When Cryptography is not the Answer (even when it is)

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Cryptopia

- Since the 1970's our cryptography has matured:
  - Secret-key primitives (DES, AES, RC4, ...)
  - Public-key algorithms (DH, RSA, ECC, ...)
  - Zero Knowledge Proofs (a Turing-worthy idea)
  - Secure Multiparty computation
  - Traitor Tracing
  - Homomorphic encryption (the solution to all your problems)

Cryptodise

- Our understanding on how to use cryptography matured as well:
  - Provable security (reductions)
  - Standards
  - Protocols
  - Limitations* (e.g., privacy)

Cryptography is all around us these days

- SSL/TLS
- WPA2, WPA, WEP, ...
- IPsec/VPN
- Mobile communications — A5/1, A5/2, A5/3, A5/4, A3/A8, ...
- Software/Updates/Drivers/...
- Digital signatures on legal documents
- Bidding on sugar beets
- Digital/Electronic elections
- Car ignition, updating of pacemakers, etc.

Yet Security is not Achieved

- Viruses/Worms/Trojans/...still exist
- Internet traffic is mostly in the clear
- Most communications is not authenticated
- User authentication is based on PINs and weak passwords
- Most storage is not encrypted
- Data is not shared using the "right tools"
- 40-bit encryption is still around
- Really weak encryption is still around

Motivation of this Talk (part I)

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- Meet "Matt" — a security engineer
- Matt went to a good school in CS/EE/Math
- Matt took some courses in cryptography/computer security
- He is now working for a respectable company with other security engineers
- Matt knows how to make things secure

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- Meet "Chris" — a world renowned researcher in cryptography
- Chris has a Ph.D. in cryptography (under the supervision of a distinguished researcher)
- Chris has a position in a leading university
- Chris is involved with the computer security community as well
- Chris is also doing some consulting
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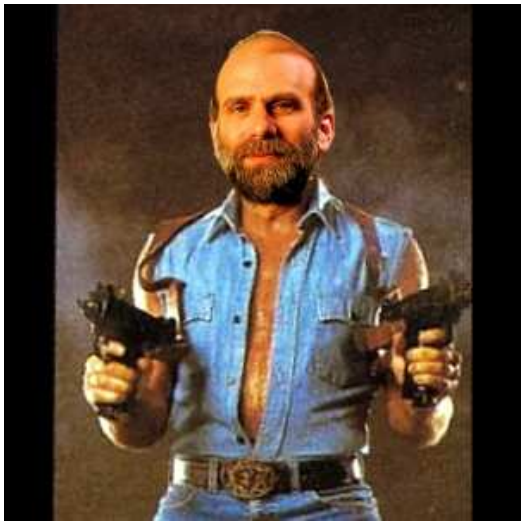

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- Later, we mention a few methods to reduce these issues in the future

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- First step in the solution: Encrypt the content on the storage
- Second step: Allow only approved entities to decrypt
- Third step: Sparkle some key management, traitor tracing schemes, and maybe watermarks

The DVD Case — CSS Algorithm

- DVDs are encrypted using the CSS encryption algorithm
- The CSS scheme is a 40-bit stream cipher
- Each DVD is encrypted using CSS with some random key
- The encryption key is encrypted under various static player keys (for approved players)
- In addition there is a key used for authenticating the reader to the DVD

Recall the DeCSS

- Well, once one of the static keys is found, game is over
- DeCSS just finds keys (40-bit security at its best)
- After decryption the content is no longer protected
- CSS also suffers from design weakness, exhaustive search takes only 2^{16}
- To make things worse, the AACS 128-bit key 09 F9 used for HD DVD and Blu-ray was also found (as well as others)

You Should Have Known Better

- Master keys (and static keys) used to encrypt a lot of data is bad
- 40-bit key is not enough
- Weak cryptography with long keys is not enough as well
- The user can attack the system however she wishes
- Make sure your adversarial model is correct

The MD/SHA Family

- Started with Rivest's MD4 (1990)
- Following a few cryptanalytic attempts, was upgraded to MD5
- MD5, also known to many as **md5sum**, generates tags of 128 bits
- Became very popular given its high speed, alleged security, and lack of true competition...
- Later, it was used as the basis for the SHA-0 and SHA-1 hash functions

The (Quick and Dirty) History of MD5's Security

1993 den Boer & Bosselares: Compression function collision

1996 Dobbertin: Free-start collision

2004 Wang: Practical collision attacks (one hour for a collision)

2005 Klima: Collisions in 8 hours on a laptop

2006 Klima or Stevens: Collisions in a minute

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The cryptographic community called for the removal of MD5 from anything important...

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You Should Have Known Better!

The Wired Equivalent Protocol (WEP)

- WEP was designed in the late 1990's to have WiFi with the same security as Ethernet
- A static 40-bit key is used in each network
- The key is fed into RC4, along with per-packet 24-bit IV (chosen by the sender)
- Comes with a simple challenge-response protocol for authentication of users
- Also comes with CRC padding on the data, which is also encrypted...

