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Agile Cryptography

About & Beyond PKI

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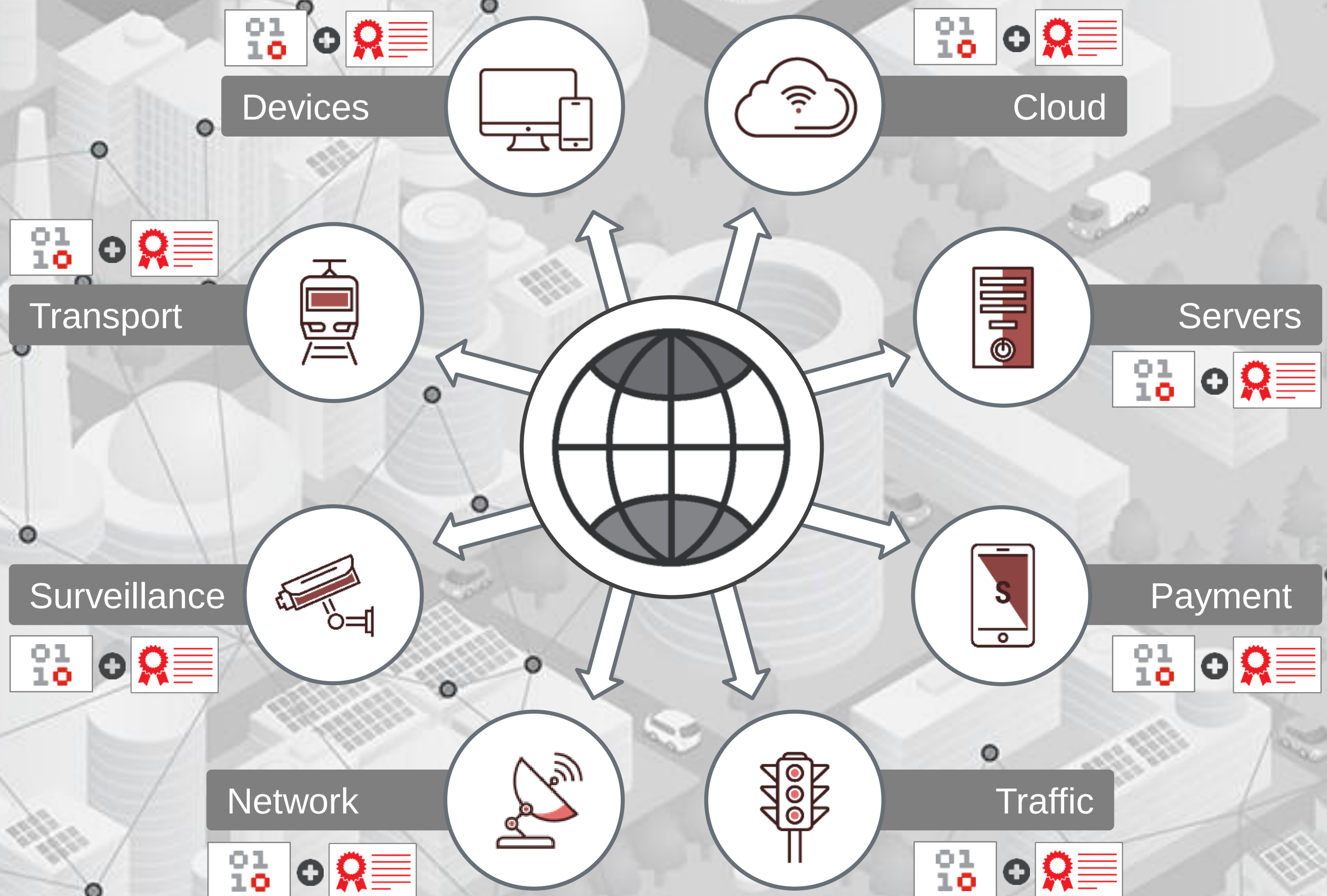
Digital safety relies on cryptography



STRONG CRYPTOGRAPHY IS CORE OF SECURITY

Confidentiality	Integrity	Authenticity

What if foundation becomes in-secure ?

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Impact of weak crypto is material

IMPACT OF WEAK CRYPTOGRAHY

Risk	Risk	Risk	Impact
Financial Loss	**Public Safety**	**Data Loss**	**Compliance**

