ECRYPT

http://www.ecrypt.eu.org

Research Challenges in Cryptography

Prof. Bart Preneel
COSIC, K.U.Leuven, Belgium
Bart.Preneel(at)esat.kuleuven.be
http://homes.esat.kuleuven.be/~preneel
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Information processing

- the Internet of things, ubiquitous computing, pervasive computing, ambient intelligence (10^{12})
- Internet and mobile (10^9)
- PCs and LANs (10^7)
- mainframe (10^5)
- mechanical processing (10^4)
- manual processing (10^2)

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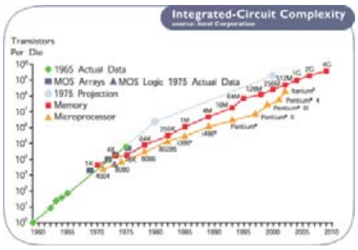
Exponential growth

Ray Kurzweil, KurzweilAI.net

- Human brain: 10^{14} …10^{15} ops and 10^{13} bits memory
- 2025: 1 computer can perform 10^{16} ops (2^{53})
- 2013: 10^{13} RAM bits (1 Terabyte) cost 1000$



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Context

DES, RSA, DH, CBC-MAC	**HARDWARE** Limited (govt+financial sector) DES, 3DES	70
Provable security (PKC), ZK, ElGamal, ECC, stream ciphers		80
MD4, MD5 Provable security (SKC)	**SOFTWARE** GSM, PGP C libraries (RSA, DH) SSL/TLS, IPsec, SSH, S/MIME Java crypto libraries WLAN	90
Key escrow		
How to use RSA? Alternatives to RSA		
PKI		
AES	**EVERYWHERE** Trusted computing, DRM, 3GPP, RFID, sensor nodes …	
ID-Based Crypto		

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TLS 1.0 Data Encapsulation Options

(01/'99)

Integrity		
key size	144	160
algorithm options	HMAC-MD5	**HMAC-SHA**
		mandatory

Confidentiality				
key size	40	56	128	168
algorithm options	RC4_40 RC4_40 RC2_CBC_40 DES_CBC_40	DES_CBC	RC4 IDEA_CBC	**3DES_ EDE_CBC**
				mandatory

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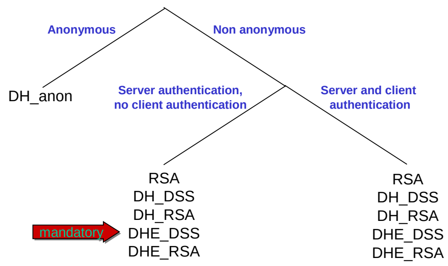
TLS 1.0 Key Management Options
(01/'99)



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RFC 3268: AES Ciphersuites for TLS
(06/'02)

CipherSuite	Key Exchange	Certificate Type
TLS_RSA_WITH_AES_128_CBC_SHA	RSA	RSA
TLS_DH_DSS_WITH_AES_128_CBC_SHA	DH_DSS	DSS
TLS_DH_RSA_WITH_AES_128_CBC_SHA	DH_RSA	RSA
TLS_DHE_DSS_WITH_AES_128_CBC_SHA	DHE_DSS	DSS
TLS_DHE_RSA_WITH_AES_128_CBC_SHA	DHE_RSA	RSA
TLS_DH_anon_WITH_AES_128_CBC_SHA	DH_anon	
TLS_RSA_WITH_AES_256_CBC_SHA	RSA	RSA
TLS_DH_DSS_WITH_AES_256_CBC_SHA	DH_DSS	DSS
TLS_DH_RSA_WITH_AES_256_CBC_SHA	DH_RSA	RSA
TLS_DHE_DSS_WITH_AES_256_CBC_SHA	DHE_DSS	DSS
TLS_DHE_RSA_WITH_AES_256_CBC_SHA	DHE_RSA	RSA
TLS_DH_anon_WITH_AES_256_CBC_SHA	DH_anon	

Version 1.2: reduce dependency on MD5/SHA-1, AES mandatory

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IKE Algorithm Selection Mandatory Algorithms

