Trojan-tolerant Hardware

+ Supply Chain Security in Practice

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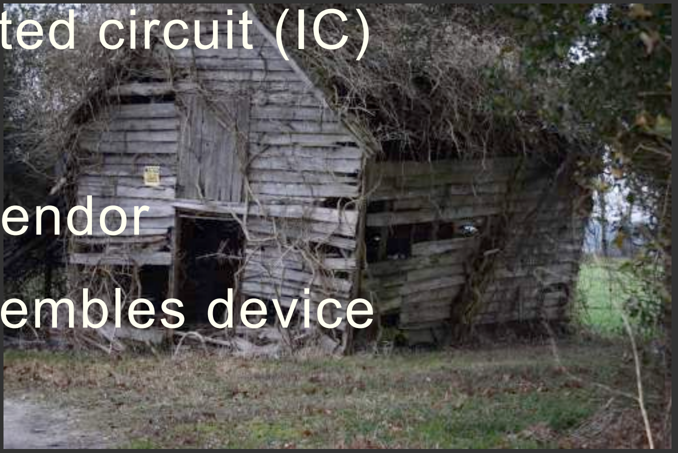
Highlights

- The private life of keys
- Weak links of the supply chain
- Lessons learned from airplanes
- Demo of our crypto hardware
- Protocols, Maths & Magic
- Politics, Distrust & Hardware Security

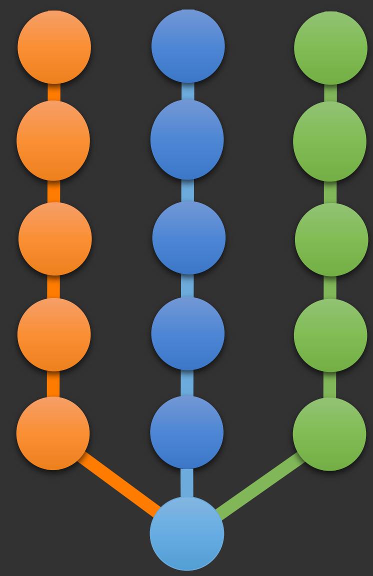
The Private Life of Keys

1. Someone designs an integrated circuit (IC)
2. IC is fabricated
3. IC is delivered to hardware vendor
4. Vendor loads firmware & assembles device
5. Device is sent to customer
6. Customer generates and stores key on the device



The Private Life of Keys

1. Someone designs the processor chip
2. Foundry fabricates the chip
3. Haulage transports chips
4. System vendor programs firmware
5. Distributors deliver a device to you
6. You create and use your key on the device



We can’t protect all the steps

…but we can duplicate them

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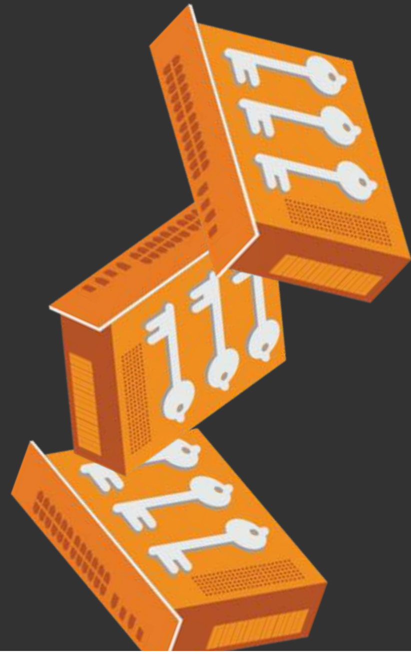
Hardware Security Modules

Physical computing device that safeguards and manages digital keys for strong authentication and provides cryptoprocessing.

Features:

- Cryptographic key generation, storage, management
- Tamper-evidence, Tamper-resistance, Tamper-response
- Security Validation & Certification



Crypto Operations are carried out in the device

No need to output the private keys!

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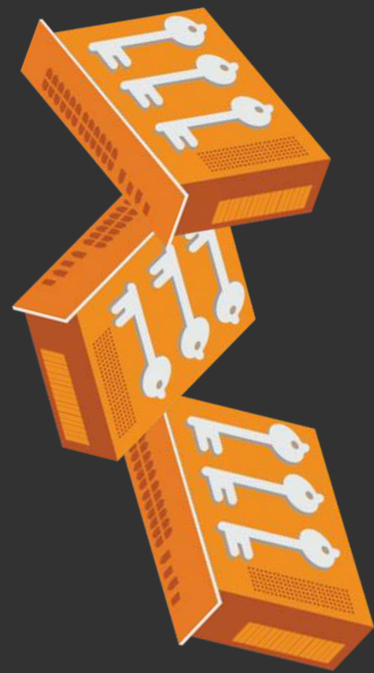
Hardware Security Modules

Common Applications

- Public Key Infrastructures
- Payment Processing Systems
- SSL Connections
- DNSSEC
- Transparent Data Encryption

Cost

- Hardware (>$10k)
- Integration Cost
- Operational/Support



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HSM Guarantees

1. Someone designs an integrated circuit (IC)
2. IC is fabricated
3. IC is delivered to hardware vendor
4. Vendor loads firmware & assembles device
5. Device is sent to customer
6. Customer generates and stores key on the device

What could go wrong?

- Bugs

CVE-2015-5464
The HSM allows remote authenticated users to bypass intended key-export restrictions …

- Backdoors/HT?

THIS 'DEMONICALLY CLEVER' BACKDOOR HIDES IN A TINY SLICE OF A COMPUTER CHIP

NSA's Own Hardware Backdoors May Still Be a "Problem from Hell"

Expert Says NSA Have Backdoors Built Into Intel And AMD Processors

Snowden: The NSA planted backdoors in Cisco products

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Proposed Solutions

- Trusted Foundries
  - Very expensive
  - Prone to errors/bugs
- Split-Manufacturing
  - Still Expensive
  - Prone to errors/bugs
- Post-fabrication Inspection
  - Expensive (+ re-tooling)
  - A huge pain, doesn't scale

Arms Race

- Adversaries always one step forward
- Can never be 100% certain

It's safe to assume we will never win

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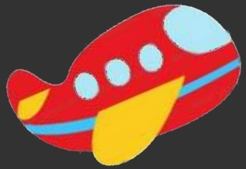
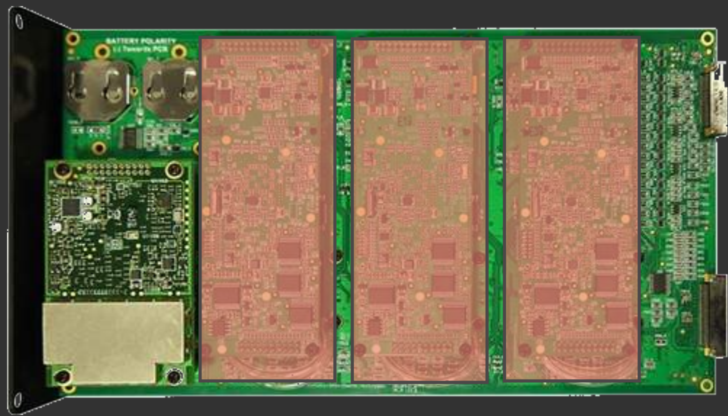


Solution from the sky and space

***Lockstep systems** are fault-tolerant computer systems that run the same set of operations at the same time in parallel.*

- Dual redundancy
  allows error detection and error correction
- Triple redundancy
  automatic error correction, via majority vote
  → Triple Redundant 777 Primary Flight Computer



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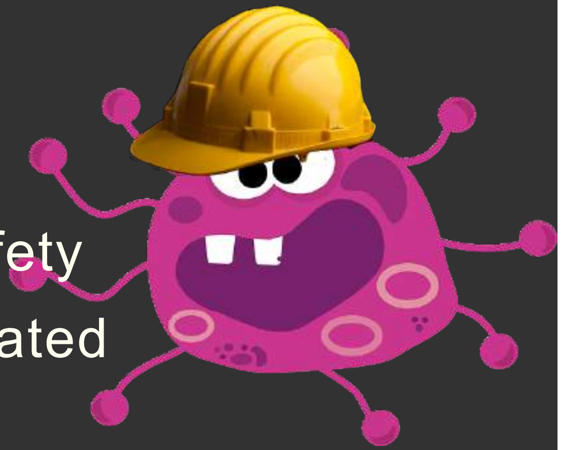
Safety != Security



Fault-tolerant systems are built for safety
and the computations are simply replicated

Not enough for security!

Keys would have to be copied across all processors

Security of our keys would depend on the weakest link

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Our Solution

1. Someone designs an integrated circuit (IC)
2. IC is fabricated
3. IC is delivered to hardware vendor
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Who we are

Vasilios Mavroudis
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CEO, Enigma Bridge

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Professor, UCL

Petr Svenda
Assistant Professor, MUni
CTO, Enigma Bridge

Ingredients of the Solution

1. Hardware Components (IC)
   - Independent Fabrication
   - Non-overlapping Supply Chains
   - Programmable
   - Affordable
   - Bonus if COTS
2. Cryptographic Protocols
   - No single trusted party
   - Full Distribution of Secrets
   - Distributed Processing
   - Provably Secure (i.e., Math)

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Smart Cards

Many Independent Manufacturers

- Private Fabrication Facilities
- Disjoint Supply Chains (location, factories, design)

Programmable Secure Execution Environment

- NIST FIPS140-2 standard, Level 4
- Common Criteria EAL4+/5+

Off-the-shelf Cost $5-$40

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Multiparty Computation Protocols

Distributed Operations

- ❑ Random number Generation
- ❑ Key Pair Generation
- ❑ Decryption
- ❑ Signing

Provably Protect against

- ❑ *N-1* Malicious & Colluding parties
- ❑ *N* Malicious & non-colluding parties

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THE prototype

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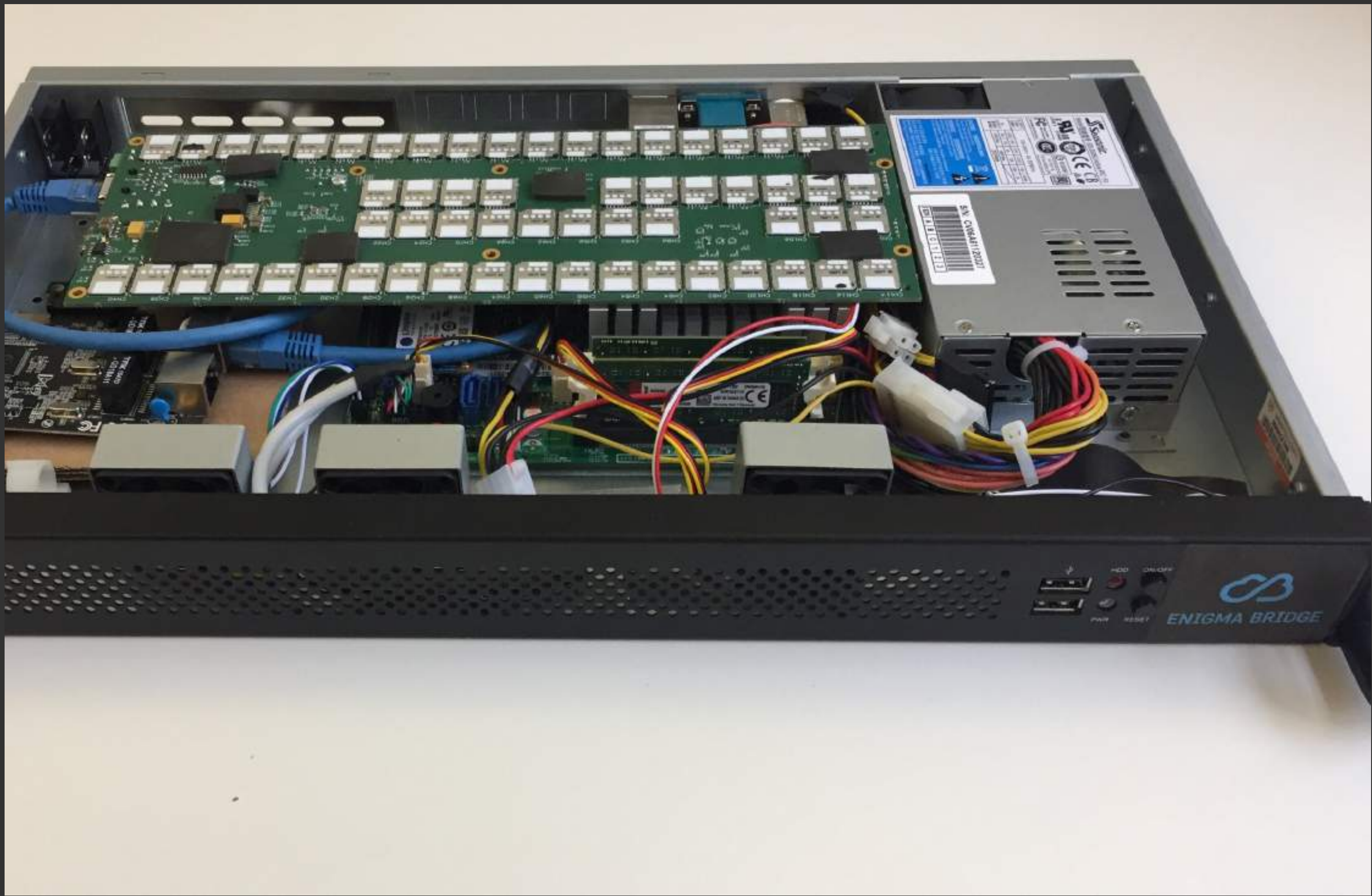

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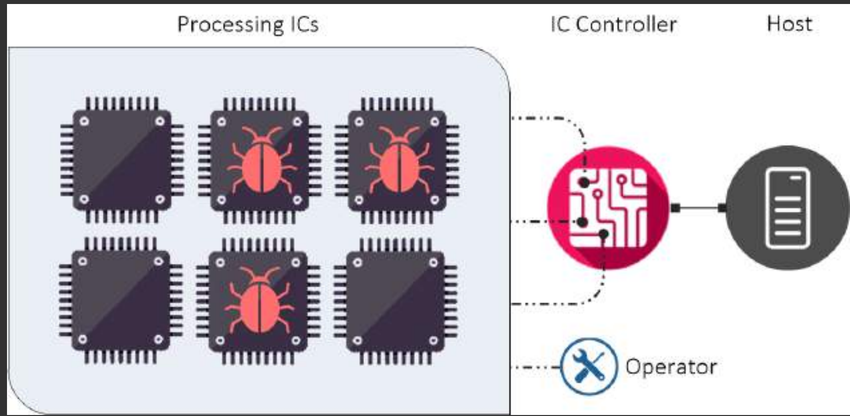
Many Smart Cards