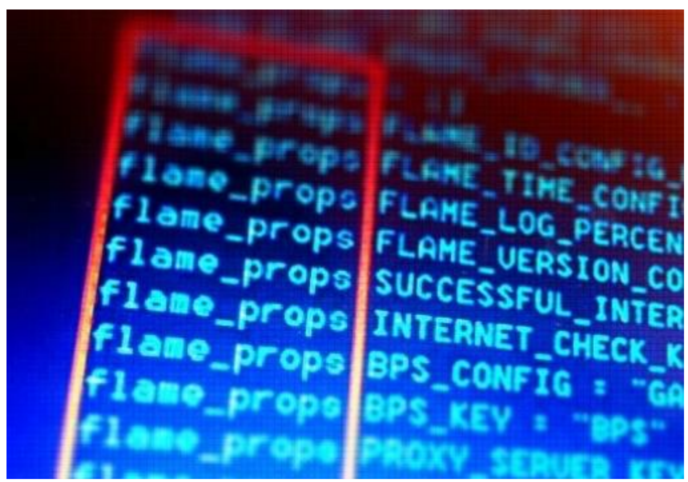
CRYPTO VULNERABILITY | **SHALL IMMEDIATELY BE FIXED**

Cryptographic failures

Malware Flame

MD5 Certificates

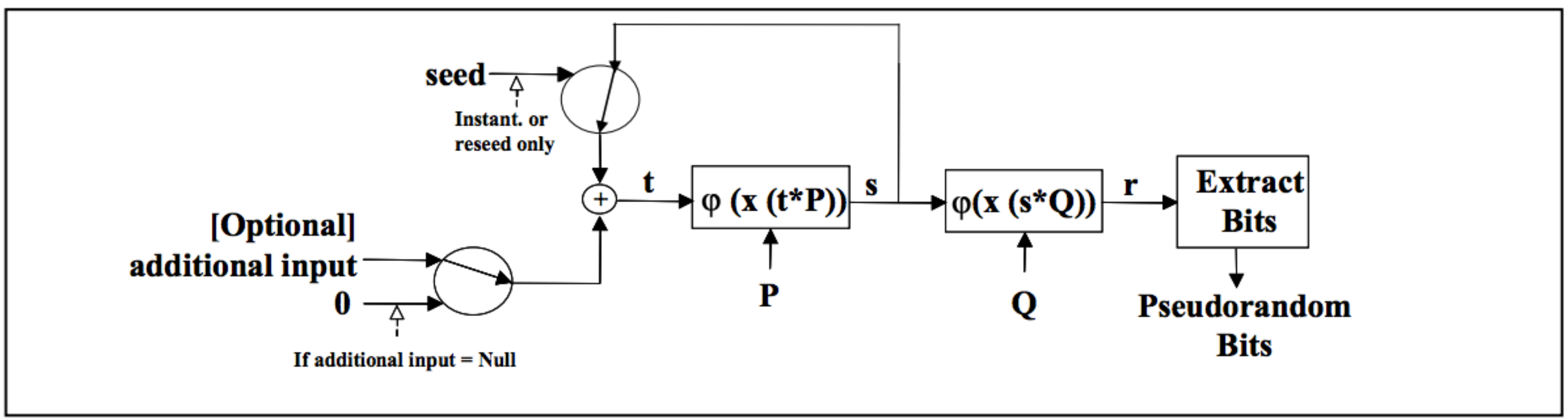
- Discovered 2012, attacks Windows
- Components of Flame were signed with a fraudulent certificate, made it appear to have originated from Microsoft
- Specific Microsoft certificate still used MD5 as hash function
- Malware authors produced a counterfeit copy of the certificate
- Rogue certificates demonstrated in 2008 by Sotirov et.al.
- MD5 is a cryptographic hash function published in 1992 and broken in 2004



DUAL_EC_DRBG

RNG with backdoor

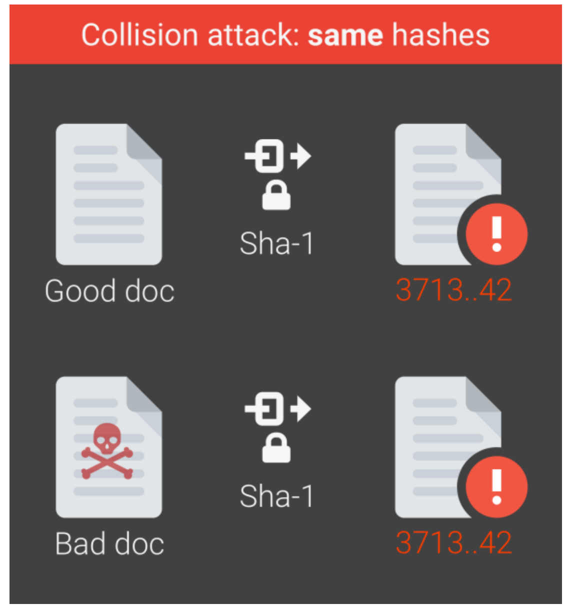
- Algorithm that was presented as a cryptographically secure pseudorandom number generator
- Standardized by ANSI, NIST and ISO
- RSA made Dual_EC_DRBG the default CSPRNG in BSAFE
- Juniper were using it in their VPN products
- Contains a backdoor



SHATTERED

SHA-1 collisions

- SHA-1 is a cryptographic hash function
- SHA-1 theoretically broken in 2005
- Since 2005 constant progress towards a practical attack
- Officially deprecated by NIST in 2011
- SHA-1 is used everywhere
  - Digital Certificate signatures
  - Email PGP/GPG signatures
  - Software signatures
  - Backup systems
  - etc...