Algorithm Type	IKE v1	IKE v2
Payload Encryption	DES-CBC	**3DES** _CBC (**AES_128**_CBC
Payload Integrity	HMAC-MD5 HMAC-SHA1	HMAC-SHA1
DH Group	768 Bit	**1024** (2048) Bit
Transfer Type 1 (Encryption)	ENCR_DES_CBC	ENCR_**3DES** (ENCR_**AES_128**_CBC)
Transfer Type 2 (PRF)	PRF_HMAC_SHA1 [RFC2104]	PRF_HMAC_SHA1 [RFC2104]
Transfer Type 3 (Integrity)	AUTH_HMAC_SHA1_96 [RFC2404]	AUTH_HMAC_SHA1_96 [RFC2404]

Source: RFC 3407, December 05

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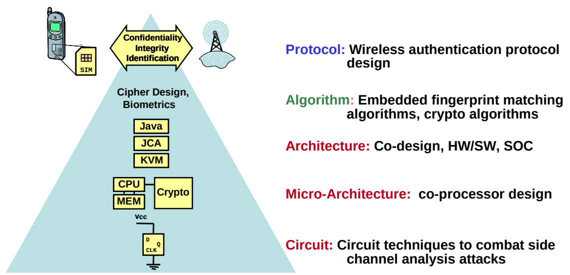
Implementations in embedded systems



Technology aware solutions?

Slide credit: Prof. Ingrid Verbauwhede 10

Disclaimer: cryptography ≠ security

- crypto is only a tiny piece of the security puzzle
  - but an important one
- most systems break elsewhere
  - incorrect requirements or specifications
  - implementation errors
  - application level
  - social engineering
- for intelligence, traffic analysis (SIGINT) is often much more important than cryptanalysis

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Outline

- Complexity
- Evaluation
- Human factor
- Privacy and autonomy
- Economics
- **Cryptology**

- [Adi Shamir] We are winning yesterday's information security battles, but we are losing the war. Security gets worse by a factor of 2 every year

- [Andrew Odlyzko] Humans can live with insecure systems. We couldn't live with secure ones.

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Complexity

- Billions of devices
- EMV specifications: thousands of pages
- O/S: 50-100 millions of lines of code
- Virtual machines
- Middleware
- Application software
- Smart cards: used to be simple ☺
- TPM: 125 commands and hundreds of pages of specifications

Have we learned how to manage complexity?
Or is it just impossible to build large secure systems?

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Evaluation

- Conformance testing
- Security evaluation: FIPS and CC
  - a step forward but are we stuck with this approach for the next 20 years?
- How to check a hardware random number generator?
- Is protection profile correct?
- What about new threats and attacks?
- What about upgrades?
- How open is the procedure?
- Evaluators have incentive for product to pass
- Is every lab reliable? (mutual recognition)

Research on security evaluation?

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Privacy breaches

- Lost control of sensitive data concerning millions of victims in total:
  - payroll handler PayMaxx, Bank of America, San Jose Medical Group, California State University at Chico, Boston College, University of California at Berkeley, and a large shoe retailer called DSW, ChoicePoint, LexisNexis
- US Citizens: complaints received by FTC for identity theft/fraud in general
  - 2005: 255,000/431,000
  - 2007: 246,000/674,000
  - total numbers are claimed to be 10 million +
- UK (Nov 2007): 25 million records lost on a CD in the mail

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Privacy and technology

- search engines
- XML
- biometry
- location (GSM, GPS)
- printers
- DRM
- spyware and cookies
- huge databases
- data mining
- video cameras
- RFID

- PET: Privacy Enhancing Technologies
- proxies
- pseudonyms
- cryptology
- mixes
- credentials

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The privacy debate

- user: convenience and improved service
- businesses:
  - protect company assets (email, DRM)
  - price discrimination
- law enforcement: fraud, theft, stalking, counterfeiting
- national security

- privacy is essential for a democracy
- legislation
- technology

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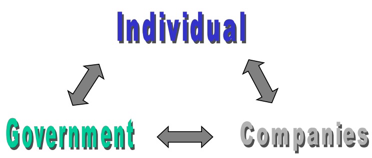
Balancing the rights of



privacy versus security: a false trade-off?