Components

- Multiples of 120 smartcards
- TCP/UDP access to smartcards
- FPGA manages the communication bus
  - 1Gbit/s bandwidth for requests

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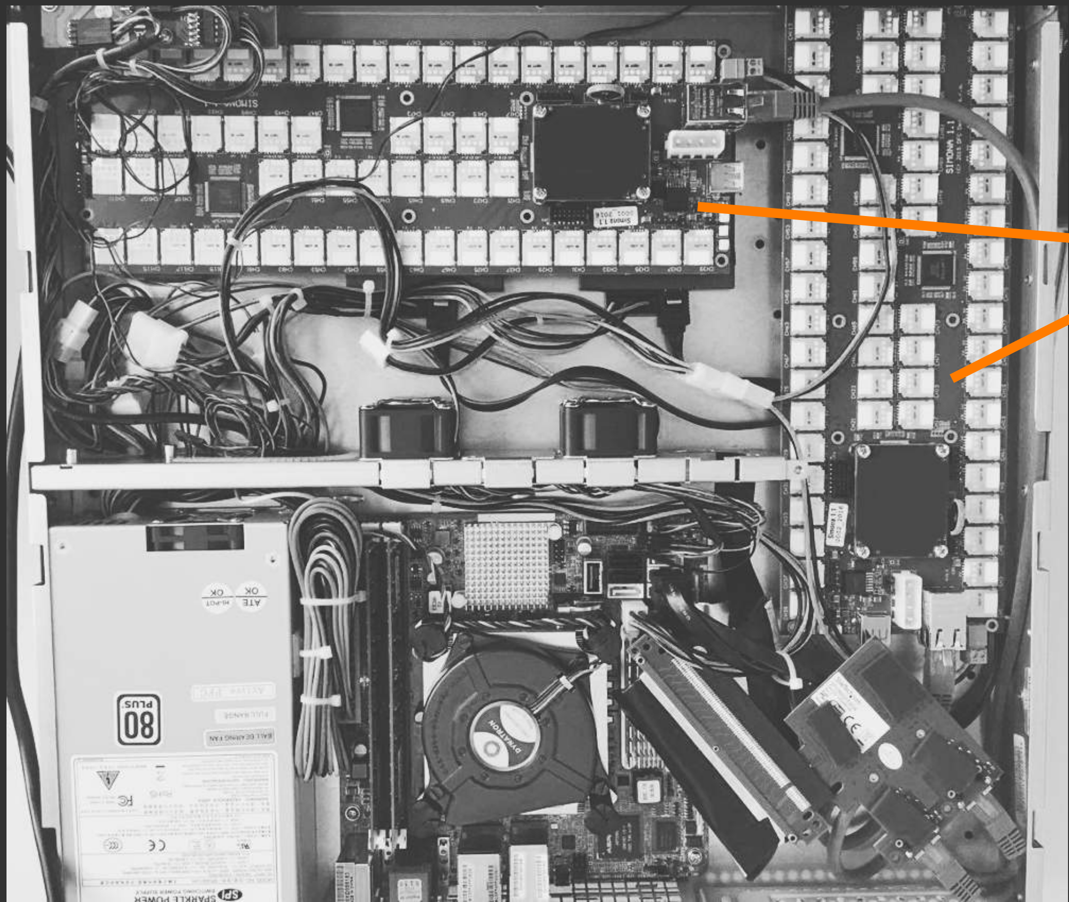

SIMONA boards
with 120 JCs

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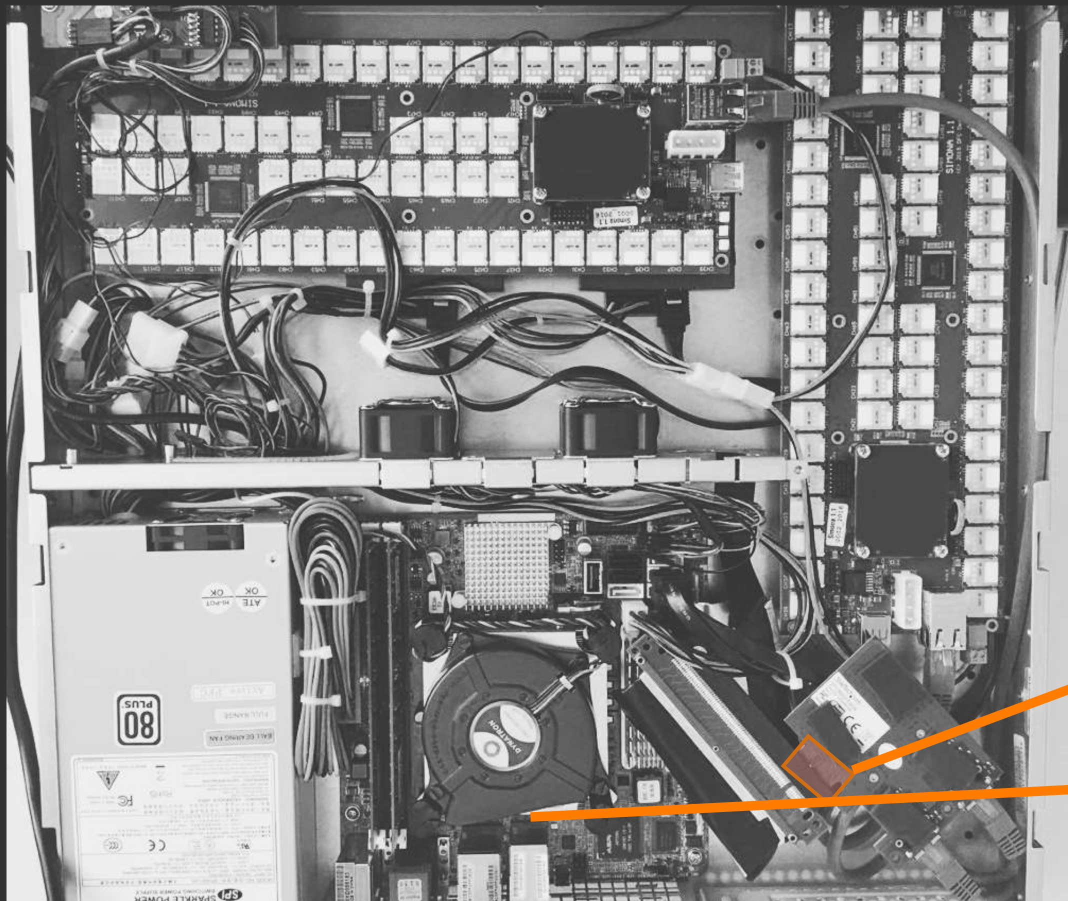

Gigabit link to untrusted Linux server

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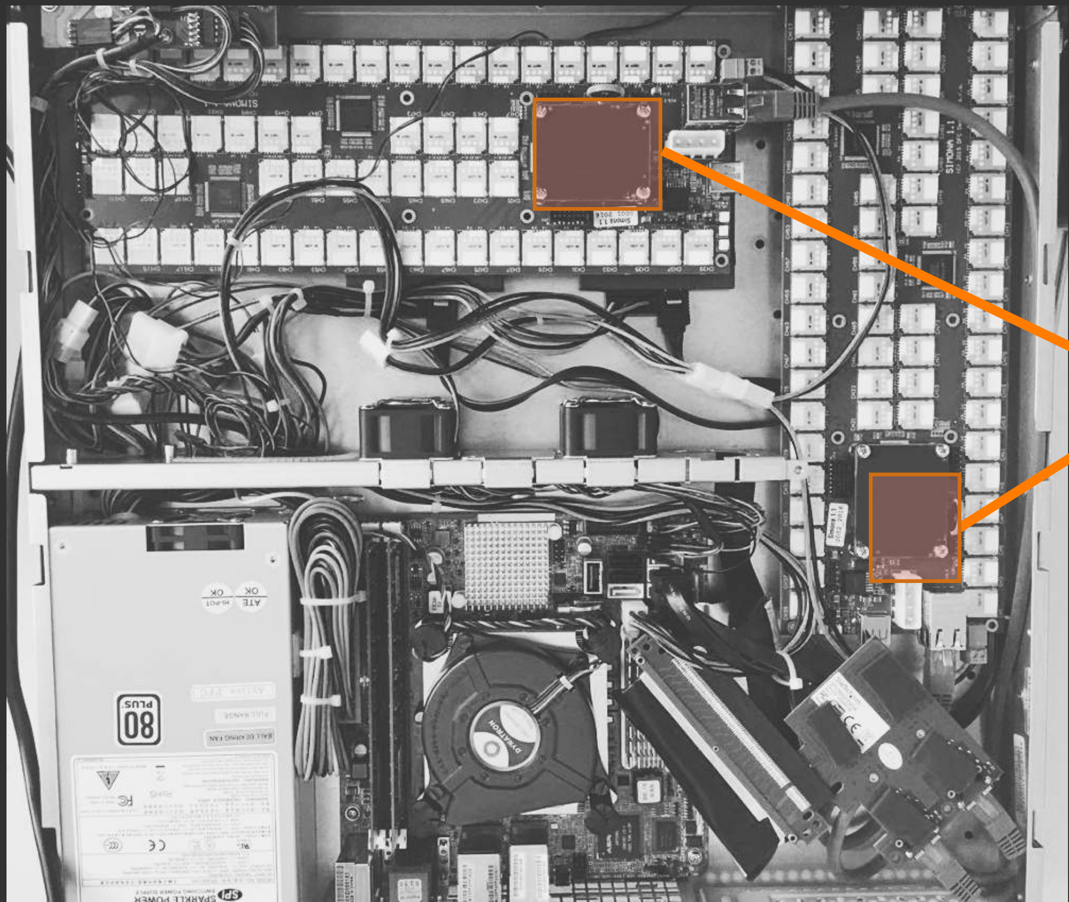

FPGA
- JC /ISO7816->TCP

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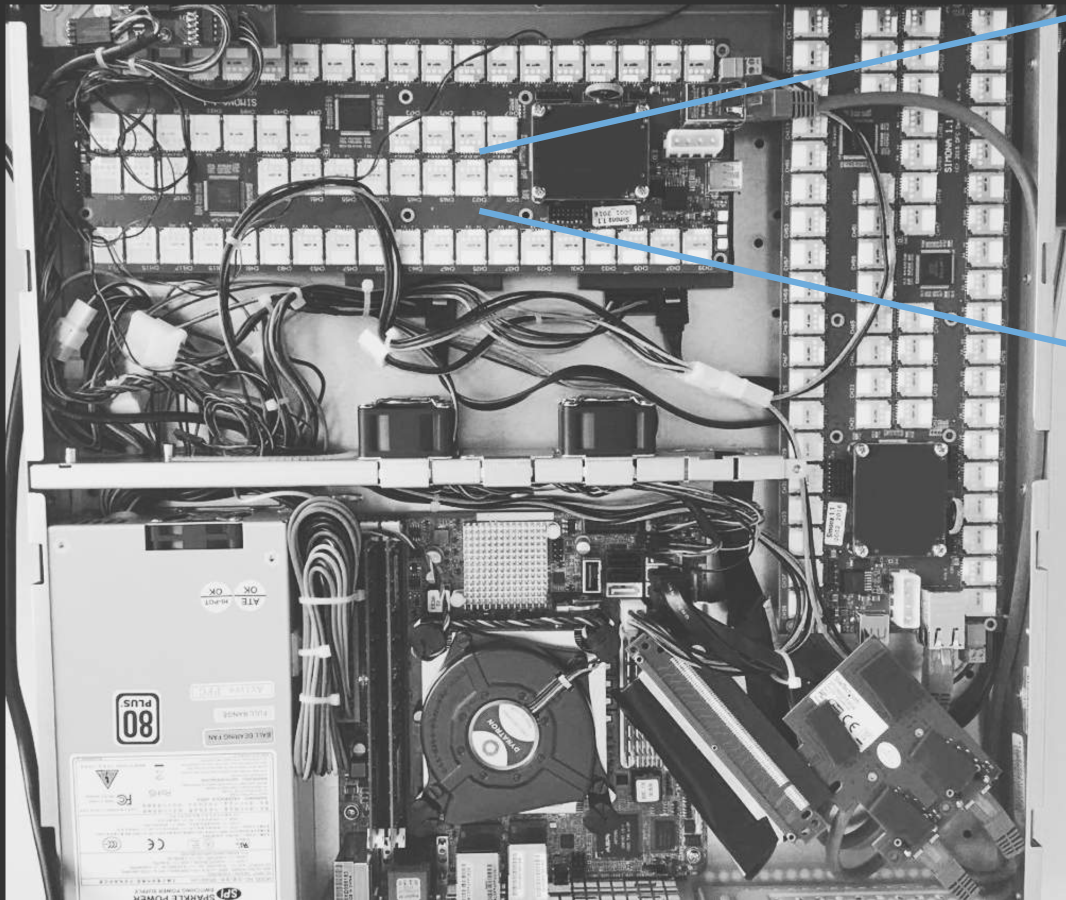

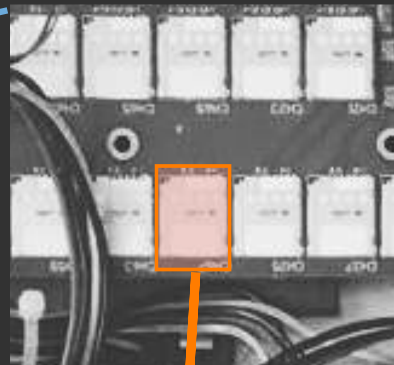

JavaCards
- FIPS140-2 Level 3
- CC EAL5+

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Plugging it into a cloud service