https://shattered.io

WEP

Weak crypto

- WEP introduced in 1997 in 802.11 wireless standard
- Uses weak stream cipher (RC4) and short IVs
- First attacks in 2001 by various researchers
- Since then constant improvements have been published

- WEP was blamed for the theft of 45 million credit card numbers in 2007

https://arstechnica.com/information-technology/2007/05/blame-for-record-breaking-credit-card-data-theft-laid-at-the-feet-of-wep/

Lucky 13

Padding oracle attack on TLS

- Attack on TLS up to version 1.2 published in 2013
- Attacks apply to CBC-mode in all TLS and DTLS implementations
- Issue with the order MAC-Encode-Encrypt, padding not included in MAC
- Man-in-the-middle attacker who sees only ciphertext and can inject ciphertexts of his own composition into the network
- Allows plaintext recovery in certain circumstances

http://www.isg.rhul.ac.uk/tls/Lucky13.html

Keeloq

Proprietary block cipher

- Is/was used in many remote keyless entry systems for cars
- Details of the algorithm were leaked in 2006
- Researchers broke the system in 2007
  - Recover 64-bit Keeloq key using only 2^{16} known plaintexts and $2^{44.5}$ encryptions
- In 2008 independent researchers show improved results
  - Their attack works on all known car and building access control systems that rely on the Keeloq cipher
  - Recovers the secret master keys embedded in both the receiver and the remote control using side-channel attacks

https://www.cosic.esat.kuleuven.be/keeloq/
http://www.emsec.rub.de/keeloq

ROCA

Vulnerable RSA generation

- Faulty generation of RSA keys used in cryptographic smartcards, security tokens and other secure hardware chips manufactured by Infineon Technologies AG
- Code complies with two security certification standards, NIST FIPS 140-2 and CC EAL5+,

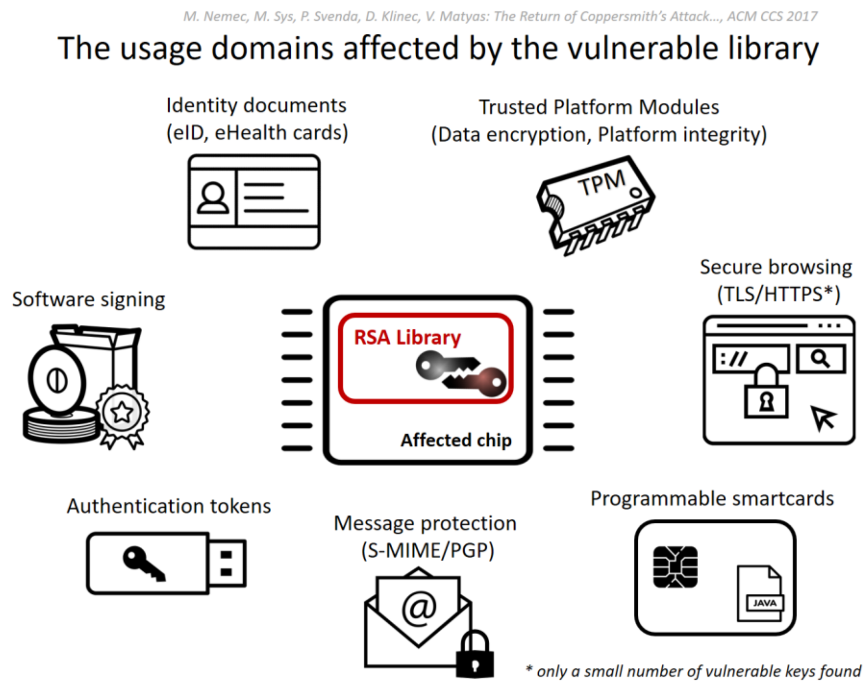
- Allows for a practical factorization attack: remote attacker can compute an RSA private key from the public key

https://crocs.fi.muni.cz/public/papers/rsa_ccs17

ROCA

Vulnerable RSA generation

- Estonia announced that 750.000 government identify cards, issued since October 2014, might be effected
- Vulnerable keys in TLS certificates discovered
- PGP keys used for email encryption effected
- Keys on GitHub submissions
- Etc…

