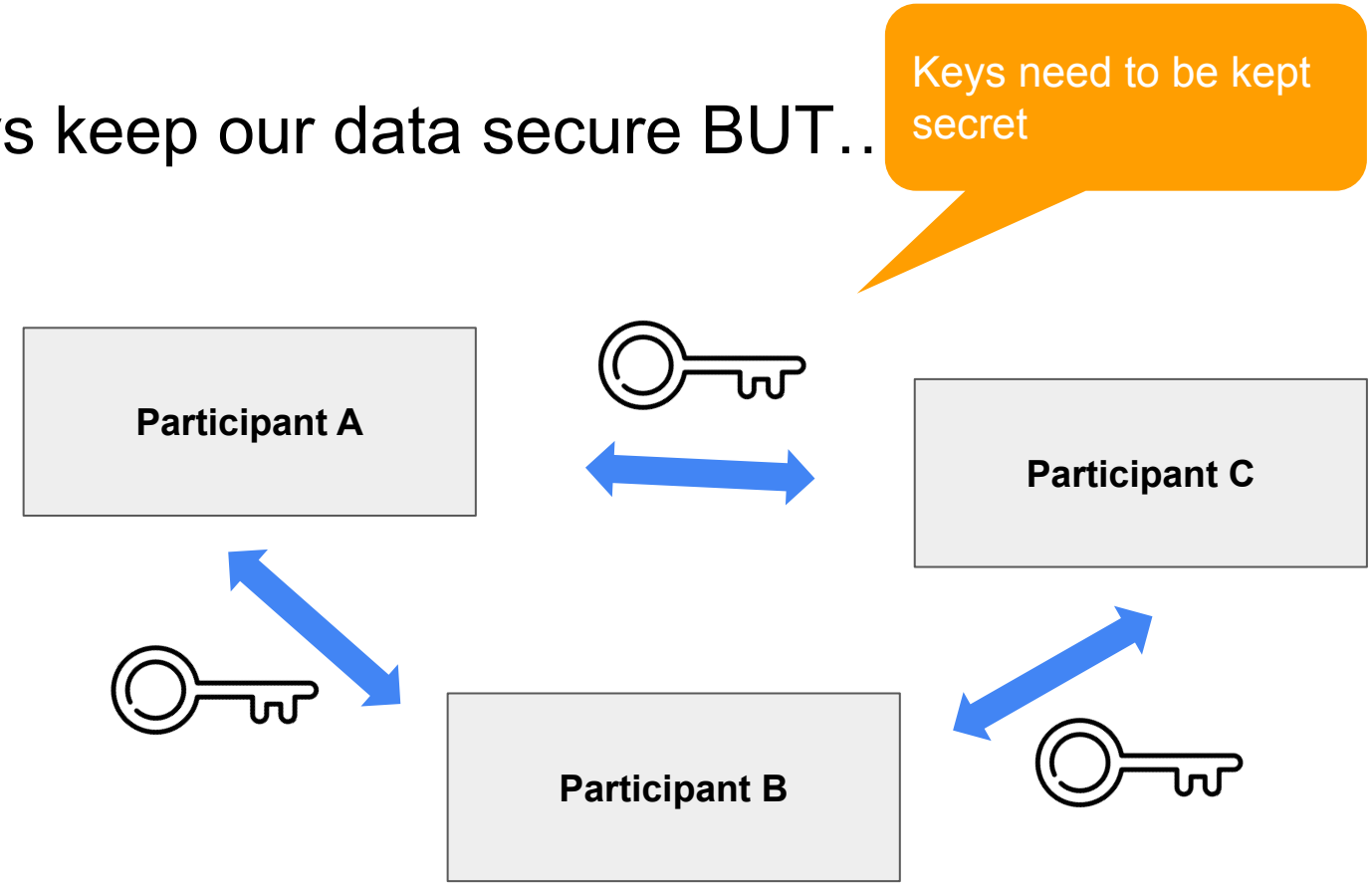

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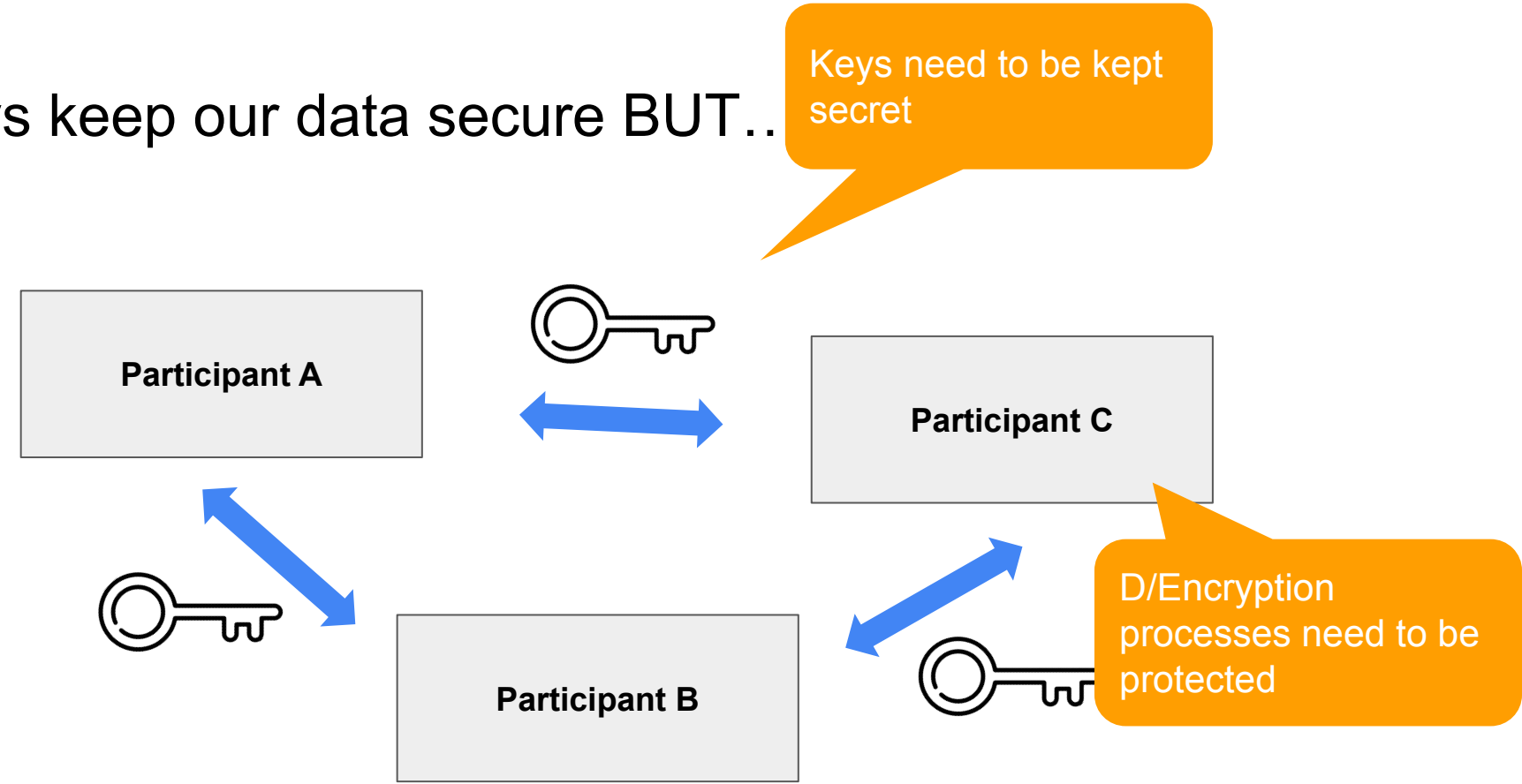

Where can things go wrong?

Many things can go wrong on many different levels

Software	Software deviates from the intended behaviour, Weak randomness

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Environment	Malware attacks, Infrastructure weaknesses

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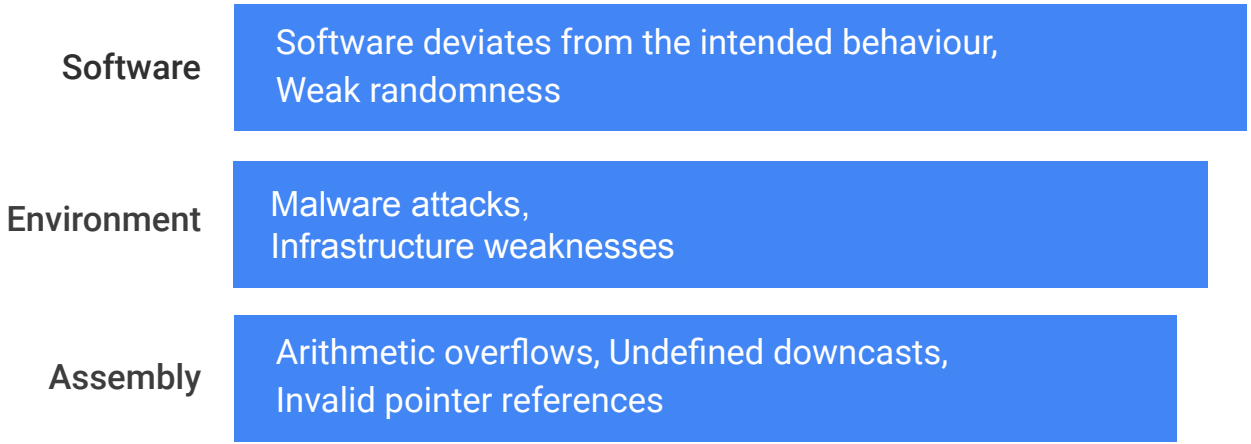

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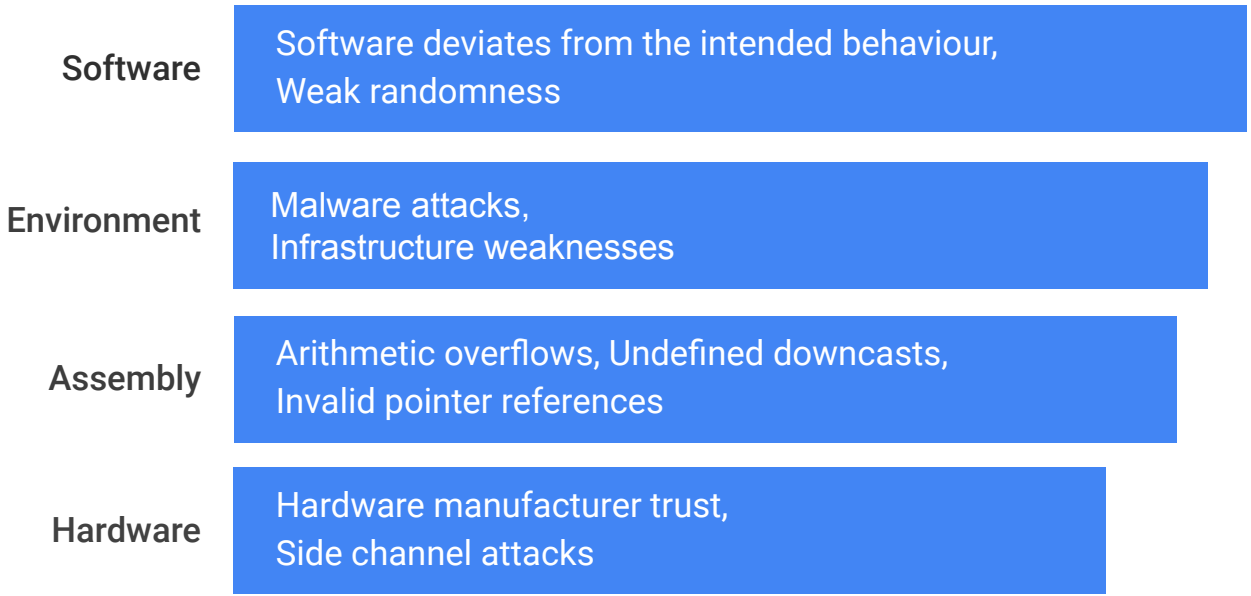