Registration proxy | Wrapper (e.g. PKCS11) | Language binding

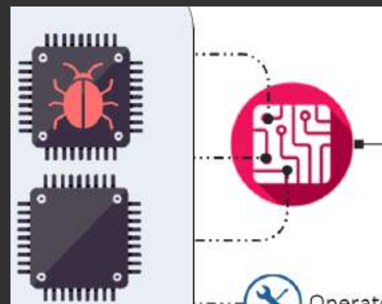
External API (JSON)

Security domain Manager (virtualisation)

Monitoring dashboards

Controller | Controller | Controller

FIPS140-2 L3 hardware | FIPS140-2 L3 hardware | FIPS140-2 L3 hardware



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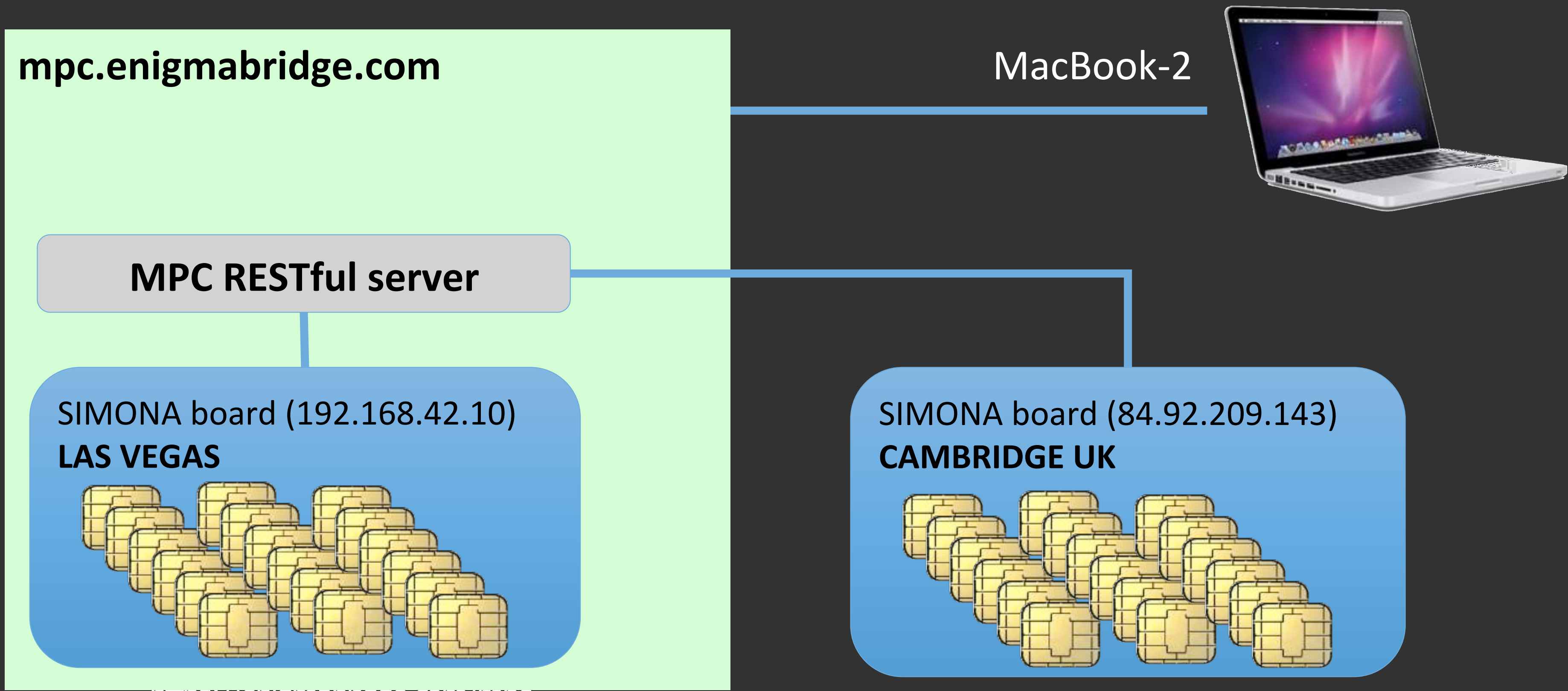
Giving smart-cards an infrastructure



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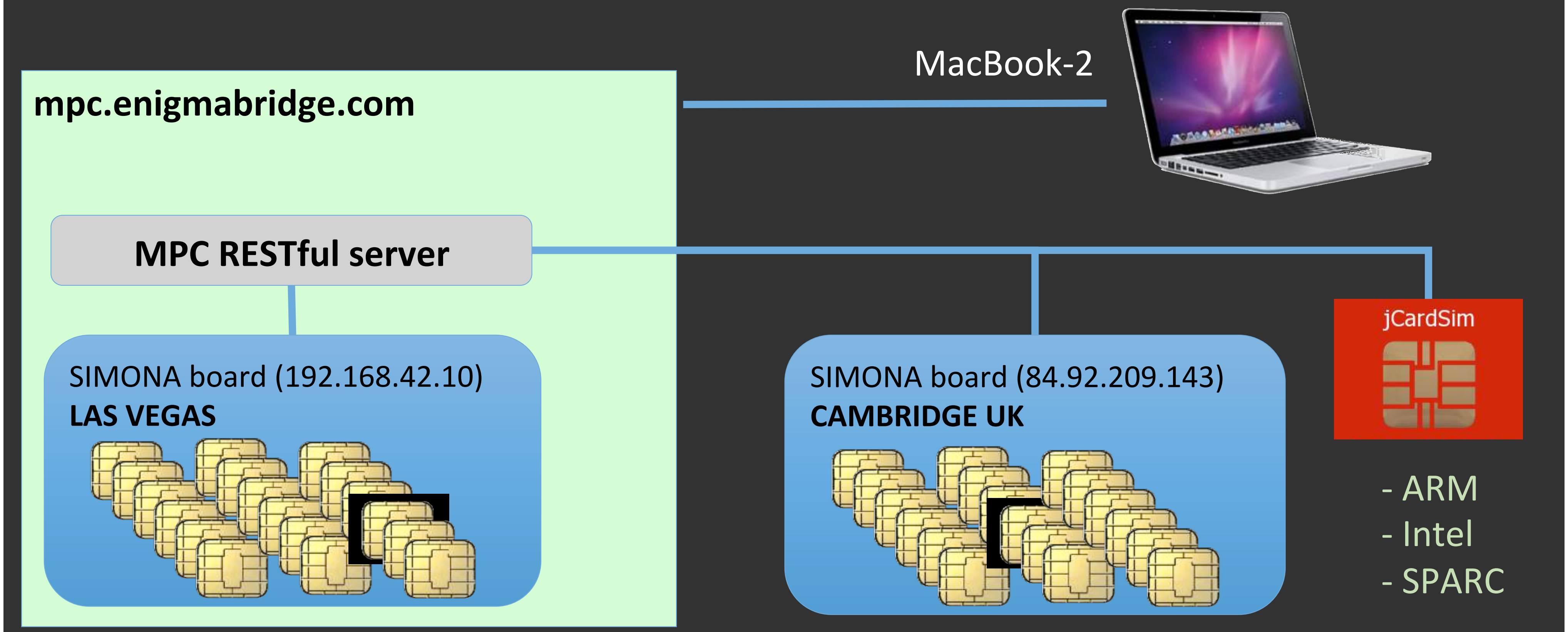
Demo 1

Giving smart-cards an infrastructure



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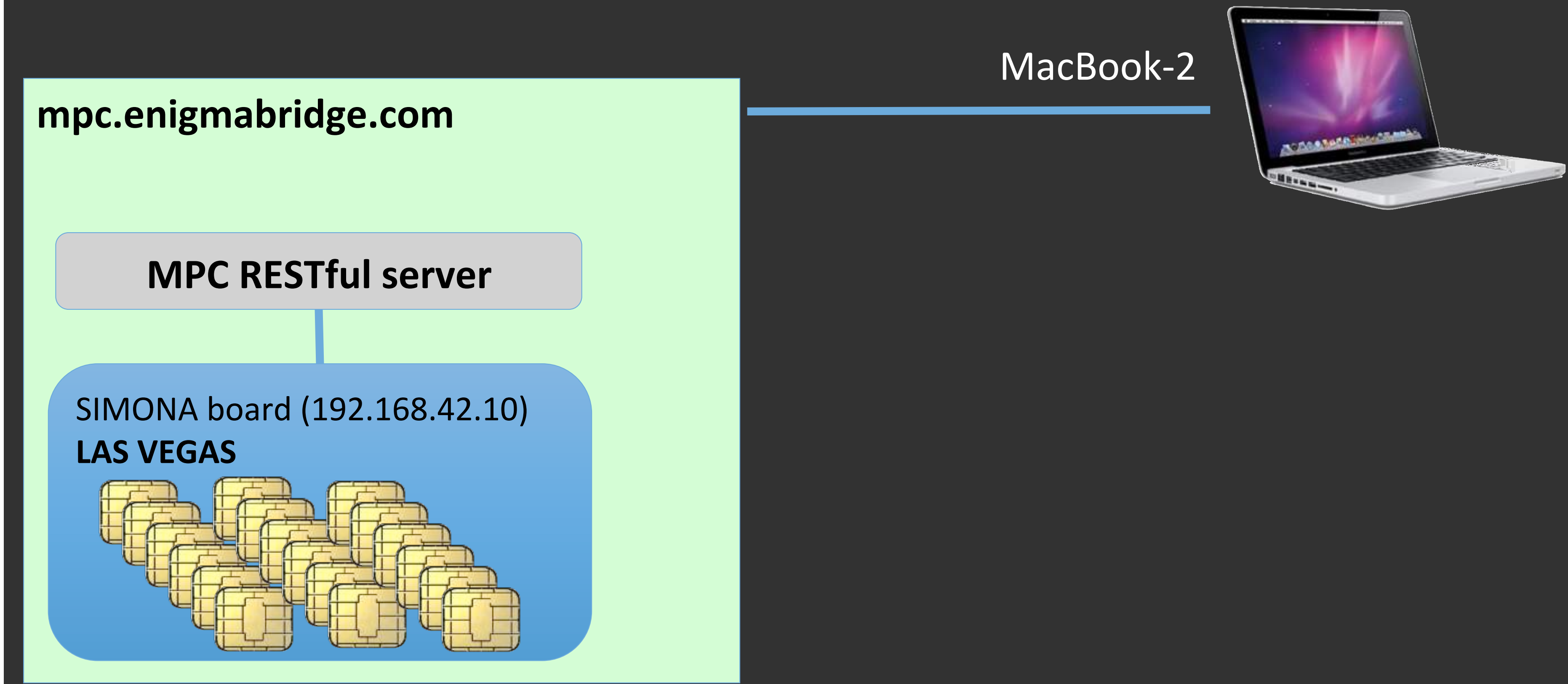
Giving smart-cards an infrastructure



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Demo 2

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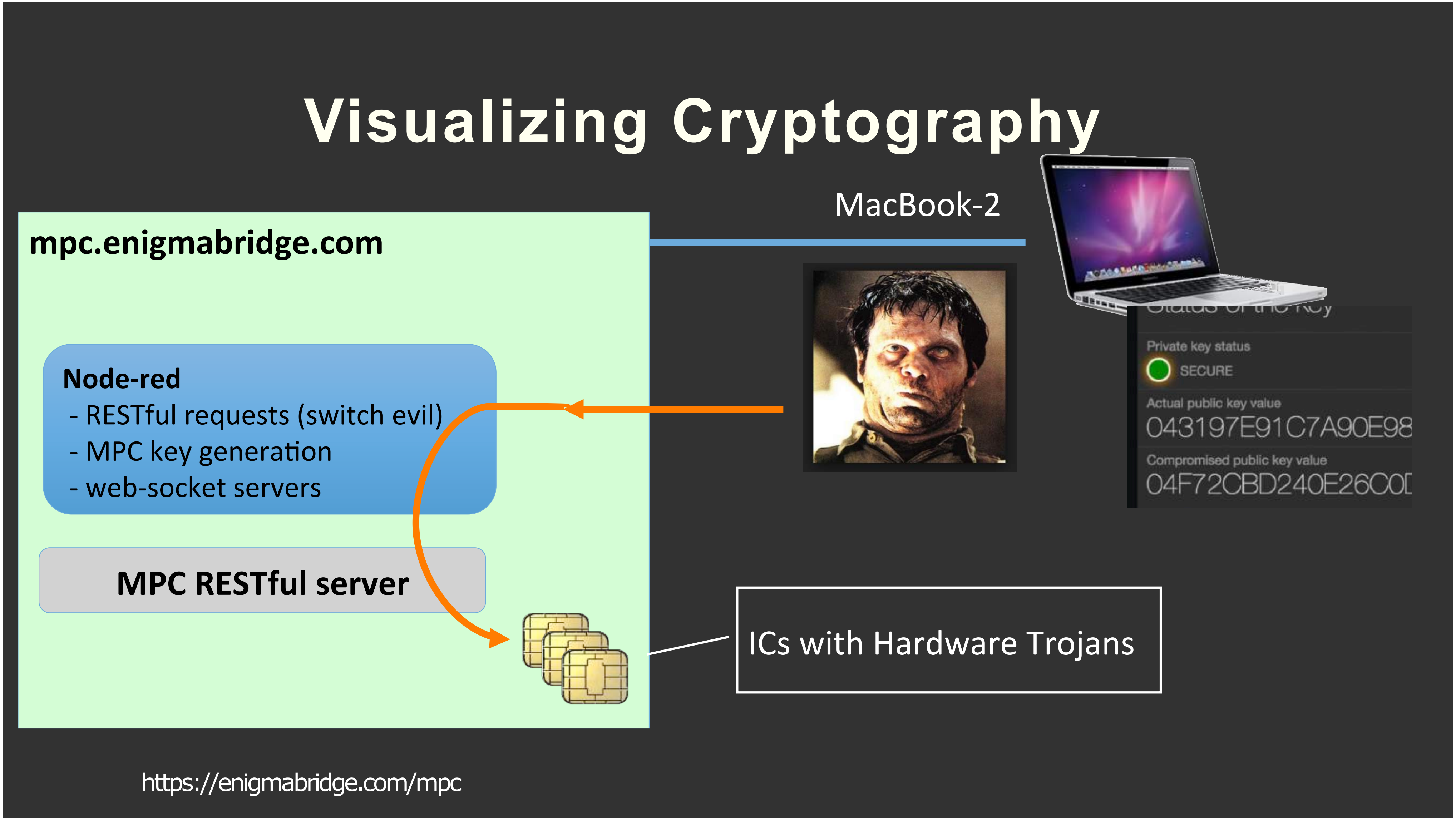

