New developments in cryptology

Prof. Bart Preneel

COSIC

Bart.Preneel(at)esatDOTkuleuven.be

http://homes.esat.kuleuven.be/~preneel

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Outline

- 1. Cryptology: concepts and algorithms
- 2. Cryptology: protocols
- 3. Public-Key Infrastructure principles
- 4. Networking protocols
- **5. New developments in cryptology**
- 6. How to use cryptography well
- 7. Hash functions

Outline

- Block ciphers/stream ciphers/MAC algorithms
- Modes of operation
- The hash function disaster
- How to encrypt using RSA
- Algorithm: secure design and implementation
- Obfuscation
- SPAM fighting

Block ciphers: Keeloq

- Microchip Inc algorithm, designed in the 1980s
- Allegedly used in large % of the cars for car locks, car alarms
- Block cipher with 32-bit blocks, 64-bit keys and 528 simple rounds
- Leaked on the internet early 2007

[redacted]

Block ciphers: Keeloq (2)

[Bogdanov07] Car key = Master key + Car ID

[Biham-Dunkelman-Indesteeghe-Keller-Preneel07]:

- 1 hour access to token + 2 days of calculation

[Eisenbarth-Kasper-Moradi-Paar-Salmasizadeh-Manzuri ShalmaniPaar 08]

- **Side channel attack allows to recover master key in hopping mode**

in 2010 cryptographers will drive expensive cars

Stream ciphers

- historically very important (compact)
  - LFSR-based: A5/1, A5/2, E0 – practical attacks known
  - software-oriented: RC4 – serious weaknesses
  - block cipher in CTR or OFB (slower)
- today:
  - many broken schemes
  - exception: SNOW2.0, MUGI
  - lack of standards and open solutions

Open competition for stream ciphers

http://www.ecrypt.eu.org

- run by ECRYPT
  - high performance in software (32/64-bit): 128-bit key
  - low-gate count hardware (< 1000 gates): 80-bit key
  - variants: authenticated encryption
- April 2005: 33 submissions
- many broken in first year
- April 2008: end of competition

The eSTREAM Portfolio

Apr. 2008 (Rev1 Sept. 2008)

(in alphabetical order)

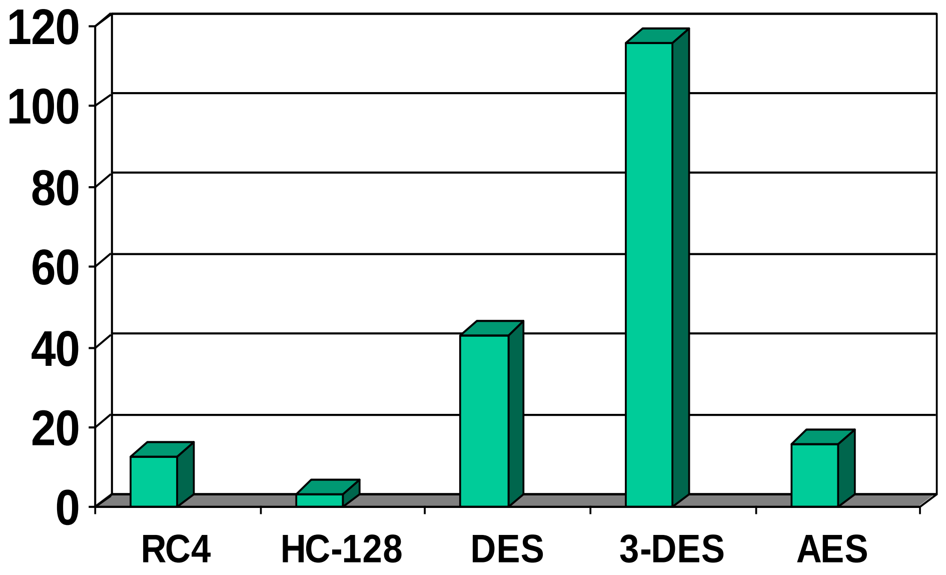
Software	**Hardware**
HC-128	~~F-FCSR-H~~
Rabbit	Grain v1
Salsa20/12	MICKEY v2
Sosemanuk	Trivium

3-10 cycles per byte 1500..3000 gates

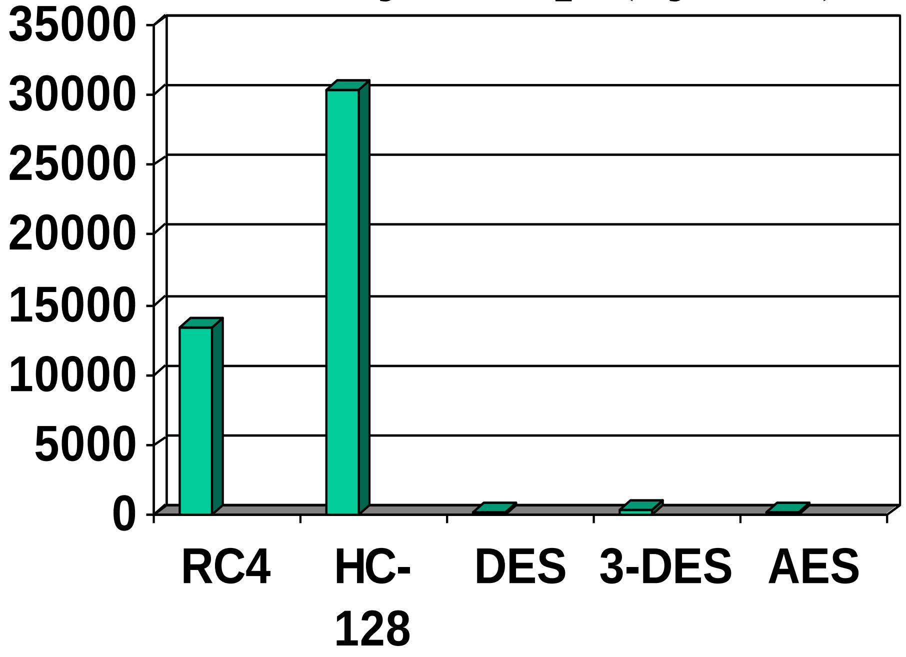
Performance reference data

(Pentium M 1.70GHz Model 6/9/5)

encryption speed (cycles/byte)



key setup (cycles)



Cube attack [Dinur-Shamir'08]

- Exploits low degree equations in stream cipher
- Can break certain ciphers which could not be broken before
- …Media hype

- Trivium:
  - key setup can be broken if number of rounds is reduced from 1024 to 735
  - attack can probably be further improved
  - solution: increase number of rounds to 2048

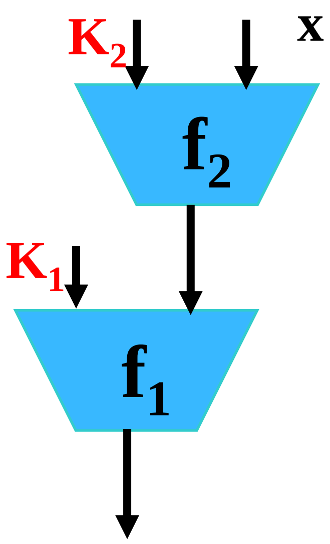
MAC algorithms

- EMAC based on AES
- HMAC based on MD5/SHA-1
- GMAC
- UMAC

- NIST: 2 new standards for authenticated encryption
  - CCM: CTR + CBC-MAC [NIST SP 800-38C]
  - GCM: CTR + GMAC [NIST SP 800-38C]

HMAC based on MDx, SHA

- Widely used in SSL/TLS/IPsec
  - Attacks not yet dramatic
- NMAC weaker than HMAC



	Rounds in f1	Rounds in f2	Data complexity
MD4	48	48	2^{88} CP & 2^{95} time
MD5	64	33 of 64	2^{126} CP
MD5	64	64	2^{51} CP & 2^{100} time (RK)
SHA(-0)	80	80	2^{109} CP
SHA-1	80	43 of 80	$2^{154.9}$ CP

GMAC: polynomial MAC (NIST SP 800-38D ‘07 + 3GSM)

- keys K_1, $K_2 \in GF(2^{128})$
- input x: $x_1, x_2, \ldots, x_t$, with $x_i \in GF(2^{128})$
  - $g(x) = K_1 + \sum_{i=1}^{t} x_i \bullet (K_2)^i$
- in practice: compute $K_1 = \text{AES}_K(n)$ (CTR mode)
- properties:
  - fast in software and hardware (support from Intel)
  - not very robust w.r.t. nonce reuse, truncation, MAC verifications, due to reuse of K_2 *(not in 3GSM!)*
  - versions over GF(p) (e.g. Poly1305-AES) seem more robust

UMAC RFC 4418 (2006)

- key $K, k_1, k_2 .., k_{256} \in GF(2^{32})$ *(1024 bytes)*
- input x: $x_1, x_2, \ldots, x_{256}$, with $x_i \in GF(2^{32})$
- $g(x) = prf_K(h(x))$
- $h(x) = (\Sigma_{i=1}^{512} (x_{2i-1} + k_{2i-1}) \bmod 2^{32} \cdot (x_{2i} + k_{2i}) \bmod 2^{32}) \bmod 2^{64}$

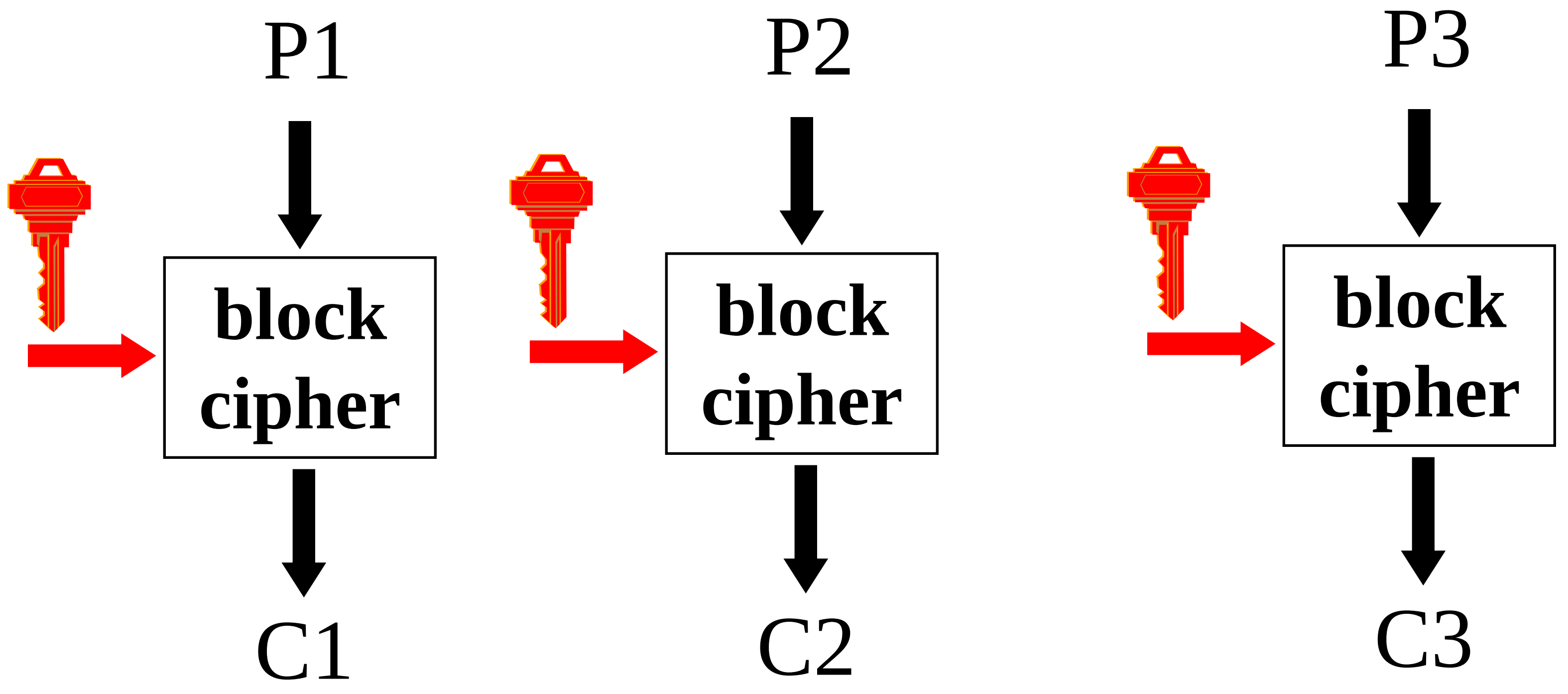
- properties
  - software performance: 1-2 cycles/byte
  - forgery probability: $1/2^{30}$ (provable lower bound)
  - [Handschuh-Preneel08] full key recovery with 2^{40} verification queries