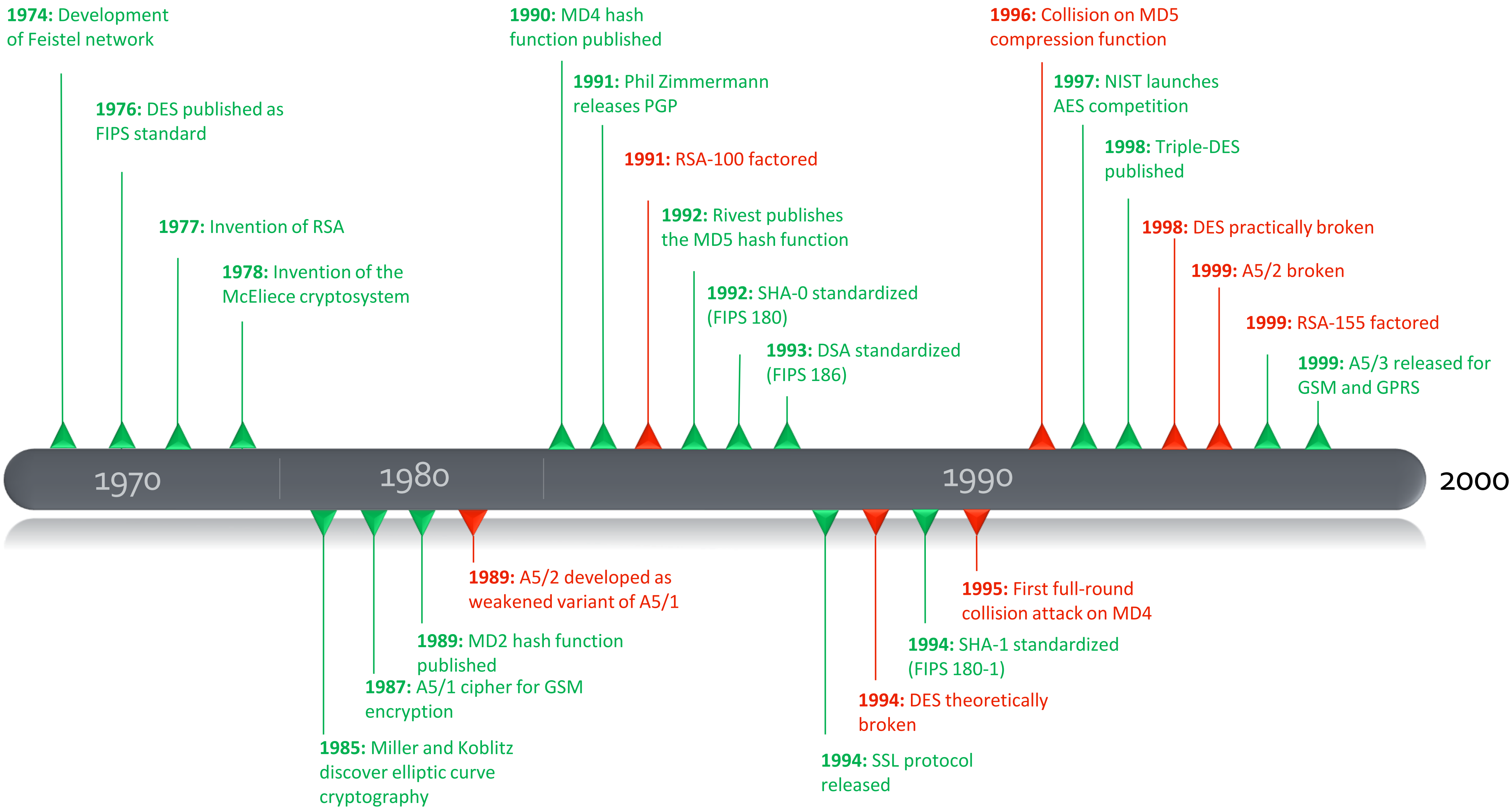


https://crocs.fi.muni.cz/public/papers/rsa_ccs17

How does crypto evolve?