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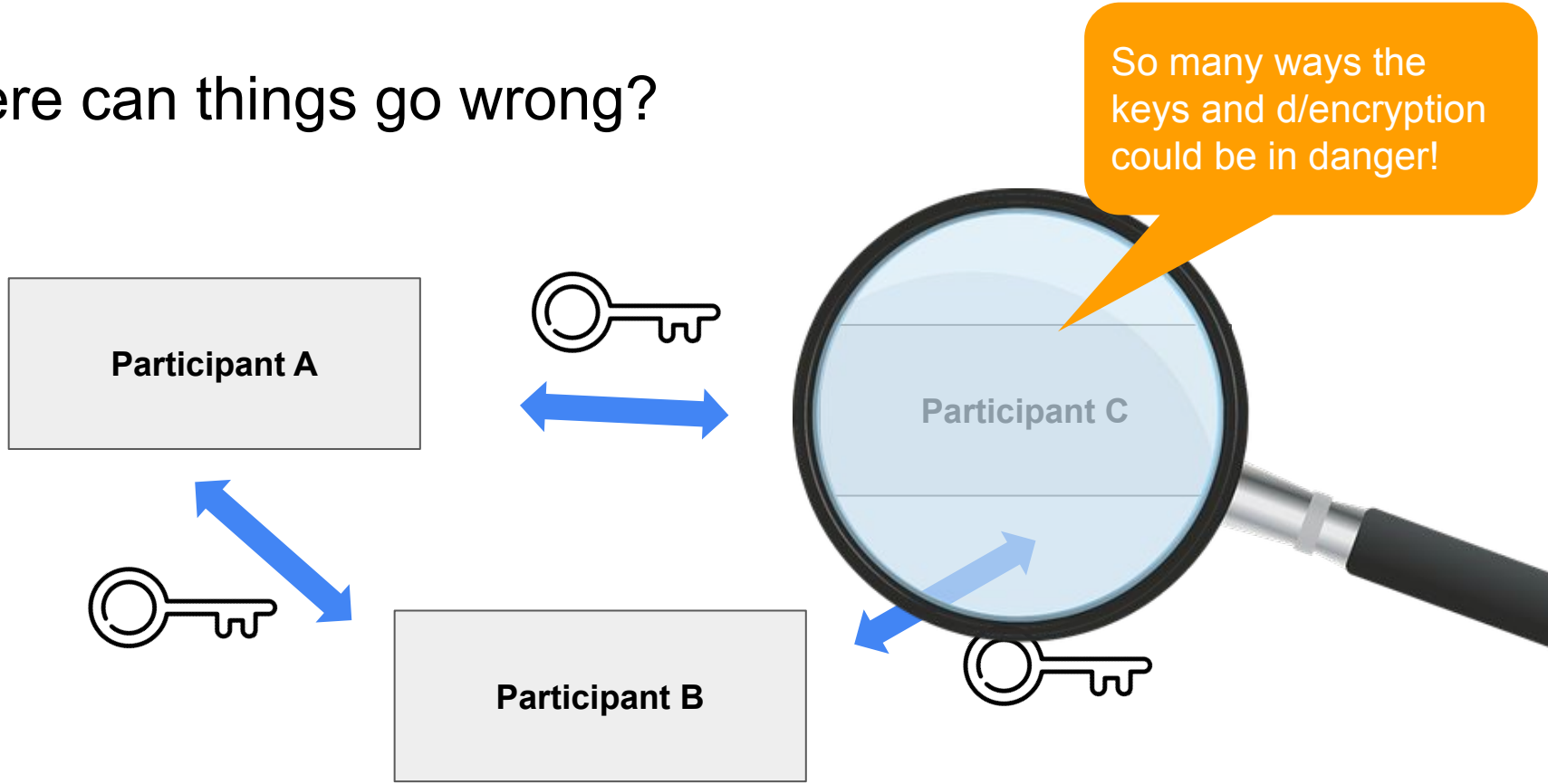
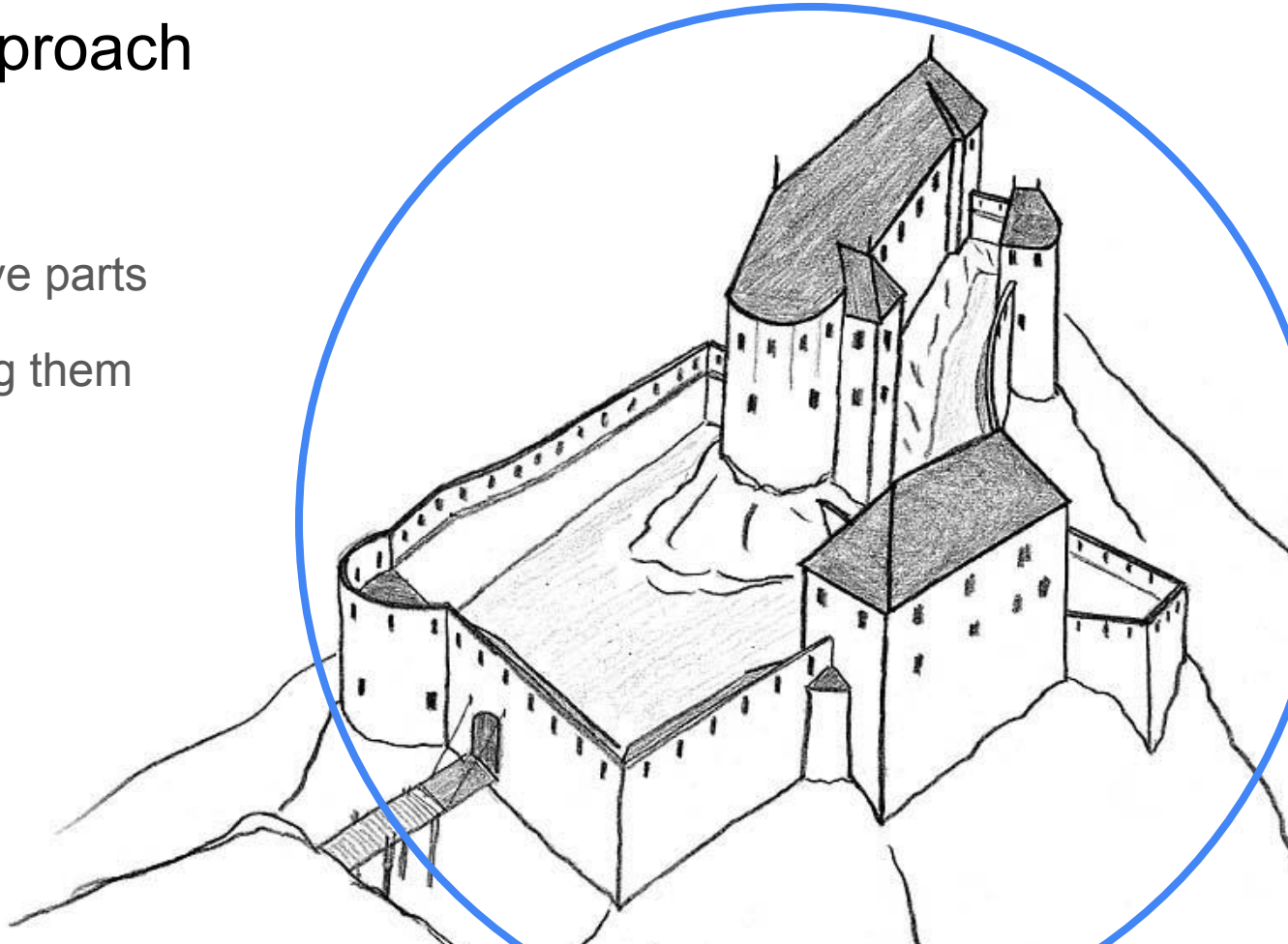


A Risk-Based Approach

Isolate the most sensitive parts

Spend more on securing them



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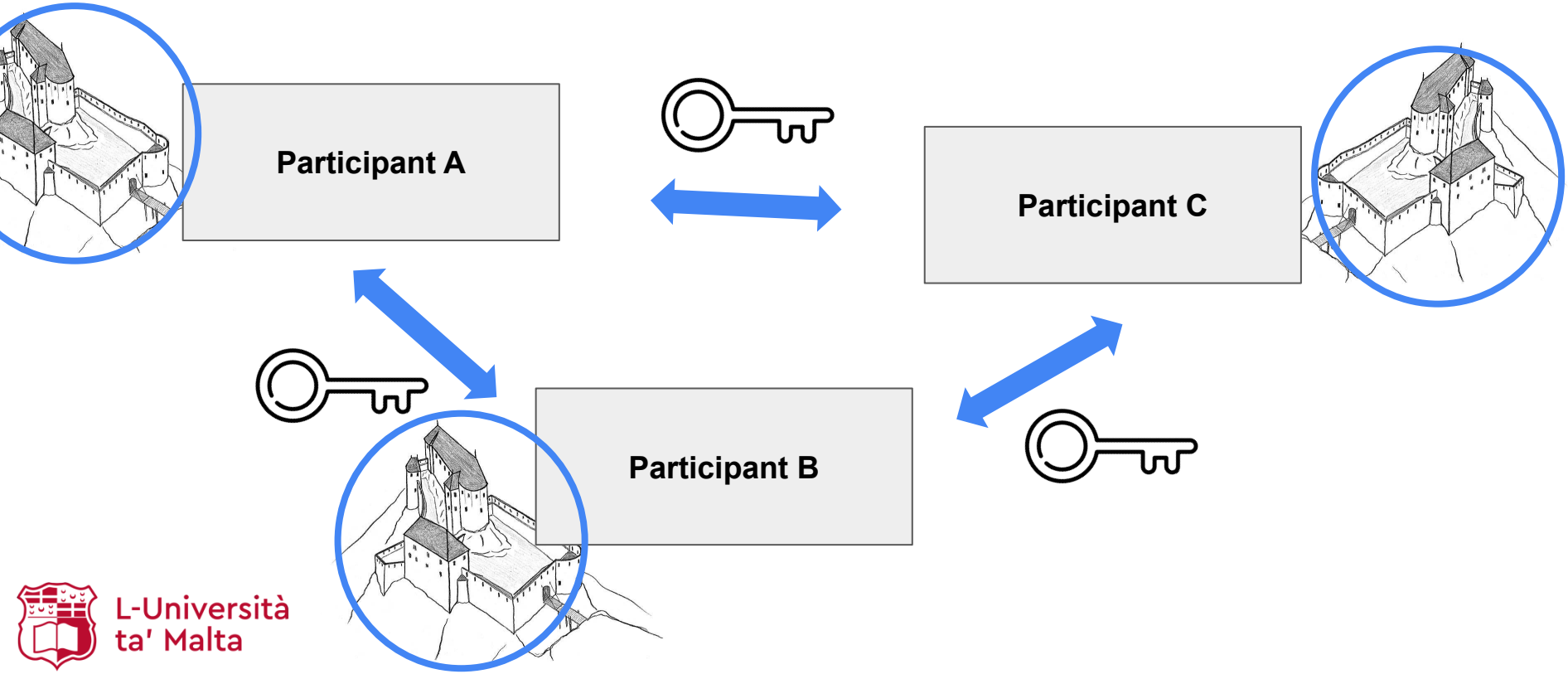
Isolating the most sensitive parts