How to use cryptographic algorithms

- Modes of operation
- Padding and error messages
- Authenticated encryption

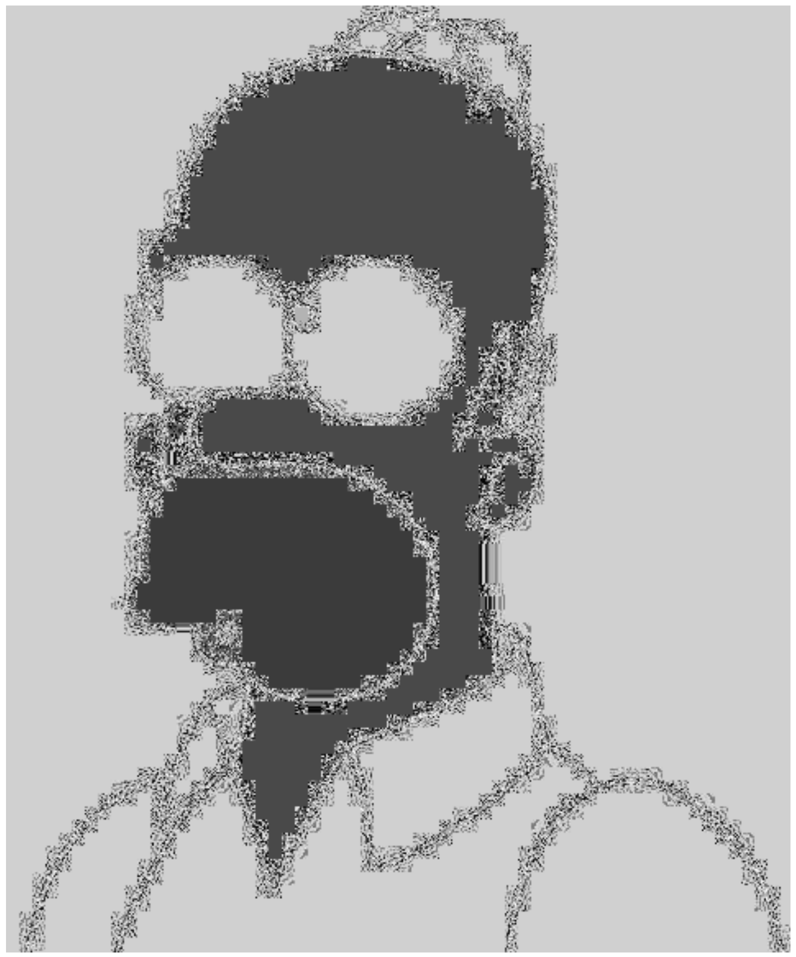
- How to encrypt with RSA

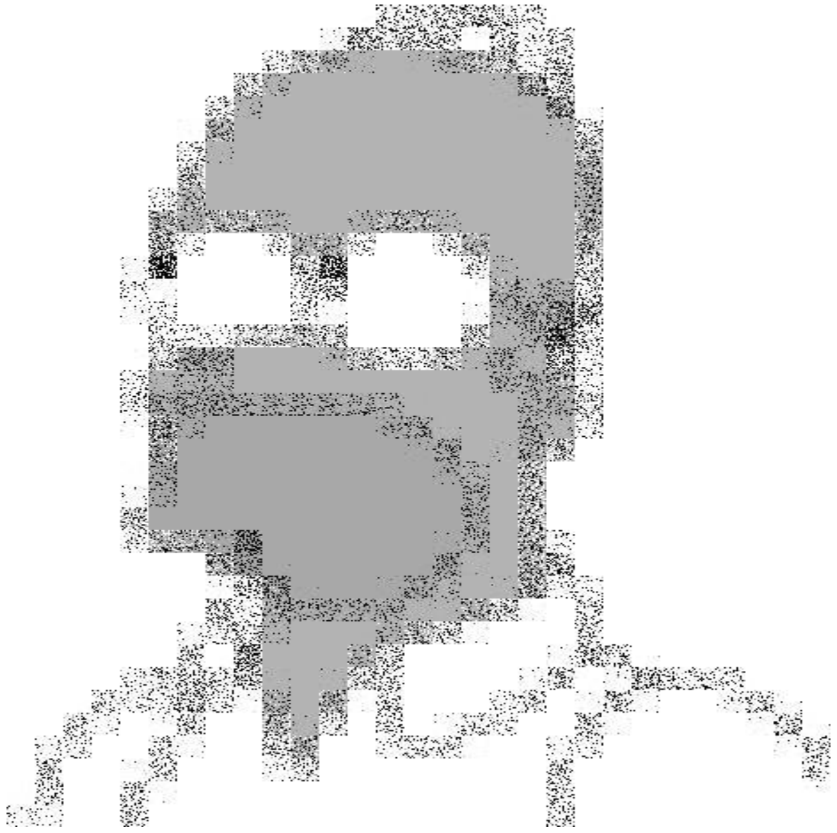
How NOT to use a block cipher: ECB mode



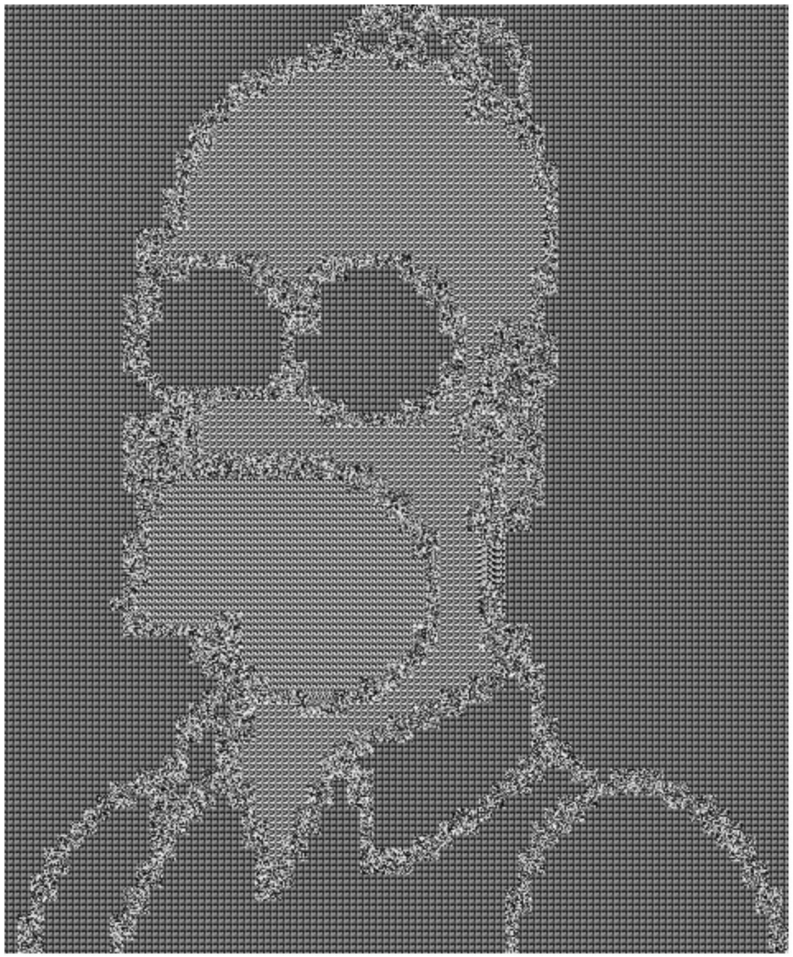
An example plaintext

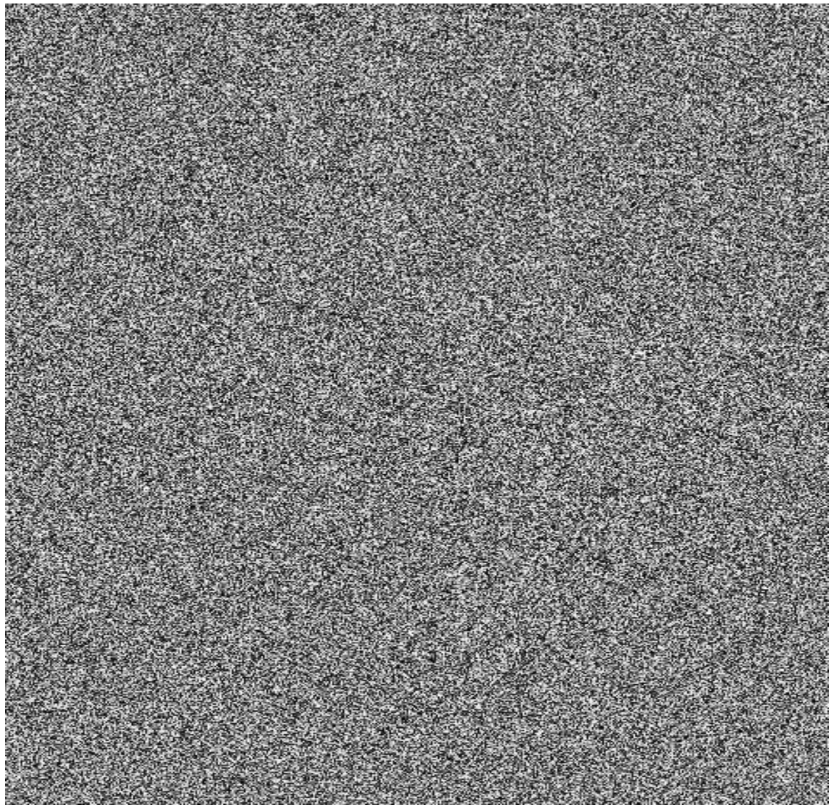
Encrypted with substitution and transposition cipher



