Impact of Recent Attacks on Hash Functions

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http://www.iaik.tugraz.at/aboutus/people/pramstaller/index.php

Hash&Stream, Salzburg, 2007/02/02

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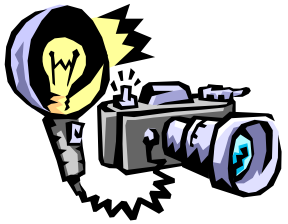
A Legal Case in Australia

- **„NSW speed cameras in doubt”** (August, 2005)



- RTA‘s speed monitoring device uses MD5
  - picture taken by approved device
  - picture has not been altered

- Lawyer of defendant: MD5 is broken
- RTA: no expert to show authenticity of taken picture
- Magistrate: dismissed speeding case

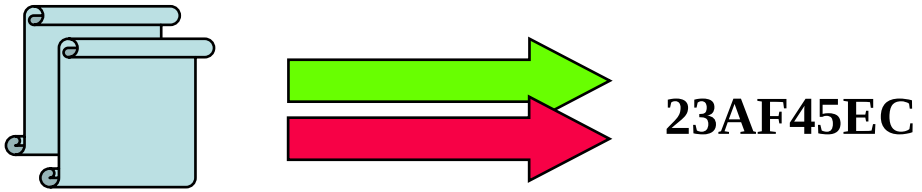
? **security problem or smart lawyer** ?

Outline

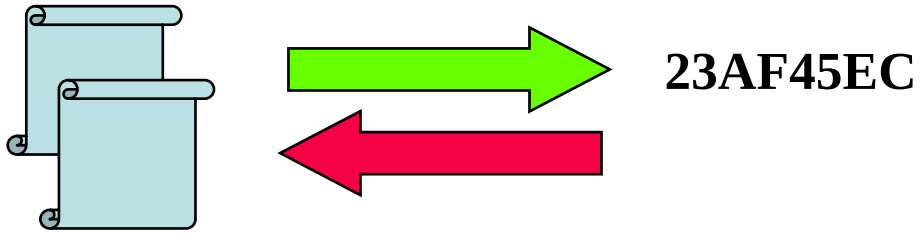
- Refresher
  - Requirements for cryptographic hash functions
- Application of hash functions and the impact of recent advances in cryptanalysis
  - electronic (digital) signatures
  - message authentication codes
  - password protection
  - some other applications and practical examples
    - colliding PS documents and colliding X.509 certificates
- Efforts in design and analysis of crypt. hash functions
  - NIST/ECRYPT

Requirements for Cryptographic Hash Functions

- Collision resistance

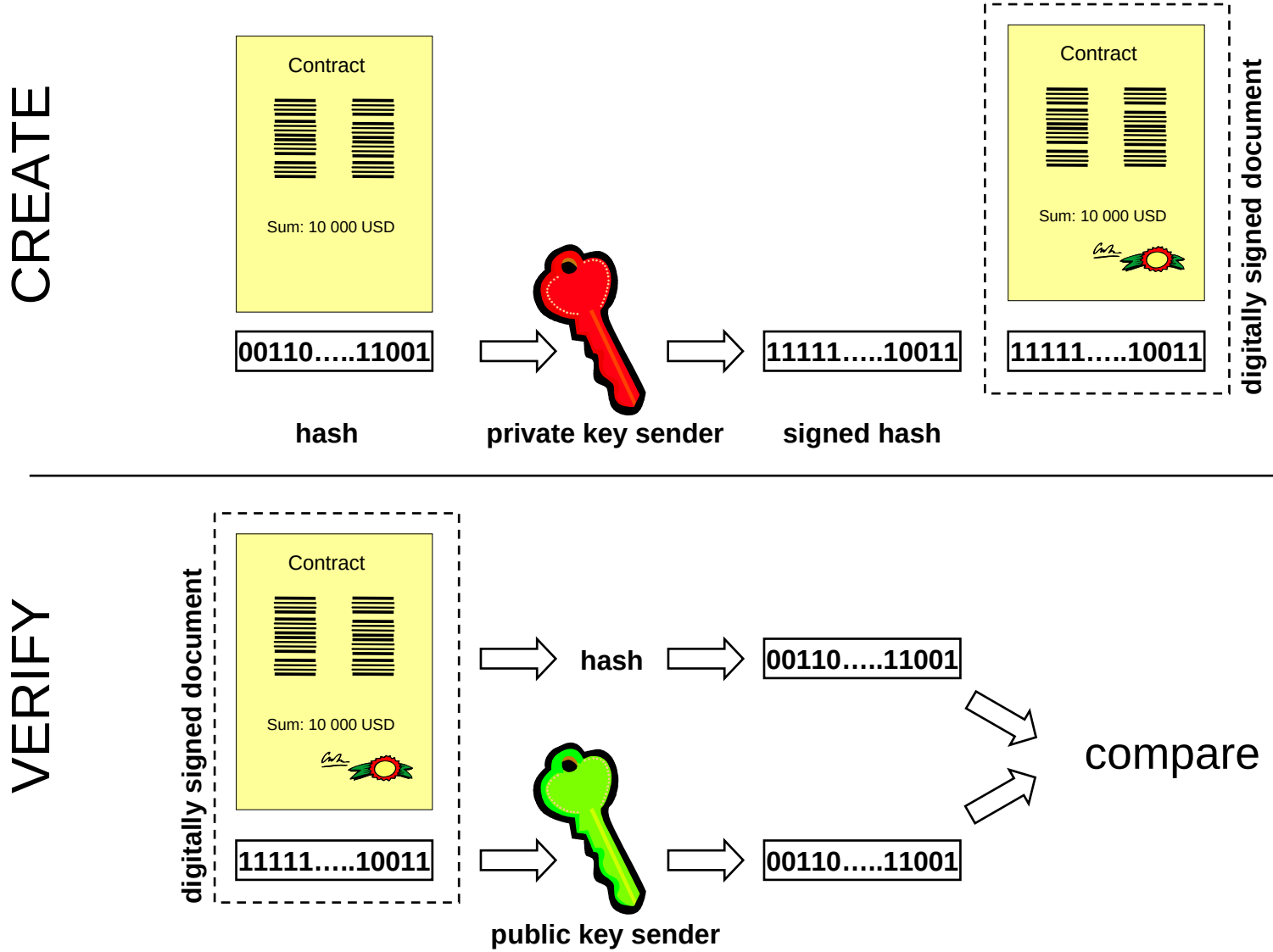


- 2nd preimage resistance



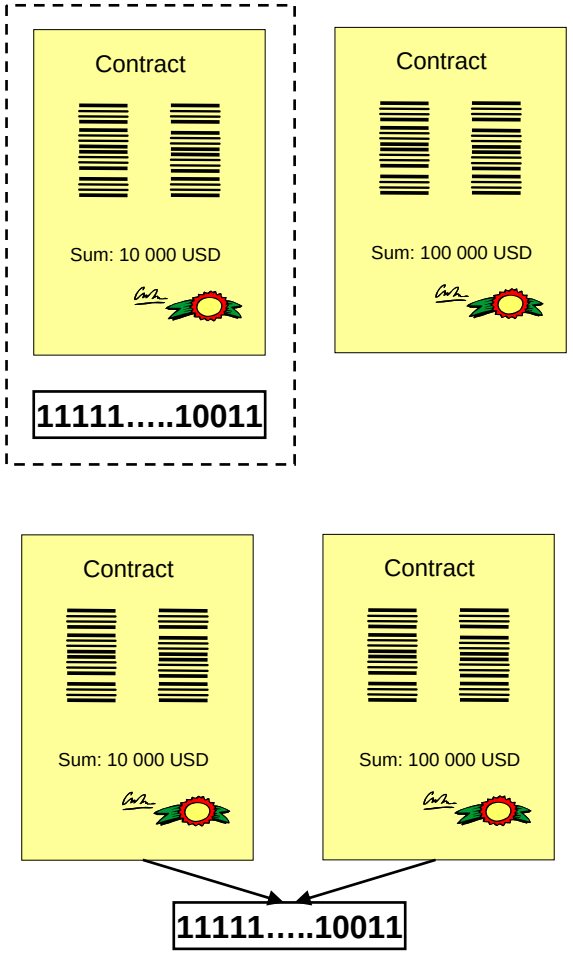
- Preimage resistance

Digital Signatures



Digital Signatures

- Second preimages
  - forgery
  - anybody can forge signature
  - can be done at anytime (after first signing)
- Collisions
  - allows signer to repudiate signature
  - must be done before signing
    - adversary needs to control both messages
    - old documents are not endangered
  - specifications demand collision resistance
- Preimages
  - second preimages (different message)