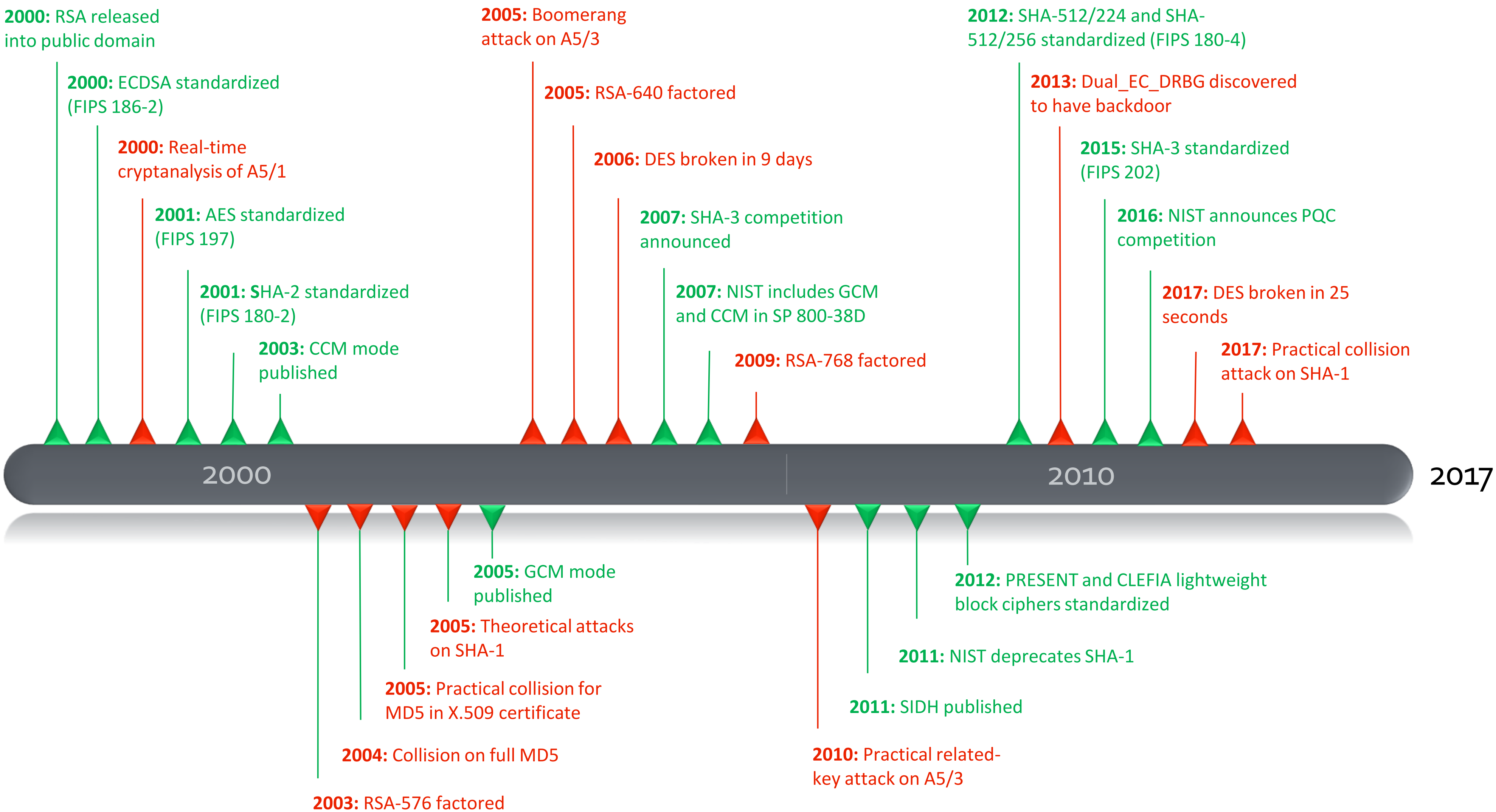
Constant progress in cryptography

1970-1999



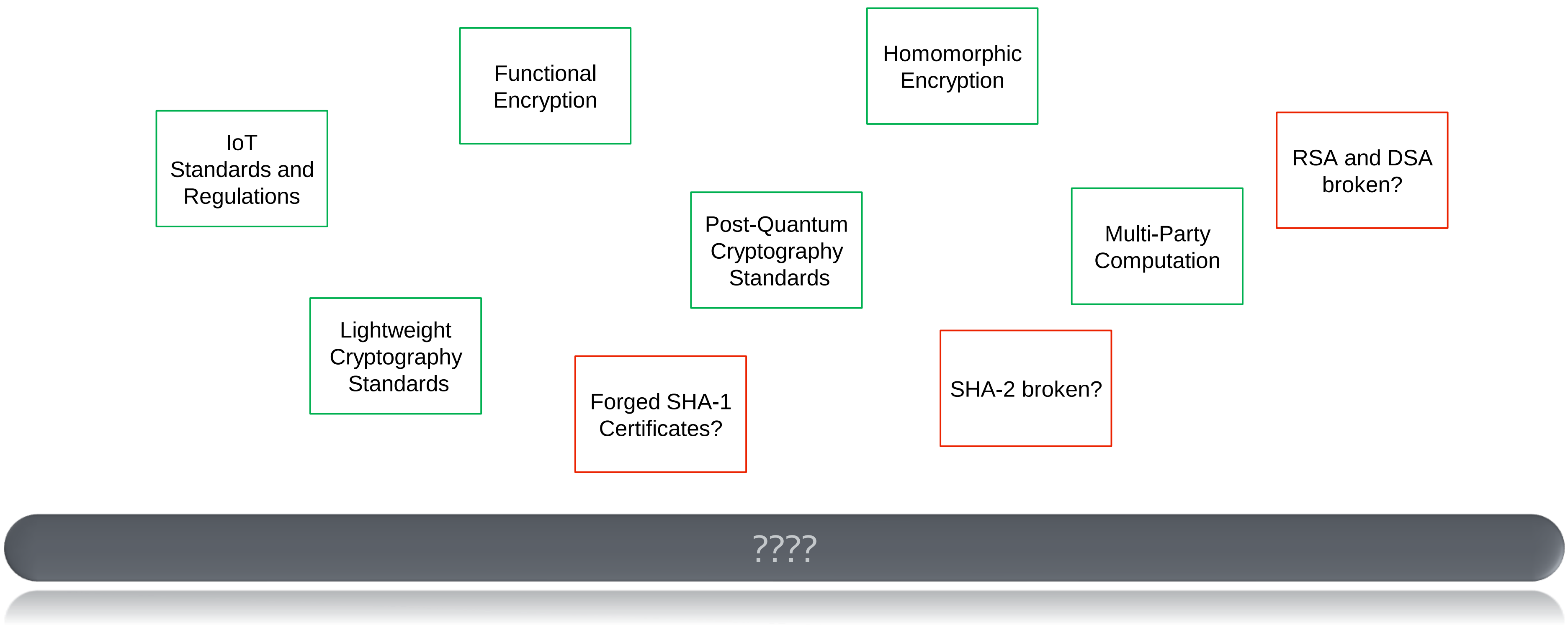
Constant progress in cryptography

2000-2017



Constant progress in cryptography

2017-20??



How diverse is crypto?

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Many options

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Traditional cryptography	**Lightweight** cryptography	**National** cryptography	**Post-Quantum** Cryptography
RSA	**CLEFIA**	USA **Suite A**	**Code**-Based
ECC	**PRESENT**	GER **ECGDSA**	**Hash**-Based
AES	**PHOTON**	RU **GOST**	**Isogeny**-Based
Serpent	**SPONGENT**	KOR **KCDSA**	**Lattice**-Based
…	**…**	**…**	**Multivariate**-Based

Why do we care?

Need for Agility

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Compliance

- National crypto requires that hardware vendors comply to local algorithms and standards
- Supply Chains are managed globally, management of critical systems reside in one country and deployed globally
- Crypto agility required to comply with country standards

Longevity of IoT

- IoT devices in operation for 10+ years
- Often without possibility to update critical components
- Crypto agility required to adapt to new threats and new standards during the whole life cycle

Cryptographic Threats

- Vulnerable implementations
- Outdated algorithms
- New attacks on existing algorithms
- Crypto agility required to quickly react on these threats

Future Cryptography

- Post Quantum Cryptography
- New algorithm and standards
- New use cases
- Crypto agility required to be prepared when standards are announced

What is the solution?