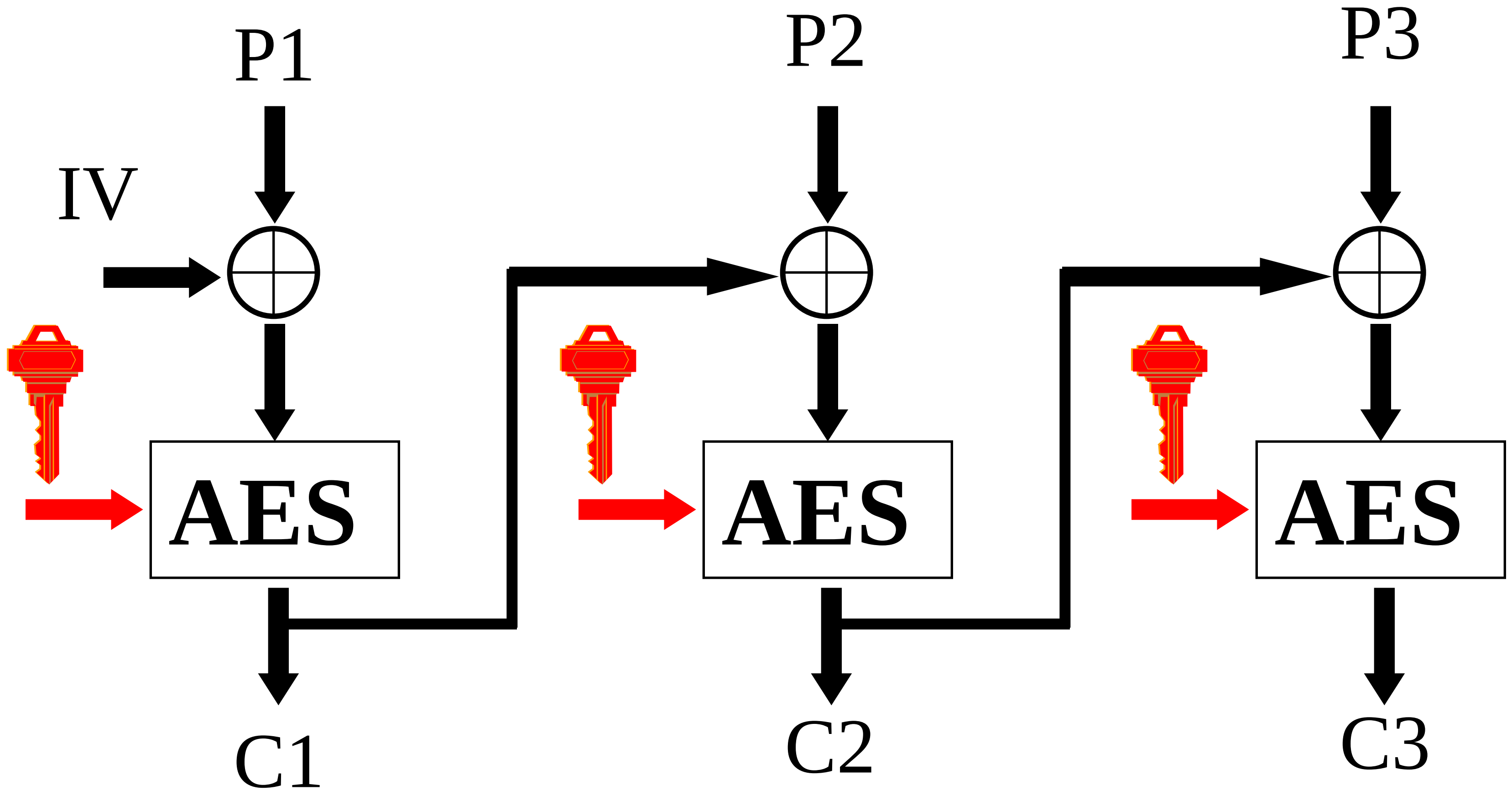


Encrypted with AES in ECB and CBC mode

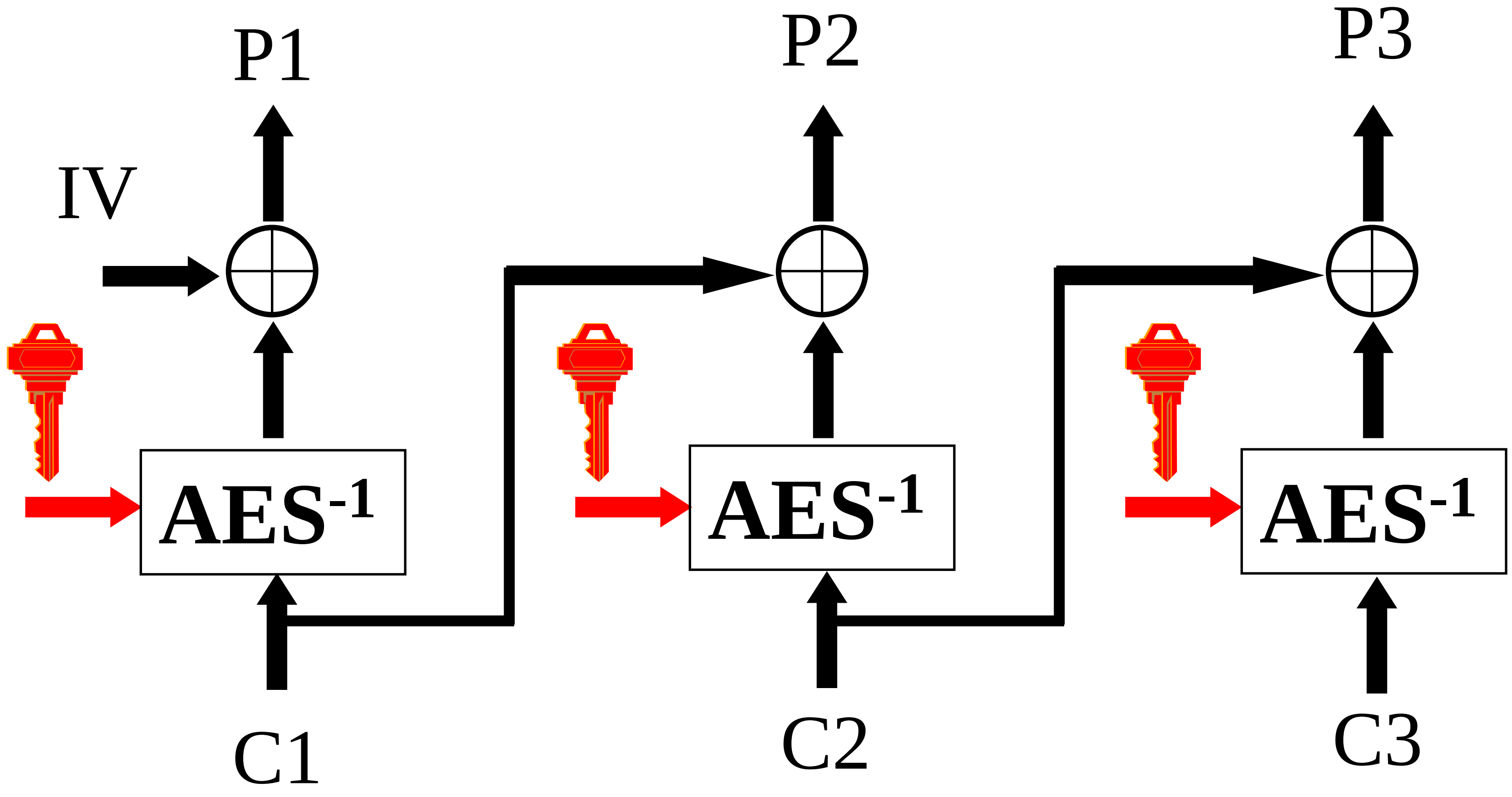




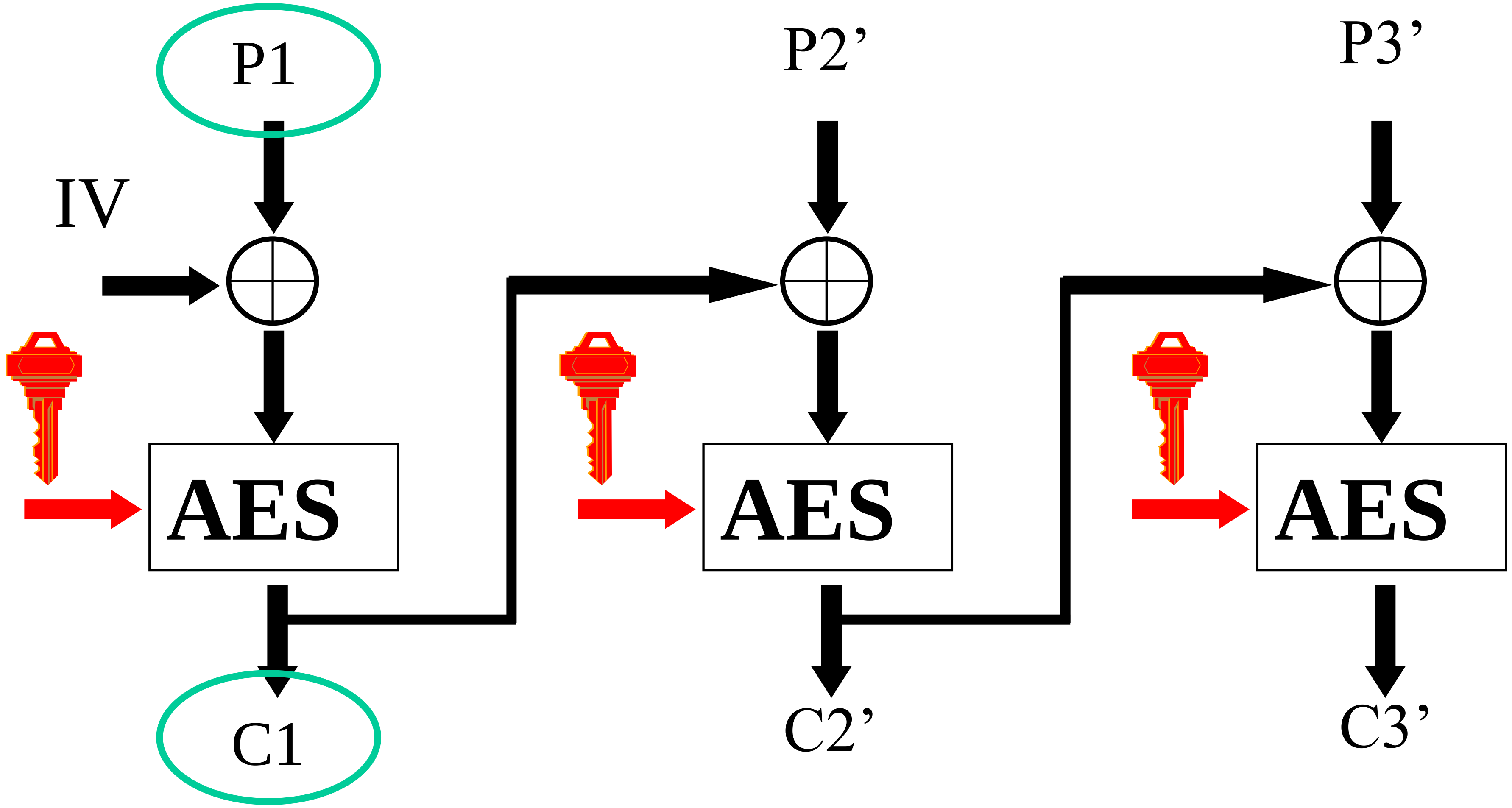
How to use a block cipher: CBC mode



CBC mode decryption



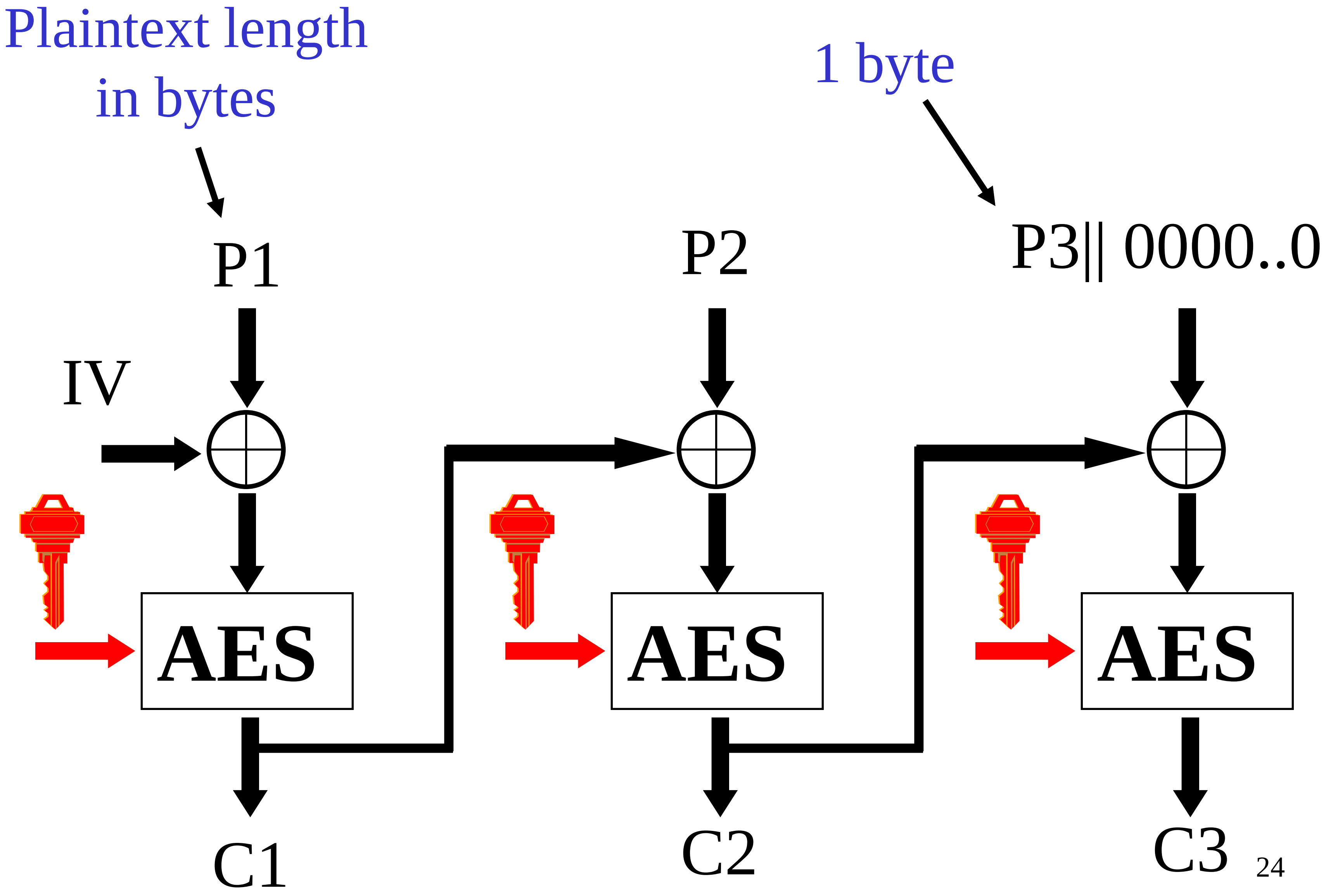
What if IV is constant?



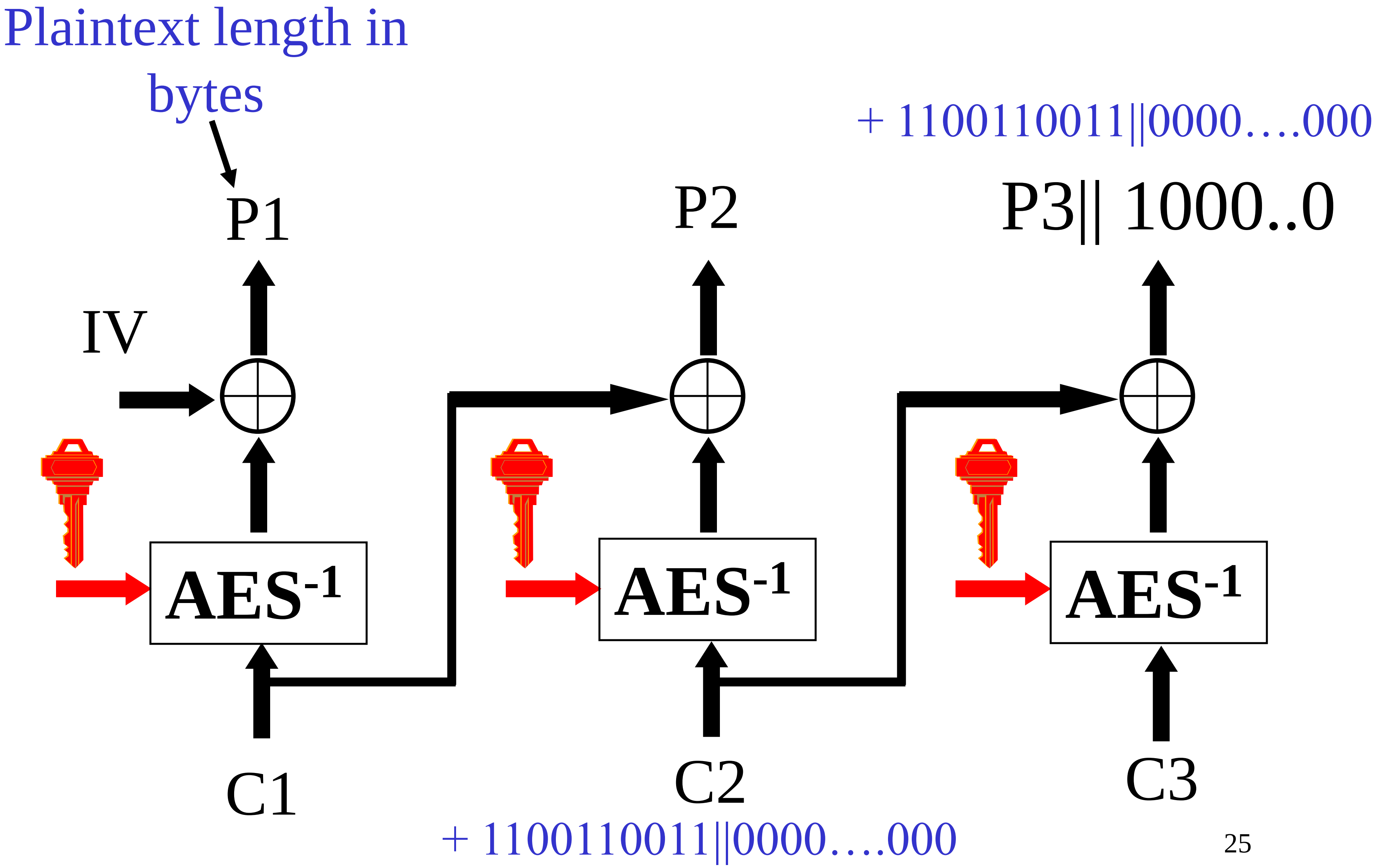
Repetition in P results in repetition in C: ⇒ information leakage

need random and secret IV

CBC with incomplete plaintext (1)



CBC with incomplete plaintext (2)



CBC with incomplete plaintext (3)