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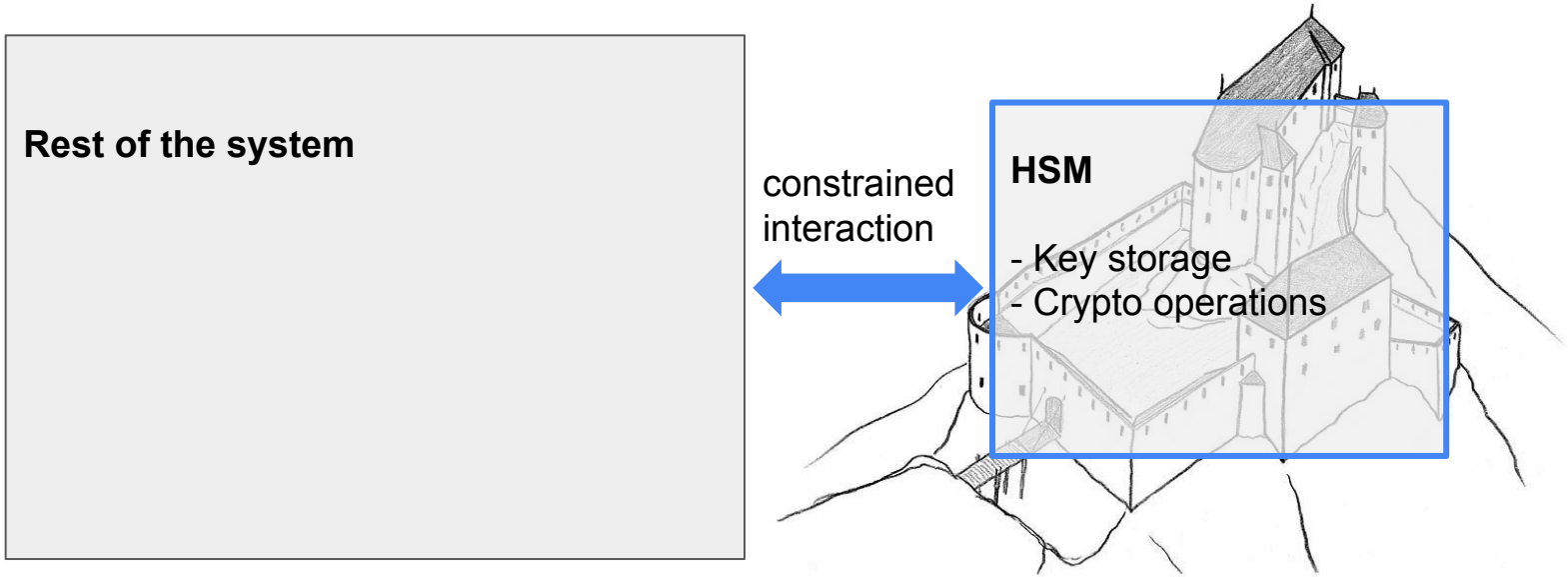
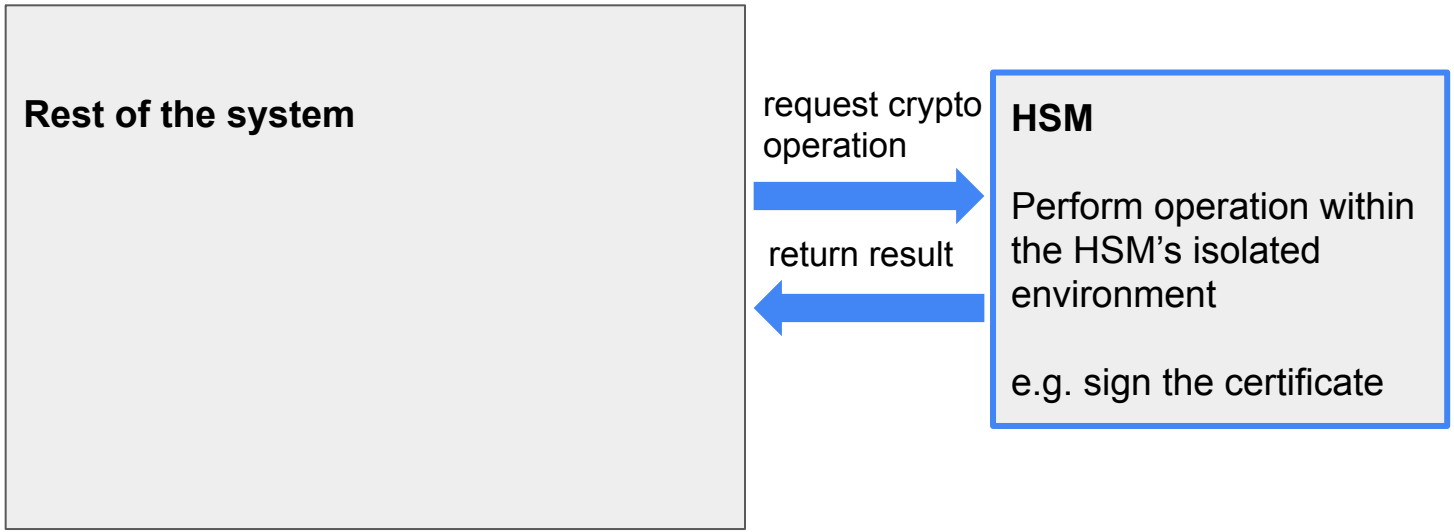
Hardware Security Module (HSM) to the Rescue



Example - Signing a Digital Certificate



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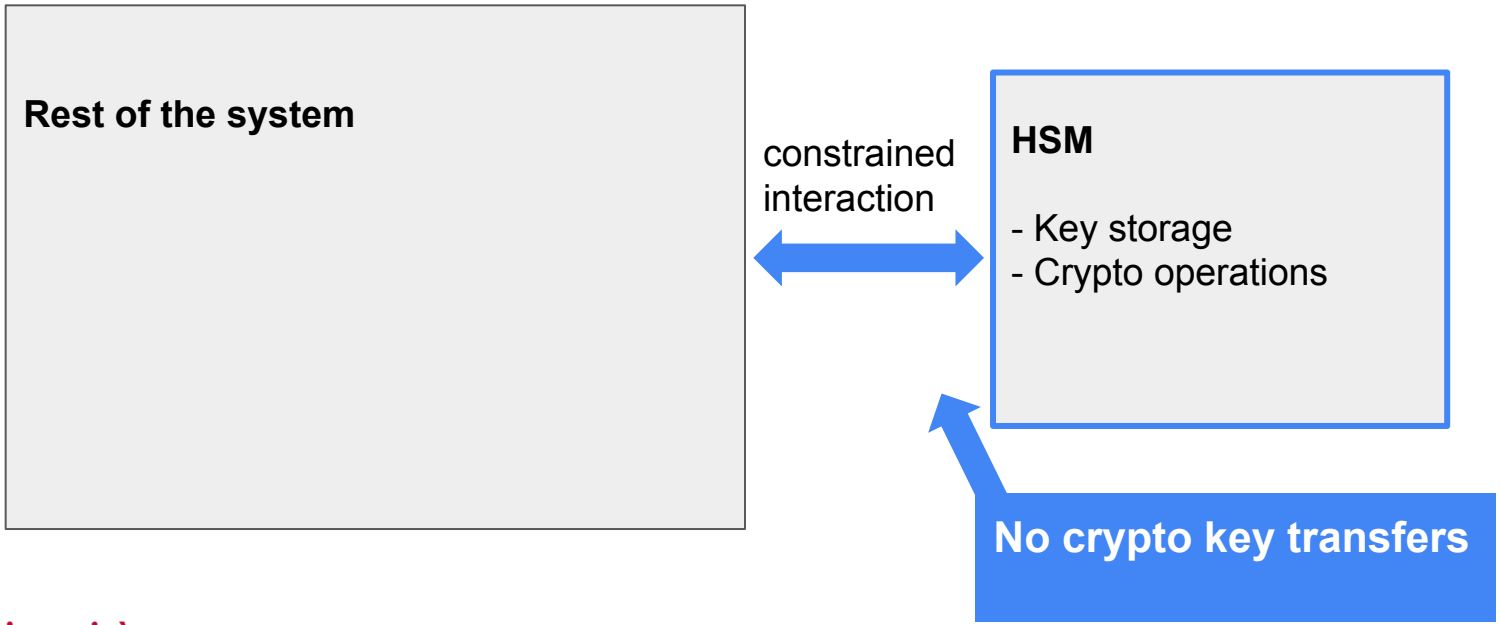