Privacy: information self-determination (autonomy)

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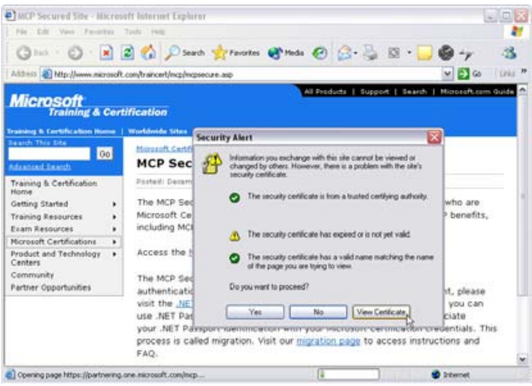
Challenges: human factors



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Human factors

- unusable security
- passwords
- phishing
  - growing problem: more than 25.000 reports per month
  - even by legitimate companies
  - even experts can't tell

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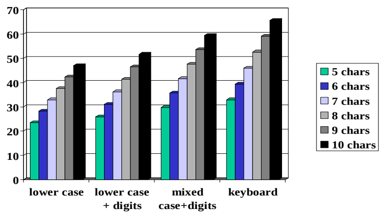
Password lengths



Moore's law: loose 1 bit every 18 months

- Users can no longer remember passwords that are resistant against exhaustive search
  - Things can be improved with very slow password hashing
- Need to make sure that number of guessing attempts is limited; in that case 30-bit security is sufficient
- Need to make sure that passwords are not intercepted in networks or on end systems (including phishing)

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Human factors: real risks versus perceived risks [Schneier]

- Human models for risk assessment are inherently wrong: we tend to overestimate
  - Large catastropic events versus real risks
  - Unknown risks
  - Risks to our children

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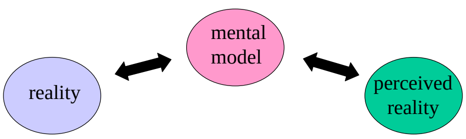
Human factors: perception of security [Schneier]



- Need to bring reality and perceived reality closer together
- In a fast changing world, mental models do not change quickly enough
- Security theater may sometimes be effective

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Economics of security

- systems are often insecure because no investment is made in security
  - entity benefiting from investment is not the entity paying for it (the Tragedy of the Commons)
- examples:
  - software (no liability)
  - DDOS
  - credit cards
  - …
- **See: Ross Anderson: Why Information Security is Hard. An Economic Perspective**

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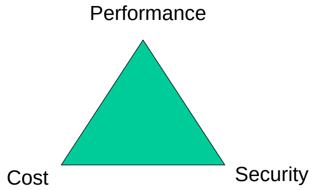
Challenges for crypto

- security for 50-100 years
- authenticated encryption of Terabit/s networks
- ultra-low power/footprint

secure software and hardware implementations

Algorithm agility



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Outline

- Block ciphers
- Hash functions
- Stream ciphers
- Public-key cryptology
- Protocols
- Implementations issues
- Research challenges

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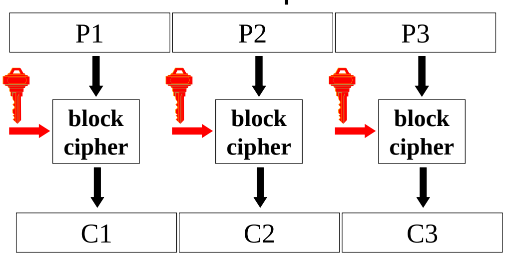
Block cipher



- larger data units: 64…128 bits
- memoryless
- repeat simple operation (round) many times

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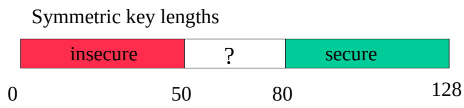
Block ciphers

- 3-DES (112-168)
- AES (128-192-256)
- KASUMI (128 in 3G, 64 in 2G)
- IDEA (128)



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DES (1977)

- 56-bit key length is too short
- 25/10/99: DES reaffirmed for the 4th time as FIPS 46-3
- 2007: $1 million search machine: 20 seconds
  - cost per key: less than $0.50
- 2007: 500 PCs at night: 1 month
  - Cost per key: essentially 0 (+ some patience)

Federal Register, July 24, 2004

DEPARTMENT OF COMMERCE

National Institute of Standards and Technology
[Docket No. 040602169– 4169– 01]

Announcing Proposed Withdrawal of Federal Information Processing Standard (FIPS) for the Data Encryption Standard (DES) and Request for Comments

AGENCY: National Institute of Standards and Technology (NIST), Commerce.

ACTION: Notice; request for comments.