Plaintext length in bytes

+ 1100110011||0000….000

P1 P2 P3|| 1000..0

- If the first 10 bits of P3 are equal to 1100110011 then after the modification P3’ will be equal to 0
- The decryption will then produce an error message because the plaintext length field is incorrect
- Conclusion: information on 1 byte of P3 can be obtained using on average 128 chosen ciphertexts
- Protection: random padding or authenticated encryption

Modes of Operation

- CTR mode allows for pipelining
  - Better area/speed trade-off
- authentication: E-MAC and CMAC
  - E-MAC is CBC-MAC with extra encryption in last block
  - NIST prefers CMAC (was OMAC)
- authenticated encryption:
  - most applications need this primitive (ssh, TLS, IPsec, …)
  - for security against chosen ciphertext this is essential
  - NIST solution: GCM (very fast but lacks robustness)

Authenticated encryption

Inefficient solution: encrypt then MAC

We can do better

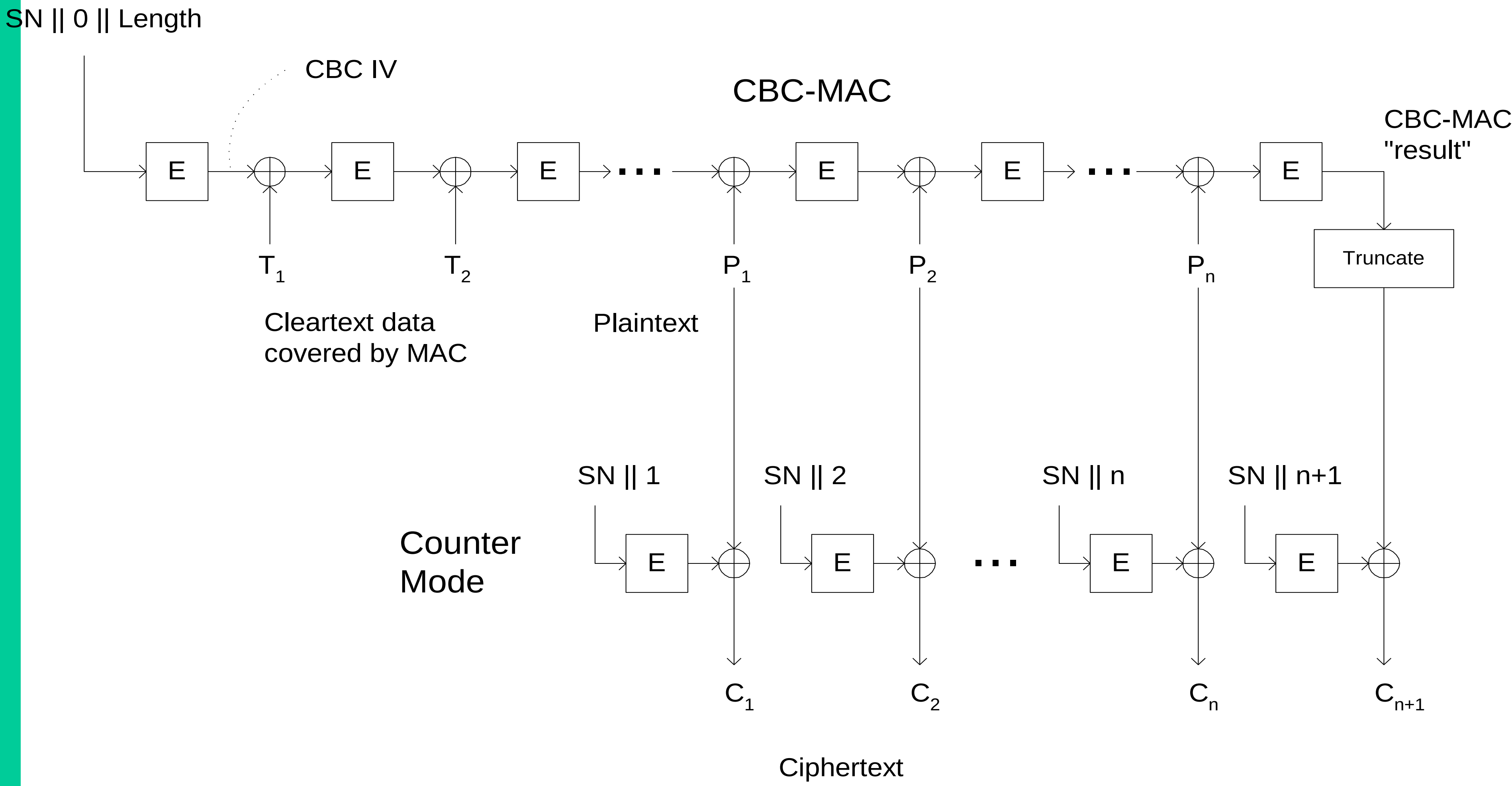
Issues:

- associated data
- parallelizable
- on-line
- patent-free
- provable security

- IAPM
- XECB
- OCB

- CCM
- EAX
- CWC
- GCM

Example: CCM: CTR + CBC-MAC



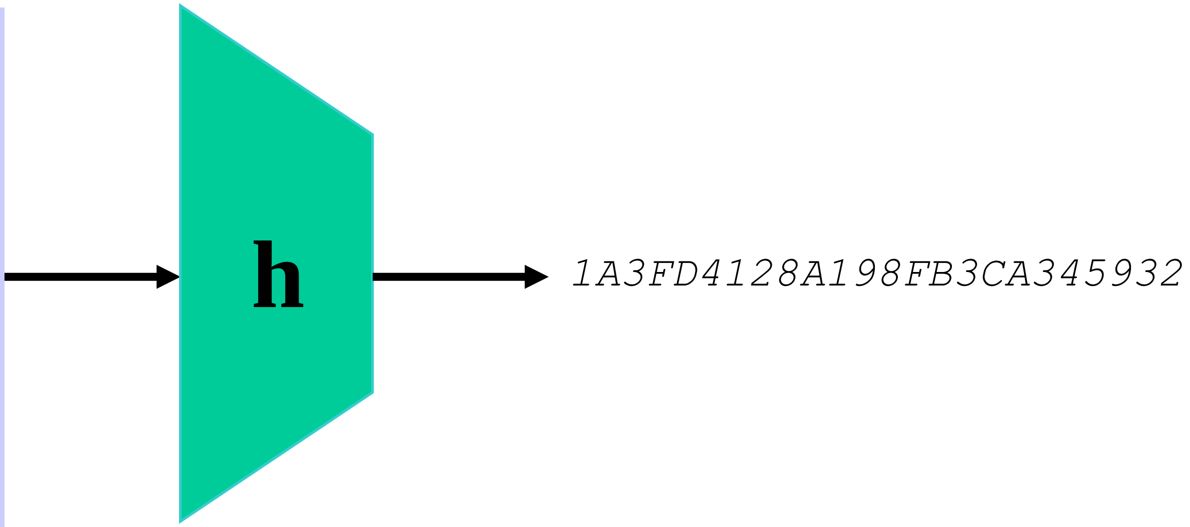
SN = packet sequence number (WEP "IV")

Hash functions

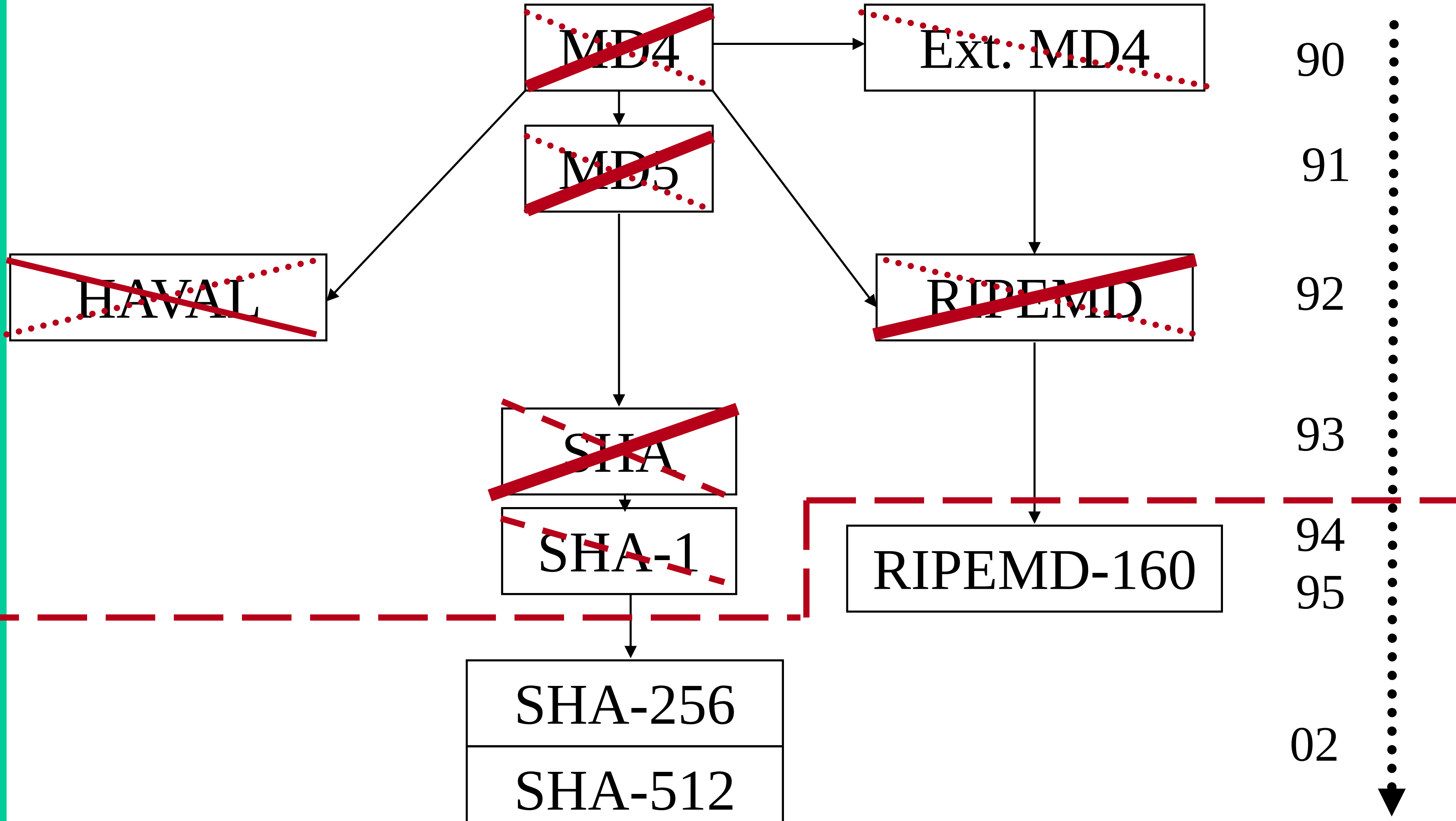
- MDC (manipulation detection code)
- Protect short hash value rather than long text

- collision resistance
- preimage resistance
- 2nd preimage resistance

This is an input to a crypto-graphic hash function. The input is a very long string, that is reduced by the hash function to a string of fixed length. There are additional security conditions: it should be very hard to find an input hashing to a given value (a preimage) or to find two colliding inputs (a collision).



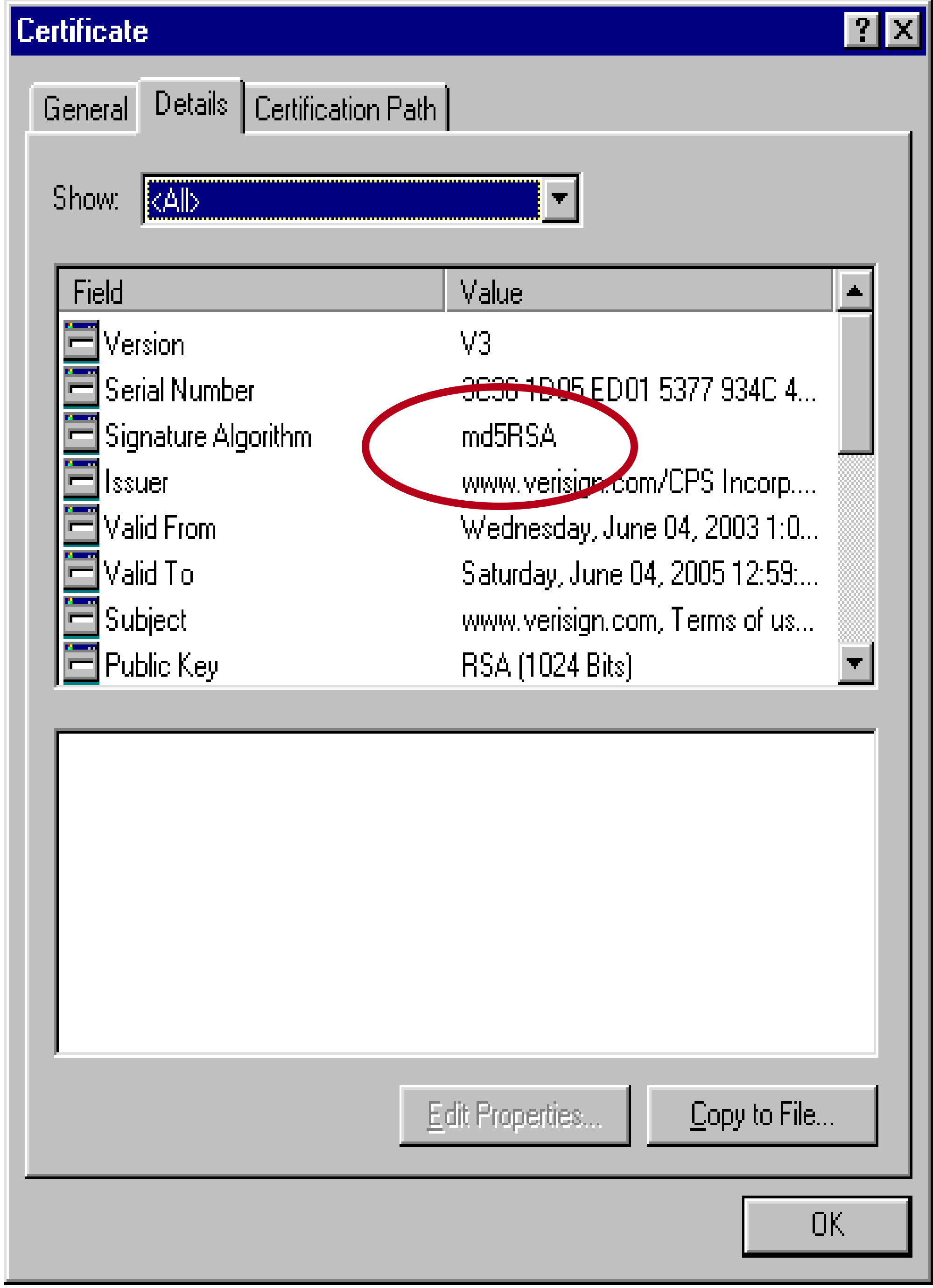
MDx-type hash function history



MD5

- Advice (RIPE since ‘92, RSA since ‘96): stop using MD5
- Largely ignored by industry (click on a cert…)