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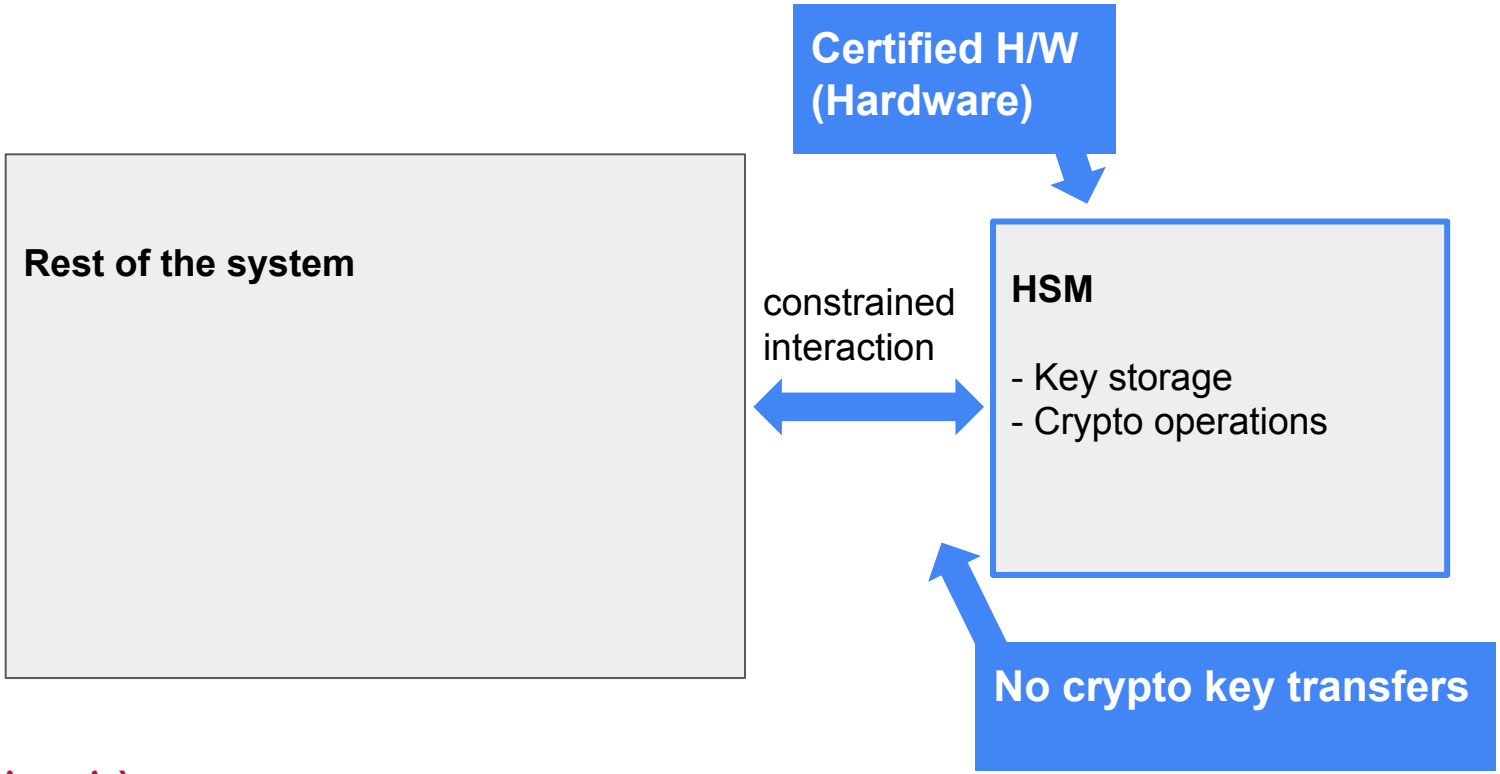

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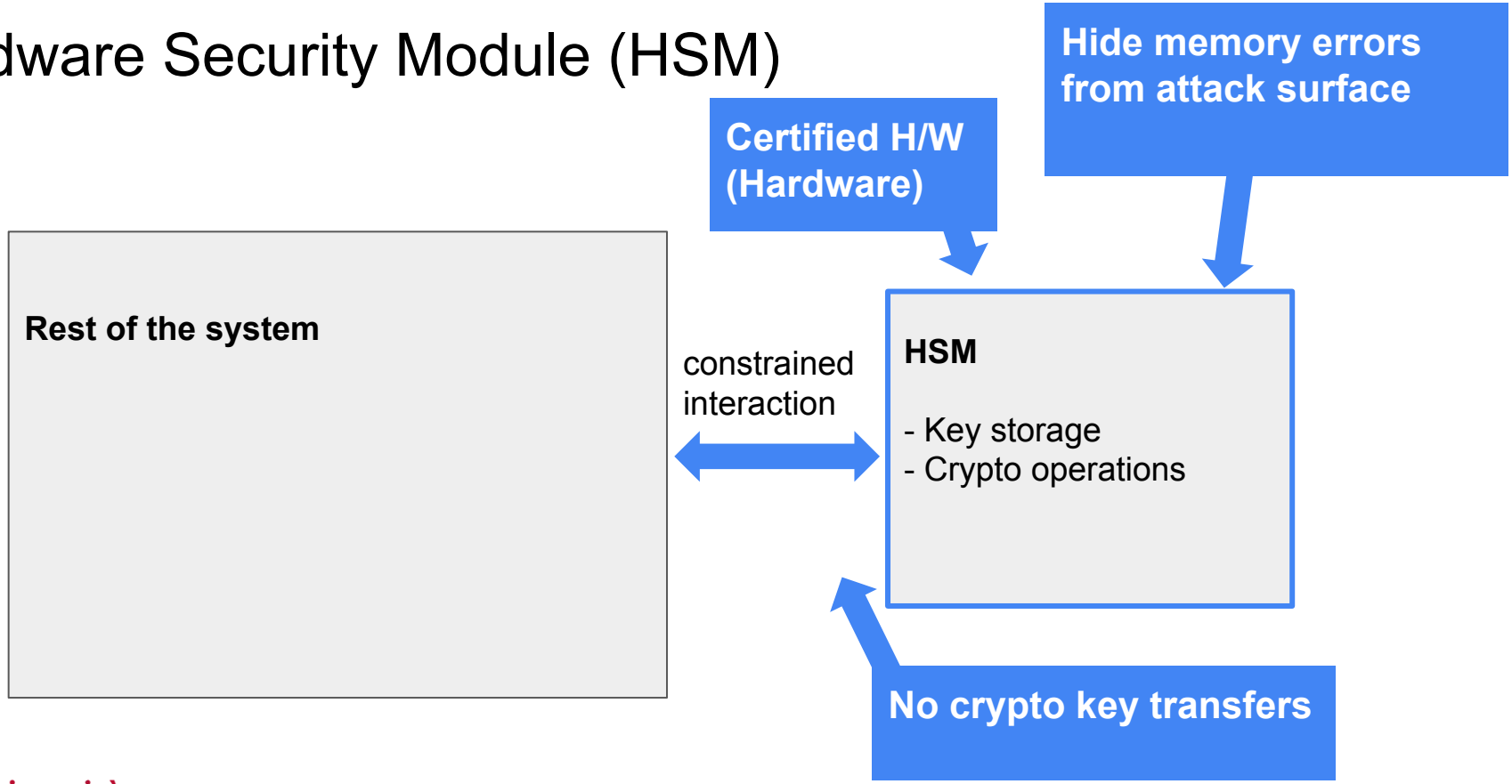
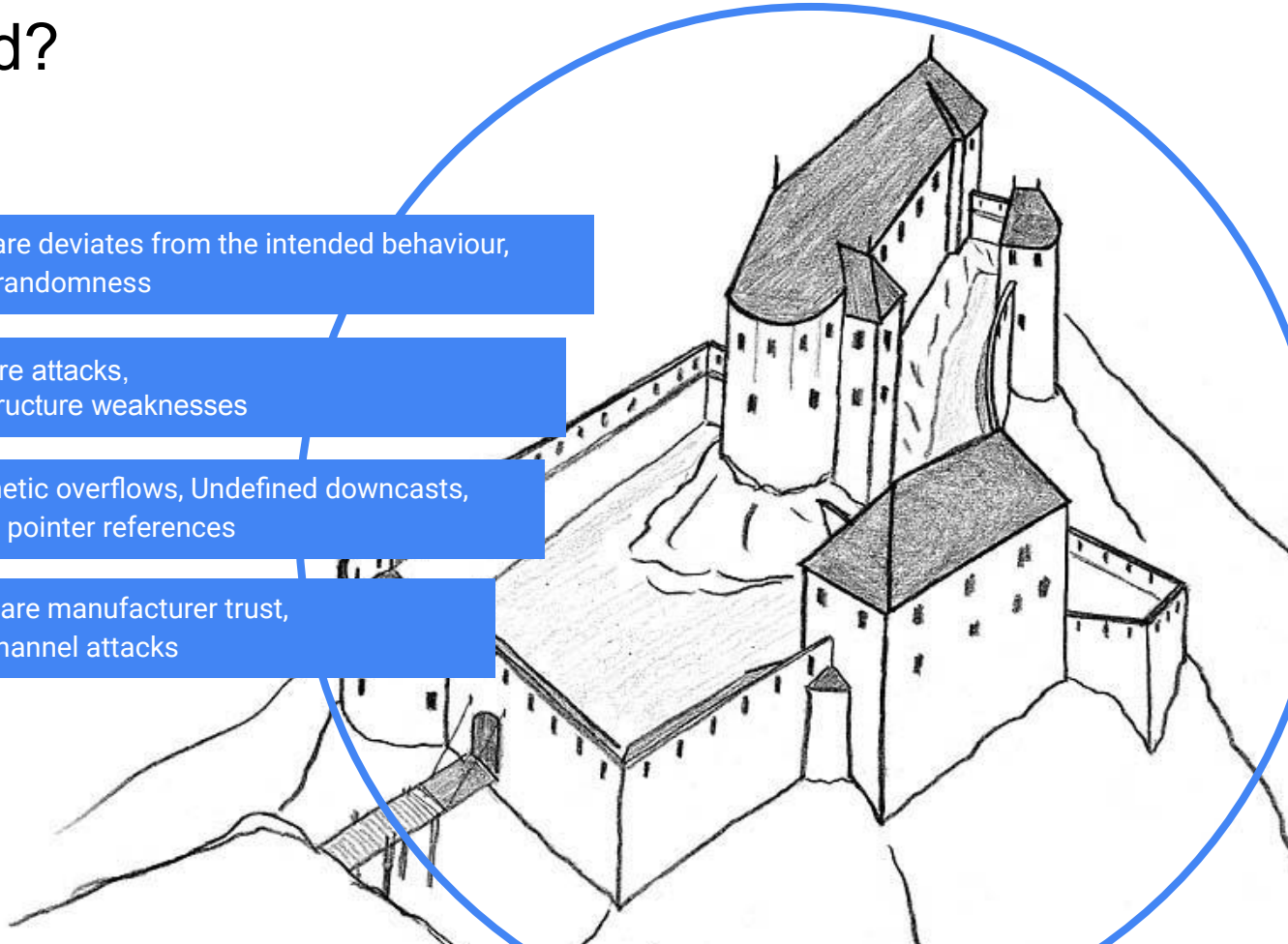


What is Protected?

Limit attack surface

Software	Software deviates from the intended behaviour, Weak randomness
Environment	Malware attacks, Infrastructure weaknesses
Assembly	Arithmetic overflows, Undefined downcasts, Invalid pointer references
Hardware	Hardware manufacturer trust, Side channel attacks



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What is an HSM?