Visualizing Cryptography
MacBook-2
mpc.enigmabridge.com
Node-red
- RESTful requests (switch evil)
- MPC key generation
- web-socket servers
MPC RESTful server
Private key status
SECURE
Actual public key value
043197E91C7A90E98
Compromised public key value
04F72CBD240E26C0
ICs with Hardware Trojans
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Demo 3

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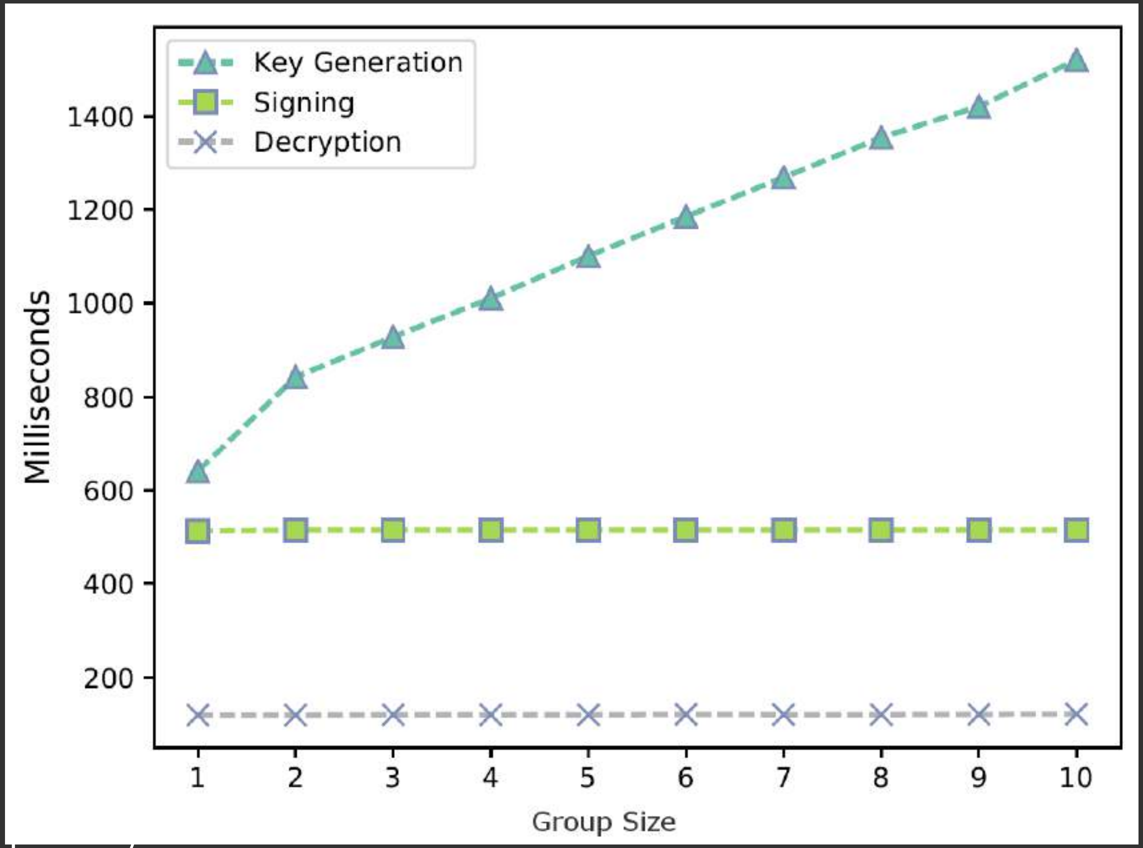
PERFORMANCE

Tolerance vs Runtime



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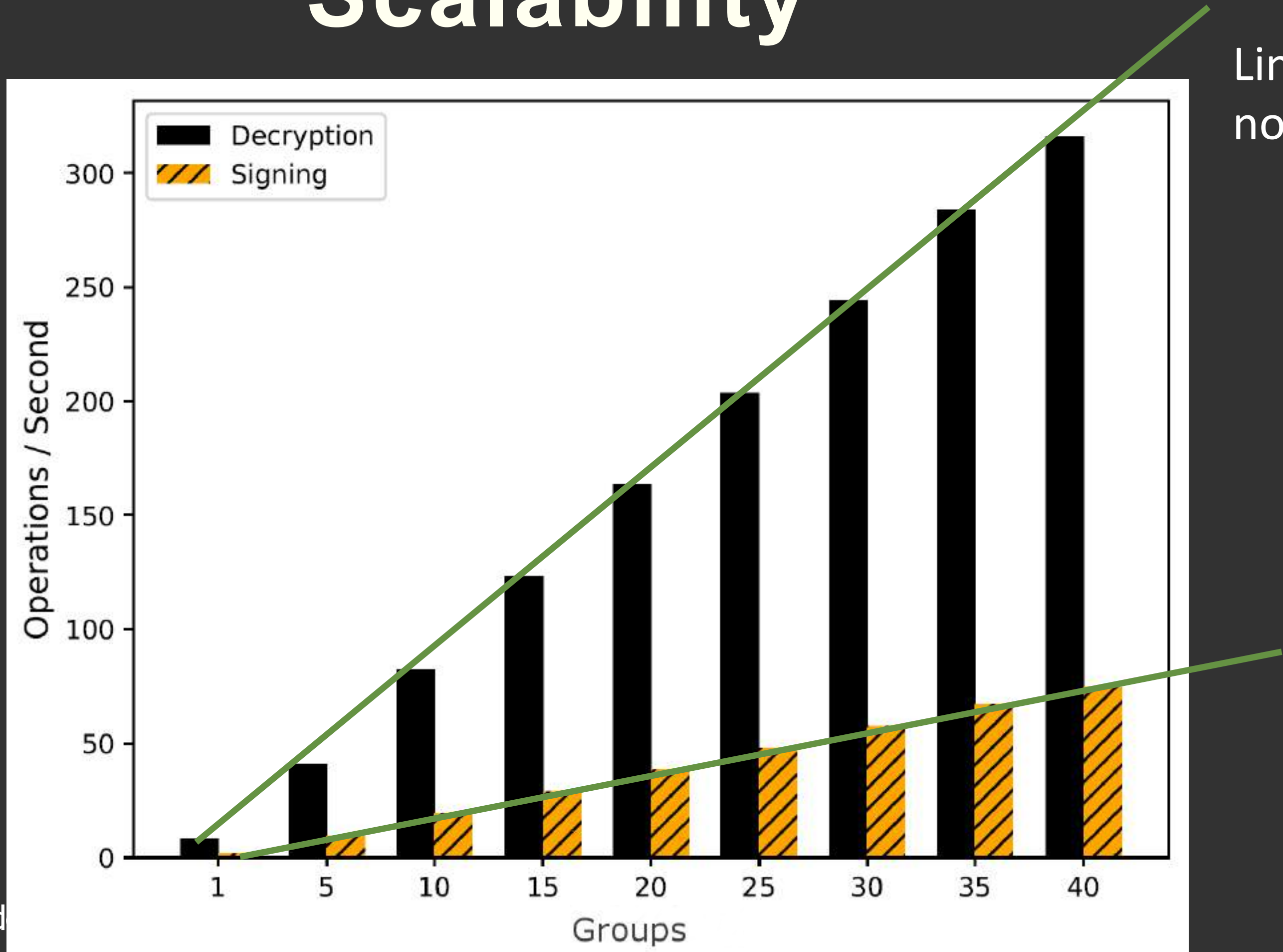
Scalability



Linear,
no bottleneck

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Protocols

Key Points

- No single IC is trusted with a secret (e.g., private key)
- Misbehaving ICs can be detected by honest ones
- If one IC is excluded from any protocol, user can tell

Bonus: Minimize interaction between ICs for performance

Sharing a Secret

- Split a secret in *shares*
- The secret can be reconstructed later
- Without *sufficient* shares not a single bit is leaked
- Splitting Parameters:
  - How many shares the secret is split into (n)
  - How many shares you need to reconstruct the secret (t)

In our case: Each 3 ICs hold shares for a secret

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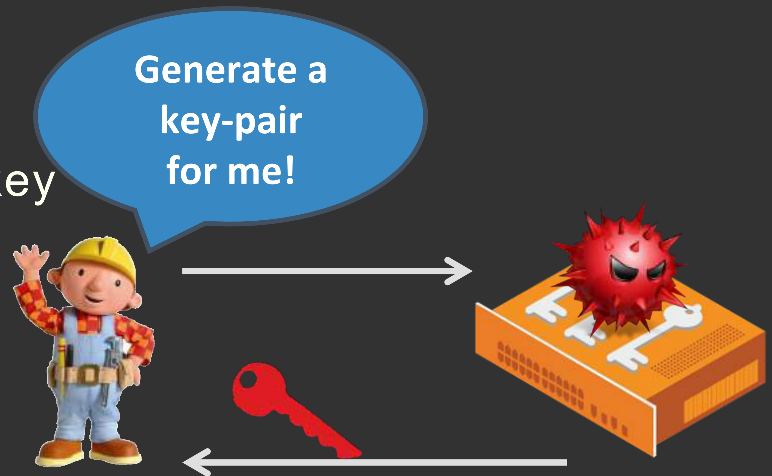
Classic Key Generation

Single IC System

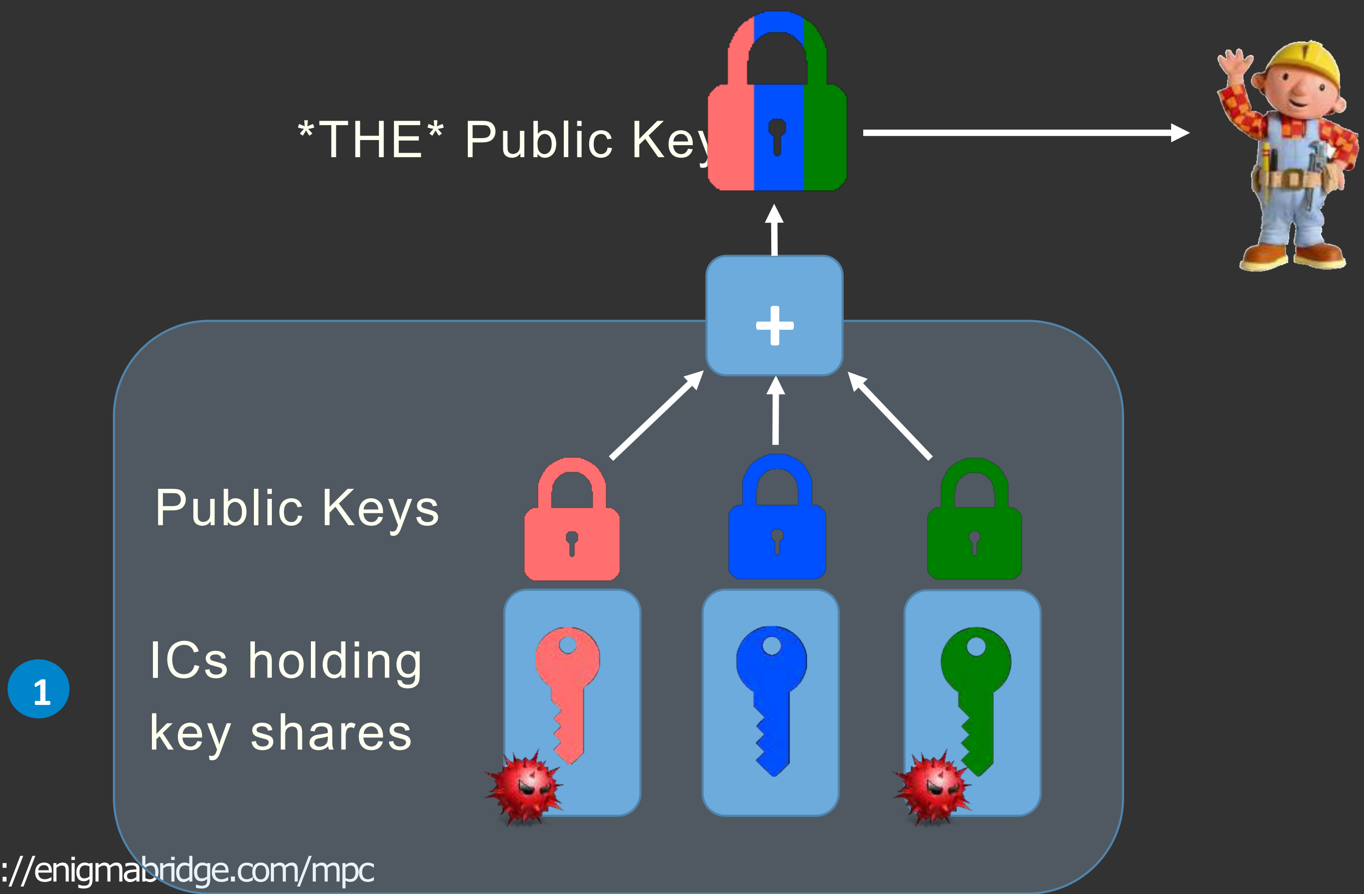
1. Bob asks for new key pair
2. Backdoored IC generates compromised key
3. Private Key is “securely” stored
4. Weak Public key is returned



Problems

- Malicious IC has full access to the private key
- Bob can’t tell if he got a “bad” key