- Collisions for MD5 are within range of a brute force attack anyway (2^{64})
- [Wang+’04] collision in 15 minutes
- Today: collisions in seconds



Show: <All>

Field	Value
Version	V3
Serial Number	3C30 1D05 ED01 5377 934C 4...
Signature Algorithm	md5RSA
Issuer	www.verisign.com/CPS Incorp....
Valid From	Wednesday, June 04, 2003 1:0...
Valid To	Saturday, June 04, 2005 12:59:...
Subject	www.verisign.com, Terms of us...
Public Key	RSA (1024 Bits)

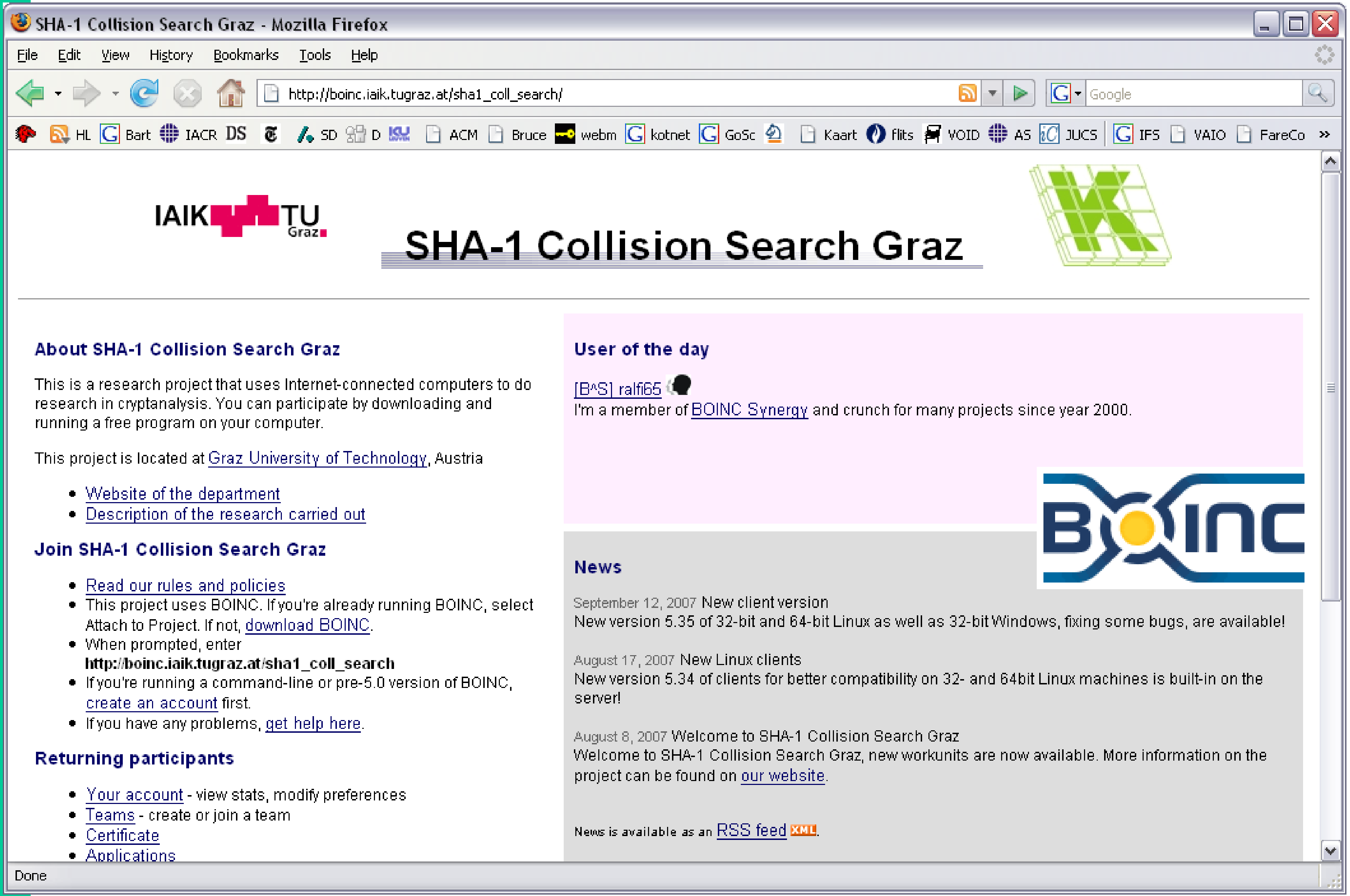
SHA-1

- SHA designed by NIST (NSA) in ‘93
- redesign after 2 years (’95) to SHA-1

- Collisions found for SHA-0 in 2^{51} [Joux+’04]
- Reduced to 2^{39} [Wang+’05] and 2^{32} [Rechberger+’07]

- **Collisions for SHA-1 in 2^{63} [Wang+’05]**
- ***Structured* collisions for SHA-1 found for 64 out of 80 rounds [De Cannière-Rechberger’06]**
- **Collisions for 70 out of 80 rounds of SHA-1 and for SHA-1 in 2^{60} [Rechberger+07]**

Prediction: collision for SHA-1 in the next 12 months


SHA-1 Collision Search Graz - Mozilla Firefox
File Edit View History Bookmarks Tools Help
http://boinc.iaik.tugraz.at/sha1_coll_search/
Google
HL Bart IACR DS SD D ACM Bruce webm kotnet GoSc Kaart flits VOID AS JUCS IFS VAIO FareCo
IAIK TU Graz
Done

SHA-1 Collision Search Graz

About SHA-1 Collision Search Graz

This is a research project that uses Internet-connected computers to do research in cryptanalysis. You can participate by downloading and running a free program on your computer.

This project is located at Graz University of Technology, Austria

- Website of the department
- Description of the research carried out

Join SHA-1 Collision Search Graz

- Read our rules and policies
- This project uses BOINC. If you're already running BOINC, select Attach to Project. If not, download BOINC.
- When prompted, enter **http://boinc.iaik.tugraz.at/sha1_coll_search**
- If you're running a command-line or pre-5.0 version of BOINC, create an account first.
- If you have any problems, get help here.

Returning participants

- Your account - view stats, modify preferences
- Teams - create or join a team
- Certificate
- Applications

User of the day

[B^S] ralfi65
I'm a member of BOINC Synergy and crunch for many projects since year 2000.

BOINC

News

September 12, 2007 New client version
New version 5.35 of 32-bit and 64-bit Linux as well as 32-bit Windows, fixing some bugs, are available!

August 17, 2007 New Linux clients
New version 5.34 of clients for better compatibility on 32- and 64bit Linux machines is built-in on the server!

August 8, 2007 Welcome to SHA-1 Collision Search Graz
Welcome to SHA-1 Collision Search Graz, new workunits are now available. More information on the project can be found on our website.

News is available as an RSS feed XML.

From: “Cryptography Simplified in Microsoft .NET”
Paul D. Sheriff (PDSA.com) [Oct. 2003]

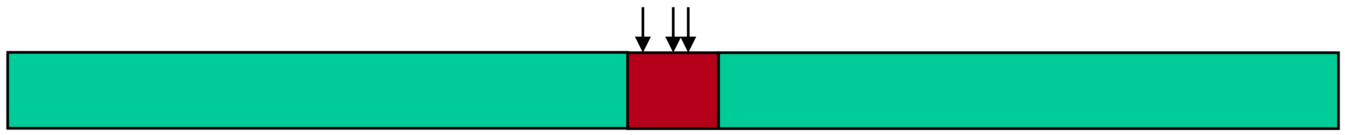
How to Choose an Algorithm

- For example, SHA1 uses a 160-bit encryption key, whereas MD5 uses a 128-bit encryption key; thus, SHA1 is more secure than MD5.
- Another point to consider about hashing algorithms is whether or not there are practical or theoretical possibilities of collisions. Collisions are bad since two different words could produce the same hash. SHA1, for example, has no practical or theoretical possibilities of collision. MD5 has the possibility of theoretical collisions, but no practical possibilities.

In February 2008 this information wa still available on MSDN

Impact of collisions (1)

- collisions for MD5, SHA-0, SHA-1
  - two messages differ in a few bits in 1 to 3 512-bit input blocks
  - limited control over message bits in these blocks
  - but arbitrary choice of bits before and after them
    - 2 colliding executables, postscript documents and gif files [Lucks, Daum ‘05]
    - 2 colliding RSA public keys – thus with colliding X.509 certificates [Lenstra, Wang, de Weger ’04]



  - Chosen prefix collisions [Stevens+’07]
  - 2 arbitrary colliding files (no constraints) for 100K$

Impact of collisions (2)

- digital signatures: only an issue if for non-repudiation
- none for signatures computed before attacks were public (1 August 2004)
- none for certificates if public keys are generated at random in a controlled environment
- substantial for signatures after 1 August 2005 (cf. traffic tickets in Australia)

Other properties?

- 2nd preimage attack are not as infeasible as we once believed: for MD4/MD5 definitely less than 2^{128}
- HMAC
  - HMAC-MD4 is theoretically broken
  - HMAC-MD5 is questionable
  - HMAC-SHA1 seems ok
- many other issues have been identified with all our hash functions
- standards that are yet unbroken:
  - RIPEMD-160 ☺
  - SHA-256, SHA-512
  - Whirlpool
- upgrading MD5 and SHA-1 in Internet protocols:
  - algorithm flexibility is much harder than expected

NIST hash function competition

The algorithm must support 224, 256, 384, and 512-bit message digests, and must support a maximum message length of at least $\mathbf{2^{64}}$ bits."

- 3Q07 Finalize and publish the minimum acceptability requirements, submission requirements, and evaluation criteria for candidate hash functions
- 3Q08 Submission deadline for new hash functions.
- 2Q10 Announce finalists
- 4Q11 Announce decision
- 3Q12 Publish Advanced Hash Function Standard

How to encrypt with RSA?

- Assume that the RSA problem is hard
- … so a fortiori we assume that factoring is hard

- How to encrypt with RSA?
  – Hint: ensure that the plaintext is mapped to a random element of [0,n-1] and then apply the RSA Encryption Permutation (RSAEP)

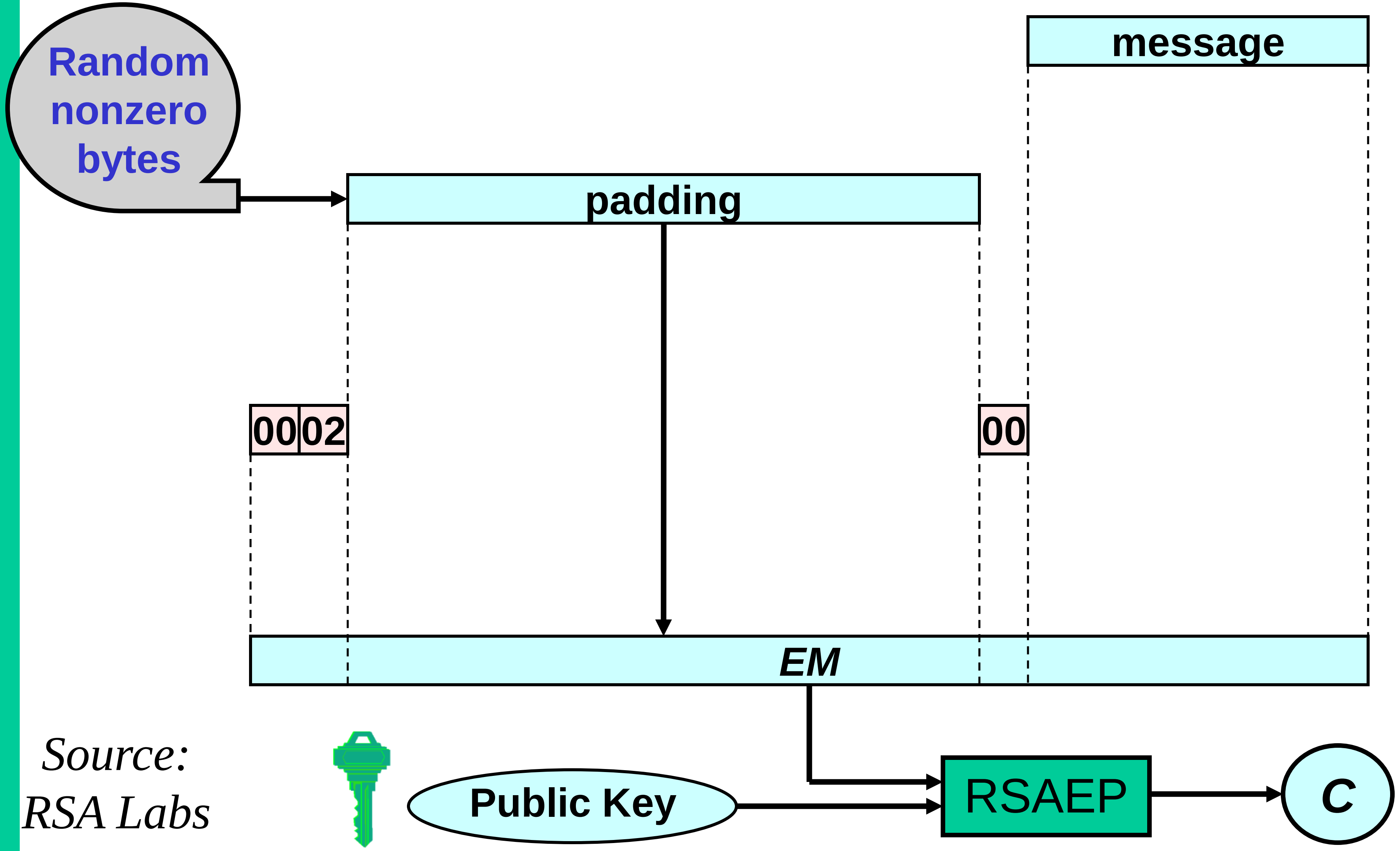
How (not) to encrypt with RSA?