We need crypto agility

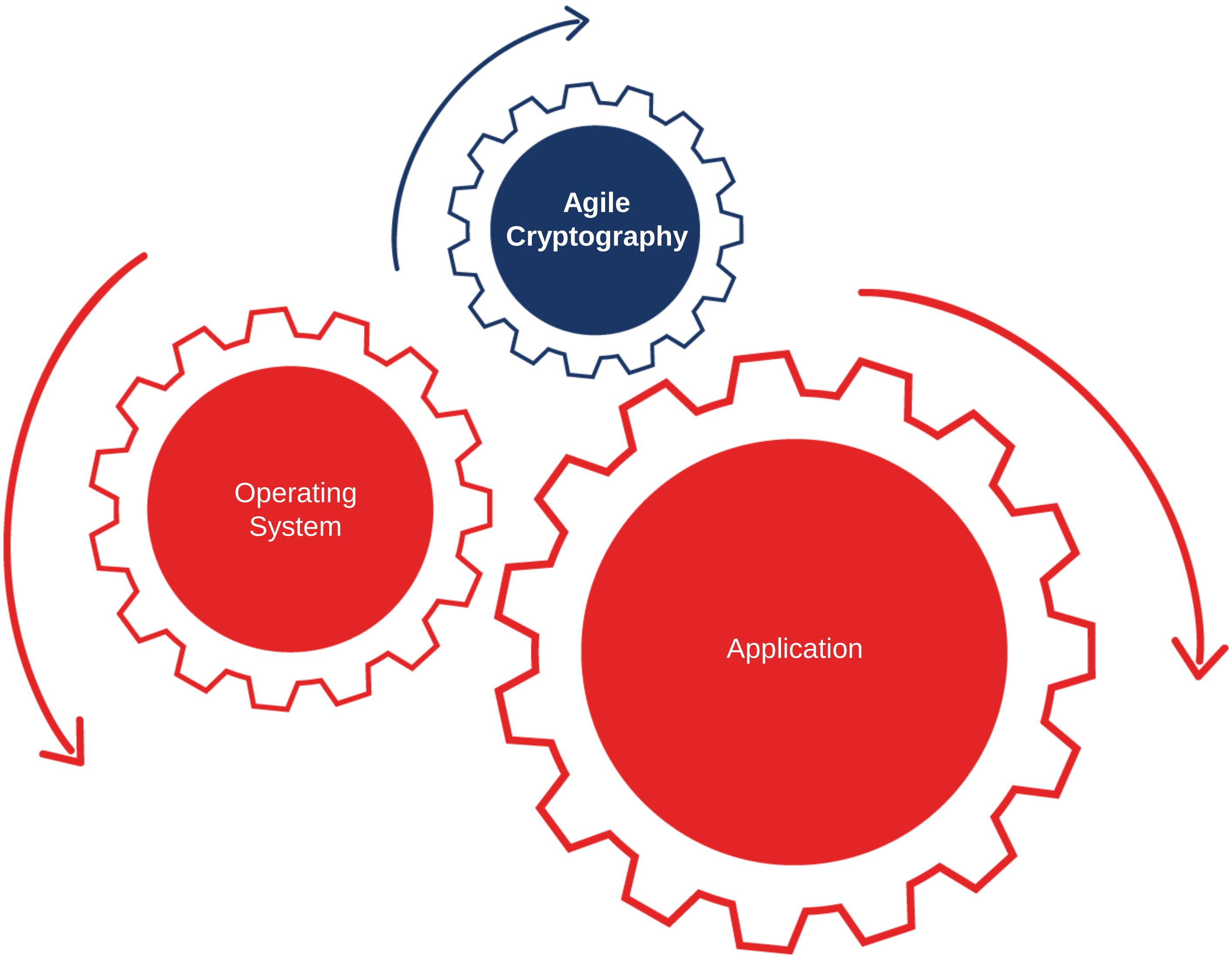
Cryptographic Agility

Definition

Cryptographic agility is the ability of a system to easily adopt alternatives to the cryptographic primitives it was originally designed to use.

Cryptographic Agility

Decouple applications from cryptography



Agile Crypto Library

Abstract, Dynamic and Manageable

Abstract API
Hide crypto complexity to developers

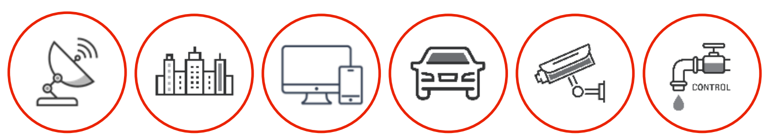
Dynamically Loadable
Change crypto during runtime

Select Implementation Type
Depending on use case

Deploy New Algorithm
Without modifying application code

Let experts decide which crypto to use
Make it manageable by others

Make it run on everything
Support as many platforms as possible



SOFTWARE | HARDWARE

How could it look like?

Portability

```
GenerateKey() {
 provider = LoadProvider(“path to implementation”);
 error    = GenerateSymKey(provider, key);
 if(error)…;
 return key;
}

Encrypt(data, key) {
 provider = LoadProvider(“path to implementation”);
 error    = Encrypt(provider, data, key, ciphertext);
 if(error)…;
}
```

Existing Libraries?

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Many open source libraries

How agile are they?

- OpenSSL
- BouncyCastle/Java Cryptographic Architecture
- libsodium
- Crypto++
- wolfSSL
- libgcrypt
- Network Security Services
- …

OpenSSL

EVP interface

- EVP functions provide a high level interface to OpenSSL cryptographic functions

- Support for an extensive range of algorithms
- Encryption/Decryption
- Sign/Verify
- Key derivation
- Secure Hash functions
- Message Authentication Codes
- Support for external crypto engines

https://wiki.openssl.org/index.php/EVP

OpenSSL

EVP symmetric encryption and decryption

```
EVP_CIPHER_CTX *ctx;
int len;
int ciphertext_len;


if(!(ctx = EVP_CIPHER_CTX_new())) handleErrors();


if(1 != EVP_EncryptInit_ex(ctx, EVP_aes_256_cbc(), NULL, key, iv))
  handleErrors();


if(1 != EVP_EncryptUpdate(ctx, ciphertext, &len, plaintext, plaintext_len))
  handleErrors();
ciphertext_len = len;


if(1 != EVP_EncryptFinal_ex(ctx, ciphertext + len, &len)) handleErrors();
ciphertext_len += len;

EVP_CIPHER_CTX_free(ctx);
```

https://wiki.openssl.org/index.php/EVP_Symmetric_Encryption_and_Decryption

OpenSSL

Engine interface

- Exposes an *Engine API*, which makes it possible to plug in alternative implementations of some or all of the cryptographic operations implemented by OpenSSL
- Usually used for cryptographic acceleration using a hardware device
- Engines can dynamically be loaded at runtime

- Example: PKCS11 engine
- Can only replace already existing algorithms
- Inherits limitations from EVP interface

OpenSSL

How agile is it?