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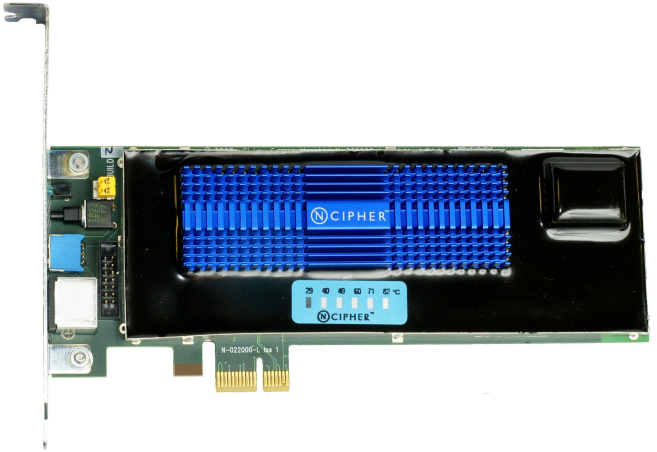

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What is Special about an HSM?

Tamper resistance + evidence

Certified CC EAL 4+ / FIPS 140-3 (3+)

Hardware-based entropy generator

Hardware-accelerated crypto operations

HSM raises alerts / becomes inoperable / deletes keys upon tamper detection

What is Special about an HSM?

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Common Criteria - CC
(Evaluation Assurance Level)

Federal Information Processing Standards - FIPS
(Security Level)

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Certified CC EAL 4+ / FIPS 140-3 (3+)

Hardware-based entropy generator

Hardware-accelerated crypto operations

Enabling high quality random number generation (central to crypto operations)

What is Special about an HSM?

Tamper resistance + evidence

Certified CC EAL 4+ / FIPS 140-3 (3+)

Hardware-based entropy generator

Hardware-accelerated crypto operations

Offloads particular operations to specialized hardware - resulting in time savings and resource/power efficiency

Ecosystem of Hardware-Supported Security

HSM

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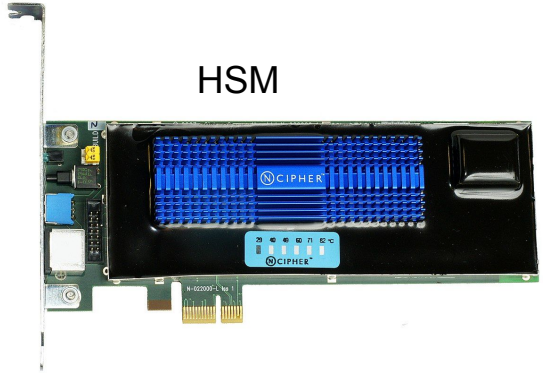
Ecosystem of Hardware-Supported Security

Smart card/Secure element

HSM



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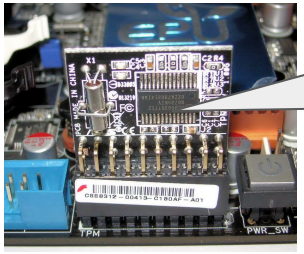

Secure element on the motherboard

Trusted Platform Module (TPM)
[ISO11889 standard]

Ecosystem of Hardware-Supported Security

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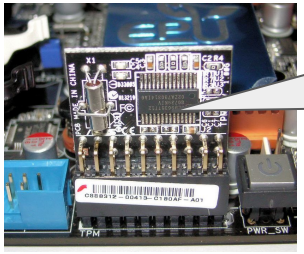
HSM



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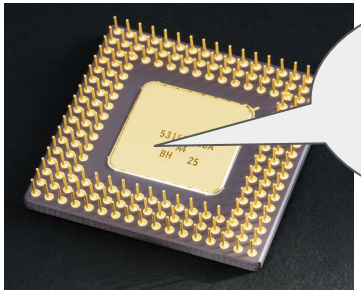

Secure element within the CPU

Trusted Execution Environment

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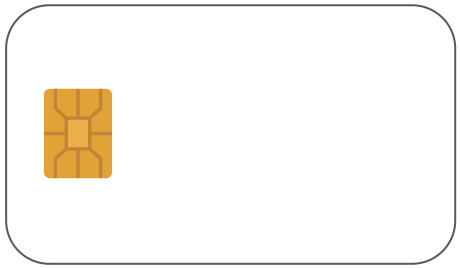
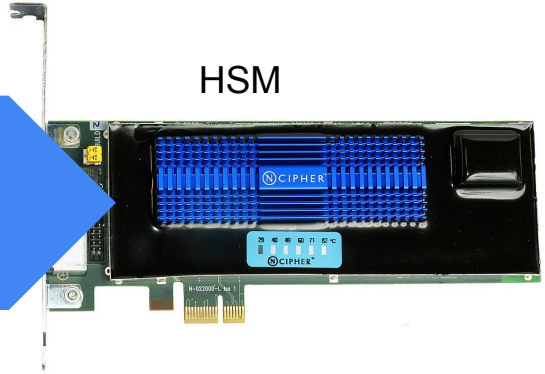
Ecosystem of Hardware-Supported Security

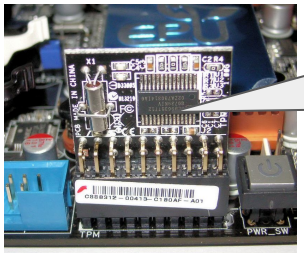
Smart card/Secure element



More processing power and flexibility

HSM





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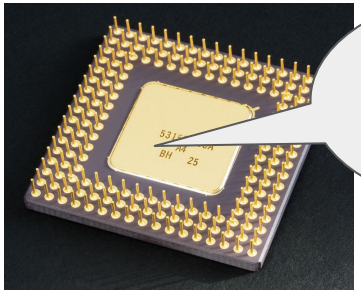

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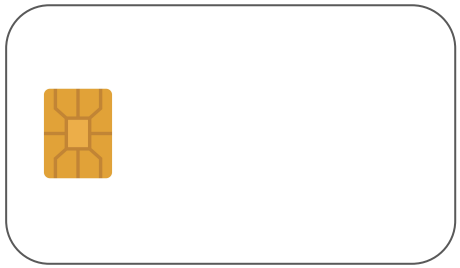
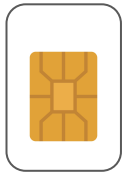
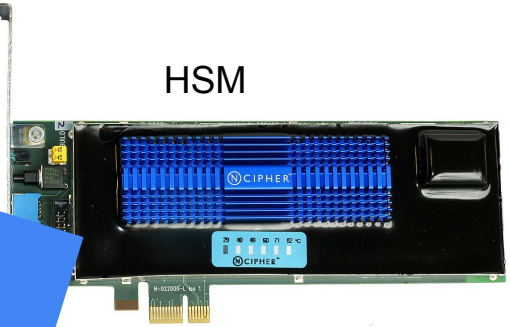
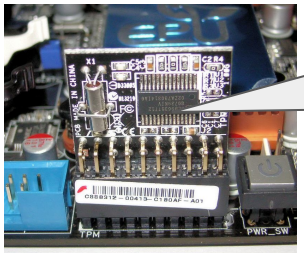




HSM

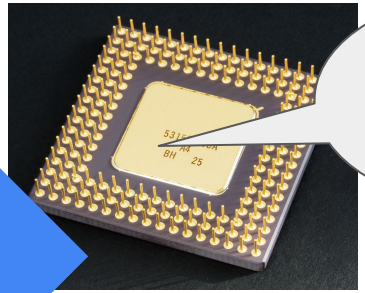


More independence from host



Trusted Platform Module (TP
[ISO11889 standard]

Closer to host



Secure element within the CPU

ed Execution Environment

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Choosing your HSM

Variety of HSMs

- **USB** - Low-volume transaction environments
- **PCIe** - High speed on-premises solution
- **Network** - Easier to share across applications
- **Cloud** - Could be outsourced

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- **BringYOK** - client provides the key to the cloud provider
- **ControlYOK** - client controls all the key's life cycle
- **HoldYOK** - key never leaves the clients infrastructure (cloud provider only deals with encrypted data)

Use Cases of HSMs

- Credential management
- Authentication
- Database/cloud encryption
- Document signing
- Secure communication
- Payments processing
- Application level encryption

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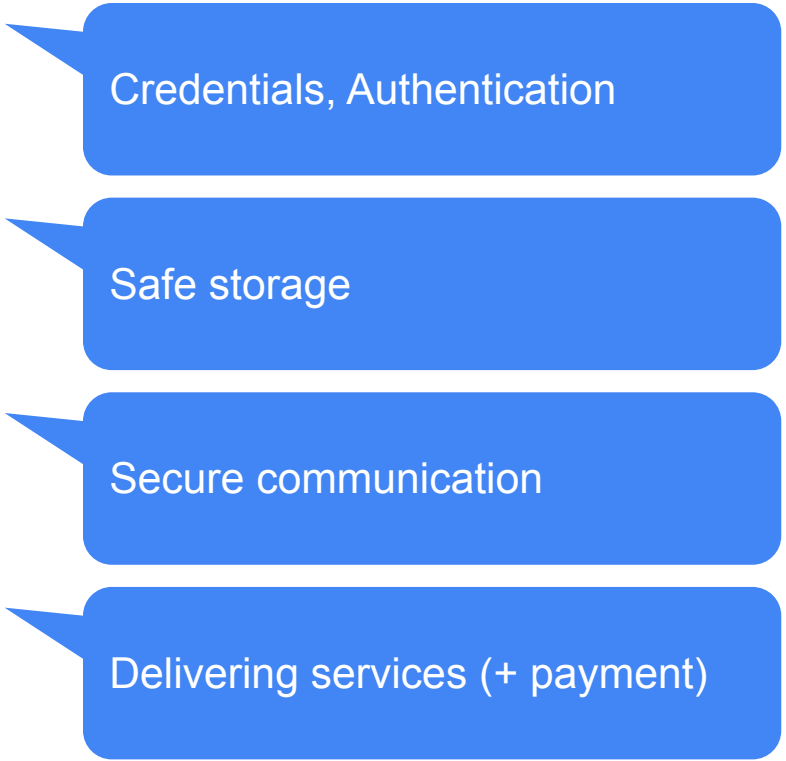

Automotive Industry

- Supply chain security through device attestation
- Secure firmware updates
- Digital car key
- Enable car parts to interact with each other securely
- Car communication with a charging station, road infrastructure
- In-car payments

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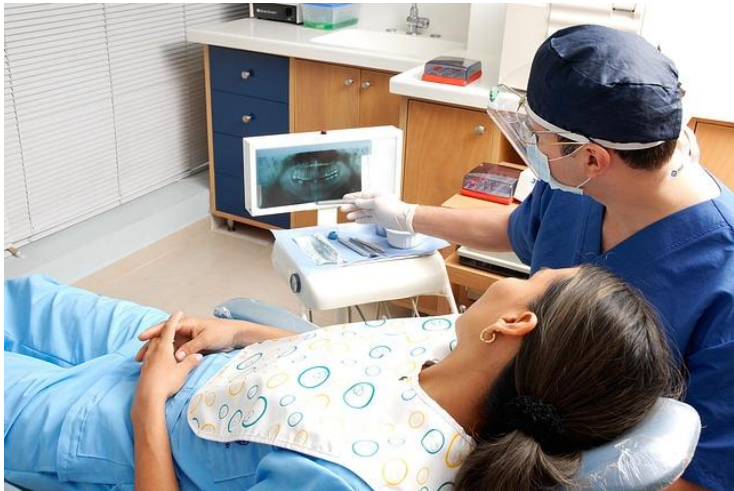
eHealth