- **SUMMARY:** The Data Encryption Standard (DES), currently specified in Federal Information Processing Standard (FIPS) 46–3, was evaluated pursuant to its scheduled review. At the conclusion of this review, **NIST determined that the strength of the DES algorithm is no longer sufficient to adequately protect Federal government information.** As a result, NIST proposes to withdraw FIPS 46–3, and the associated FIPS 74 and FIPS 81. Future use of DES by Federal agencies is to be permitted only as a component function of the Triple Data Encryption Algorithm (TDEA).

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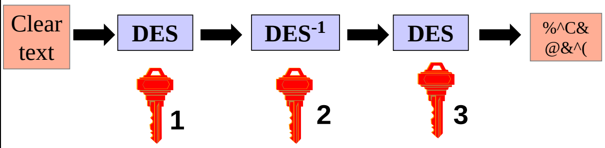
3-DES: NIST Spec. Pub. 800-67

(May 2004)

- two-key triple DES: until 2009
- three-key triple DES: until 2030



Financial sector will not be ready with upgrade to 3-key 3-DES in 2010

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AES (2001)

- open competition: 1997-2000
- FIPS 197 published on December 2001
- mandatory for sensitive US govt. information

- fast adoption in the market
  - > 1000 products
  - October 2007: 650 AES product certifications by NIST
  - standardization: ISO, IETF, IEEE 802.11,…
- slower adoption in financial sector
- mid 2003: AES-128 also for classified information and AES-192/-256 for secret and top secret information!

AES may well be the last block cipher

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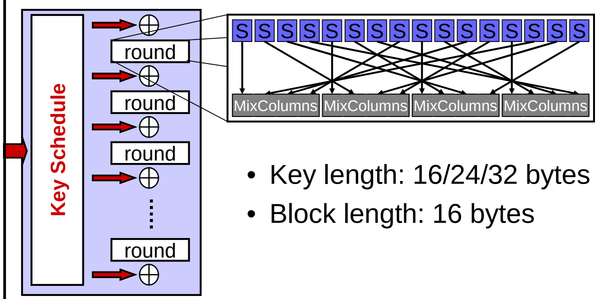
AES/Rijndael



- Key length: 16/24/32 bytes
- Block length: 16 bytes

A machine that cracks a DES key in 1 second would take 149 trillion years to crack a 128-bit key

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AES: rich mathematical structure

- very compact/efficient implementations
  - SW: 14 cycles per byte or 1-2 Gbit/s on high end PCs
  - HW: most compact: 3600 gates
  - HW: fastest up to 43 Gbit/s in 130nm CMOS
- security
  - No attack has been found that can exploit this structure (in spite of earlier claims)
  - main threat is implementation level attack (cache timing, fault attacks): requires special countermeasures

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Modes of Operation for AES

- encryption: ECB/CBC/CFB/OFB; new CTR mode allows for pipelining (Dec '01)
- data authentication: CMAC (May '05, was OMAC), EMAC
- applications need authenticated encryption:
  - **GCM Galois Counter Mode (final draft: July 07)**

Issues:
- associated data
- parallelizable
- on-line
- provable security

- IAPM
- XECB
- OCB

patented

- GCM
- EAX
- CCM

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Block ciphers: Keeloq

- Microchip Inc algorithm, designed in the 1980s
- Allegedly used in 80% of the cars for car locks, car alarms
- Block cipher with 32-bit blocks, 64-bit keys and 528 simple rounds

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Block ciphers: Keeloq (2)

- Leaked on the internet in 2006
- [Bogdanov07] in some cases car key = Master key + Car ID
- [Bogdanov07], [Courtois-Bard-Wagner07] first cryptanalysis
- [Biham-Dunkelman-Indesteeghe-Keller-Preneel07]:
  - 1 hour access to token (2^{16} known texts)
  - 2 days of calculation on 50 PCs (10.000$) - $2^{44.5}$ encryptions
- [Eisenbarth-Kasper-Moradi-Paar-Salmasizadeh-Manzuri ShalmaniPaar 08]
  - Side channel attack allows to recover master key

in 2010 cryptographers will drive expensive cars

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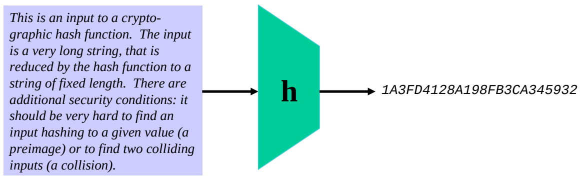
Hash functions