"Non-Cryptanalytic" Problems

1. Short key
2. IV space too small
3. For each IV the same key stream is generated
4. Easy to change the ciphertext to change the plaintext
5. Easy to bypass authentication/integrity check (which actually leaks key stream per IV)

Some Common Sense

- WEP first uses a linear error correction code and then encrypts using the XOR operation
- Thus, violating (one of the) first rule of cryptography:

  "Thou shalt compress, encrypt, and then authenticate. Thou shalt have no other sequences before this"

- In addition, everything is commutative . . .

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The Cryptanalytic Problem

- For each key, there are weak IVs, so weak you can find the key [FMS01]
- (One of the nicest examples why related-key attacks are real)
- First attacks required a few million known "packets"
- Quickly implemented (e.g., [SIR01]), and became very popular in software packages
- New attacks emerge now and then
- Best known attack requires only 4,000 "known" packets [SVV11]

And Then Some More Anecdotes

- Shared prime numbers among RSA public keys
- Debian's lack of sufficient entropy
- "hard disk encryption" done using ECB
- GSM/3G security — weak algorithms, encryption after error correction, unauthenticated control channel, etc.
- Using 80's ciphers today — MiFare, KeeLoq, DES(!)
- Making up your own crypto-algorithms
- MD5 **still** used in the context of digital signatures
- Keeping keys in swappable memory (or accessible memory)
- Broken standards/protocols still in use
- ...

And Now For Something Completely Different

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- Despite what it seems, not all crypto-related security issues are caused by Matt
- Despite common belief, many are caused by the cryptographers
- Some of these problems are the result of the way **cryptographers** think of the problem
- Some of these problems are due to the way the problem is communicated to the cryptographic circles
- Some of it is plain "Cryptographers should have known better"

The RC4 Stream Cipher

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- Passed huge amounts of statistical tests
- Common "Folklore": a good cipher to use

Security Issues in RC4

- Surprisingly, RC4's output is biased
- Several well known biases:
  1. Second byte is zero with probability $2/256$ [MS01],
  2. Each output byte is zero with probability slightly more than $1/256$ [MPS11],
  3. Second byte is two with probability significantly lower than $1/256$ [S13],
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- Lots of research about these biases
- Recently: [A+13] showed the existence of sets of biases allowing retrieving the first 256 bytes of a plaintext encrypted under 2^{32} random RC4 keys.

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- Result: though RC4 is “secure”, using it in any broadcast environment is a bad idea

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The Advanced Encryption Standard

- Rijndael was selected as AES in 2000
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  - Linear,
  - Meet in the middle,
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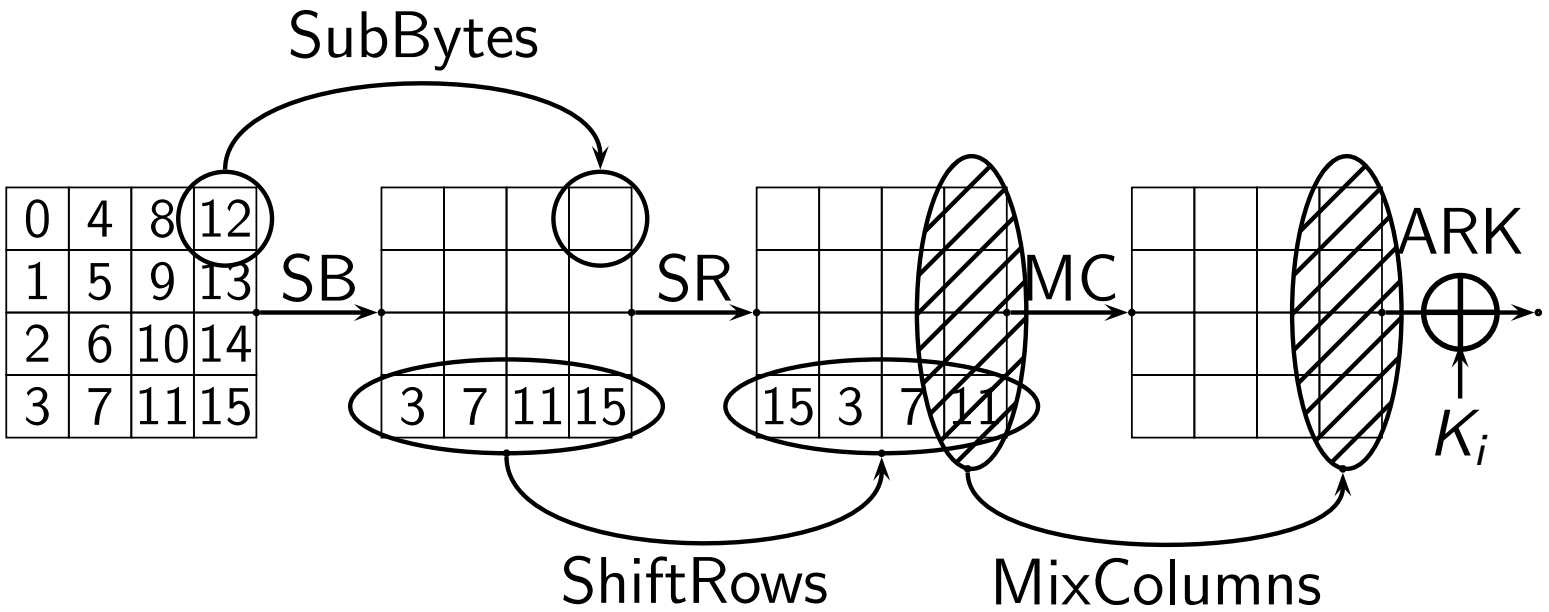
- Up to a few small issues in very special attack models/small reduction in exhaustive search's complexity — this is the cipher to use

The Advanced Encryption Standard (cont.)