- Non-hybrid schemes
  - RSA-PKCS-1v1_5 (RSA Laboratories, 1993)
  - RSA-OAEP (Bellare-Rogaway, 1994)
  - RSA-OAEP+ (Shoup, 2000)
  - RSA-SAEP (Johnson et al., 2001)
  - RSA-SAEP+ (Boneh, 2001)
- Hybrid schemes
  - RSA-KEM (Zheng-Seberry, 1992)
    - RSA-KEM-DEM (Shoup, 2001)
    - RSA-REACT (Okamoto-Pointcheval, 2001)
  - RSA-GEM (Coron et al., 2002)

RSA PKCS-1v1_5

- Introduced in 1993 in PKCS #1 v1.5
- *De facto* standard for RSA encryption and key transport
  - Appears in protocols such as TLS, S/MIME, ...

RSA-PKCS-1v1_5 Diagram



Source: RSA Labs

RSA-PKCS-1v1_5 Cryptanalysis

- Low-exponent RSA when very long messages are encrypted [Coppersmith+ ‘96/Coron ‘00]
  - large parts of a plaintext is known or similar messages are encrypted with the same public key
- Chosen ciphertext attack [Bleichenbacher ’98]
  - decryption oracle: ciphertext valid or not?
  - 1024-bit modulus: 1 million decryption queries
- These attacks are precluded by fixes in TLS

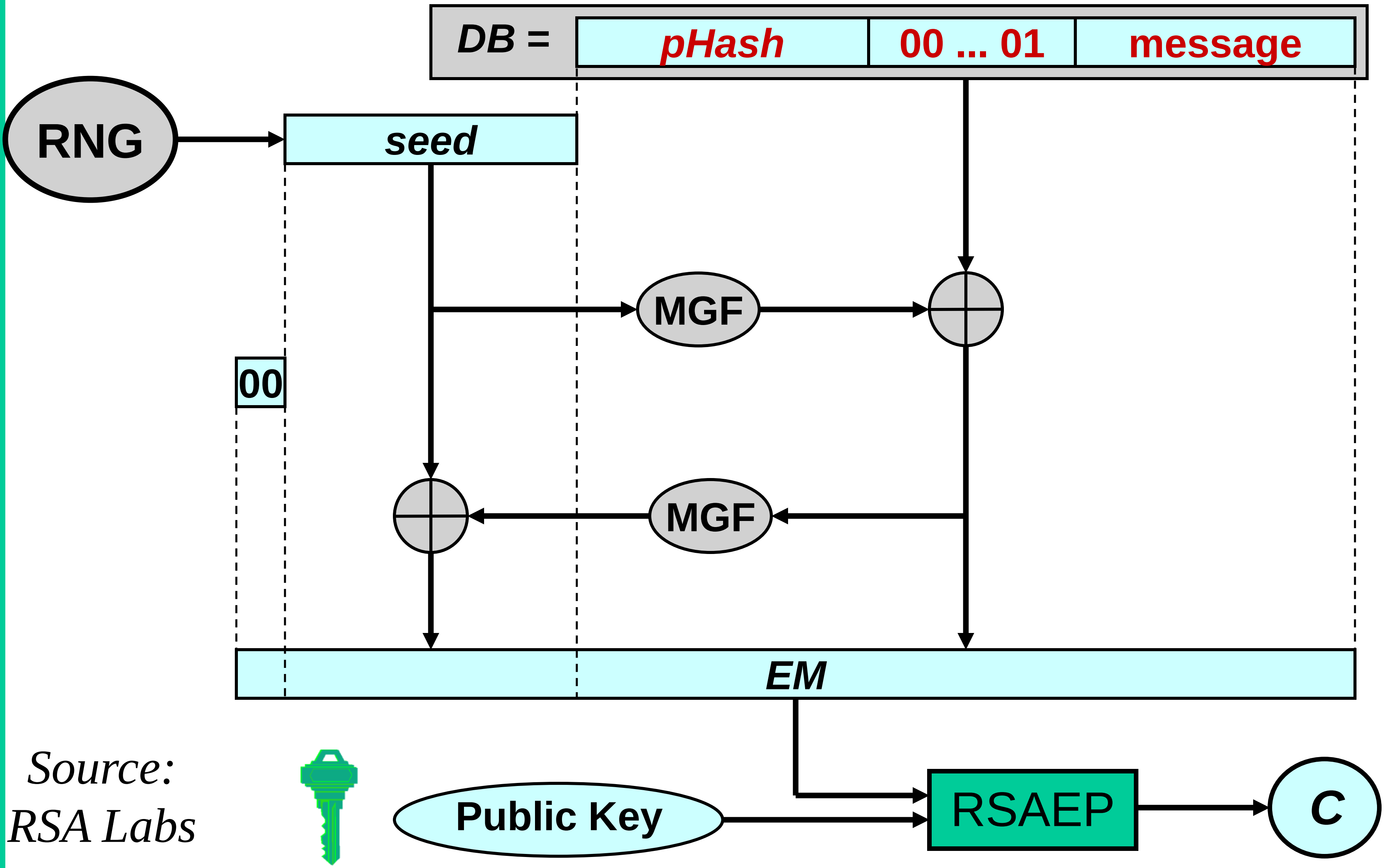
Bleichenbacher's attack

- Goal: decrypt c
  - choose random s, $0 < s < n$
  - computer $c' = c\, s^e \bmod n$
  - ask for decryption of c': m'
  - compute m as $m'/s \bmod n$
- but m' does not have the right format!
- idea: try many random choices for s:
  - if no error message is received, we know that $2B < (m\, s \bmod n) < 3B$
  - with $B = 2^{8(k-2)}$ (k length in bytes of the modulus)

RSA-OAEP

- designers: Bellare and Rogaway 1993
- enhancements by Johnson and Matyas in 1996 (“encoding parameters”)
- already widely adopted in standards
  - IEEE P1363 draft
  - ANSI X9.44 draft
  - PKCS #1 v2.0 (PKCS #1 v2.1 draft)
  - ISO 18033-2 working draft 2000

RSA-OAEP Diagram



Source: RSA Labs

RSA OAEP - security

~~*[BR'93] RSA-OAEP is IND-CCA2 secure under RSA assumption in ROM*~~

Shoup '00: the proof is wrong

[FOPS 01] RSA-OAEP is IND-CCA2 secure under partial domain one-wayness RSA assumption in ROM

for RSA: partial domain one-wayness $\Leftrightarrow$ *one-wayness*

Reduction is very weak

ROM assumption is questionable

RSA OAEP - security

- Improved chosen ciphertext attack [Manger, Crypto '01]

- requires a few thousand queries (1.1 $\log_2 n$)
- opponent needs oracle that tells whether there is an error in the integer-to-byte conversion or in the OAEP decoding

- overall conclusion: RSA Inc. is no longer recommending the use of RSA-OAEP

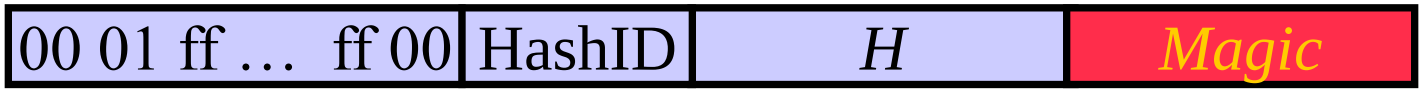
if it's provable secure, it probably isn't

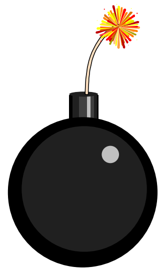
How to encrypt with RSA

- RSA-KEM
  - encrypt 2 session keys with RSA
  - encrypt and MAC data with these 2 keys
- Recommended in NESSIE report (http://www.cryptonessie.org) and to be included in ISO 18033
- Similar problems for signatures:
  ISO 9796-1 broken, PKCS#1 v1.0 questionable

Attack on PKCS #1 v1.5 implementations (1)

[Bleichenbacher06]



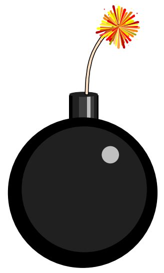


- Consider RSA with public exponent 3
- For any hash value H, it is easy to compute a string "Magic" such that the above string is a perfect cube of 3072 bits
- Consequence:
  - One can sign any message (H) without knowing the private key
  - This signature works for any public key that is longer than 3072 bits
- Vulnerable: OpenSSL, Mozilla NSS, GnuTLS

Attack on PKCS #1 v1.5 implementations (2)

[Bleichenbacher06]

00 01 ff … ff 00	HashID	*H*	*Magic*



- Fix
  - Write proper verification code (but the signer cannot know which code the verifier will use)
  - Use a public exponent that is at least 32 bits
  - Upgrade – finally – to RSA-PSS

Cryptographic algorithm selection

- Standards?
- Public domain versus proprietary
- Upgrades

Cryptographic standards

- Algorithms historically sensitive (e.g., GSM)
- Choices with little technical motivation (e.g., RC2 and MD2)
- Little or no coordination effort (even within IETF)
- Technically difficult

A.S. Tanenbaum: “The nice thing about standards is there's so many to choose from”

Major Standardization Bodies in Cryptography

- International
  - ISO and ISO/IEC International Organization for Standardi
  - ITU: International Telecommunications Union
  - IETF: Internet Engineering Task Force
  - IEEE: Institute of Electrical and Electronic Engineers
- National
  - ANSI: American National Standards Institute
  - NIST: National Institute of Standards and Technology
- European
  - CEN: Comité Européen de Normalisation
  - ETSI: European Telecommunications Standards Institute
- Industry
  - PKCS, SECG
  - W3C, OASIS, Liberty Alliance, Wi-Fi Alliance, BioAPI, WS-Security, TCG
  - GP, PC/SC, Open Card Framework, Multos

Independent evaluation efforts

- NIST (US) (1997-2001): block cipher AES for FIPS 197 (http://csrc.nist.gov/CryptoToolkit/aes/)
- CRYPTREC (Japan) (2000-2003): cryptographic algorithms and protocols for government use in Japan (http://www.ipa.go.jp/security)
- EU-funded IST-NESSIE Project (2000-2003): new cryptographic primitives based on an open evaluation procedure (http://www.cryptonessie.org)
- ECRYPT eSTREAM (2004-2007): stream cipher competition

Proprietary/secret algorithms

- No “free” public evaluations
- Risk of snake oil
- Cost of (re)-evaluation very high
- No economy of scale in implementations
- Reverse engineering

- Fewer problems with rumors and “New York Times” attacks
- Extra reaction time if problems
- Fewer problems with implementation attacks
- Can use crypto for IPR and licensing

Many insecure algorithms in use

- Do it yourself (snake oil)
- Export controls
- Increased computational power for attacks (64-bit keys are no longer adequate)
- Cryptanalysis progress - including errors in proofs
- Upgrading is often too hard by design
  - cost issue
  - backward compatibility
  - version roll-back attacks

Upgrade problem

- GSM: A5/3 takes a long time
- Bluetooth: E0 hardwired
- TCG: chip with fixed algorithms
- MD5 and SHA-1 widely used

- Negotiable algorithms in SSH, TLS, IPsec,…
- But even then these protocols have problems getting rid of MD5/SHA-1

Make sure that you do not use the same key with a weak and a strong variant (e.g. GSM A5/2 and A5/3)

And the good news

- Many secure and free solutions available today: AES, RSA,…
- With some reasonable confidence in secure
- Cost of strong crypto decreasing except for “niche applications” (ambient intelligence)

In spite of all the problems, cryptography is certainly not the weakest link in our security chain