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

- collision resistance
- preimage resistance
- 2nd preimage resistance



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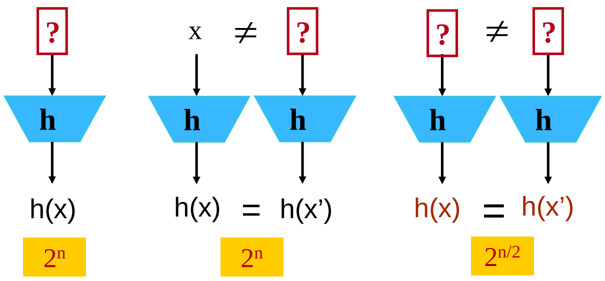
Security requirements (n-bit result)



> 90% of all designs for collision resistant hash functions are broken

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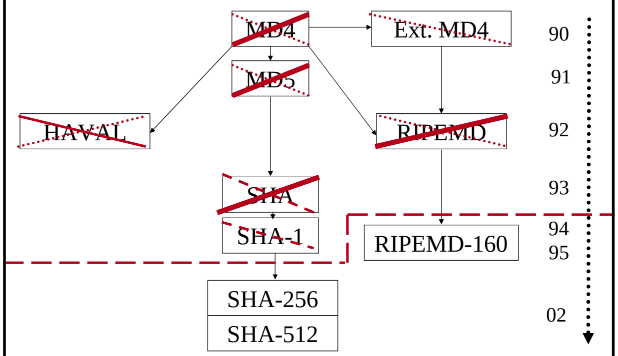
MDx-type hash function history



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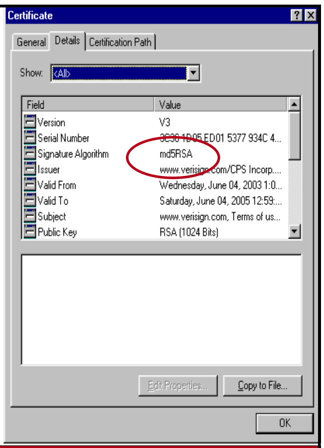
MD5

- 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}): with 100.000$ a few days
- [Wang+'04] collision in 15 minutes on a PC
- 2007: collisions in seconds



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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]
- Collisions for SHA-1 found for 70 out of 80 rounds [De Cannière-Mendel-Rechberger'07] in 2^{44}
- Prediction: collision for SHA-1 in 2008; complexity estimate is 2^{60} [Rechberger+'07]

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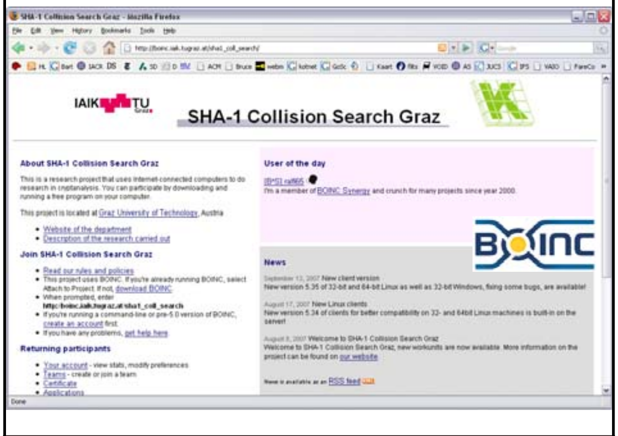

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From: "Cryptography Simplified in Microsoft .NET"
Paul D. Sheriff (PDSA.com) [Nov. 2003]

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 March 2008 this information is still available on MSDN

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Hash function attacks: impact

- collisions problematic for future
  - digital signatures for non-repudiation (cf. traffic tickets in Australia?)
- 2nd preimage only a problem for MD4
- HMAC-MD4 broken, HMAC-MD5 questionable for the long term
- RIPEMD-160 seems more secure than SHA-1 ☺
- use more recent standards (slower)
  - SHA-256, SHA-512
  - Whirlpool
- upgrading MD5 and SHA-1 in Internet protocols:
  - it doesn't work: **algorithm flexibility is much harder than expected**
- NIST will run an open competition from 2008 to 2012