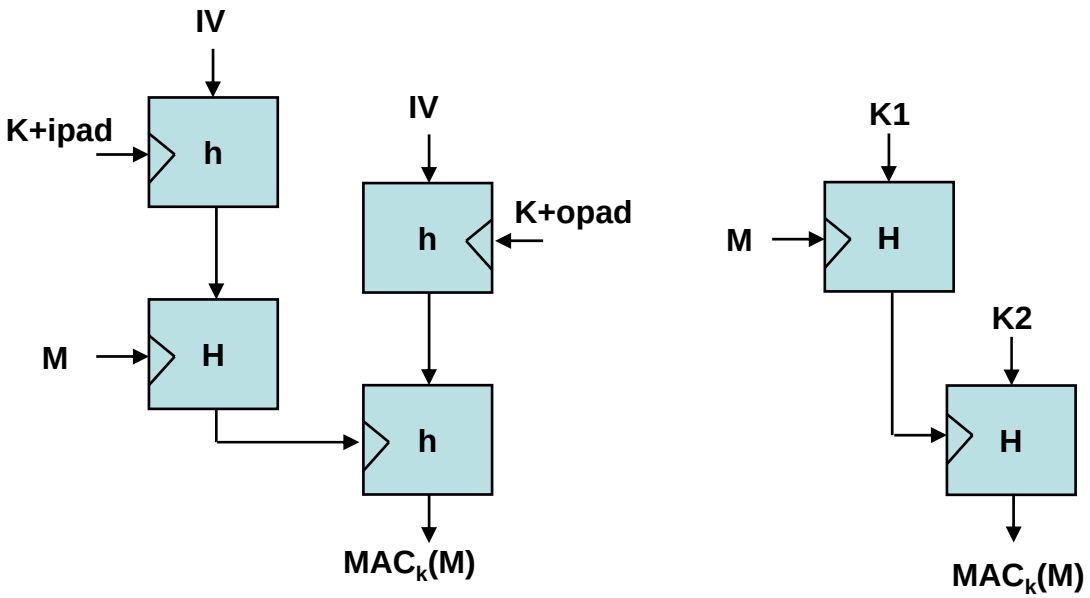


Message Authentication Codes MACs

- Verify integrity and authenticity of information
- Must resist
  - forgery
  - key recovery

message M, key k: send $MAC_k(M)||M$

- MACs based on hash functions
  - HMAC and NMAC MD5/SHA-1



Message Authentication Codes MACs

- Second preimage attacks: forgery

message M, key k: $MAC_k(M)||M$
M‘ is second preimage of M
$MAC_k(M) = MAC_k(M')$

- Collision attacks have impact
  - distinguishing and forgery attacks (MD5 and round-reduced SHA-1) [CY2006, KBPH2006, RR2007]
  - other hash functions (e.g. SHA-2) no problem yet

Password Protection

- Client authentication
  - password previously registered at server side
  - only save hash value (MD5) of password (+ salt)

- Preimages: crucial
  - */etc/passwd* `root:Npg…pfz4wuk:503:100:Full root:/root:/bin/bash`

```
-rw-r--r-- 1 root root 1366 2007-01-01 23:59 passwd
```

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```

  - */etc/passwd & /etc/shadow*

```
Passwd: root:x:0:0:root:/root:/bin/bash
Shadow: root:$1$19TNpge08pfz4wukplkDBRSQoqwxKH1:13185:0:99999:7:::
```

```
-rw-r----- 1 root shadow 111 2007-01-01 23:59 shadow
```

Meaningful Collisions

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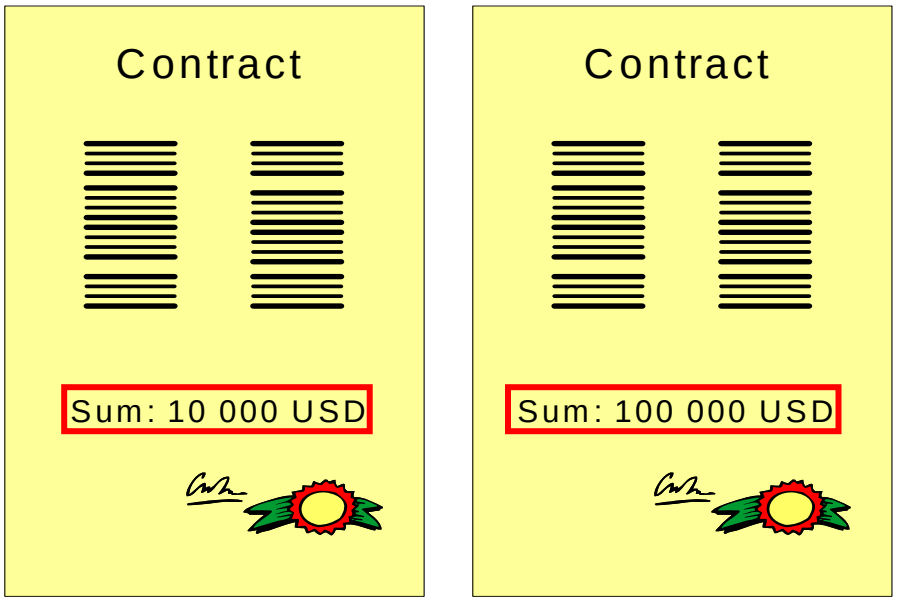
Meaningful Collisions

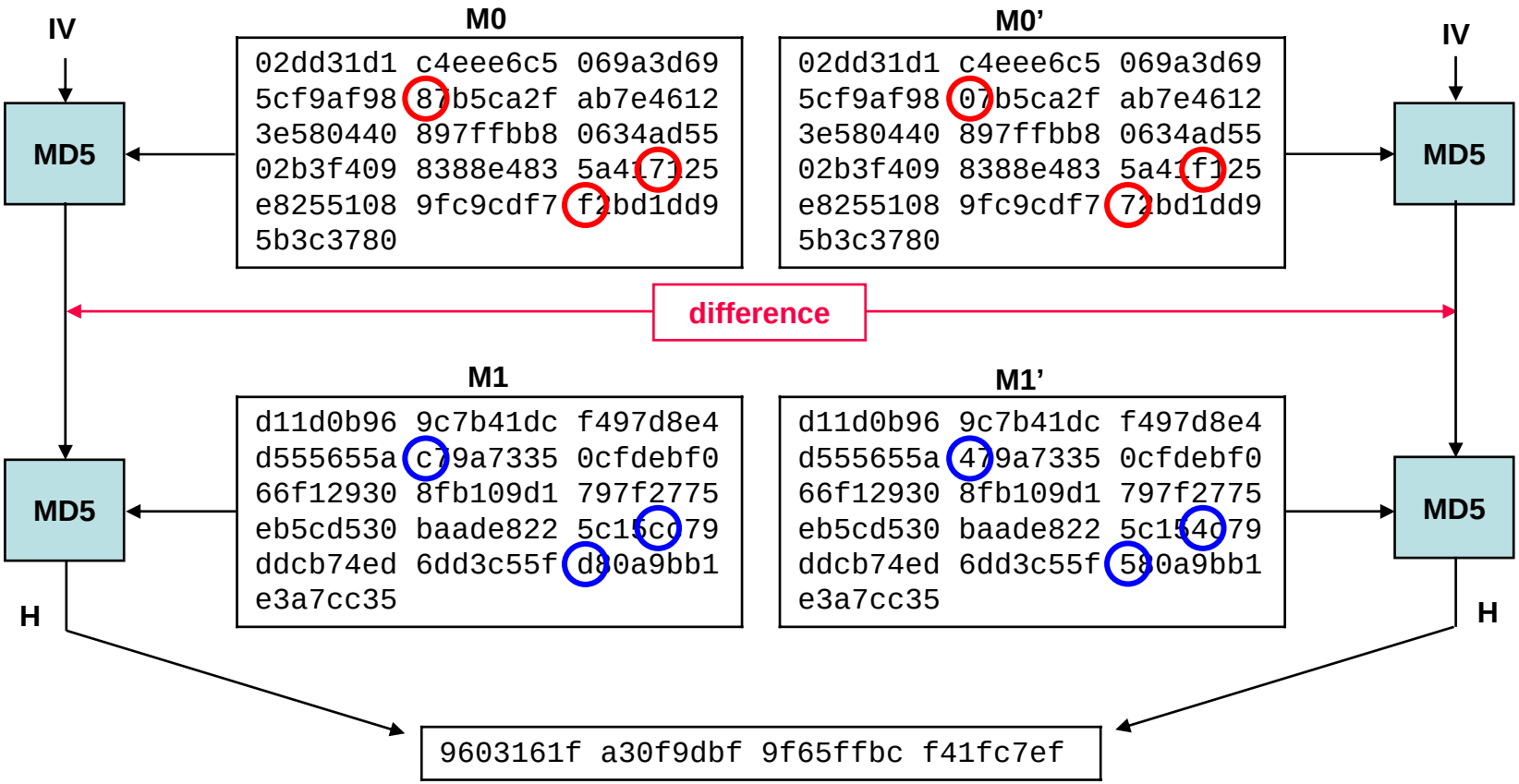
- Two documents with meaningful content that collide