- The cipher has an SP (substitution-permutation) network structure.
- Block size — 128 bits, Key size — 128, 192, or 256 bits.
- Number of rounds depends on the key length (10/12/14, respectively).



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- The last round has no MixColumns
- So there is a fifth 8-bit to 8-bit table
- This table is accessed only during the last round of encryption...

[P02, Ber05, OST06, ...]

Cache Attack on AES (Concept)

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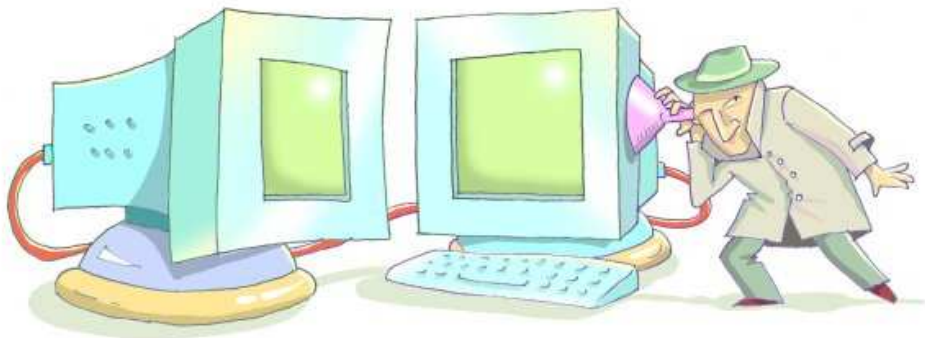

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Side Channel Attacks

- There are also hardware-based side channel attacks:
  - Power analysis (simple/differential)
  - Template attacks
  - Acoustic attacks
  - Electromagnetic radiation attacks
  - ...

Security engineers should pick not only **secure schemes**, but also **secure implementations!**

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$$c = m^e \bmod n; sig = m^d \bmod n$$

- Using textbook RSA would lead to crypto-abyss! Do not use it!
- Real life RSA-encryption (RSA-OAEP):

$$c = [(m||0||r) \oplus (G(r)||H((m||0) \oplus G(r)))]^e \bmod n$$

- Use similar constructions for RSA-PSS

Padding Attacks

- Due to difference in reactions, one can deduce when the decryption was successful
- This allowed Bleichenbacher to decrypt RSA in SSL using about 10^6 queries
- The problem: implementation first decrypts, then checks padding
- Padding errors are treated differently then "context" errors

Padding Attacks — Symmetric Key

- Similar attacks exist for symmetric-key encryption
- The times are significantly shorter, but are still applicable
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- Result: Even when "provably"-secure constructions are used with secure primitives, security flaws exist

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Cold Boot Attack

- Yesterday Alex showed the cold boot attack
- The attacks use the fact that you can literally “freeze” volatile memory to read its contents later
- As the memory stores the keys, you can read them in the lab afterwards
- Applicable to both public key and secret key primitives

Leakage Resilient Cryptography

- Once the cold boot attack was publicized, cryptographers start to construct leakage-resilient cryptography:
  - Leakage-resilient encryption,
  - Leakage-resilient signatures,
  - Leakage-resilient secure multiparty computation,
- Under different adversarial models:
  - Single leak vs. Continuous leak,
  - Amount of leaked keying material,
  - Different leakage functions,
- Conclusion: We can beat security engineering problems with the right cryptography

In Theory, there is no Difference between Theory and Practice

- [R+11] conducted a thorough analysis of leakage models
- The outcome: basic assumptions of the leakage-resilient cryptography is incorrect for new technologies
- More precisely, in new technologies, independent computations do not cause independent leakage
- In other words, the security assumption is void...

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- But authentication is cheap!

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- Cryptographers may need to do the actual "coding" / "construction" of systems
- Generally — security engineers and cryptographers should meet more often

The Real Thing

- Fault-tolerant design
- Key-agility design (especially key sizes)
- Crypto-algorithm-agility
- Better generic libraries (software/hardware)

Some of the Steps

- The CAESER competition (for authenticated-encryption solutions)
- The NaCl library
- Patent-free inclination in standards/protocols/research
- Series of Crypto-in-real-world events:
  - Real-World Cryptography (2011, 2013, 2014, ...)
  - International State of the Art in Cryptography and Computer Security (Dagstuhl 2011, ASIACRYPT 2012, EUROCRYPT 2013, ASIACRYPT 2013, ...)
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- More realistic attack models

Questions?

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