Distributed Key Generation



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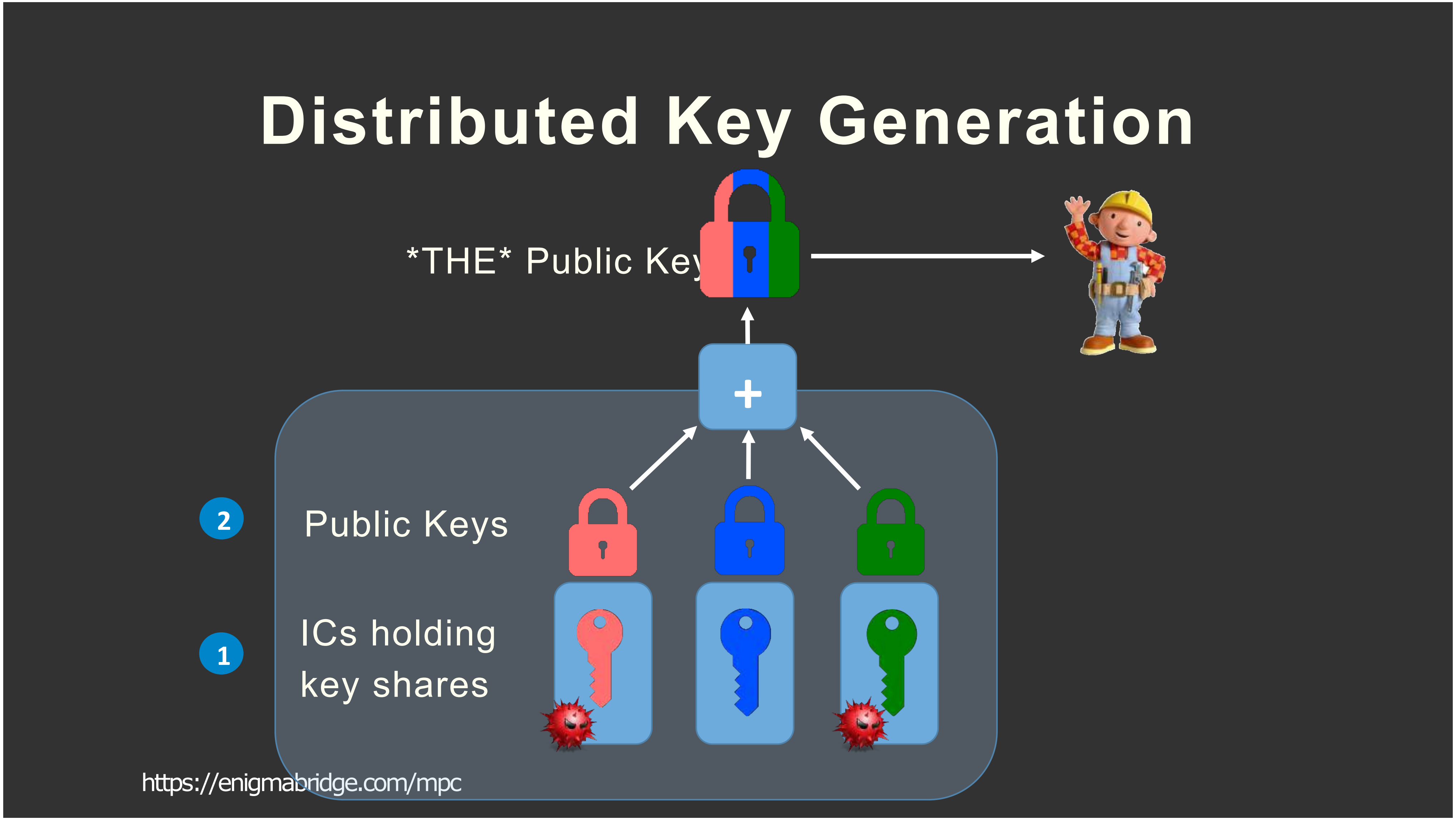
Distributed Key Generation
THE Public Key
+
2
Public Keys
1
ICs holding
key shares
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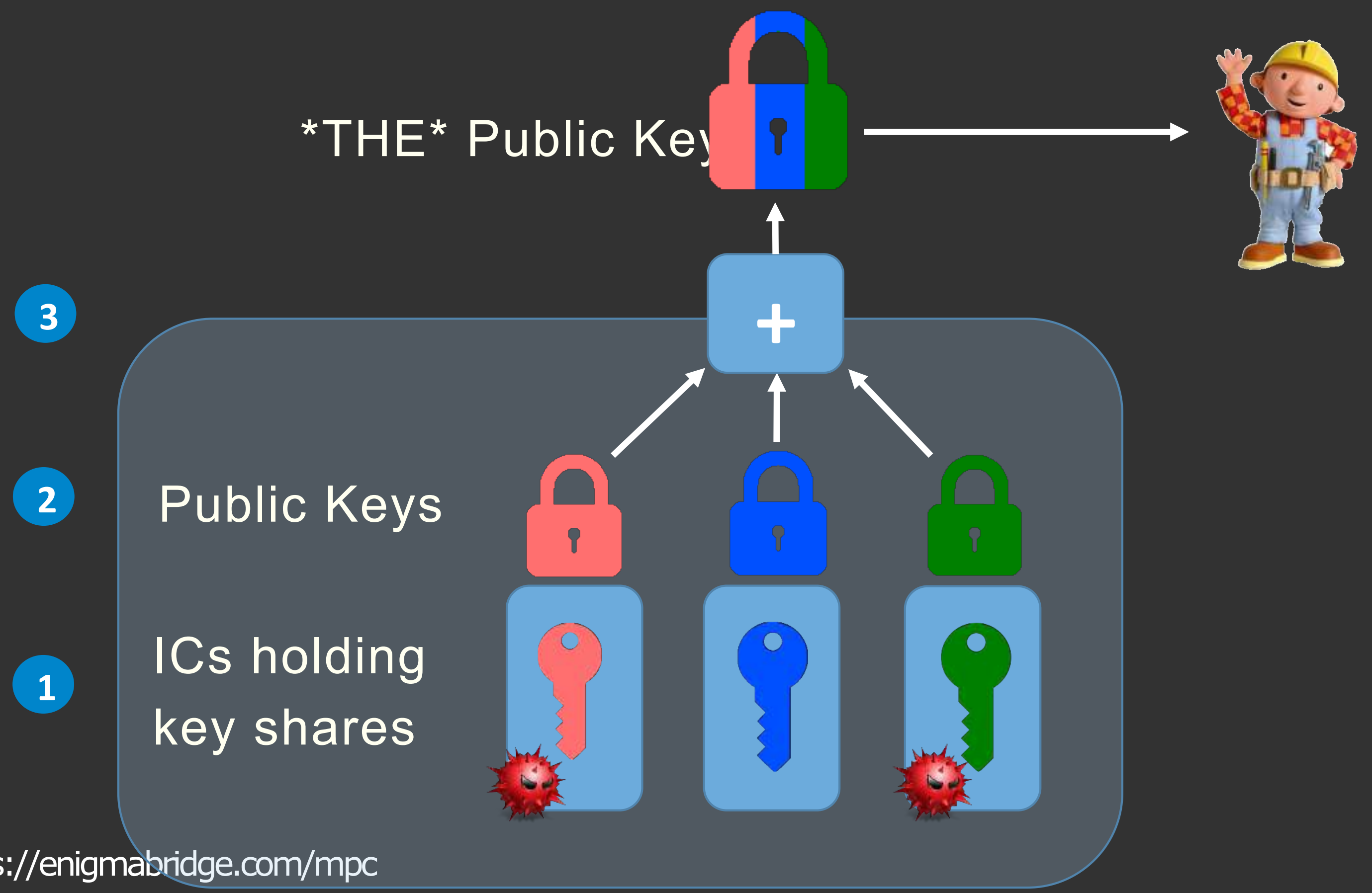
Distributed Key Generation



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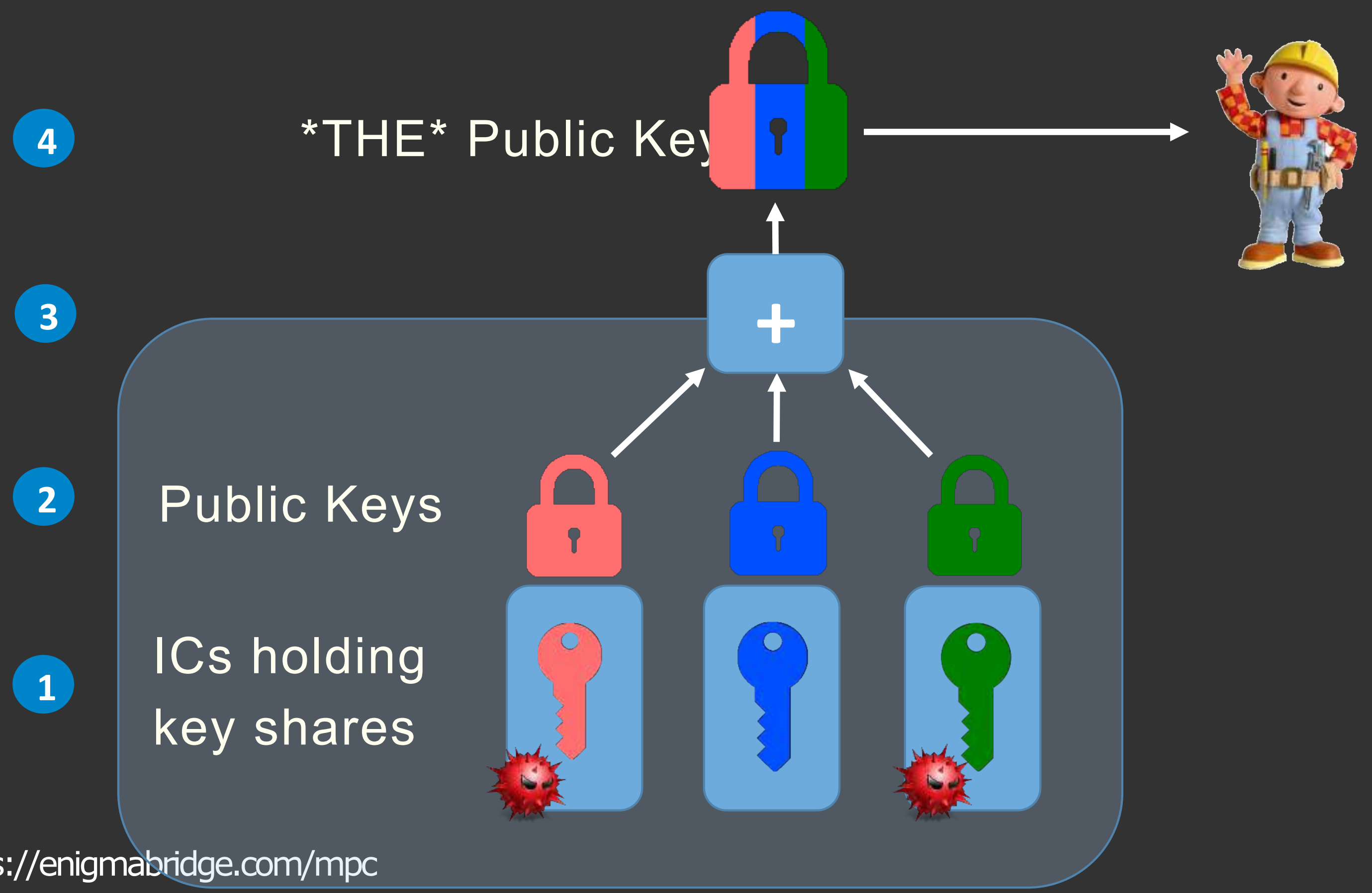
Distributed Key Generation



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Distributed Key Generation

Key Points

- No single IC is trusted with a secret (e.g., private key) ✔
- Misbehaving ICs can be detected by honest ones ✔
- If one IC is excluded from any protocol, user can tell ✔

Bonus: Minimize interaction between ICs for performance ✘

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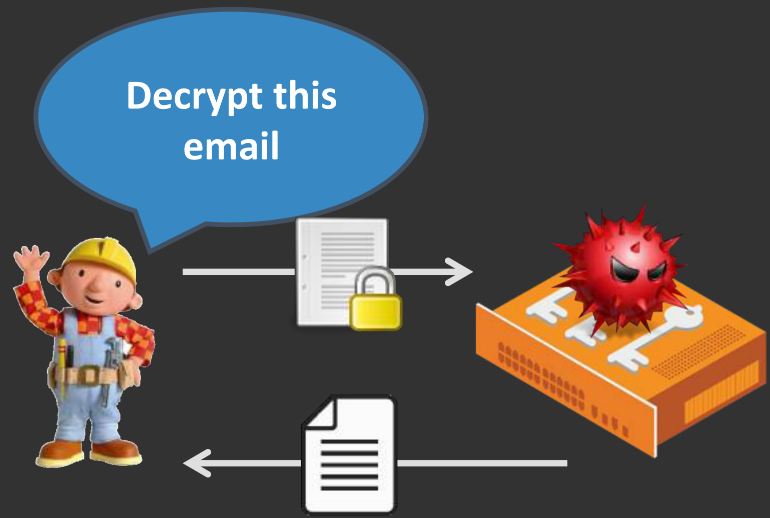
Classic Decryption

Single IC System

1. Bob asks for ciphertext decryption
2. Backdoored IC decrypts ciphertext
3. Bob retrieves plaintext



The IC needs full access to the private key to be able to decrypt ciphertexts.