- adversary does not have lot of freedom

Meaningful Collisions

- Believed to be difficult



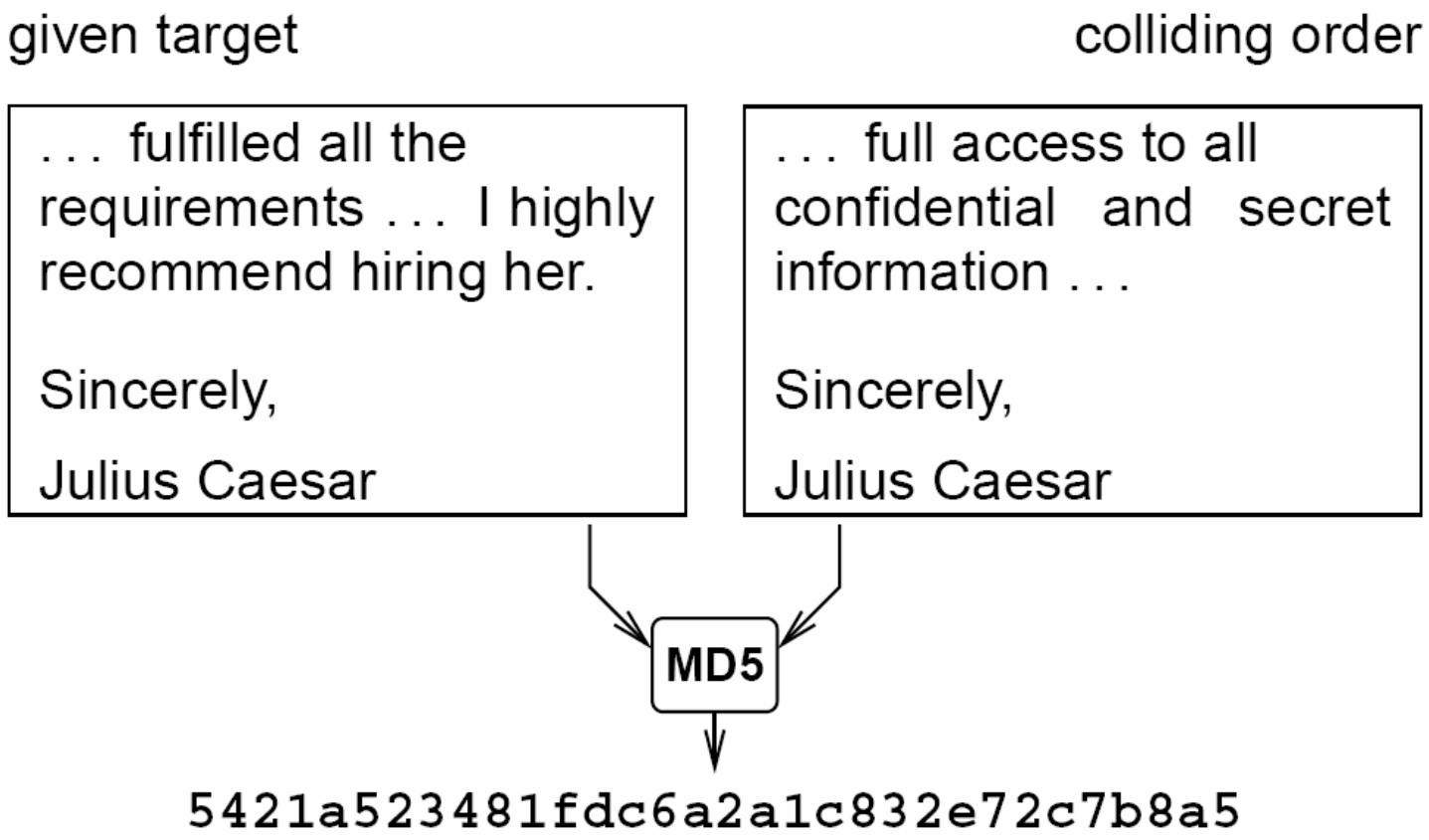
colliding message pairs for MD5 [WY2005]

Meaningful Collisions

- Now some examples demonstrating the opposite
  - kind of meaningful
    - colliding PS documents (MD5) [DL2005]
    - colliding executables (MD5) [Sel2005]
    - etc
  - meaningful
    - colliding X.509 certificates (MD5) [SLdW2006]

Colliding PS Documents [DL2005]

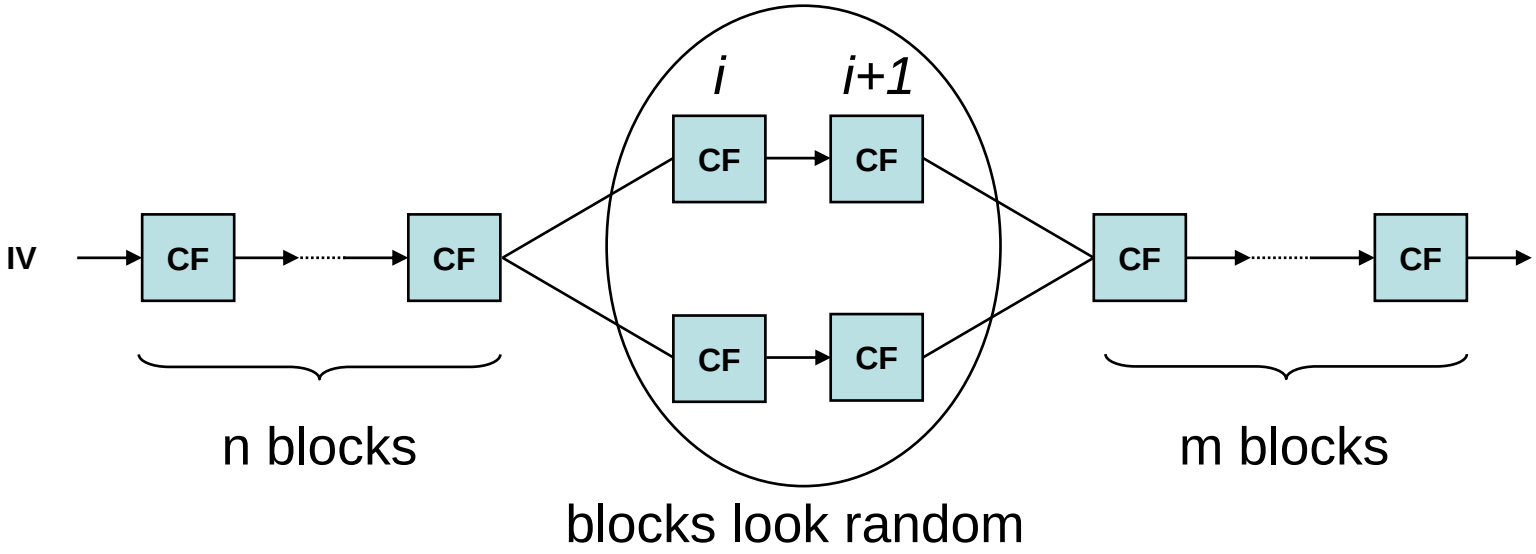
- Two different documents with same MD5 hash value