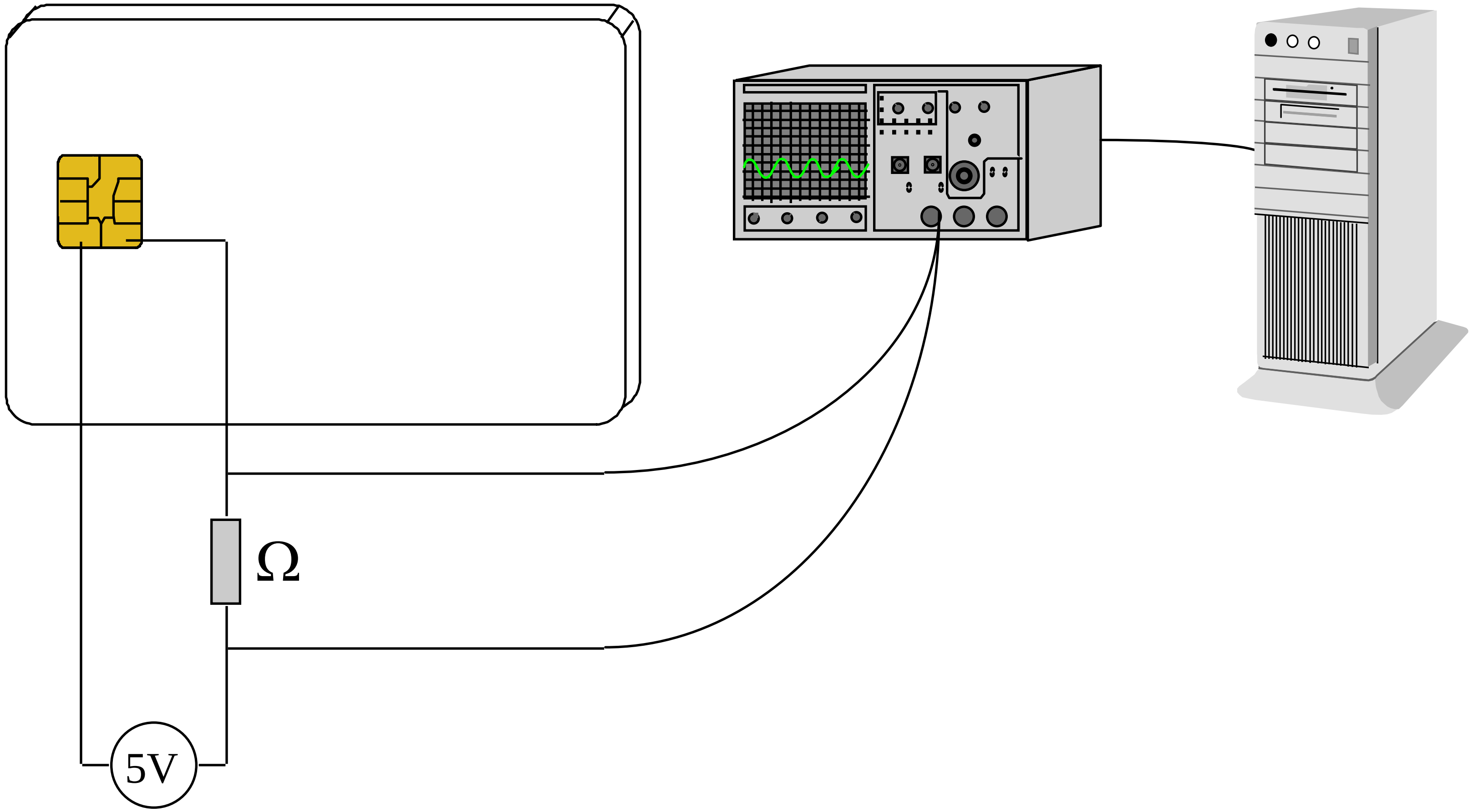
What to use (generic solutions)

- Authenticated encryption mode (OCB, CWC, CCM, or even GCM) with 3-key 3-DES or AES
- Hash functions: RIPEMD-160, SHA-256, SHA-512 or Whirlpool
- Public key encryption: RSA-KEM or ECIES
- Digital signatures: RSA-PSS or ECDSA
- Protocols: TLS, SSH, IKE(v2)

Secure implementations of cryptography

- Error messages and APIs (cf. supra)
- Side channels
  - Timing attacks
  - Power attacks
  - Acoustic attacks
  - Electromagnetic attacks
- Fault attacks

Power analysis tools for smart cards



Software: constant time is crucial

- PIN verification
- Square and multiply for RSA
- Variable rotations in RC5 and RC6
- Swaps in RC4
- Problems with cache misses in ciphers with S-boxes such as DES and AES

PIN verification

```
input (PIN_U[0..k-1],PIN[0..k-1])
i=0;
while (i < k) do {
   if (PIN_U[i] != PIN[i]) return (0);
   i = i+1;
   }
return(1);
```

Problem?

Timing attack on RSA

- "square and multiply" algorithm
- exponent bits scanned from MSB to LSB (left to right)

```
Let k = bitsize of d (say 1024)

Let s = m

For i = k-2 down to 0

  Let s = s*s mod n (SQUARE)

  If (bit i of d) is 1  then
   Let s = s*m mod n (MULTIPLY)
  End if

End for
```

Example :	$s = m^9 = m^{1001b}$
init (MSB 1)	$s = m$
round 2 (bit 0)	$s = m^2$
round 1 (bit 0)	$s = (m^2)^2 = m^4$
round 0 (bit 1)	$s = (m^4)^2 * m = m^9$

Cache attack on crypto algorithms with S-boxes (DES, AES,…)

- Cache misses influence execution time
- Uses HyperThreading to monitor the encrypting process in real time and observe its use of shared resources.

- [Tsunoo-Saito-Suzaki-Shigeri-Miyauchi 03] Cryptanalysis of DES implemented on computers with cache, CHES 2003, LNCS 2779, 62-76, 2003
- [Osvik-Shamir-Tromer 05] Cache Attacks and Countermeasures: the Case of AES, RSA CT 2006
- [Bernstein 05] Cache-timing attacks on AES

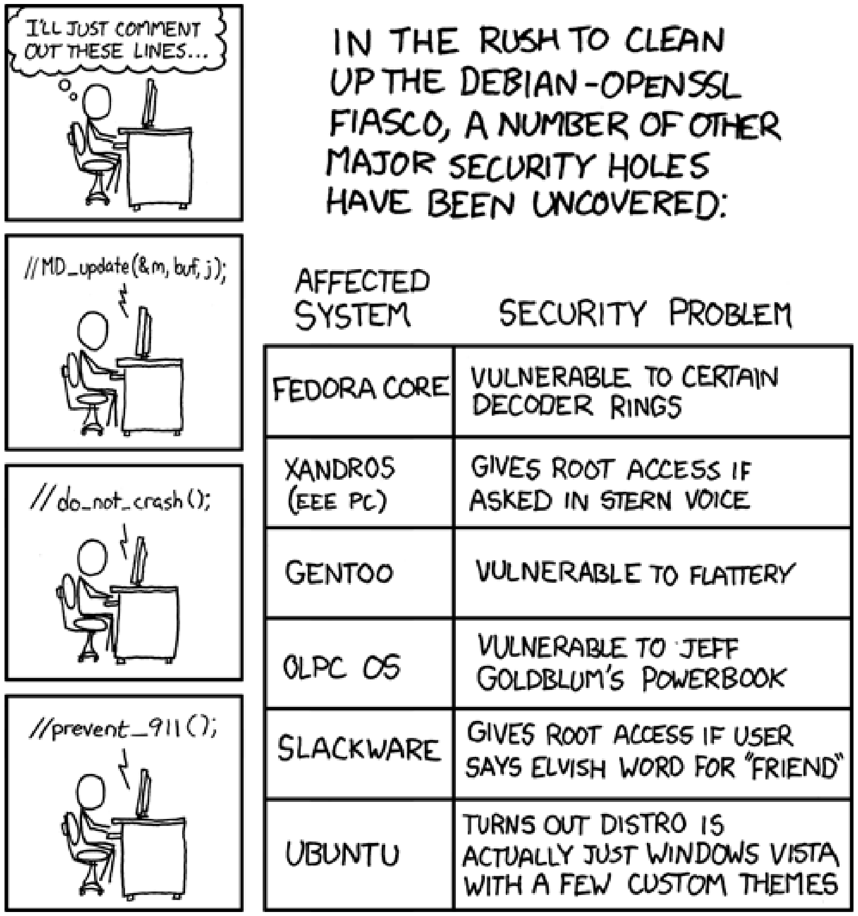
Implementation attacks (13 May '08)

Debian-OpenSSL incident

- Weak key generation:
  only 32K keys
  - easy to generate all private keys
  - collisions

- Between 13-17 May:
  280 bad keys out of 40K
  (0.6%)

- Revocation problematic



IN THE RUSH TO CLEAN UP THE DEBIAN-OPENSSL FIASCO, A NUMBER OF OTHER MAJOR SECURITY HOLES HAVE BEEN UNCOVERED:

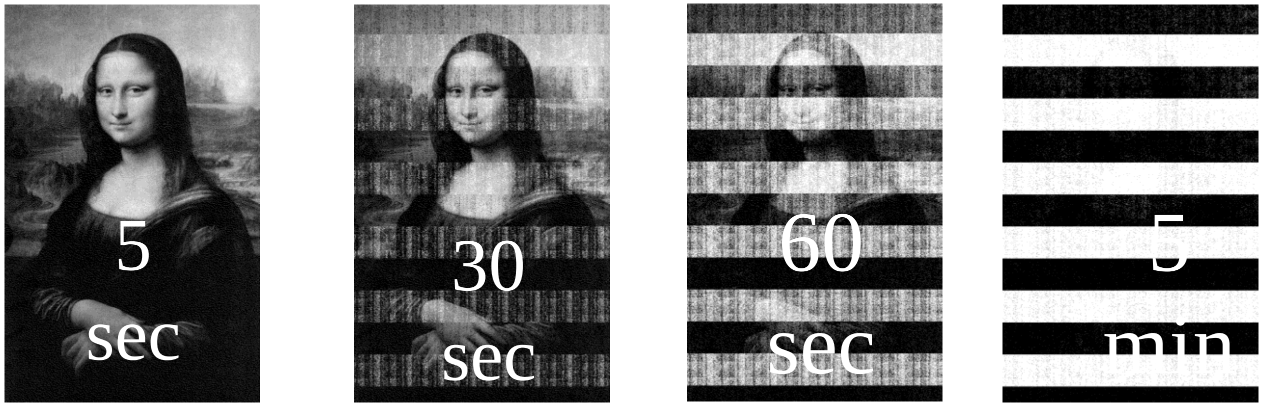
AFFECTED SYSTEM	SECURITY PROBLEM
FEDORA CORE	VULNERABLE TO CERTAIN DECODER RINGS
XANDROS (EEE PC)	GIVES ROOT ACCESS IF ASKED IN STERN VOICE
GENTOO	VULNERABLE TO FLATTERY
OLPC OS	VULNERABLE TO JEFF GOLDBLUM'S POWERBOOK
SLACKWARE	GIVES ROOT ACCESS IF USER SAYS ELVISH WORD FOR "FRIEND"
UBUNTU	TURNS OUT DISTRO IS ACTUALLY JUST WINDOWS VISTA WITH A FEW CUSTOM THEMES

Implementation attacks
cold boot attack

- Why break cryptography? Go for the key, stupid!
- Data reminence in DRAMs

  Lest We Remember: Cold Boot Attacks on Encryption Keys [Halderman-Schoen-Heninger-Clarkson-Paul- Calandrino-Feldman- Appelbaum-Felten'08]

  – Boot from USB device and dump RAM image
  – Works for AES, RSA,…
  – Products: BitLocker, FileVault, TrueCrypt, dm-crypt, loop-AES



Implementation attacks cold boot attack (2)

- Countermeasures
  - Overwrite keys in memory
  - Shut down rather than sleep/hibernate
  - Limit boot options (network, USB)
  - resilient exposure cryptography (AONT)
  - physical protection of DRAM
  - encrypt in the disk controller
  - new architecture
- Ineffective: trusted computing as implemented today

Some crypto libraries

- **OpenSSL: http://www.openssl.org/**
- **Cryptlib: http://www.cs.auckland.ac.nz/~pgut001/cryptlib/**
- **SSLeay: http://www2.psy.uq.edu.au/~ftp/Crypto/**
- **IAIK Java: http://jce.iaik.tugraz.at/products/index.php**
- **COSIC crypto library (contact B. Preneel)**
- **See also http://www.ssh.fi/support/cryptography/online_resources/practical.html**

Novel applications of cryptography

- Whitebox crypto
- SPAM fighting

Protection of software against whitebox attacks

- Software
  - Confidential information
  - Secret keys
  - Proprietary code
- Software and content distribution
- White-box setting
  - Complete accesss to implementation
  - Decompilation, reverse engineering, …

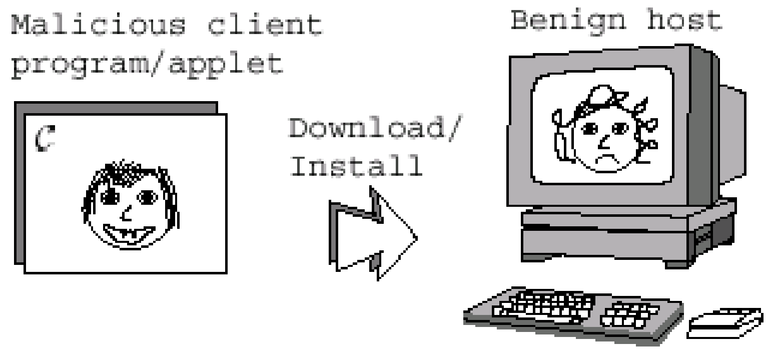
Protection of software against whitebox attacks

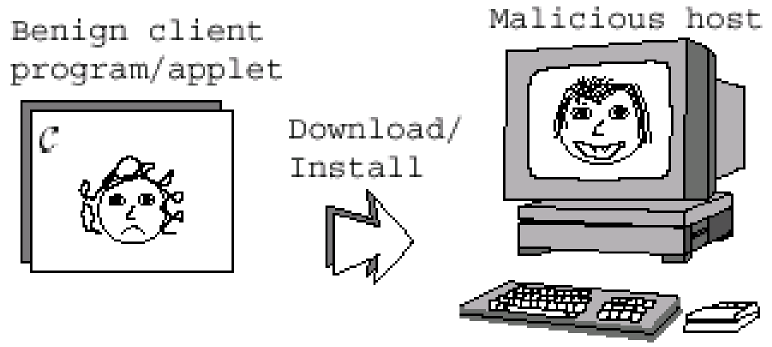
- “sandboxing”

  protect host against malware

- malicious hosts

  protect software against malicious hosts





Techniques

- White-box cryptography
  - Extra input and output coding of encryption
- Code obfuscation
  - Obfuscate code and program flow
- Other techniques:
  - Integrity checks + error detection
    → Tamper resistant software (TRS)
  - Code encryption + ‘on-the-fly’ decryption