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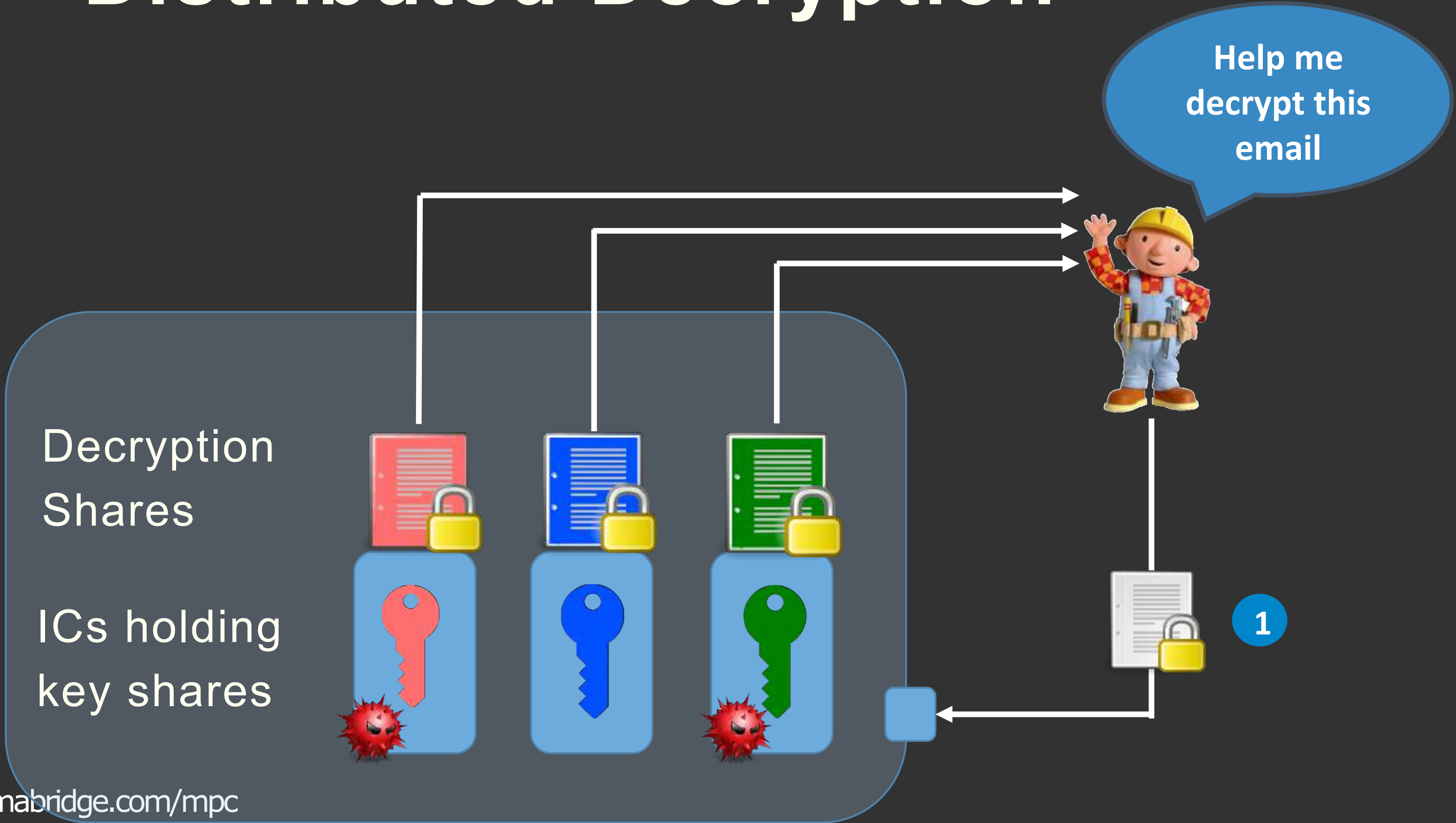
Distributed Decryption



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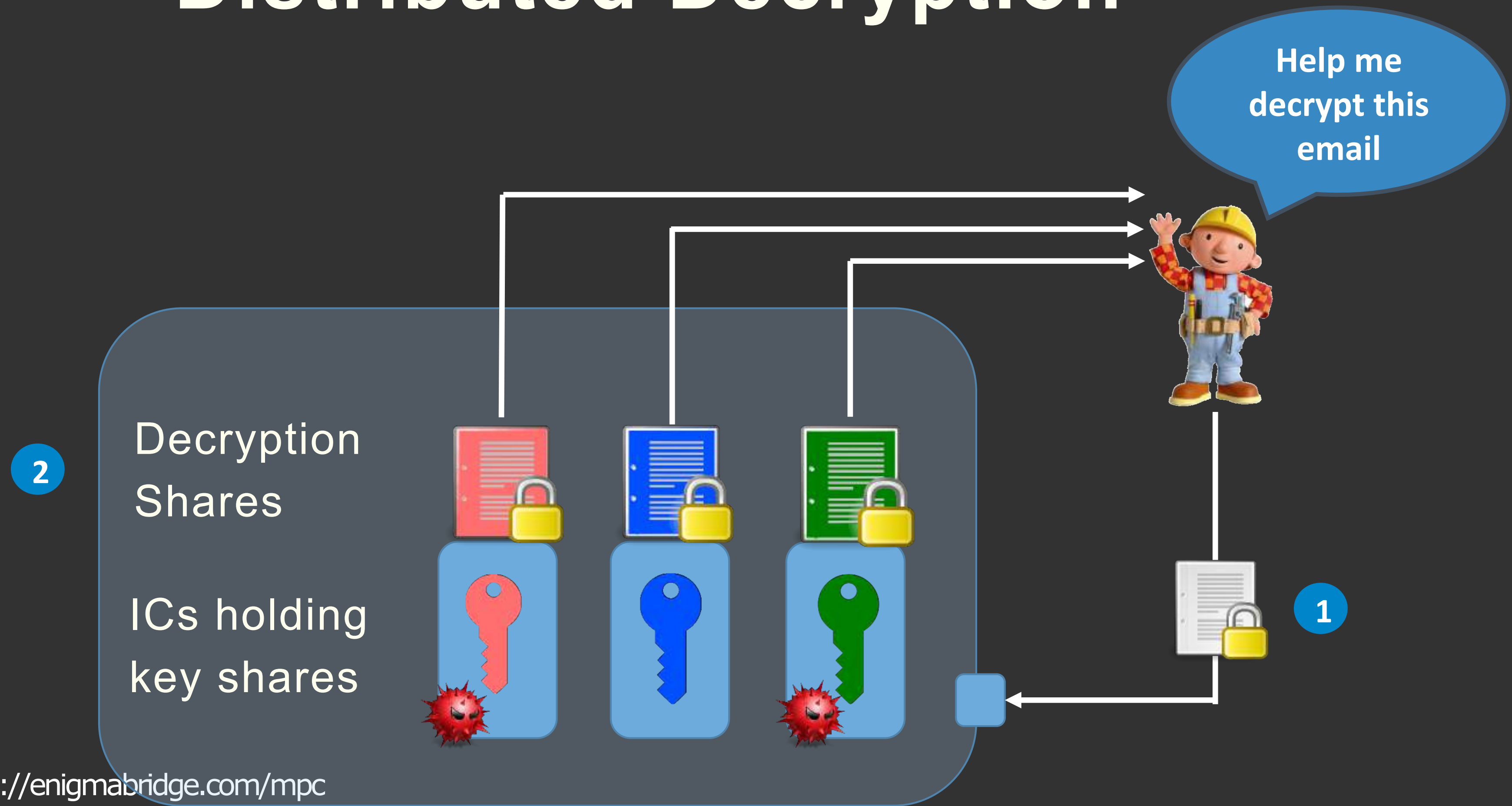
Distributed Decryption



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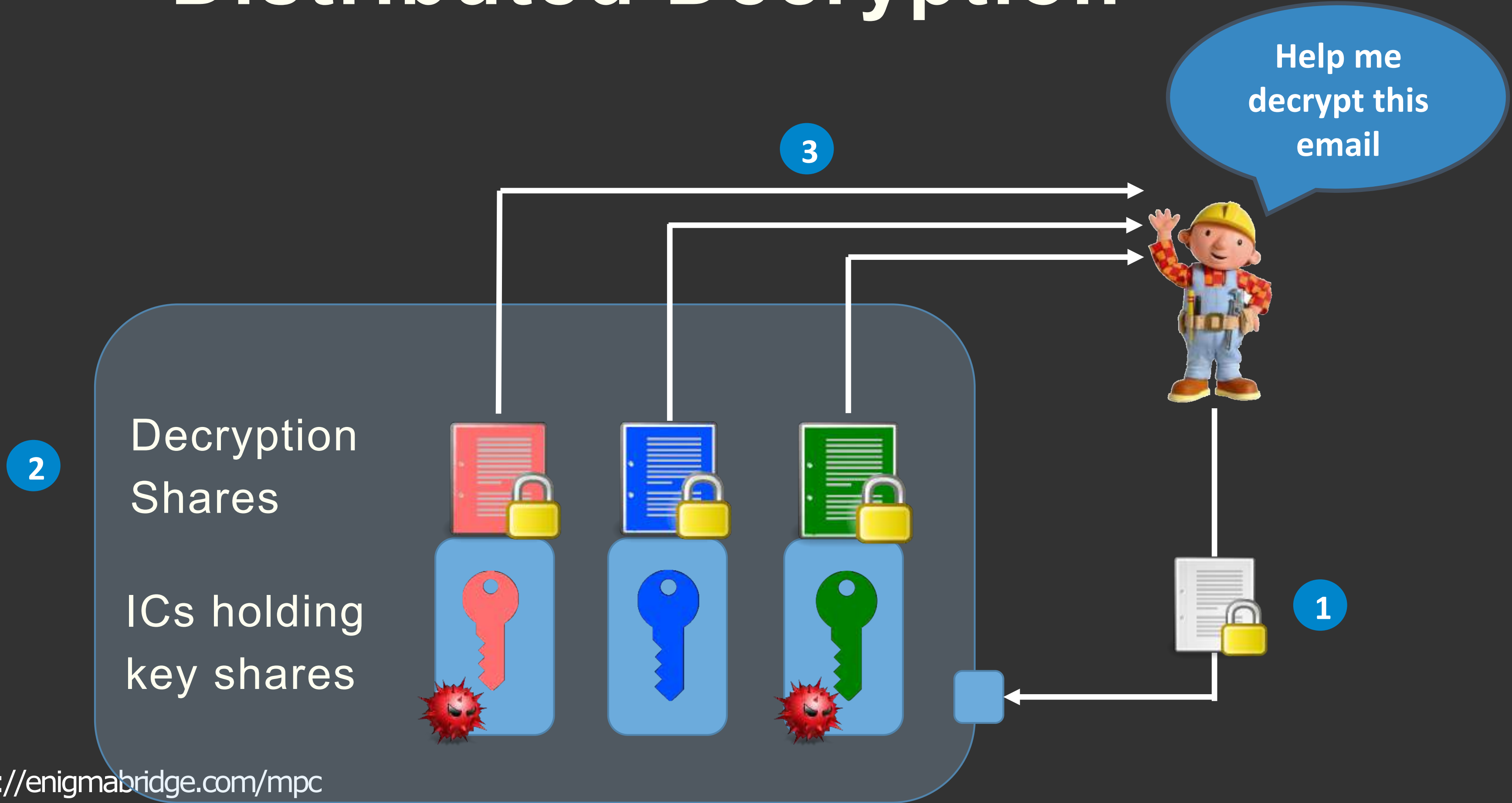
Distributed Decryption



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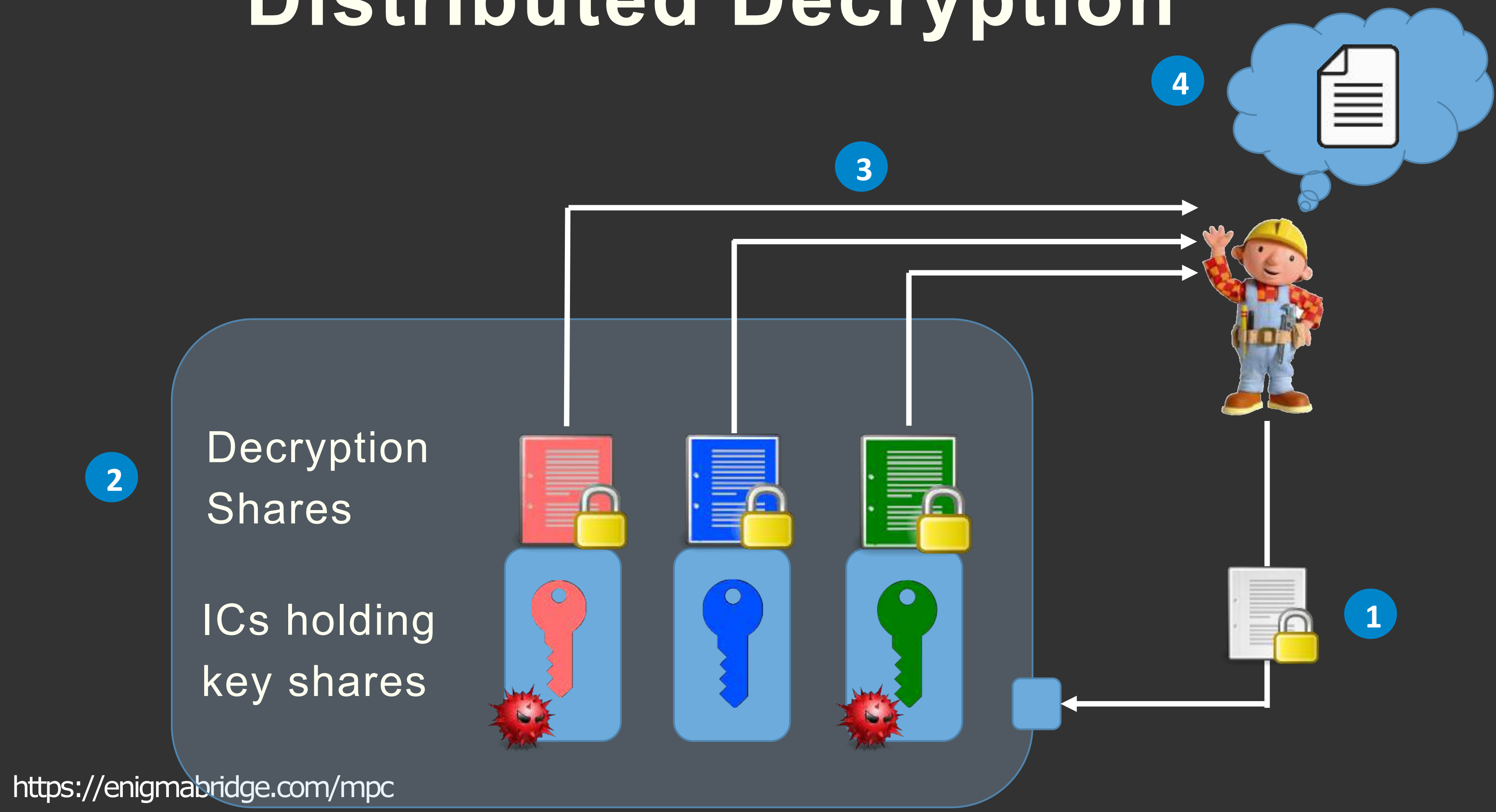
Distributed Decryption



Distributed Decryption

Key Points

- No single IC is trusted with a secret (e.g., private key) ✔
- Misbehaving ICs can be detected by honest ones -
- If one IC is excluded from any protocol, user can tell ✔

Bonus: Minimize interaction between ICs for performance ✔

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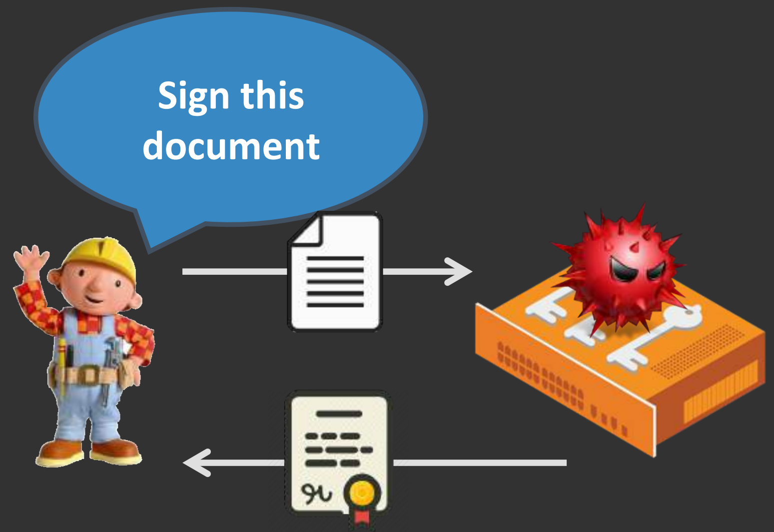
Classic Signing

Single IC System

1. Bob asks for document signing
2. Backdoored IC signs the plaintext
3. Bob retrieves signature



The IC needs full access to the private key to be able to sign plaintexts.