Source: http://www.cits.rub.de/MD5Collisions/

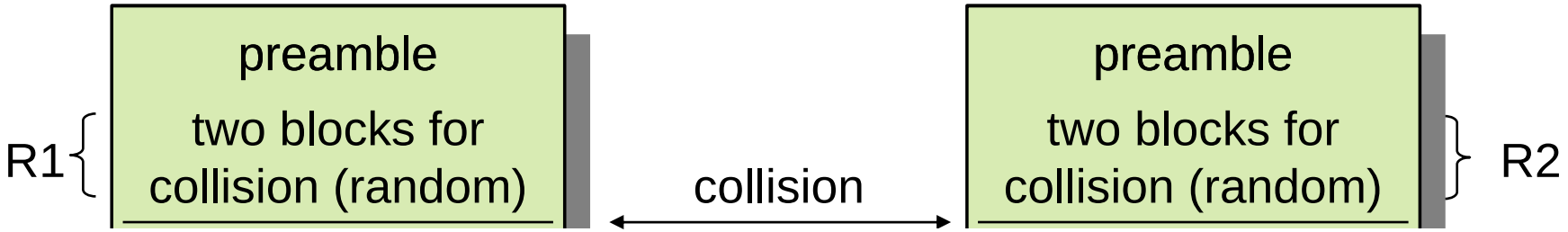
Colliding PS Documents

- Basic idea
  - after collision we can append any string
  - if collision is independent of IV (MD5) then also append prefix



Colliding PS Documents

- The working principle using postscript



Colliding PS Documents

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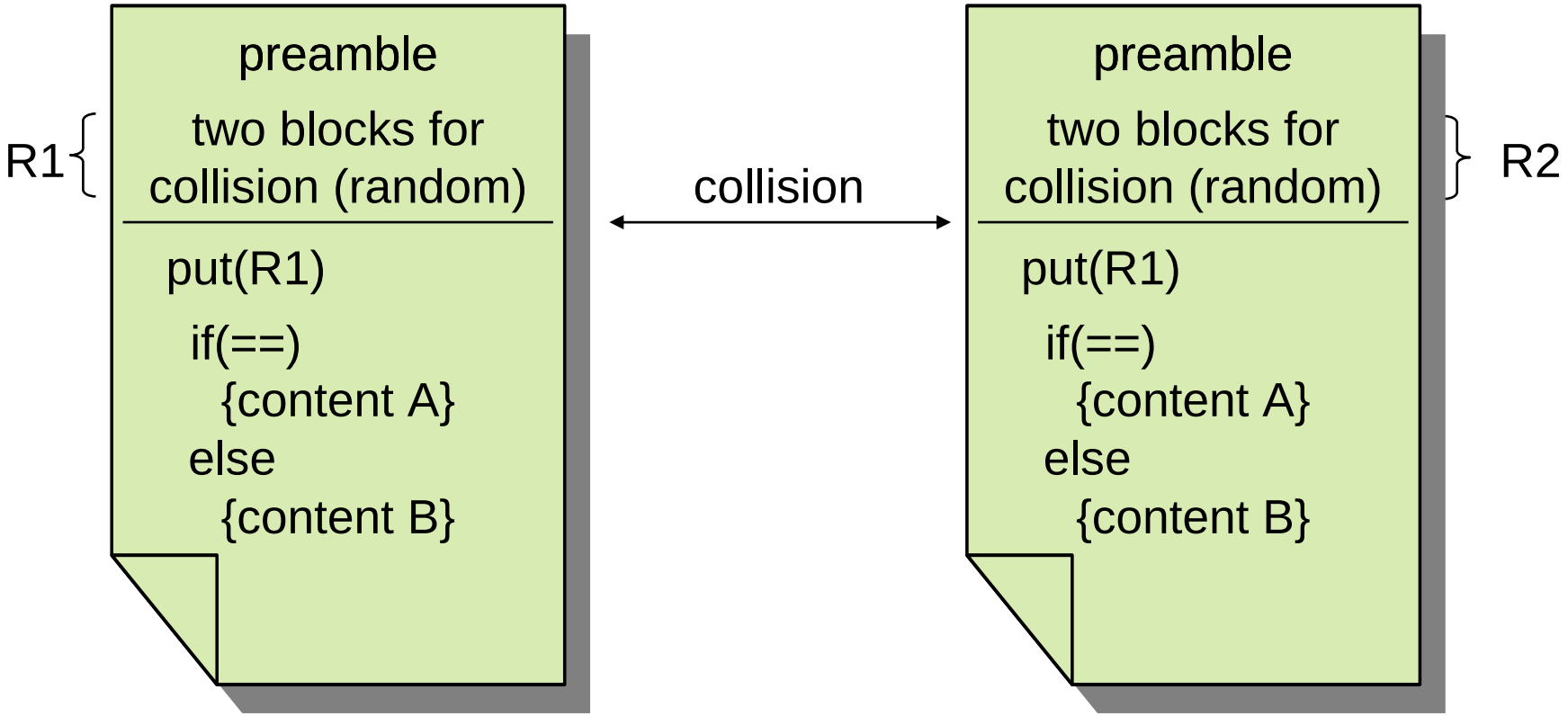
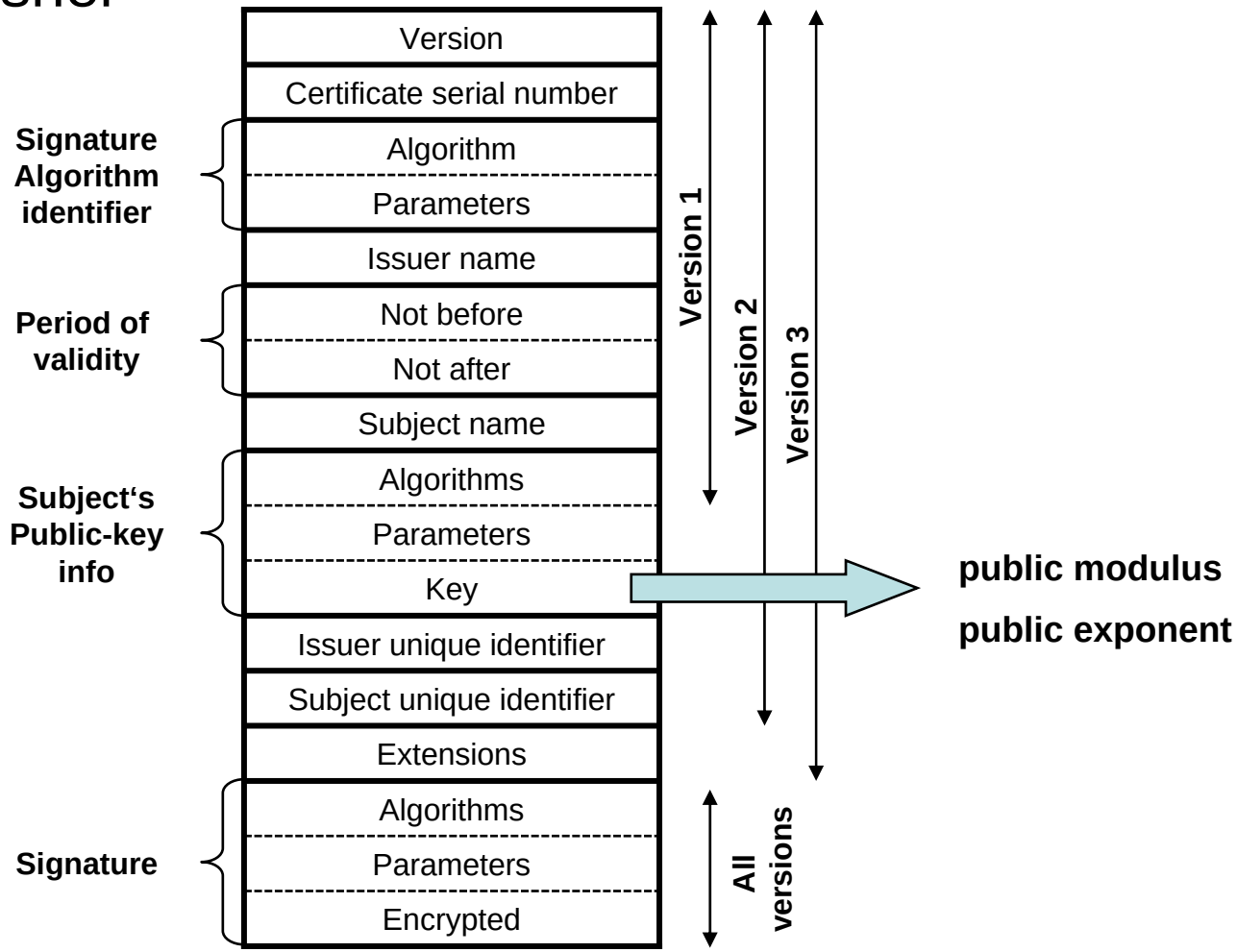