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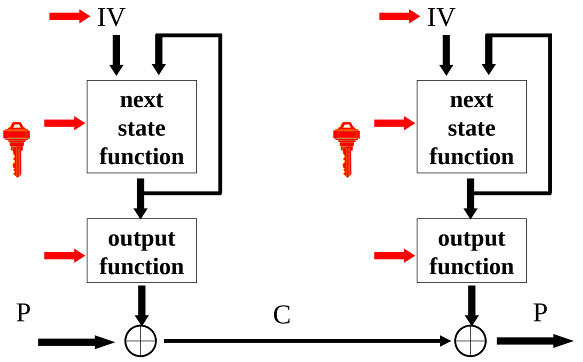
Model of a practical stream cipher



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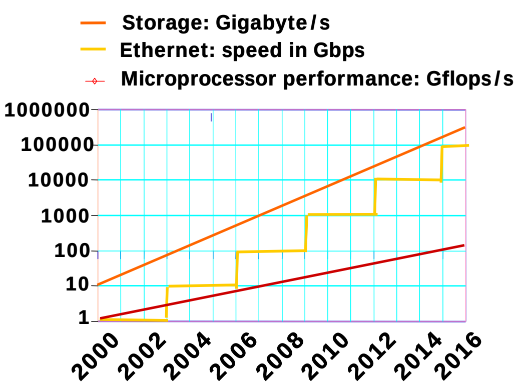
Moore's Law: computation/storage 2000-2020



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Stream ciphers

- historically very important (compact)
  - LFSR-based: A5/1, 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

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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
- 29 April 2005: 33 submissions
- Many broken in first year
- End of competition: April 2008

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Open competition: Feb. 2007 status

SW Phase 3	HW Phase 3
CryptMT	DECIM
DRAGON	~~Edon-80~~
HC-128 (-256)	F-FCSR
LEX	Grain
NLS (encrypt only)	MICKEY (-128)
Rabbit	MOUSTIQUE
Salsa20	POMARANCH
SOSEMANUK	Trivium

3-10 cycles per byte

1500..3000 gates

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The eSTREAM Portfolio April 2008

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

(In alphabetical order)

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Lightweight crypto

- SQUASH [Shamir07] – Crypto rump session
  - MAC algorithm for authentication in RFID chips
  - only 500 gates
  - security is related to modular squaring (Rabin cryptosystem)
- PRESENT [Bogdanov07] – CHES 2007
  - 64-bit block cipher for RFID chips
  - only 1750 gates (compare to 3600 for AES)

Stream cipher: because of time-memory trade-offs, for 80-bit security one needs 160 bits memory which costs 1000 gates

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Outline

- Context
- Block ciphers
- Hash functions
- Stream ciphers
- Public-key cryptology
- Protocols
- Implementations issues
- Research challenges

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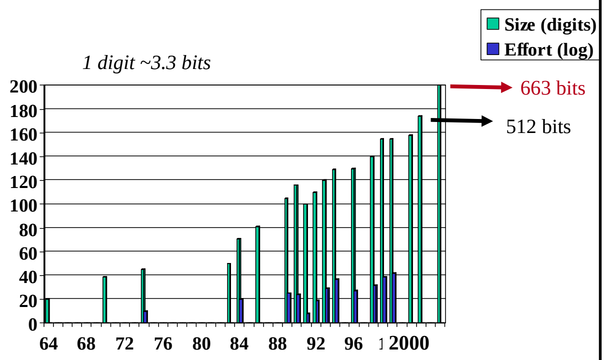
RSA: factorisation records



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Factorisation

- New record in May 2005: 663 bits (or 200 digits) using NFS
- New record in May 2007: 2^{1039}-1 (313 digits) using SNFS

- hardware factoring machine: TWIRL [TS'03]
  (The Weizmann Institute Relation Locator)
  - initial R&D cost of ~$20M
  - 512-bit RSA keys can be factored with a device costing $5K in about 10 minutes
  - 1024-bit RSA keys can be factored with a device costing $10M in about 6 weeks

- ECRYPT statement on key lengths and parameters
  http://www.ecrypt.eu.org

768-bit factorization in 2008 and 896-bit factorization in 2010

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Key lengths for confidentiality

http://www.ecrypt.eu.org

duration	symmetric	RSA	ECC
days/hours	50	512	100
5 years	73	1024	146
10-20 years	103	2048	206
30-50 years	141	4096	282

Assumptions: no quantum computers; no breakthroughs; limited budget

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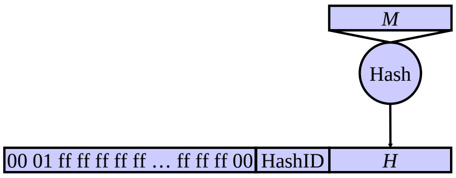
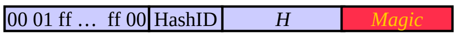
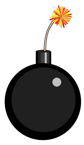
RSA Signatures: PKCS #1 v1.5 [source: RSA Labs]