- Digital authentication of patient’s health insurance card
- Security for on-premise eHealth data
- Security for cloud-stored eHealth data
- Internet of Medical Things (IoMT)
- Digital transmission of patients’ documents
- Remote healthcare services



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eGovernment

- Issuance of legal documents
- Security for on-premise eGovernment data
- Security for cloud-stored eGovernment data
- Connected public services
- Public warning solutions
- Offering digital services

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Banking/Financial Services

- Digital identity management
- Generate credit and debit cards
- CVC generation and validation
- Verify the user-entered PIN
- Secure CNP (Card Not Present) transactions
- POS (Point of Sale) security
- Digital currency transactions

Note: PCI HSM compliance certification

Telecoms

- eSIM provisioning
- Lawful interception solutions for network operators
- Trusted mobile networks
- Security for on-premise telecoms data
- Security for cloud-stored telecoms data
- Device identity protection
- Secure IoT communication
- Public warning
- Secure mobile payment

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Other Industries

- Manufacturing
- Retail
- Insurance
- Gaming
- Cloud services
- Energy and utilities
- Crypto currencies (ownership of private keys = ownership of account)

Choosing an HSM

- Different kinds of speed, volume required
- Hardware accelerated functions
- Readily available API functions
- Country of design/production
- Certification level

Other Considerations

- Backup/failover system
- Future firmware updates
- Authentication options
  (quorum of authenticated users before allowing operations)
- Cost

Secure Communication in the Quantum Era

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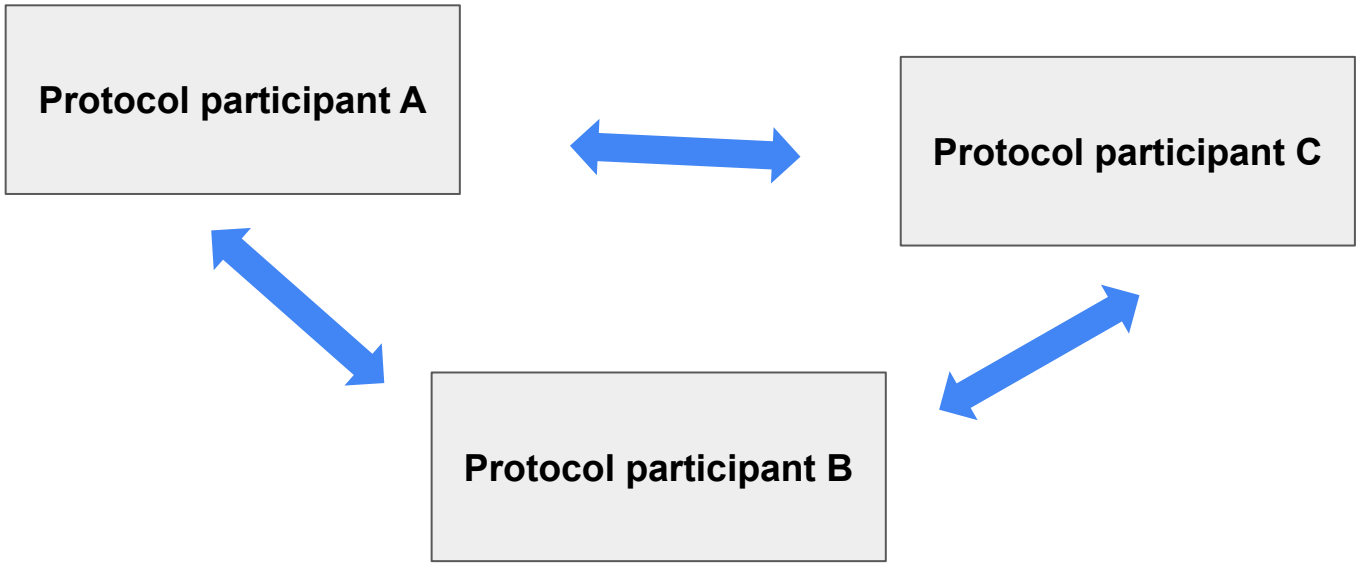
NATO OTAN

Goal: Quantum-Safe Communication Protocol



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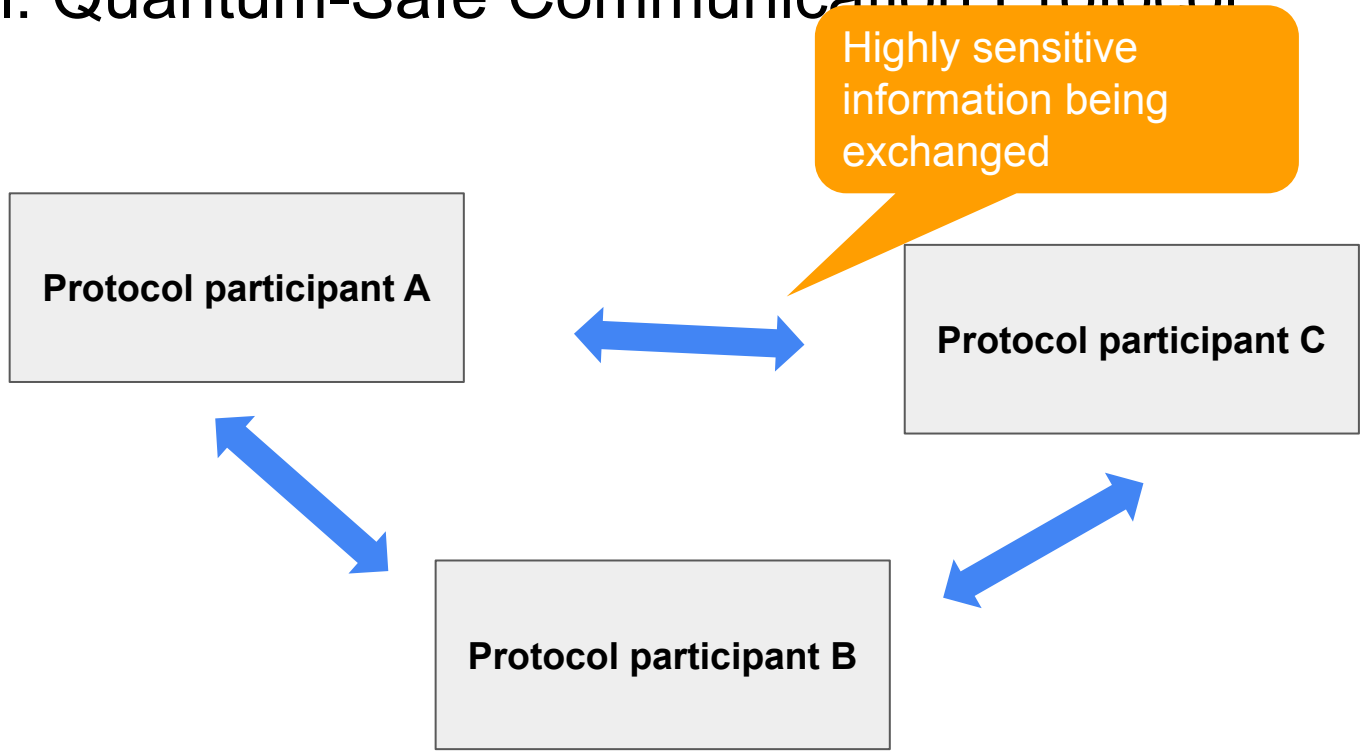

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NATO OTAN

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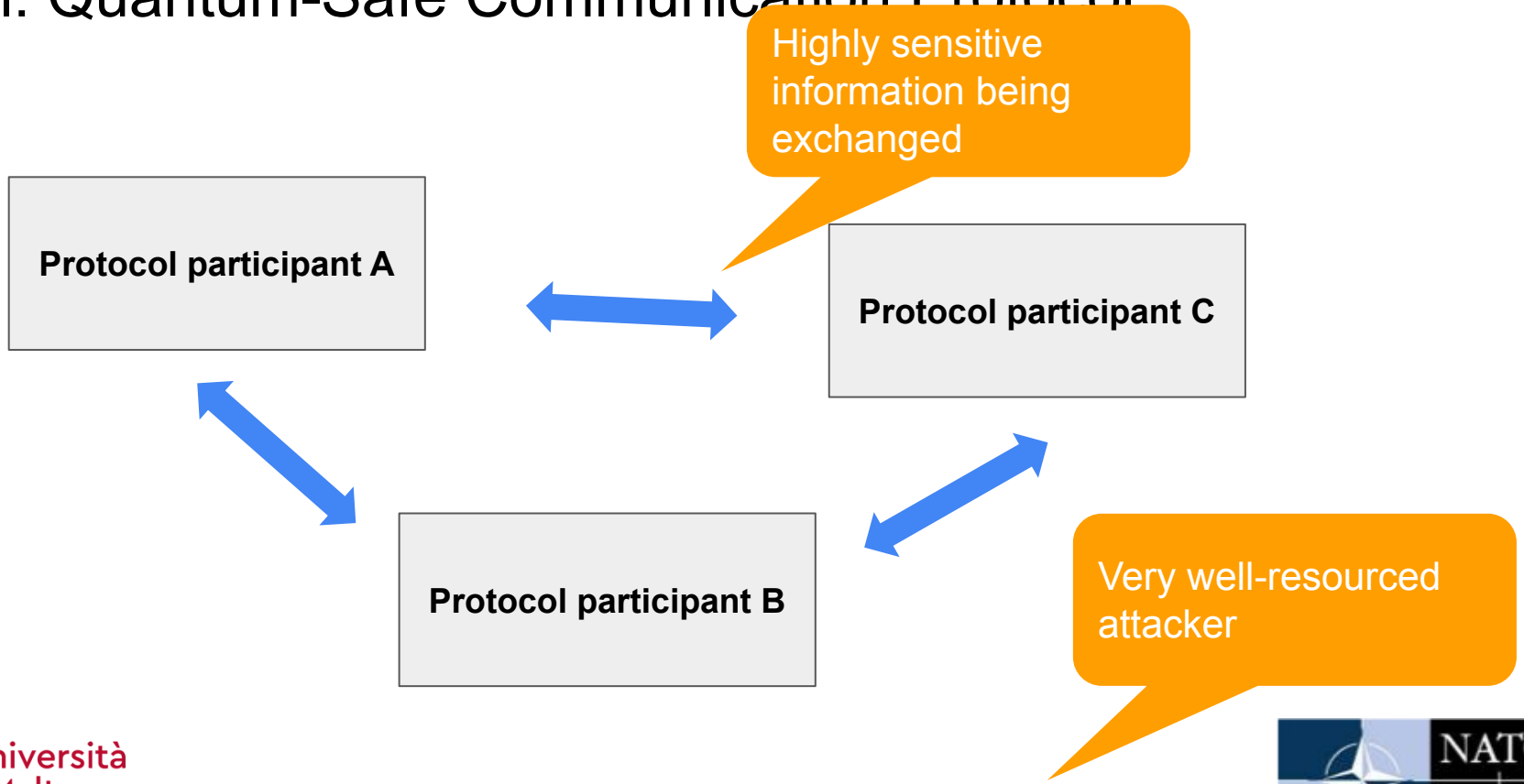

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NATO OTAN

Protocol Design

- `Computation:`
  - For $0 \leq i \leq n, U_i$ chooses $\beta_i \leftarrow \mathbb{Z}_q$ and computes $g_i = \iota(\mathtt{pw})^{\beta_i}$. U_0 sets $M_0 := (g_0)$.
  - For $1 \leq i \leq n, U_i$ computes $(pk_i, sk_i) \leftarrow \mathcal{K}.\mathtt{KeyGen}(1^l)$, and sets $M_i := (pk_i, g_i)$.
- `Communication:`
  - For $0 \leq i \leq n$, U_i broadcasts M_i.