From Random to Meaningful

- Previous example
  - colliding messages (random content) need to be hidden
  - can be counteracted by inspection (e.g. bit level)
- New approach [SLdW2006]
  - colliding X.509 certificates
  - http://www.win.tue.nl/hashclash/
  - http://eprint.iacr.org/2006/360/

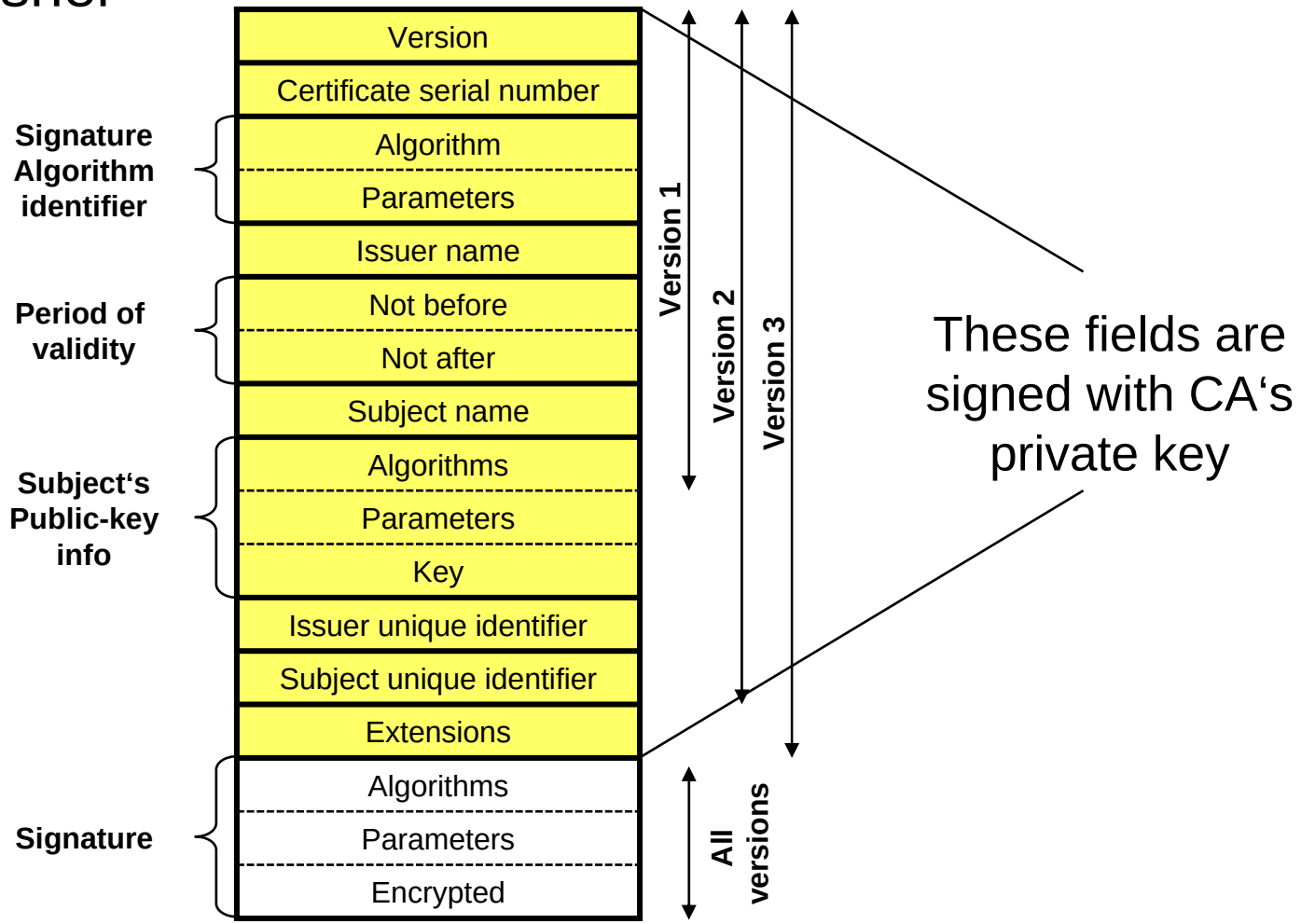
Colliding X.509 Certificates

- X.509 refresher