Most signature verification software would accept a signature on M of the following form:





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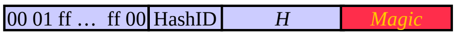
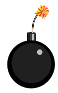
Attack on PKCS #1 v1.5 implementations

[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

- 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 long
  - Upgrade – finally – to RSA-PSS

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Protocols (1)

- key transport (email)
- authenticated key agreement (TLS, SSH, GSM, UMTS)
- time-stamping
- notarisation
- credentials (TPM)
- anonymous communication
- e-cash
- voting
- auctions
- threshold cryptography
- robust networking

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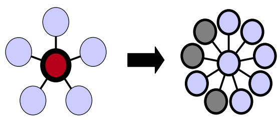
Protocols (2)

- multi-party computation
- threshold crypto
- privacy protecting data mining
- social and group crypto

decryption based on location and context

distance bounding



"you can trust it because you don't have to"

Models and reality



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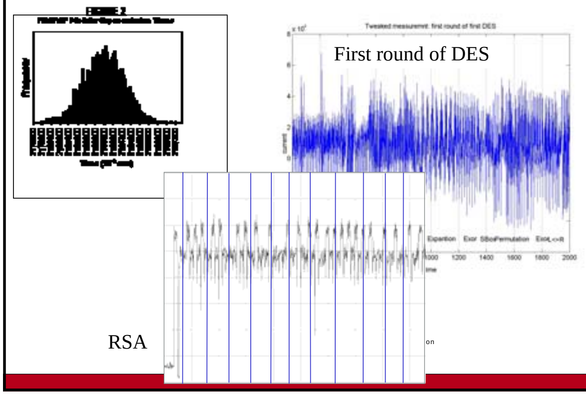
Implementations: side channel attacks



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Implementation attacks

Sun Tzu, The Art of War:
In war, avoid what is strong and attack what is weak

- measure: time, power, electromagnetic radiation, sound
- introduce faults (even in CPUs)
- combine with statistical analysis and cryptanalysis
- software: API attacks

- major impact on implementation cost

L.R. Knudsen: "It is not cryptanalysis, it is vandalism"

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Challenges for long term security

- cryptanalysis improves:
  - mathematical attacks A5/1, E0, MD5, SHA-1
  - implementation attacks
- computational power increases:
  - Moore's law
  - exponential progress with quantum computers?
- environment changes – new assumptions
  - packet switched networking
  - open networks
  - dynamic networks
  - untrusted nodes
  - ratio power CPU/memory size
  - outsourcing of data processing

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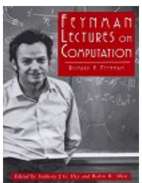
New computational models: quantum computers?

- exponential parallelism

n coupled quantum bits
⇩
2^n degrees of freedom !

- Shor 1994: perfect for factoring
- But: can a quantum computer be built?



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If a large quantum computer can be built...

- All schemes based on factoring (such as RSA) will be insecure
- Same for discrete log (ECC)
- Symmetric key sizes: x2
- Hash sizes: x1.5

- Alternatives: McEliece, HFE, NTRU,…
- So far it seems very hard to match performance of current systems while keeping the security level against conventional attacks

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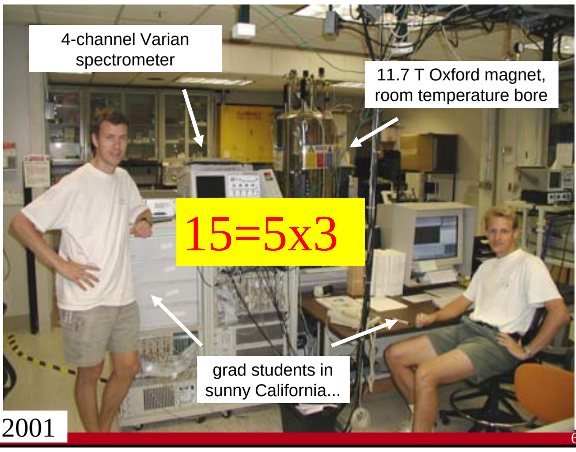

2001

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News on 13 Sept. 2007

- "Two independent teams (led by Andrew White at the University of Queensland in Brisbane, Australia, and the other by Chao-Yang Lu of the University of Science and Technology of China, in Hefei) have implemented Shor's algorithm using rudimentary laser-based quantum computers"
- Both teams have managed to factor 15, again using special properties of the number

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Layers

applications

protocols

primitives

assumptions algorithms

Proofs: link security at different levels in a quantitative way

L.R. Knudsen:
"If it is provably secure, it is probably not"

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Assumptions

research on hard problems?