White Box Cryptography

- Mathematical technique to hide keys in code

$$E'_K = \boxed{G \circ \boxed{E_K} \circ F^{-1}}$$

- *With:*
  - *EK* : encryption function, key *K*
  - *F* : arbitrary input coding
  - *G* : arbitrary output coding

Pro and Cons

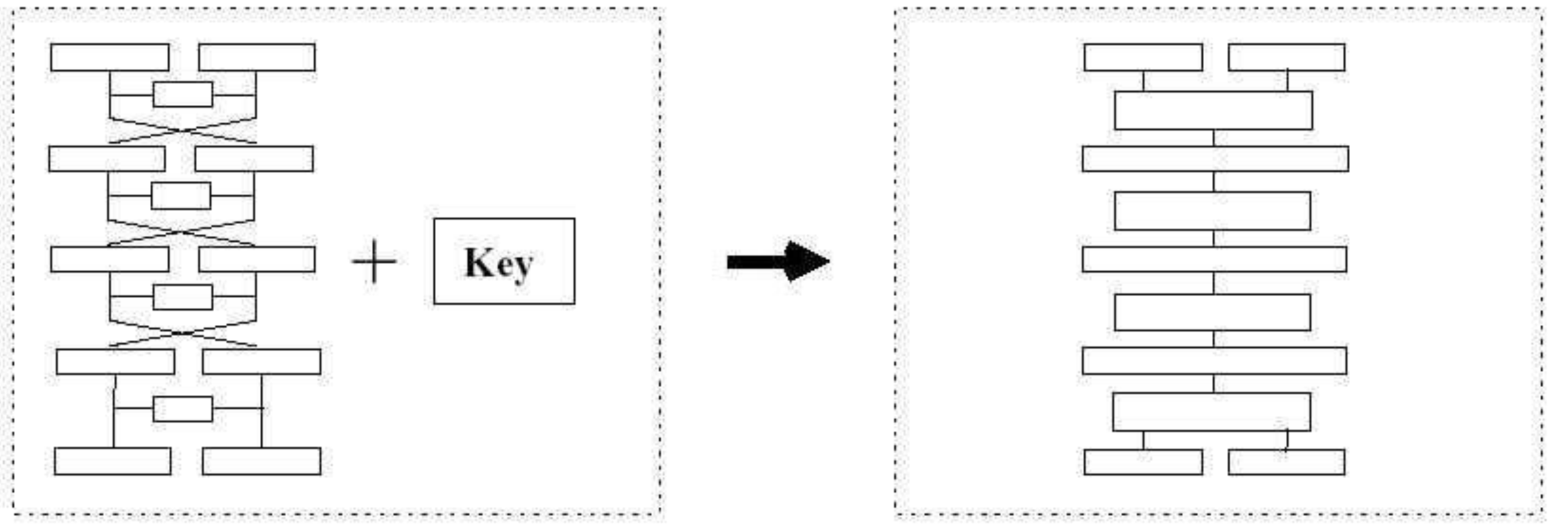
- Unique object code
  - Choose F and G
  - Integrate key
- Protect key
  - No function that computes E_K for an arbitrary key K
- Flexible
- Fast updates

- Increased memory
  - Tables for input and output coding and for function
- Increased execution time
- Security: very strong attack model
  - Trade-off with performance
- Fast key update open problem

Example

- DES
  - 16-round Feistel
  - 8 S-boxes
  - 56-bit key

- White-box DES
  - General structure
  - 12 "T-boxes"
  - Key built in code



The SPAM problem: it is about economics, stupid

- list of 10^7-10^8 “good” names
- cost per message: ~10^{-5} €; total cost 100-1000 €
- hit ratio: 10^{-6} to 10^{-4}: 10-10000 responses

- Cost to society
  - Ruining e-mail as communication tool
  - Time and attention
  - ISP fees
  - Storage and bandwidth

AND…

"The right to be left alone - the most comprehensive of rights, and the right most valued by civilized men."

- Supreme Court Justice Louis Brandeis

Fighting SPAM

- Filtering
- Make sender pay
- Ephemeral email addresses
- Data/Sender Authentication

Fighting SPAM (2)

- Filtering
  - Everyone: text-based
  - Brightmail: decoys; rules updates
  - Microsoft Research: (seeded) trainable filters
  - SpamCloud: collaborative filtering
  - SpamCop, Osirusoft, etc: IP addresses, proxies, …
- Make Sender Pay
  - Computation (CPU and/or memory)
  - Human attention
  - Cash, bonds, stamps (PennyBlack)

Fighting SPAM (3)

- Ephemeral e-mail addresses
  - E.g. SPA: Single Purpose Addresses
- Data/Sender authentication
  - Sign all emails
  - Sender Permitted From (SPF): whitelist mail senders
  - Sign domain names (Yahoo's DomainKeys)
  - Authenticated mail: AMTP (TLS)

Often bypass for friends on whitelist

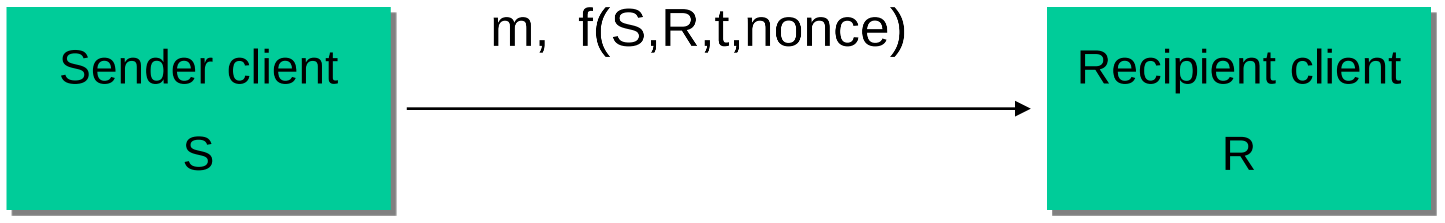
Filtering: limitations

- Still high cost if too late in the chain
- Spammers generate more sophisticated emails…
  - "Daphnia blue-crested fish cattle, darkorange fountain moss, beaverwood educating, eyeblinking advancing, dulltuned amazons...."
  - FWD: Many On Stocks. Vali/u/m + V1codin+ ; V|@GRa + /Xanax/ ; Pnter.m.in ? Som|a| muKPs

Computational Approach

- If I don't know the sender:
  - Prove sender spent 10 seconds CPU time,
  - just for me, and just for this message
- Checking proof by receiver:
  - automatically in the background
  - very efficient
- All unsolicited mail treated equally

Point-to-Point Architecture



(Ideal Message Flow)

- Single-pass “send-and-forget”
- Can augment with helper to handle slow machines
- Can add post office / pricing authority to handle money payments
- Time mostly used as nonce for avoiding replays (cache tags, discard duplicates; time controls size of cache)

Economics

- 10 seconds CPU cost a few hundreds of a cent
- (80,000 s/day) / (10s/message) = 8,000 msgs/day
- Hotmail's billion daily spams:
  - 125,000 CPUs
  - Up front capital cost just for hardware: $150 million
- The spammers can't afford it.

Cryptographic Puzzles

- Hard to compute; f(S,R,t,nonce) can’t be amortized
  - lots of work for the sender
- Easy to check “z = f(S,R,t,nonce)”
  - little work for receiver
- Parameterized to scale with Moore's Law
  - easy to exponentially increase computational cost, while barely increasing checking cost
- Can be based on (carefully) weakened signature schemes, hash collisions
- Can arrange a “shortcut” for post office

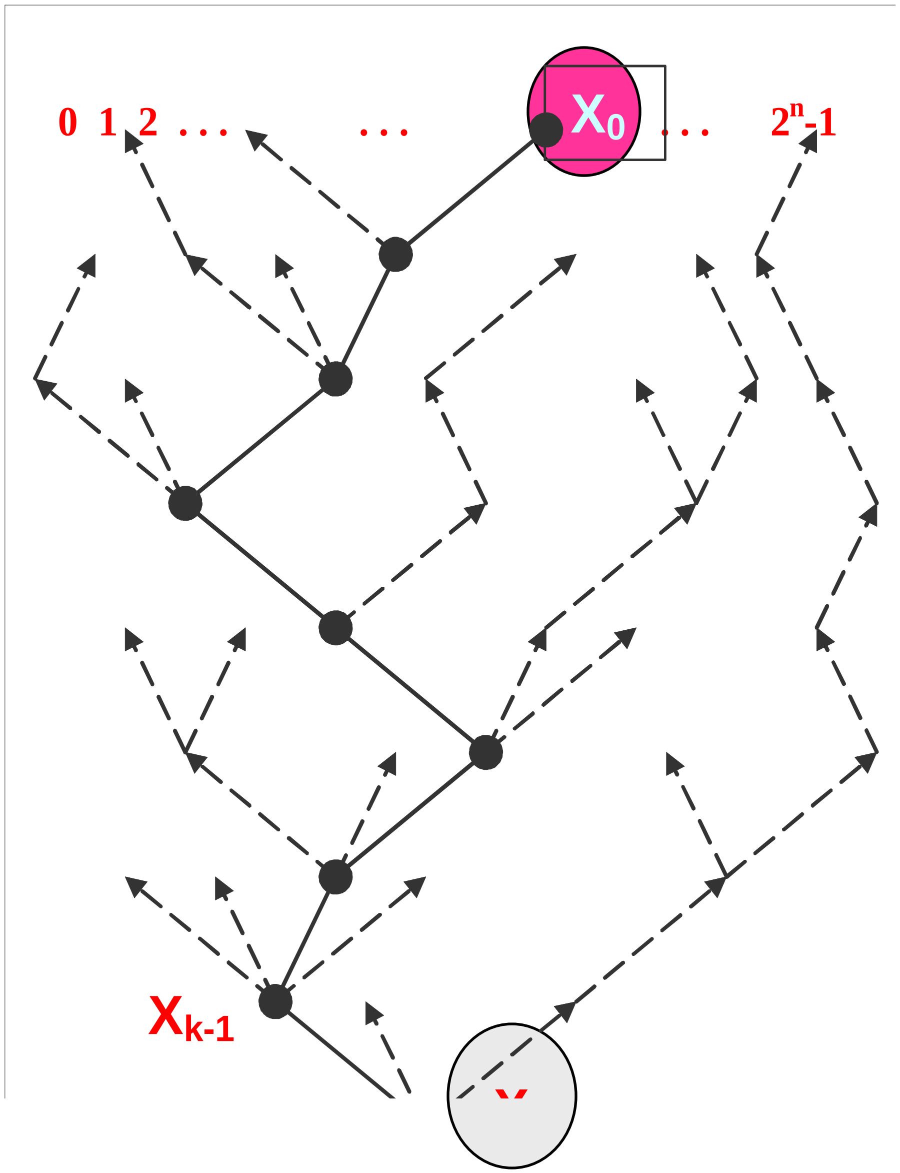
Idea: replace CPU by memory

- CPU speeds vary widely across machines, but memory latencies vary much less (20-100 vs 2-6)
    - 33 MHz PDA vs. 3 GHz PC

- design a puzzle leading to a large number of cache misses
- Concrete schemes: [ABMW02] and [DGN03]

Easy Functions [ABMW02]

- f: n bits to n bits, easy
- Given $x_k \in \text{range}(f^{(k)})$, find a pre-image with certain properties
- Hope: best solved by building table for f^{-1} and working back from x_k
- Choose n=22 so f^{-1} fits in small memory, but not in cache
- Optimism: x_k is root of tree of expected size k^2



Social Issues

- Who chooses f?
  - One global f? Who sets the price?
  - Autonomously chosen f's?
- How is f distributed (ultimately)?
  - Global f built into all mail clients? (1-pass)
  - Directory? Query-Response? (3-pass)

Technical Issues

- Distribution lists
- Awkward introductory period
  - Old versions of mail programs; bounces
- Very slow/small-memory machines
  - Can implement "post office" (CPU), but:
  - Who gets to be the Post Office? Trust?
- Cache Thrashing (memory-bound)
- The Subverters or Zombies

Conclusions: cryptography

- Can only move and simplify your problems
- Solid results, but still relying on a large number of unproven assumptions and beliefs
- Not the bottleneck or problem in most security systems

- *To paraphrase Laotse, you cannot create trust with cryptography, no matter how much cryptography you use -- Jon Callas.*

Conclusions (2): cryptography

- Leave it to the experts
- Do not do this at home
- Make sure you can upgrade
- Implementing it correctly is hard

- Secure computation very challenging and promising: reduce trust in individual building blocks

SPAM

- L. F. Cranor, B.A. LaMacchia: Spam!; Communications of the ACM 1998, 21 (8), 74-83.
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- A. Juels, J. Brainard: Client Puzzles: A Cryptographic Countermeasure Against Connection Depletion Attacks; 6th ISOC Symposium on Network and Distributed System Security (NDSS '99), IEEE Press, 1999, 151-165.
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- C. Dwork, A. Goldberg, M. Naor, On Memory-Bound Functions for Fighting Spam, Crypto 2003, 426-444.

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- D. Stinson, Cryptography: Theory and Practice, CRC Press, 3rd Ed., 2005. Solid introduction, but only for the mathematically inclined.
- A.J. Menezes, P.C. van Oorschot, S.A. Vanstone, Handbook of Applied Cryptography, CRC Press, 1997. The bible of modern cryptography. Thorough and complete reference work – not suited as a first text book. Freely available at http://www.cacr.math.uwaterloo.ca/hac
- N. Smart, Cryptography, An Introduction: 3rd Ed., 2008. Solid and up to date but on the mathematical side. Freely available at http://www.cs.bris.ac.uk/~nigel/Crypto_Book/
- B. Schneier, Applied Cryptography, Wiley, 1996. Widely popular and very accessible – make sure you get the errata.
- Other authors: Johannes Buchmann, Serge Vaudenay