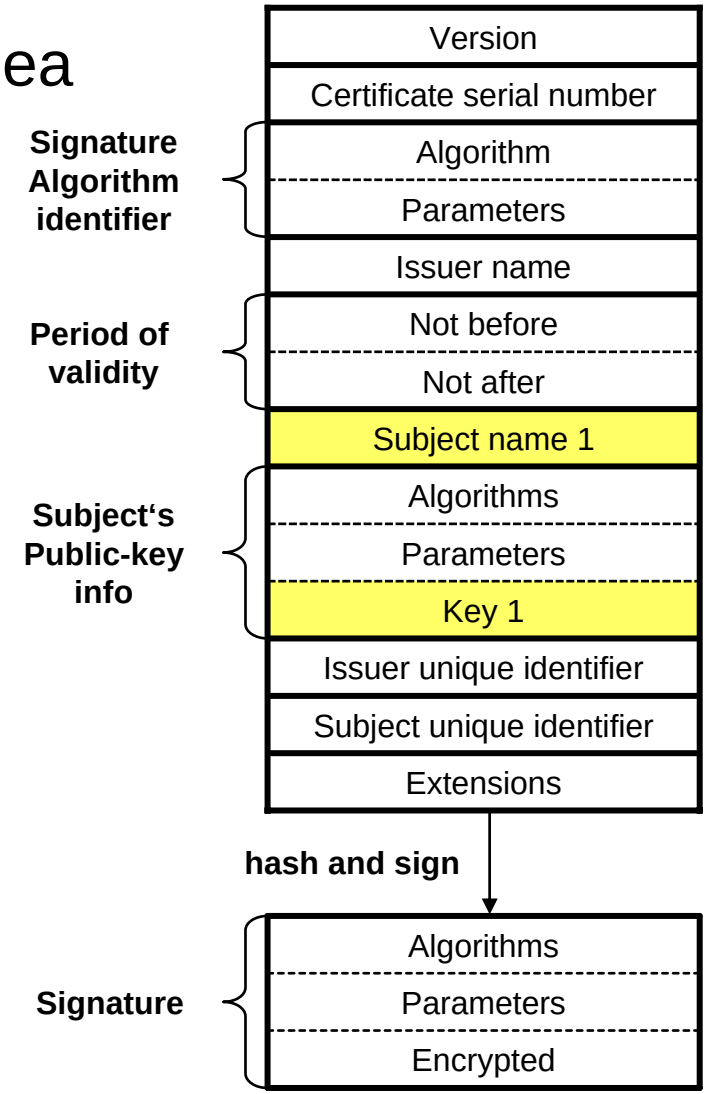
Colliding X.509 Certificates

- X.509 refresher



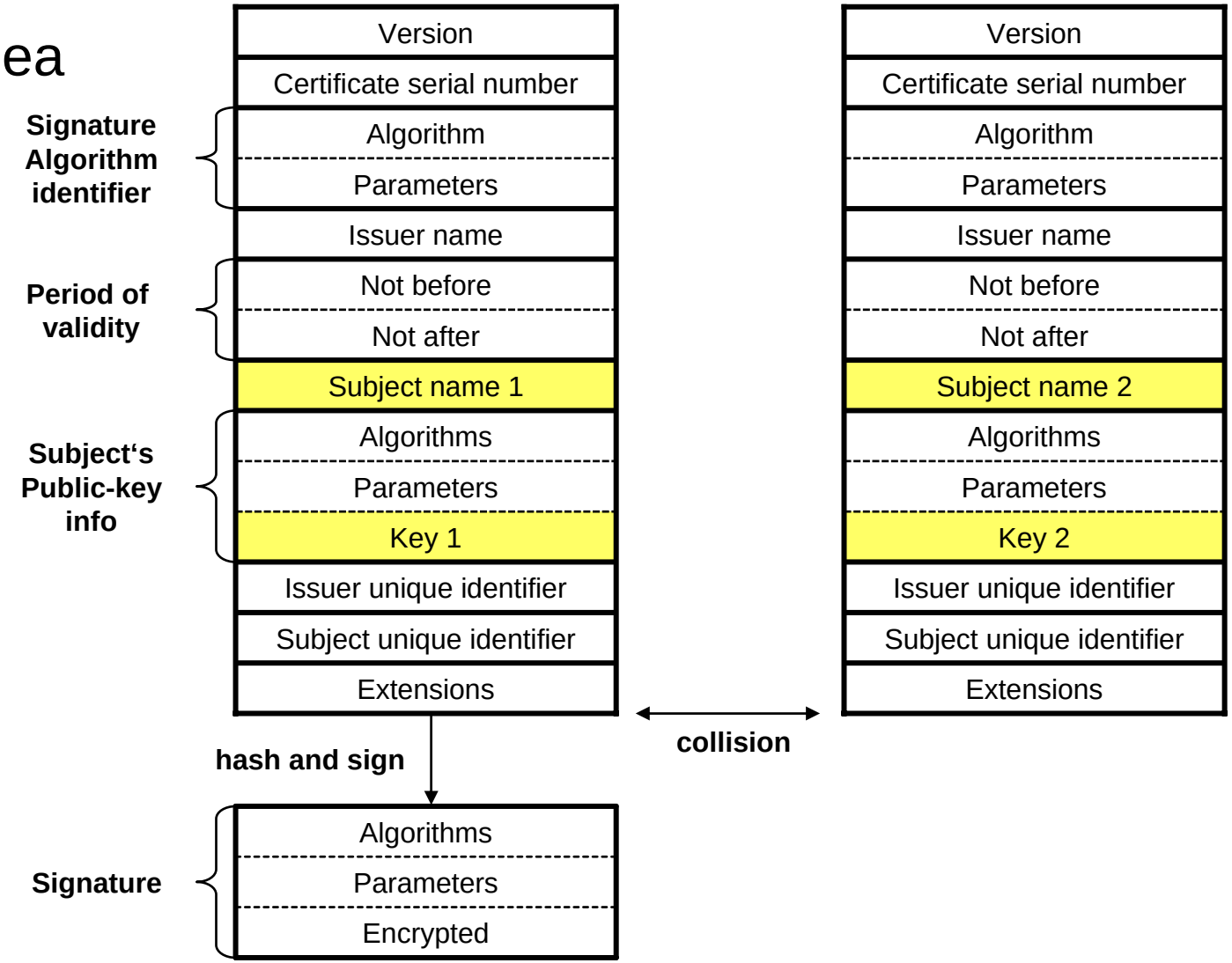
Colliding X.509 Certificates

- Basic idea



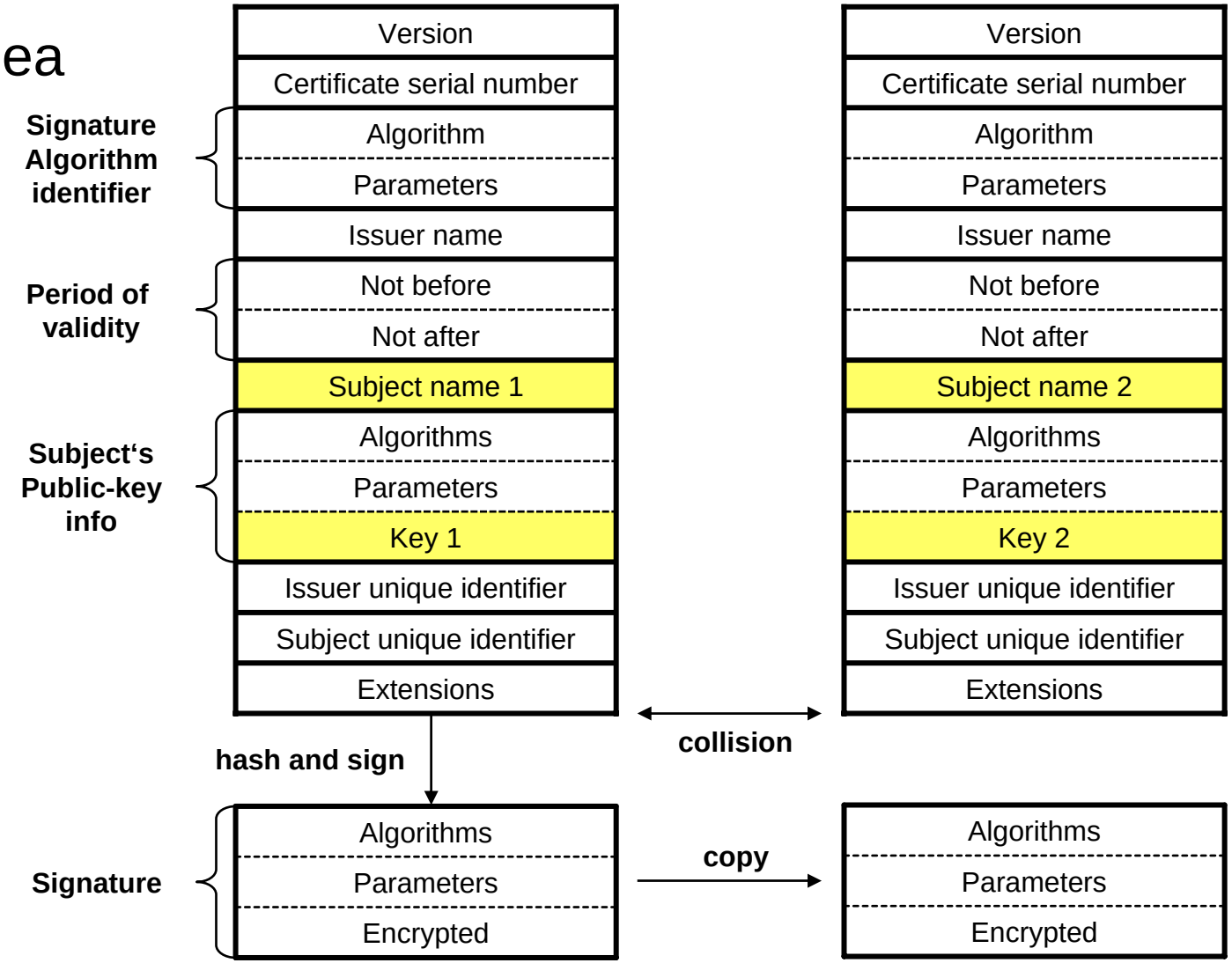
Colliding X.509 Certificates

- Basic idea



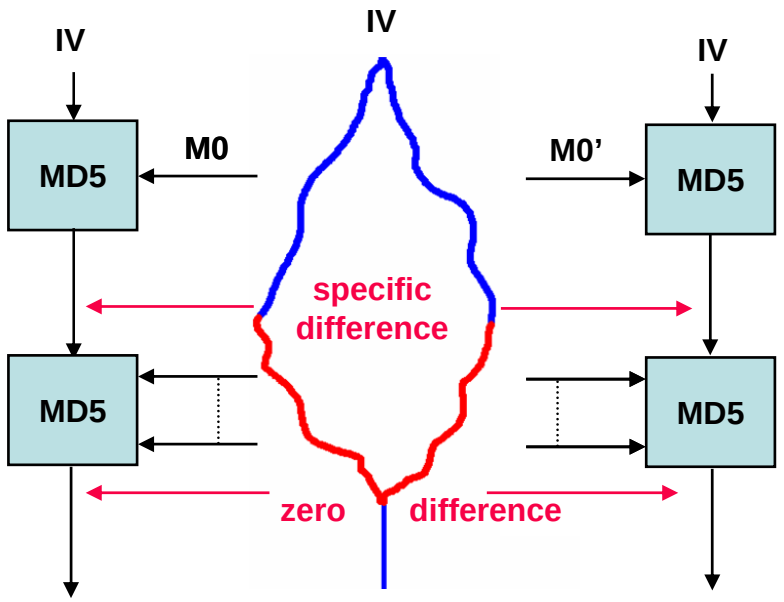
Colliding X.509 Certificates

- Basic idea



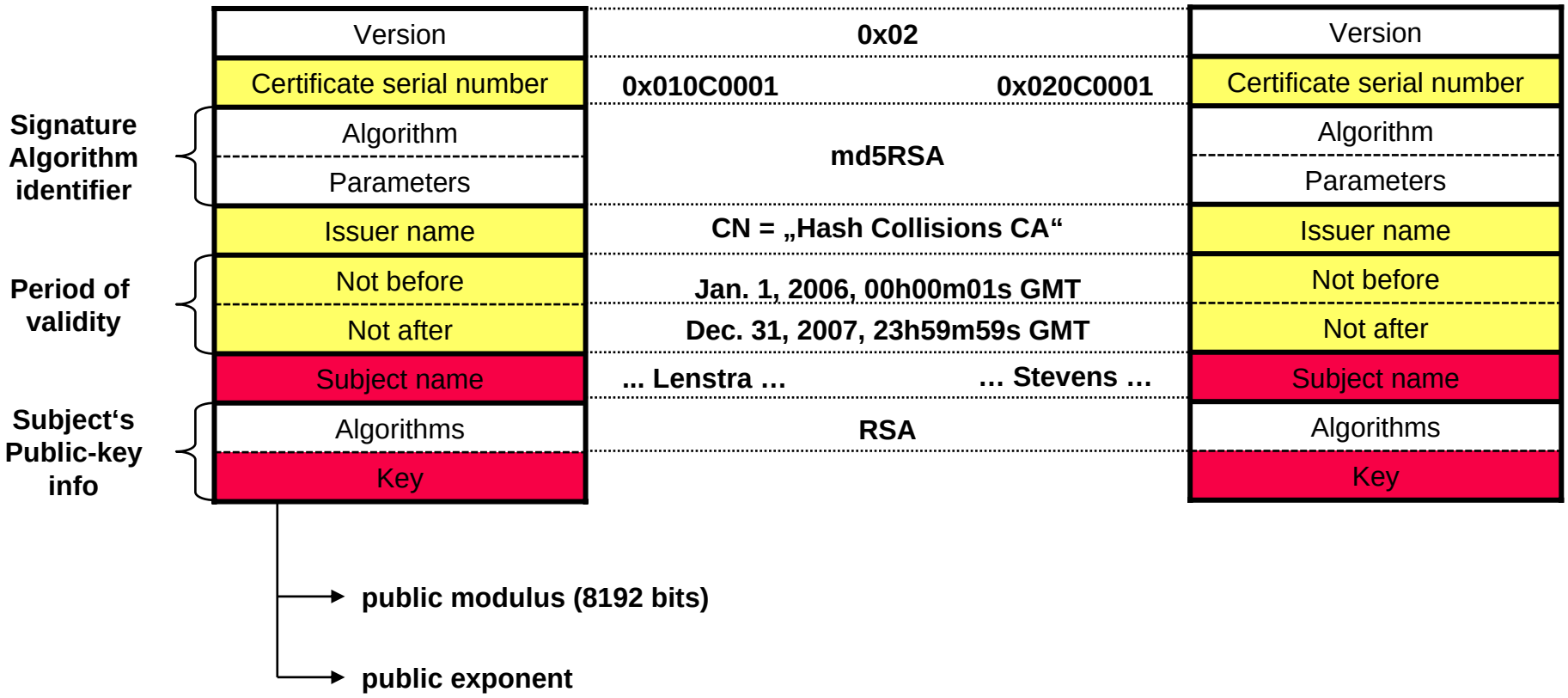