James L. Massey:
A hard problem is one that nobody works on

good lower bounds
average vs worst case
find new hard problems

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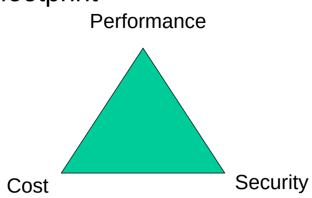
Challenges for crypto

- security for 50-100 years
- authenticated encryption of Terabit/s networks
- ultra-low power/footprint

secure software and hardware implementations

algorithm agility



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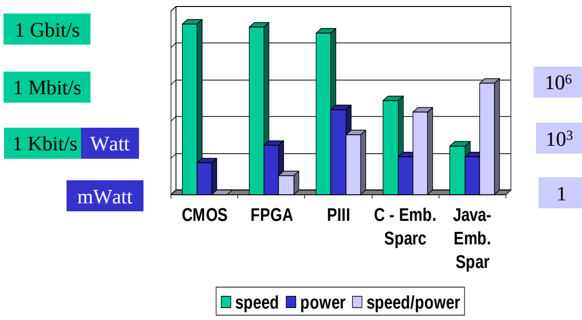
The power challenge:

AES-128 speed/power for various platforms (Gb/Joule)



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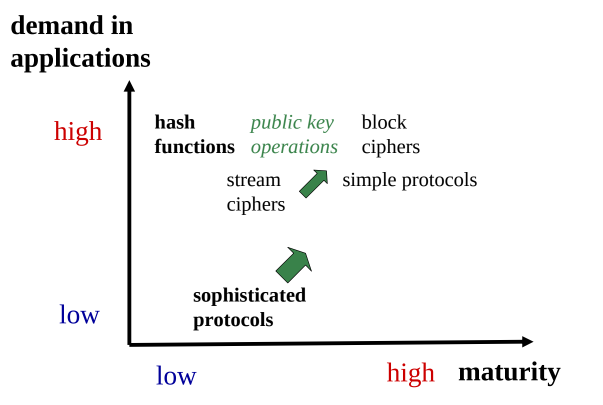
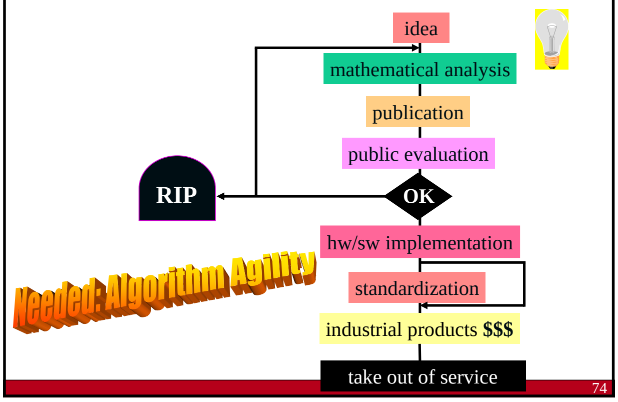


Life cycle of a cryptographic algorithm



Challenges for advanced crypto

- privacy enhancing technologies
- linking crypto with physical world
  - biometrics, physically uncloneable functions
- distributed secure execution
- whitebox cryptography
- cryptography in the encrypted domain
  - searching in encrypted databases – data mining on health care date
  - zero knowledge watermarking – intelligent media sharing
- perceptual hashing
- crypto for nanotechnology

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Conclusions

- The “security problem” is not solved
  - Many challenging problems ahead…
  - Make sure that you can upgrade your crypto algorithm and protocol
  - Bring advanced cryptographic protocols to implementations

When will the IACR hold its elections on-line?

When will everyone pay with e-cash?

Can we reconcile privacy, DRM and data mining?

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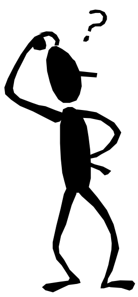
The end



Thank you for your attention

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