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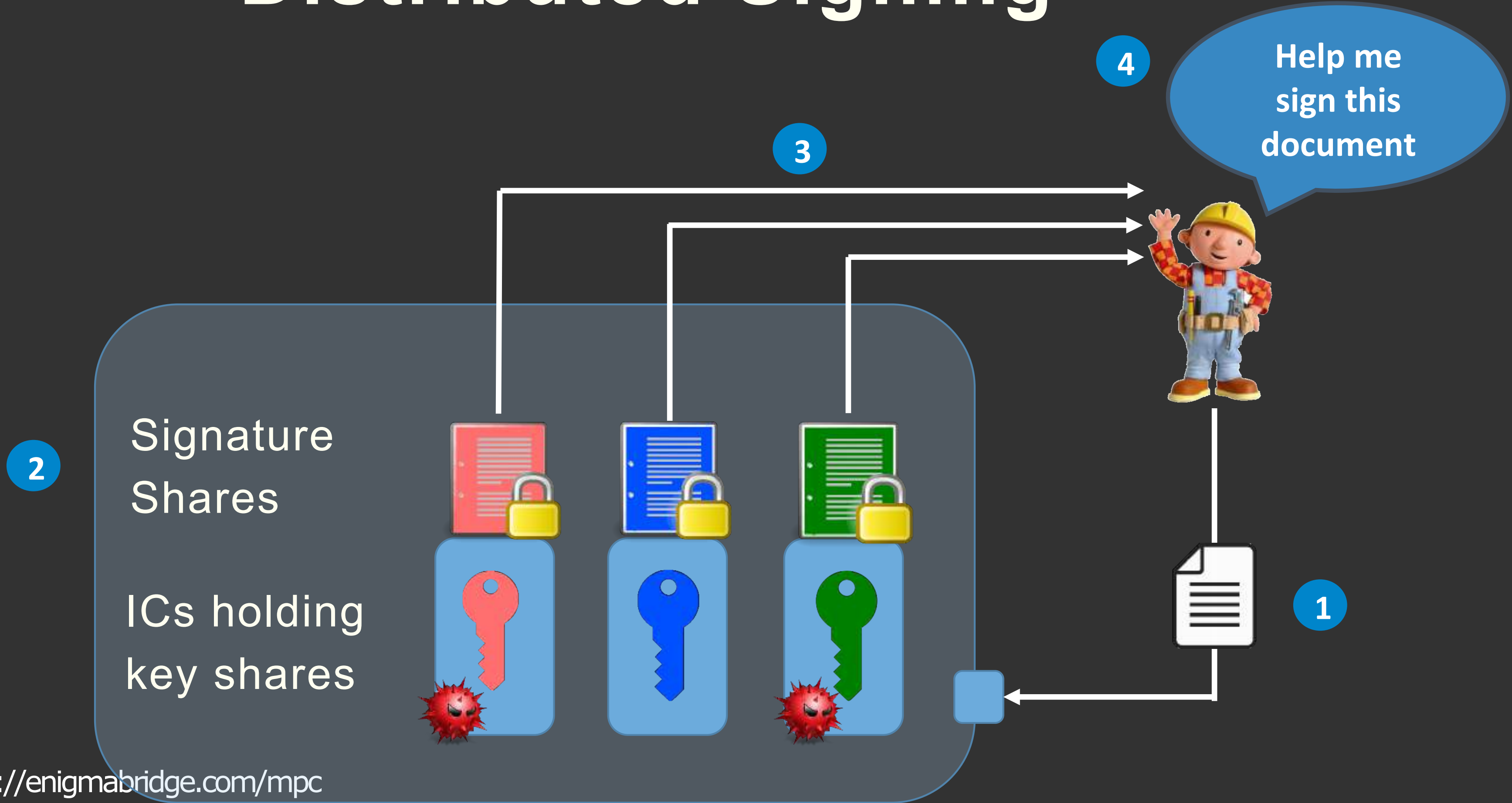
Distributed Signing



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Distributed Signing I

Caching

1. Bob sends a caching request
2. The ICs verify Bob's authorization
3. Generate a random group element based on j
4. Bob sums the random elements

Properties

- Caching for thousands of rounds (j)
- Bob stores R_j

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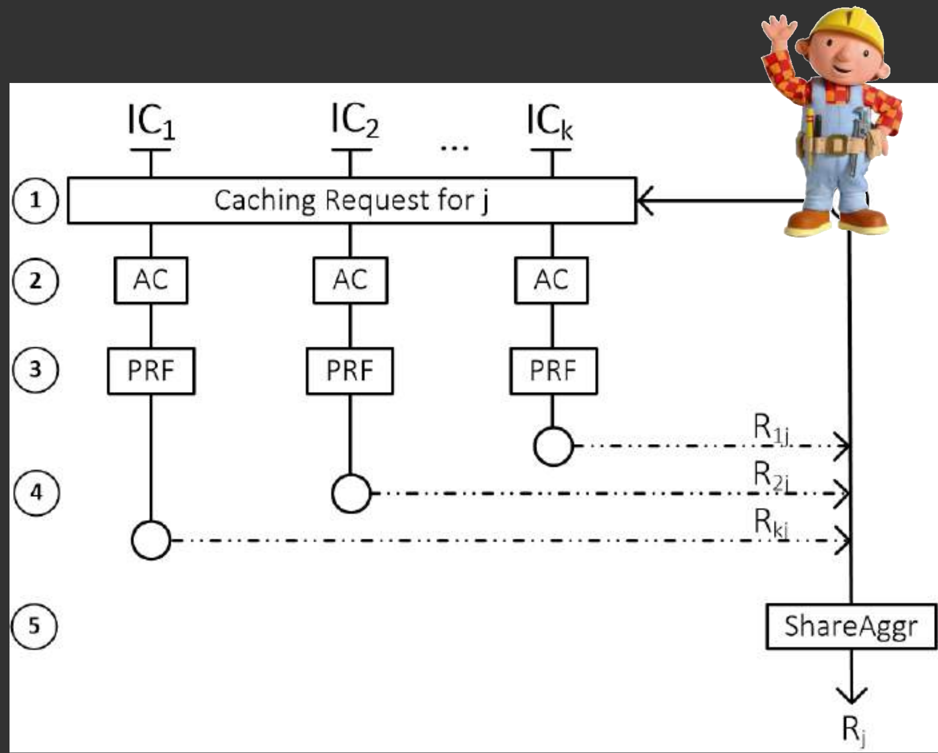

Distributed Signing II

Signing

1. Bob asks for document signing & sends R_j, j, and the hash of m
2. ICs verify his authorization
3. ICs check if j has been used again
4. ICs compute their signature share
5. Bob sums all signature shares

Properties

- All ICs must participate
- Significant speed up with caching

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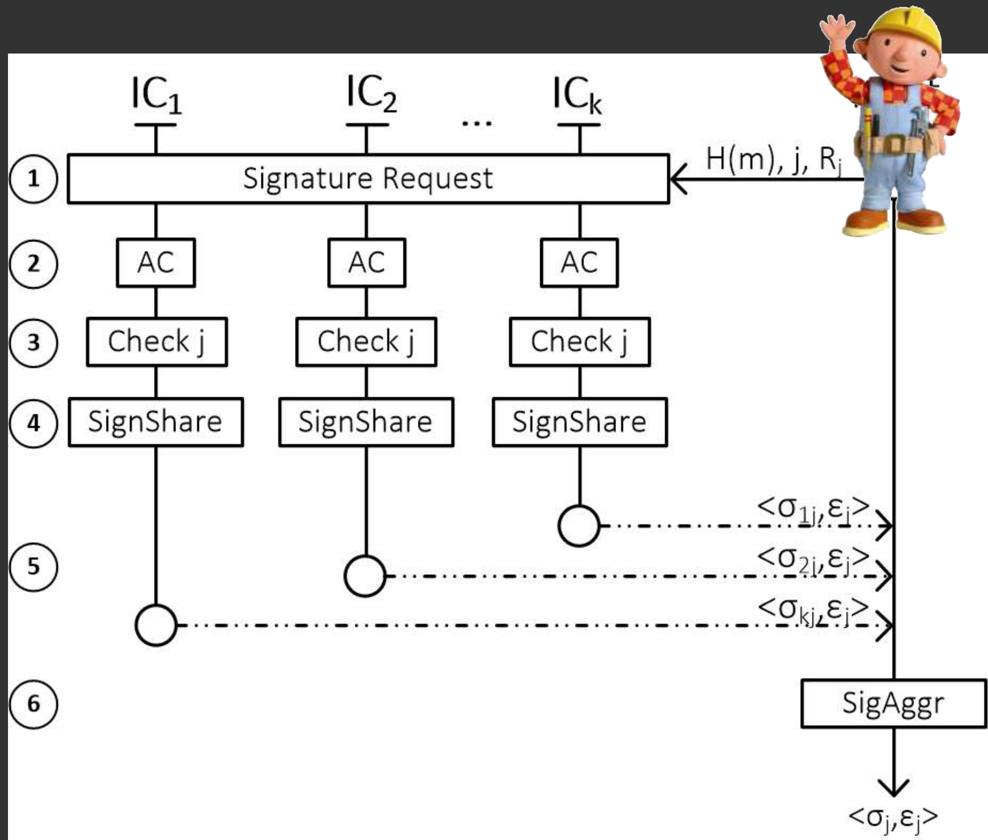

Distributed Signing

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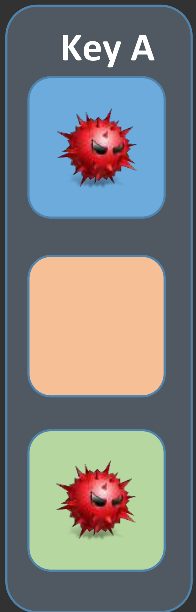
How we made it scale



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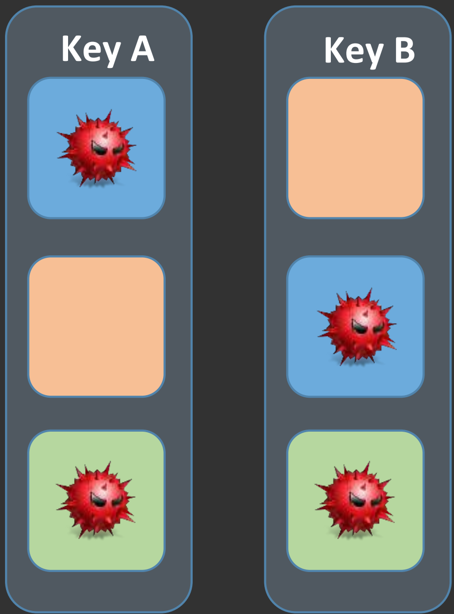

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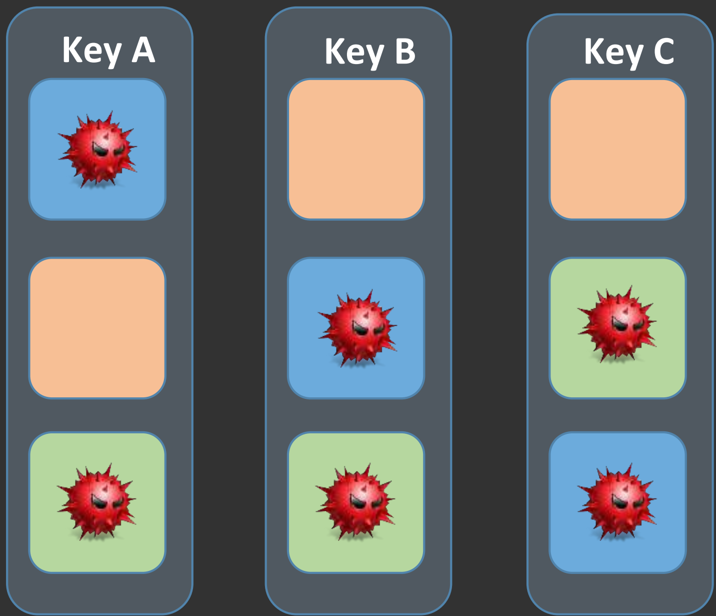