Colliding X.509 Certificates

- Arbitrary M0, M0‘
- Bit-length *416 mod 512* (96 bits of last block missing)
- Properly choose 96 bits to get specific difference
- Add certain number of blocks to cancel difference (for this example 8 blocks needed)
- Red part consists of
  - 96 + 8 x 512 = 4192 bits



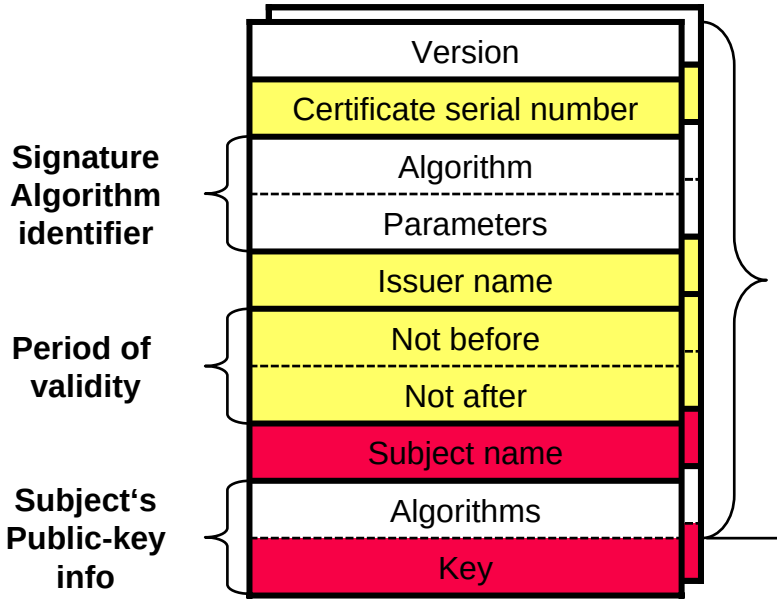
- Estimated complexity for these steps: 2^{52}