Round II.

- `Computation:`
  - Keying material:
    - U_0 chooses $k \leftarrow \{0,1\}^{p(l)}$, and for each $1 \leq j \leq n$ computes
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    - For $0 \leq i \leq n$, U_i sets $g_{i,j} := g_j^{\beta_i}$ for each $j \neq i$.
  - Tags:
    - U_0 computes $t_{0,j} := \mathtt{Tag}([g_{0,j}]_L, U_0 || m_{0,j} || M_0 || ... || M_n)$ for each $1 \leq j \leq n$.
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Proven Correct

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NATO OTAN

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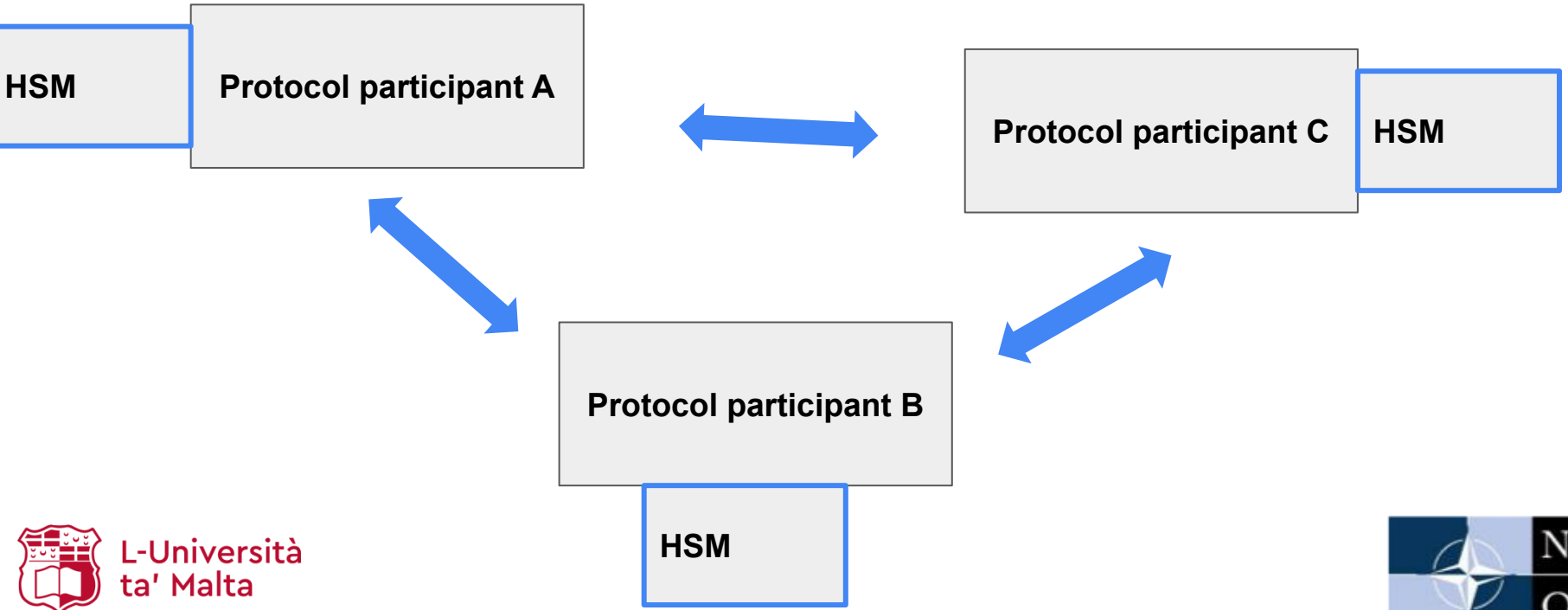
Proven Correct

What does it really mean?

Using HSMs


HSM
Protocol participant A
Protocol participant C
HSM
Protocol participant B
HSM

Which HSM? - SECube

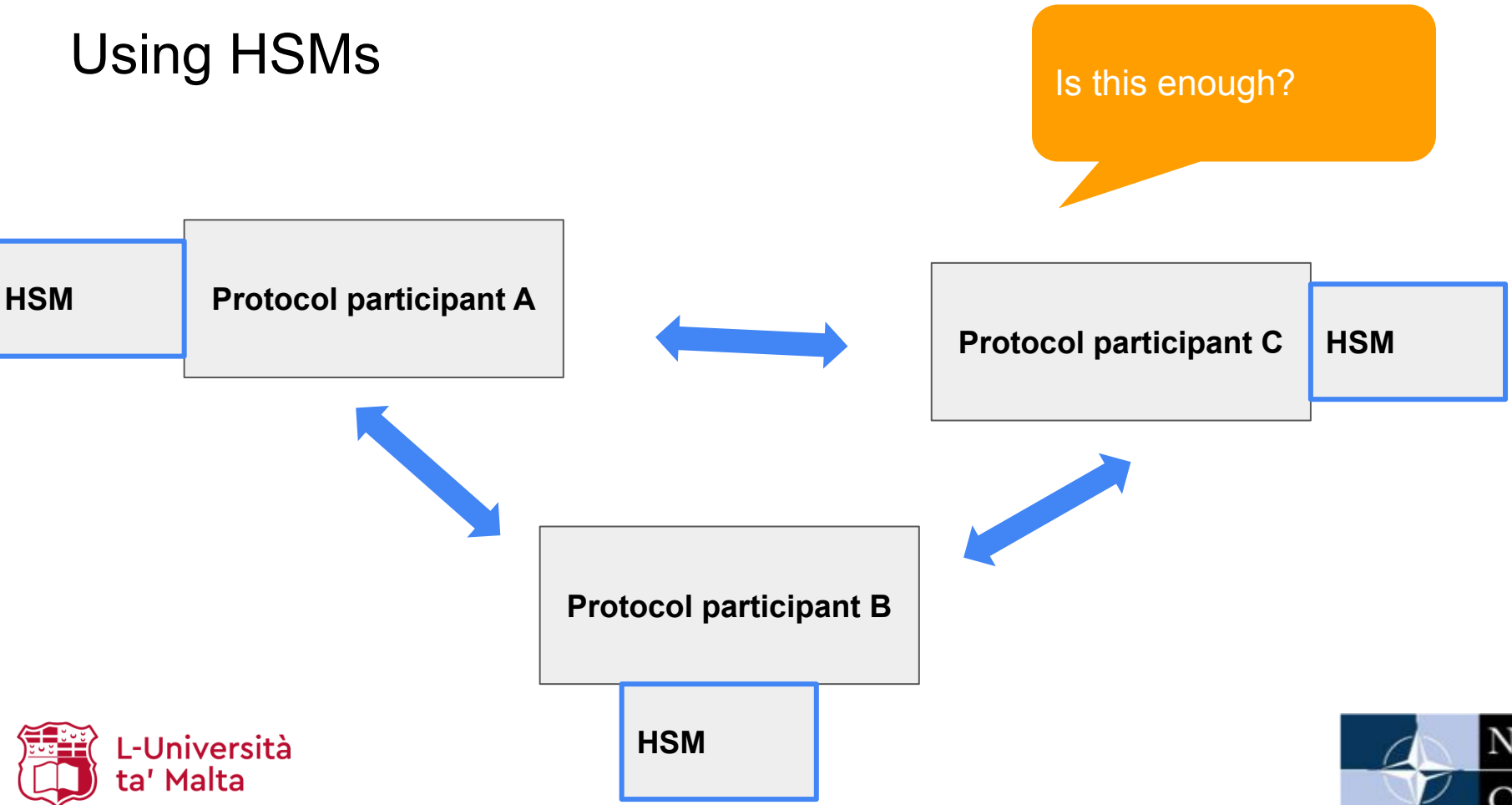
A small HSM (per protocol client)

Open source library, firmware

Three cores:

- ARM Cortex-M4 processor
- Field-Programmable-Gate-Array (FPGA)
- EAL5+ SmartCard