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How we made it scale

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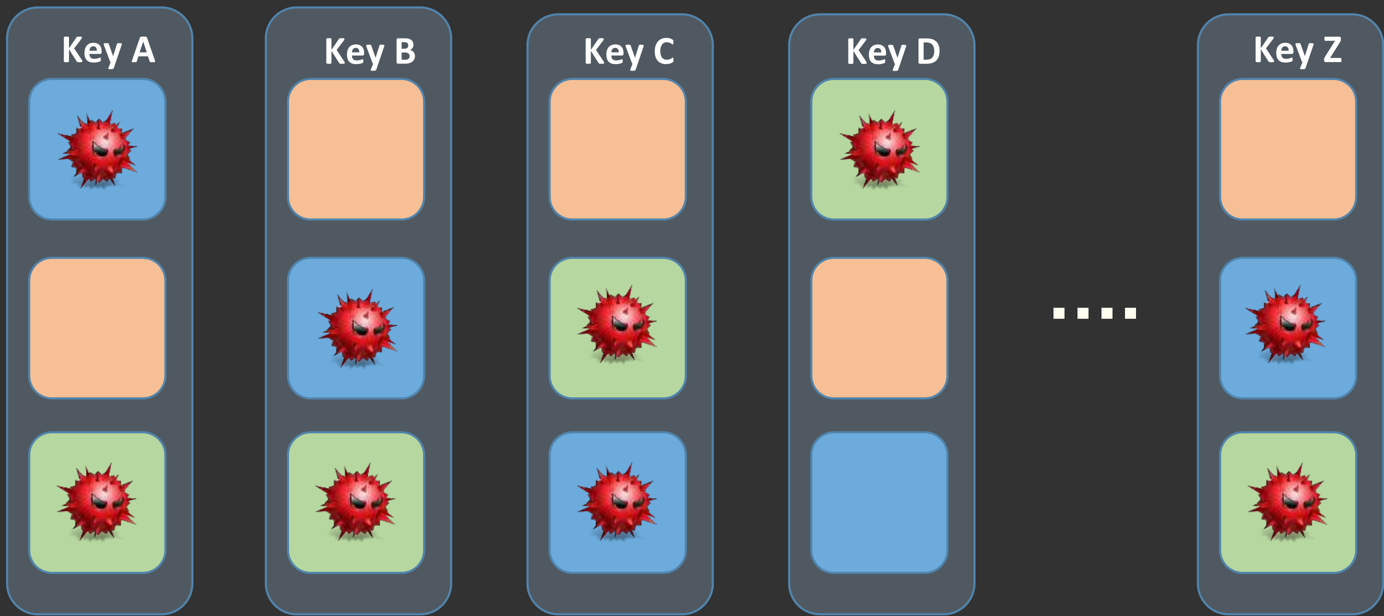
How we made it scale



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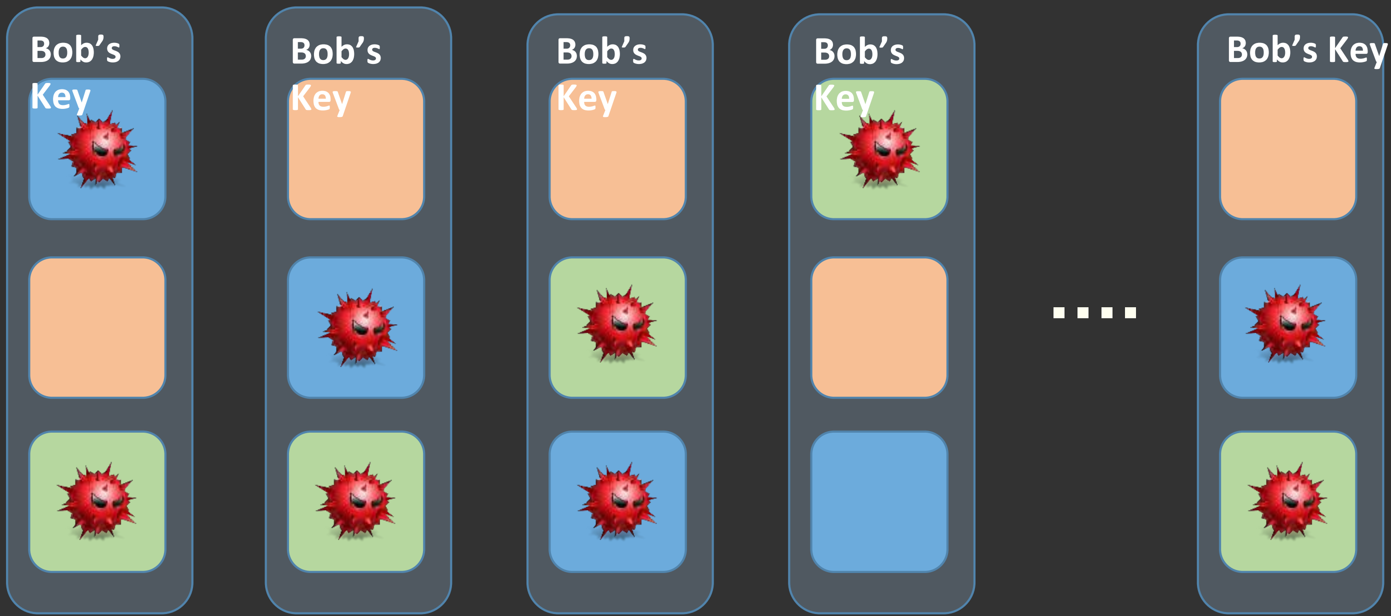
How we made it scale

But how can all these groups have shares for the same key?



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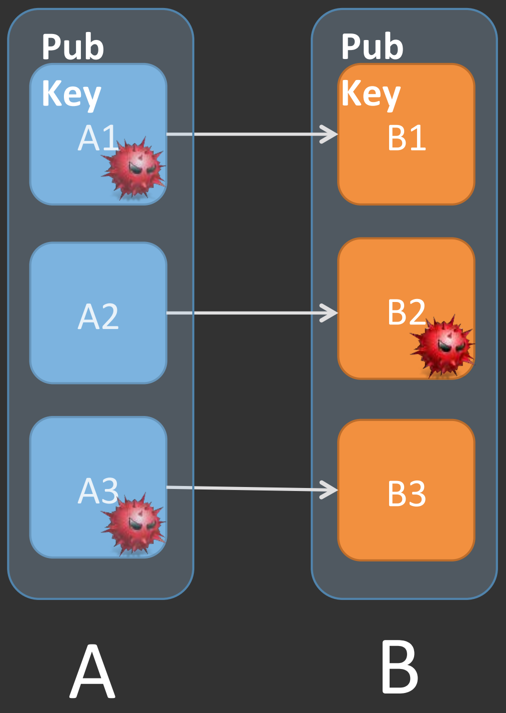
Key Replication



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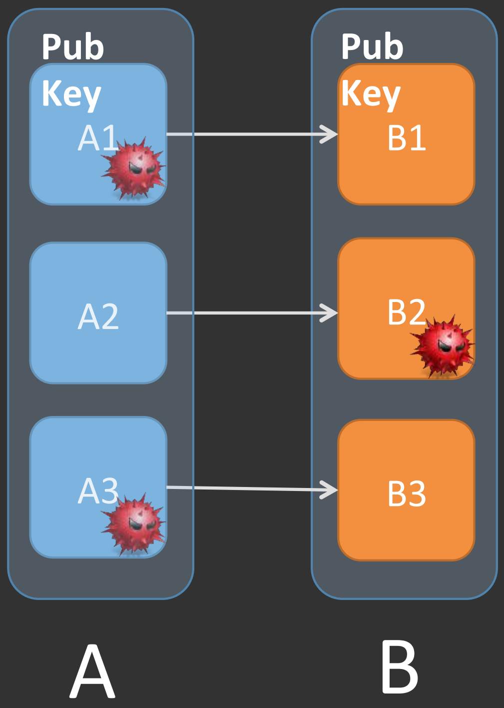
1. Group A generates a public key
2. A1, A2, A3 send their shares to B1, B2, B3
3. Each IC in B receives shares from A1, A2, A3
4. Each IC in B combines the 3 shares and retrieves its private key

~~Key Replication~~



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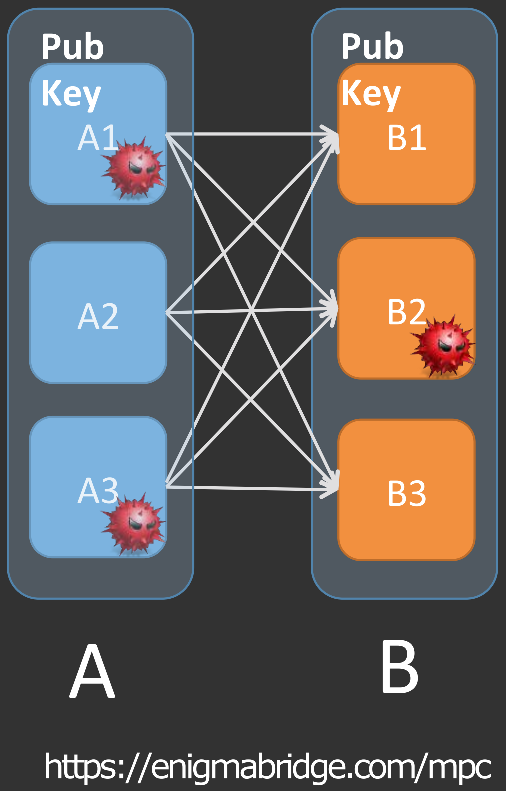
1. Group A generates a public key
2. A1, A2, A3 send their shares to B1, B2, B3
3. Each IC in B receives shares from A1, A2, A3
4. Each IC in B combines the 3 shares and retrieves its private key
5. **A1, A3 and B2 collude**

The adversary retrieves the secret!

Key Replication



1. Group A generates a public key
2. Then each IC in A splits its private key in three shares and sends them to B1, B2, B3
3. Each IC in B receives shares from A1, A2, A3
4. Each IC in B combines the 3 shares and retrieves its private key share

The full public keys of A and B are the same!

geopolitics

“We can guarantee *security* if t*here is at least one honest IC that is not backdoored or faulty.*”

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“We can guarantee *security* if t*here is at least one honest IC that is not backdoored or faulty.*”

What if all ICs are malicious?

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Government-level adversaries

- Deep access to fabrication facilities
- Very sophisticated techniques
- Very hard to detect their Backdoors/ Trojans
- Very secretive; highly classified
- Won’t share their backdoor details

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Government-level adversaries

- Deep access to fabrication facilities
- Very sophisticated techniques
- Very hard to detect their Backdoors/Trojans
- Very secretive; highly classified
- Won’t share their backdoor details
- Unlikely to collude with anyone

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“We can guarantee security even when all *ICs* *are malicious, if at least one does not collude.”*

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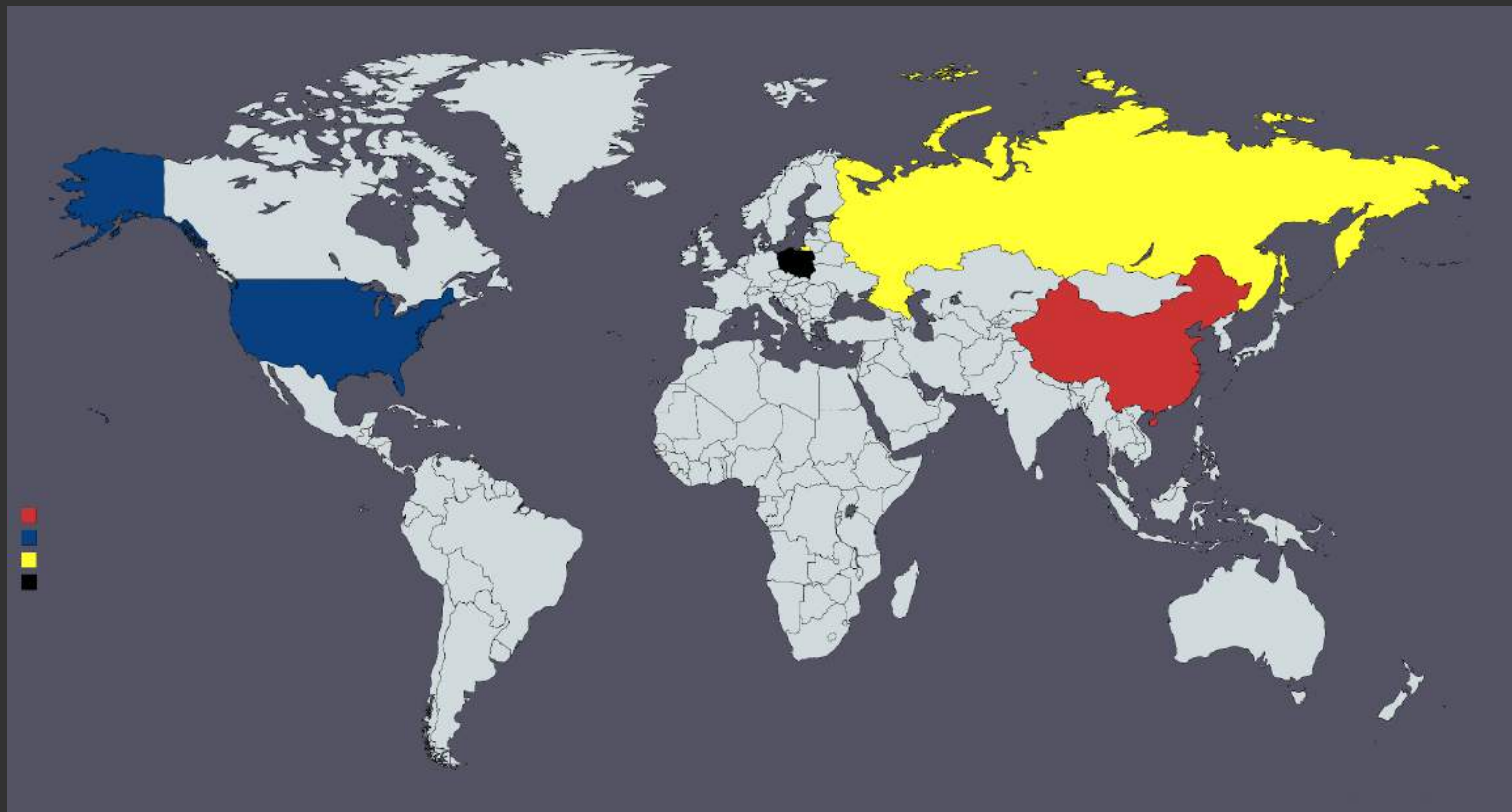

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Conclusions & Future

New crypto hardware architecture

- For the first time, tolerates faulty & malicious hw
- Decent Performance
- Scales nicely; just keep adding ICs
- Suitable for commercial-off-the-shelf components
- Existing malicious insertion countermeasures are very welcome!

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Trojan-tolerant Hardware
+ Supply Chain Security in Practice

find more at
https://enigmabridge.com/mpc

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