Colliding X.509 Certificates

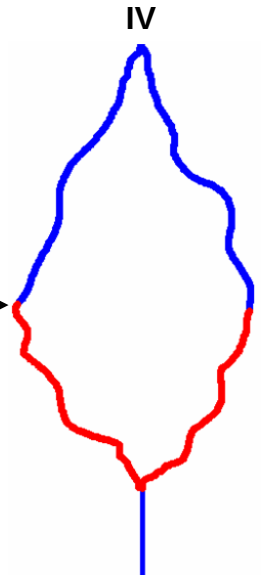


X.509 standard identical | chosen by CA | chosen by adversary not identical

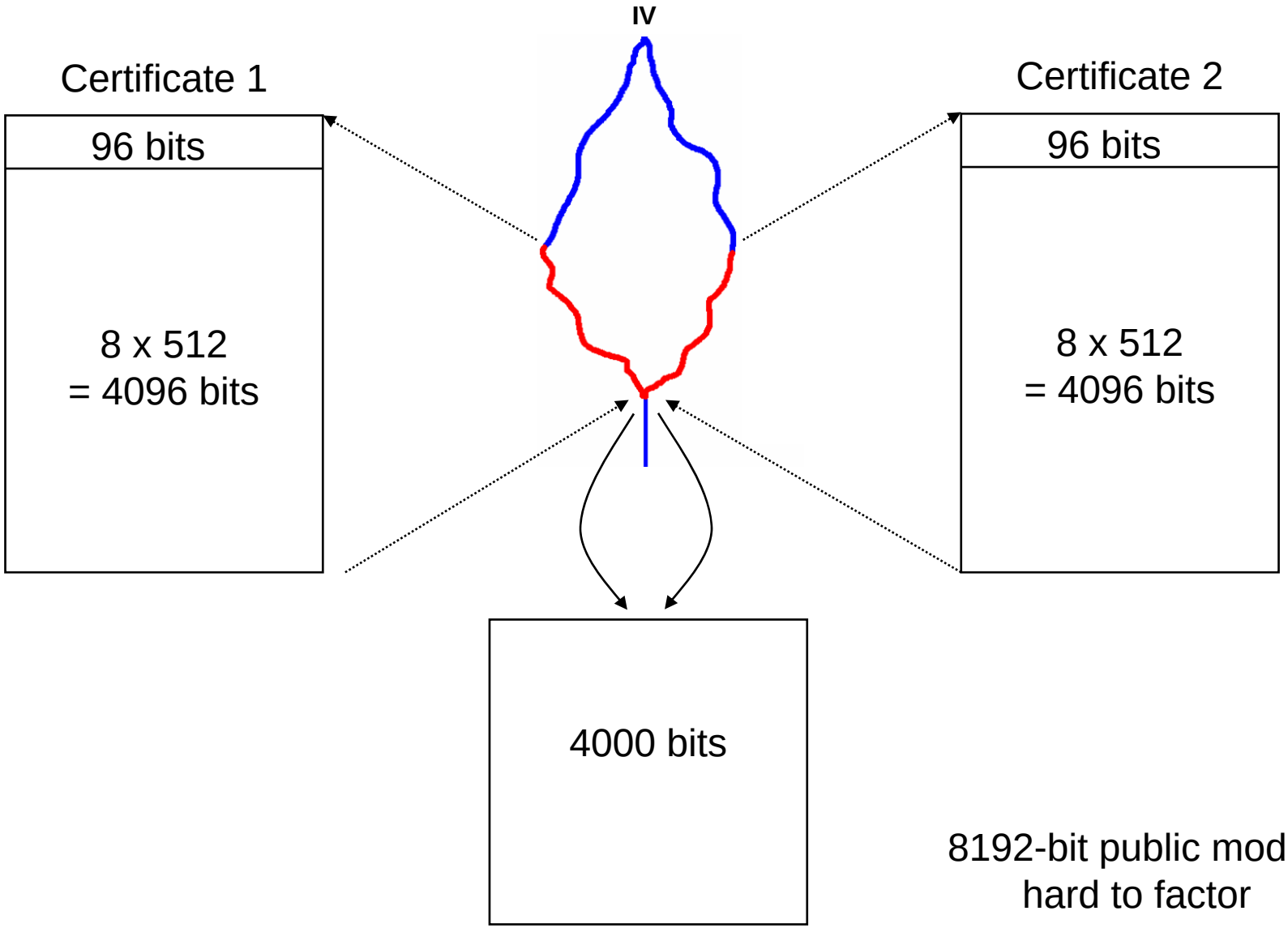
Colliding X.509 Certificates



- Until subjects public-key modulus
  - both messages equal length
  - multiple of 512 bits
  - last block 416 bits
  - arbitrary difference



Colliding X.509 Certificates



8192-bit public moduli
hard to factor

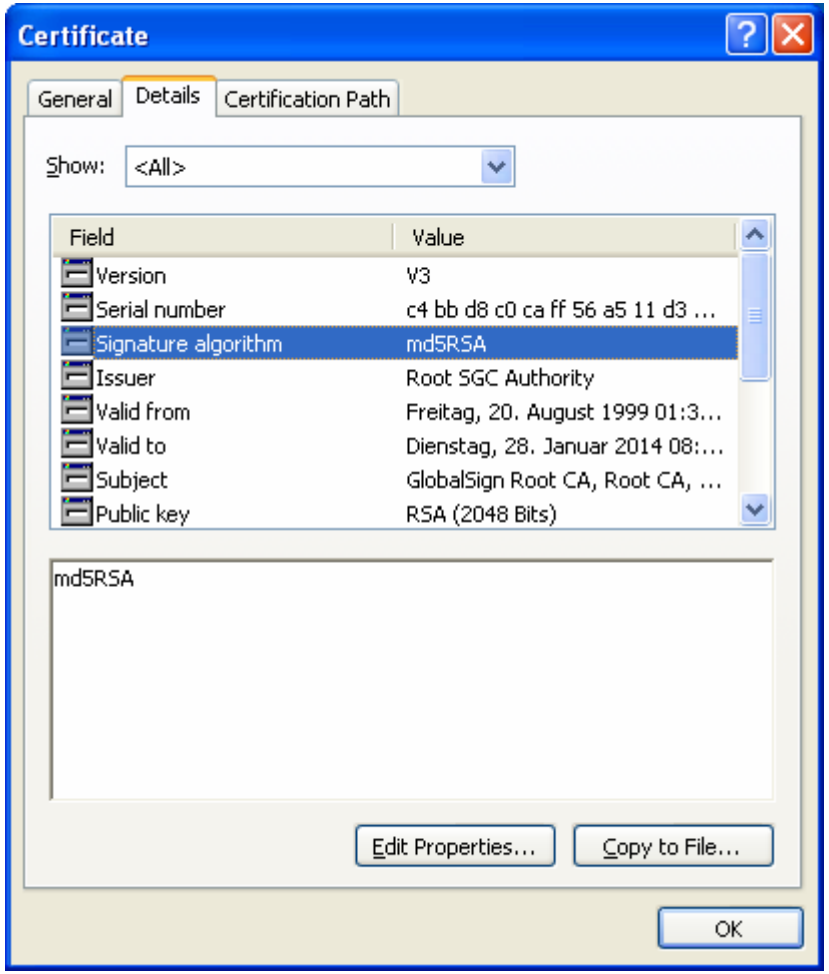
Colliding X.509 Certificates

- Two colliding certificates with different subject name and different public keys
- First example of meaningful collision
- Certificates need to be generated simultaneously
- Assumptions:
  - need sufficient control over CA
    - predict all information prior to the public key info fields
  - attacker can be identified
- To summarize: **do not use MD5 anymore**

- Similar things for SHA-1
  - http://www.iaik.tugraz.at/research/krypto/collision/

MD5 Based X.509 Certificates

- Advice: stop using MD5
  - RIPE since 1992
  - RSA since 1996 [1]
- Industry: largely ignored



[1] ftp://ftp.rsasecurity.com/pub/pdfs/bulletn4.pdf

Design of New Hash Functions

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Efforts in Design and Cryptanalysis of Hash Functions

- NIST
  - will launch similar public contest as for AES
  - one or more hash algorithms to revise FIPS 180-2
  - tentative timeline 2007-2012
    - define requirements and ask for hash function proposals
    - three *Hash Function Candidate Conferences*
    - 2011: announce new hash functions
    - 2012: standard and revise FIPS 180-2

- NoE ECRYPT
  - working group within STVL
  - Hash Workshop in Barcelona, May 24-25, 2007

    http://events.iaik.tugraz.at/hashworkshop07/

NIST

- **NIST's Policy on Hash Functions** March 15, 2006: **The SHA-2 family of hash functions (i.e., SHA-224, SHA-256, SHA-384 and SHA-512) may be used by Federal agencies for all applications using secure hash algorithms.** Federal agencies **should** stop using SHA-1 for digital signatures, digital time stamping and other applications that require collision resistance as soon as practical, and must use the SHA-2 family of hash functions for these applications after 2010. After 2010, Federal agencies may use SHA-1 only for the following applications: hash-based message authentication codes (HMACs); key derivation functions (KDFs); and random number generators (RNGs). Regardless of use, NIST encourages application and protocol designers to use the SHA-2 family of hash functions for all new applications and protocols.

http://www.csrc.nist.gov/pki/HashWorkshop/index.html

ECRYPT

- Does not recommend
  - hash functions with less than 160 bits
  - HMAC-MD5
  - digital signatures with MD5
  - SHA-1 in new deployments
- Recommendations
  - RIPEMD-160 (next 3-5 years)
  - long term use: FIPS 180-2 or alternatives such as Whirlpool

http://www.ecrypt.eu.org/documents/STVL-ERICS-2-HASH_STMT-1.1.pdf

Conclusion

- Real threat
  - second preimages and preimages
- Legally
  - collision resistance important (see speeding ticket case)
- Stop using MD5 and SHA-1
  - collisions for 80 steps expected sooner than later
  - old saying inside NSA:
    “Attacks always get better; they never get worse”
- New approaches and further details about hash functions required
  - NIST/ECRYPT

References

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