Using HSMs



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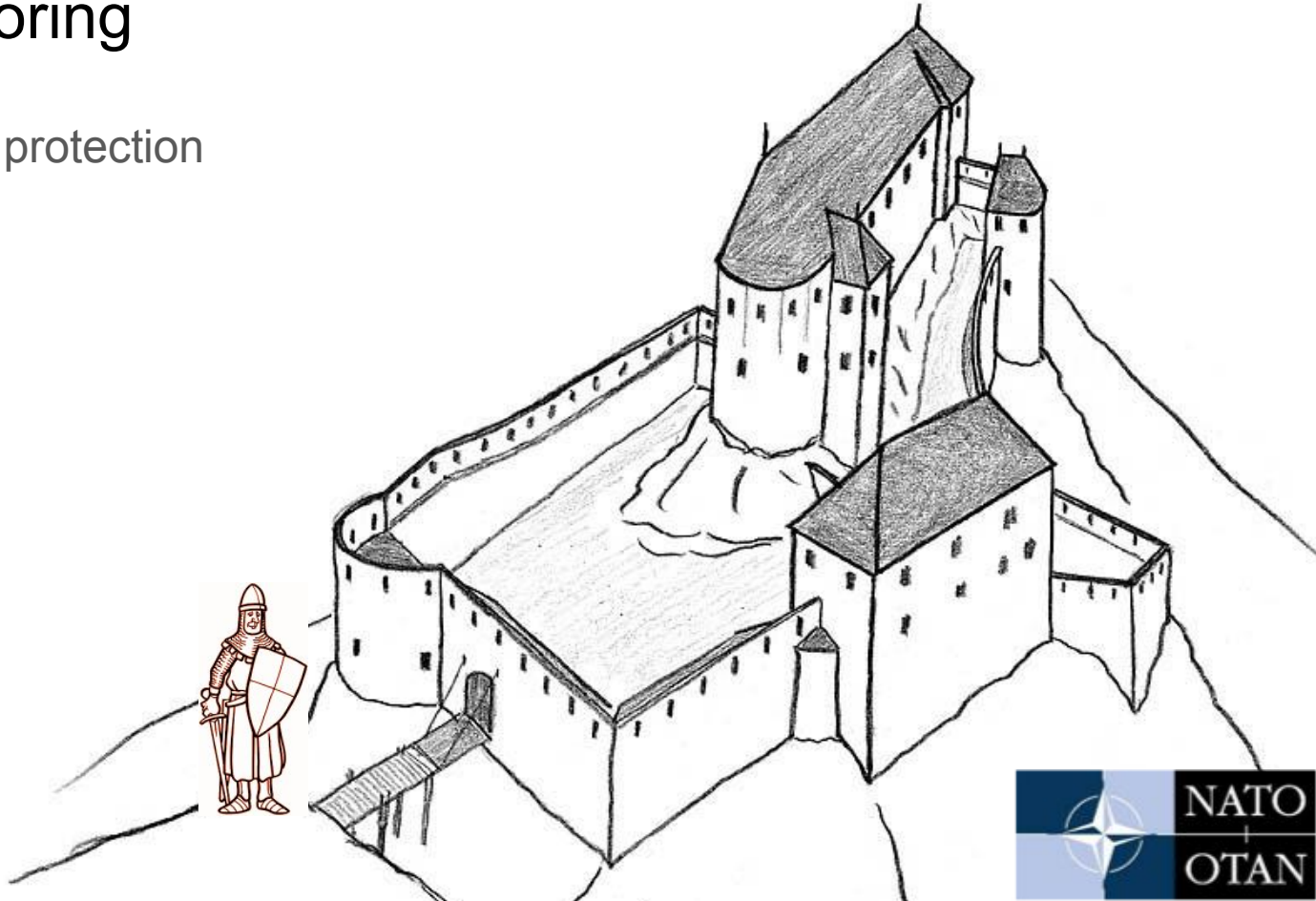
Software Monitoring

An additional layer of protection



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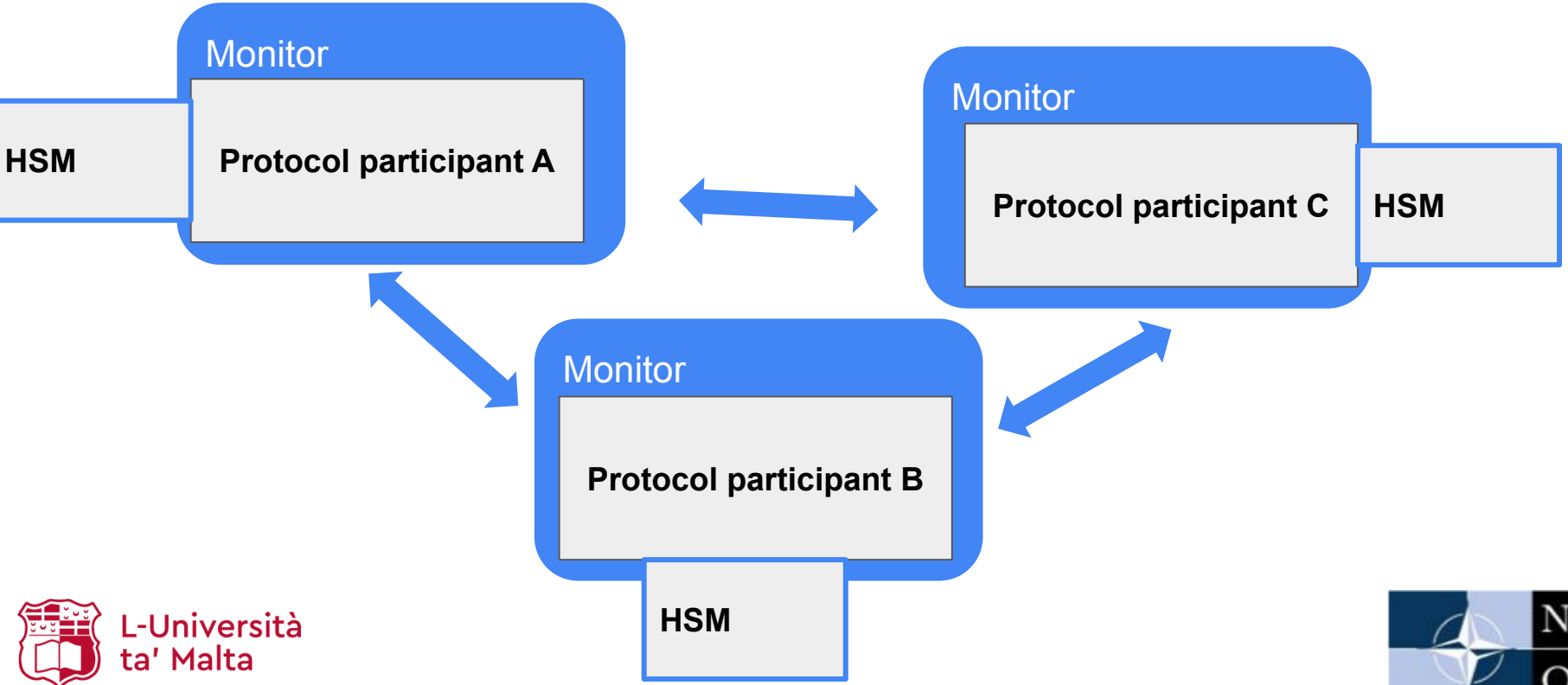
Introducing Monitors

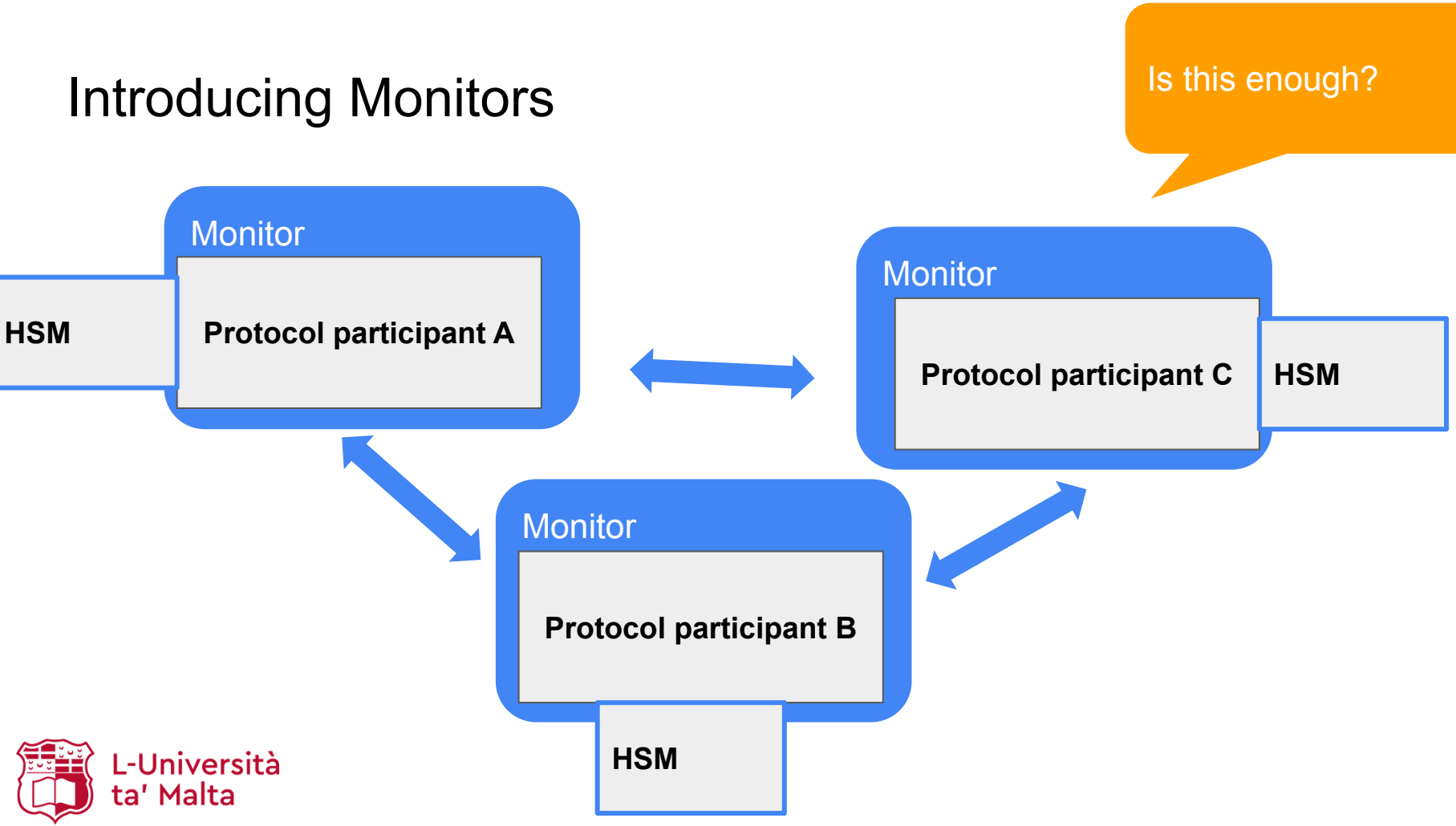


What did we Monitor?

- Function calls at different levels: app, library
- Parameter values
- Data entering and leaving the boundary of trust
- Quality of randomness

Looking Forward and Concluding

Introducing Monitors



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Safeguarding Monitors and Logs

- Isolating monitoring processes at OS level
- Making logs tamper-evident

Conclusion

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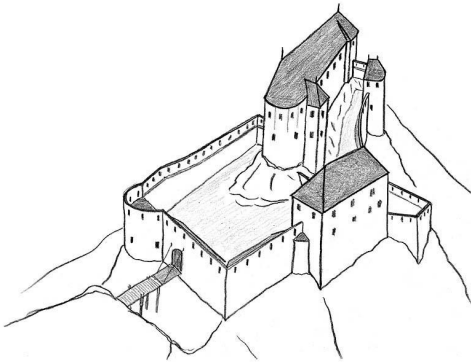

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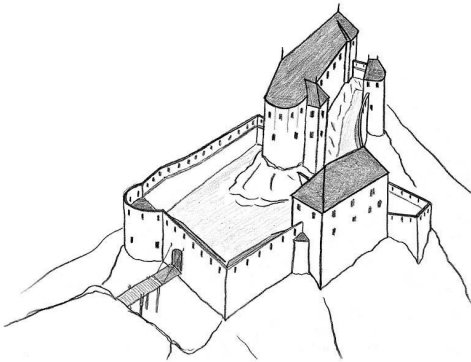

Managing the impact of attacks (layered defences, unique keys)

Increase the cost of attack up to an accepted risk

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Questions

christian.colombo@um.edu.mt

End