Implementation independence	no
Implementation simplicity*	mediocre
Implementation abstraction	mediocre
Dynamic exchangeability and extensibility	no
Manageability	no
Portability	good
Performance	good

*depends on personal preference and experience

Java Cryptography Architecture

Abstraction in Java

- Framework for cryptography in Java
- Provider-based architecture
- Abstract APIs for cryptographic operations
- Abstract data structures for cryptographic objects

- Separates the interfaces and generic classes from their implementations

Java Cryptography Extension

Abstraction in Java

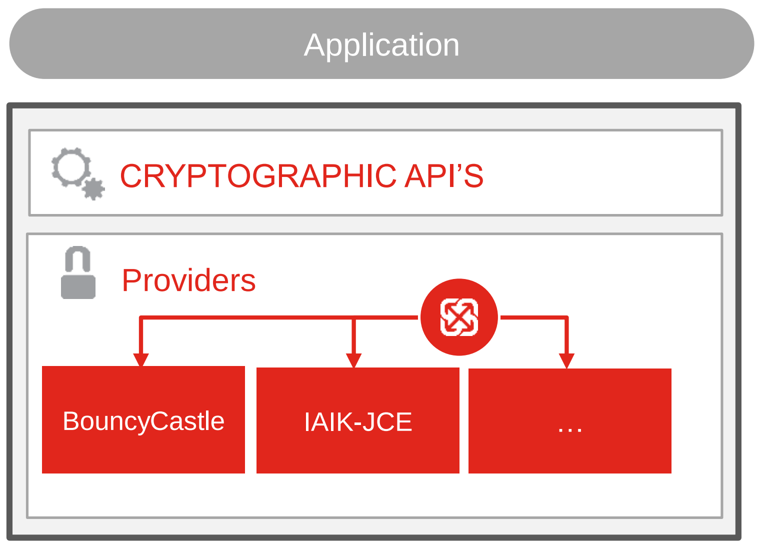
- Part of JCA
- Provides encryption, key generation, key agreement and MAC
- In the past JCA and JCE used to be treated differently by US export policies

- Restrictions
  - Oracle JDK requires each provider to be signed by Oracle
  - OpenJDK does not
  - Keys > 128 bits require *Unlimited Strength Jurisdiction Policy Files (default since* 8u161)

Providers

Abstraction in Java

- Providers implement the API defined in JCA and JCE, and they are responsible for providing the actual cryptographic algorithm
- Popular providers: BouncyCastle, IAIK-JCE
- Can be configured through the Java security file



Java Cryptography Architecture

Abstract API

- Encryption example:

```
Security.addProvider(provider_name);
Cipher c = Cipher.getInstance("AES");
c.init(ENCRYPT_MODE, key);
byte[] cipherText = c.doFinal(plainText);
```

BouncyCastle

Provider

- Provider for JCA/JCE
- Includes also a low-level API (no restrictions)

```
PBEKeySpec pbeKeySpec = new PBEKeySpec(password.toCharArray(),
                            toByte(salt), 50, 256);
SecretKeyFactory keyFactory = SecretKeyFactory.getInstance("PBEWithSHA256And256BitAES-CBC-BC");
SecretKeySpec secretKey = new SecretKeySpec(keyFactory.generateSecret(
                                    pbeKeySpec).getEncoded(), "AES");
byte[] key = secretKey.getEncoded();
....

// setup AES cipher in CBC mode with PKCS7 padding
BlockCipherPadding padding = new PKCS7Padding();
BufferedBlockCipher cipher = new PaddedBufferedBlockCipher(
                            new CBCBlockCipher(new AESEngine()), padding);
cipher.reset();
cipher.init(false, params);
....
len += cipher.doFinal(buf, len);
```

JCA/JCE

How agile is it?

Implementation independence	good
Implementation simplicity	good
Implementation abstraction	good
Dynamic exchangeability and extensibility	mediocre
Manageability	mediocre
Portability	mediocre
Performance*	no

*compared to what is possible

What about PKI?

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Agile Cryptography in PKI

Lack of Agility

- Todays PKI systems are not agile
  - No easy way to switch algorithms in **HSMs**
  - No easy way to switch algorithms in **software** stack
  - No easy way to switch algorithms in **certificates**

Agile Cryptography in PKI

Make it Agile

- **HSM and Software**
  - Make crypto updateable
  - Make crypto configurable
  - Make crypto manageable
- **Certificates**: ?

Agile Cryptography in PKI

Certificates

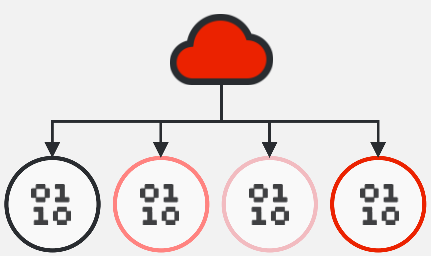
- X.509 does support crypto agility
- Replacing hash or signature algorithm = replacing certificate
- Replacing certificates costly and time consuming

Summary

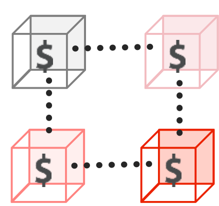
Summary

Agile Cryptography

- Crypto market has to change, we need crypto agility
  - **to be prepared for quantum computers**
  - to cope with the constant progress in cryptography
  - to comply with local regulations
  - to be prepared for future standards and challenges
- Many open questions
  - How can we achieve better data agility?
  - How can we make IoT crypto agile?
  - How can we make blockchain crypto agile?



Agile **IoT**



Agile **Blockchain**

Agile **Key Management**