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Cryptography in a White-Box World

A Presentation for the New Directions in Cryptography Workshop

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June 27, 2008

The Cryptographer's Dream

- Many people who become cryptographers do so for one of two reasons
  - To develop an unbreakable cipher
  - To break a well-known cipher
- Cipher cracking contests are very popular, involving thousands of people
- People continue to make machines to break DES, an already broken cipher
  - They want to break it <u>better</u>!

The Rules of the Game

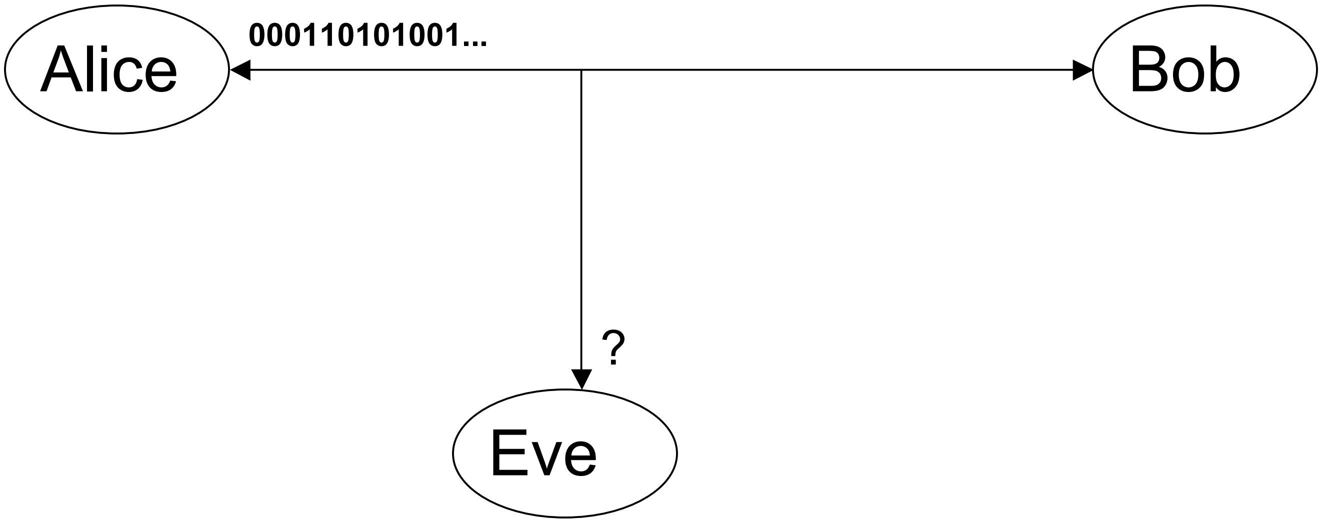
- Everyone who takes an introductory cryptography course learns that there are rules for cipher designers, and rules for cryptanalysts
- To have a cipher design taken seriously, you must
  - Publish your algorithm in complete detail
  - Provide test vectors
  - Show that your cipher resists known attacks
- History has borne out the soundness of these rules
  - Security through obscurity doesn't work for very long

The Rules of the Game (2)

- To break a cipher, here's what you get:
  - Full algorithmic details
  - Access to an implementation that encrypts under the key of interest
  - The ability to pass any plaintext you want to this implementation, and to see the resulting ciphertext (adaptive chosen plaintext attacks)
- What you don't get, however, is access to the internals of the implementation while it's running
  - This is the black-box attack model
  - Almost all new ciphers proposed today are described and attacked under this model

The Rules of the Game (3)

> Where did the cryptanalyst's rules come from?



The Rules of the Game (4)

- In secure hardware (an ever changing entity), the black-box attack model is a realistic one
  - Question: when was the last time you used secure hardware?

Times Have Changed

> Software is easier (and therefore cheaper) to
  - design
  - implement (fabricate)
  - test
  - distribute
  - diversify
  - revoke
  - update
  - retire

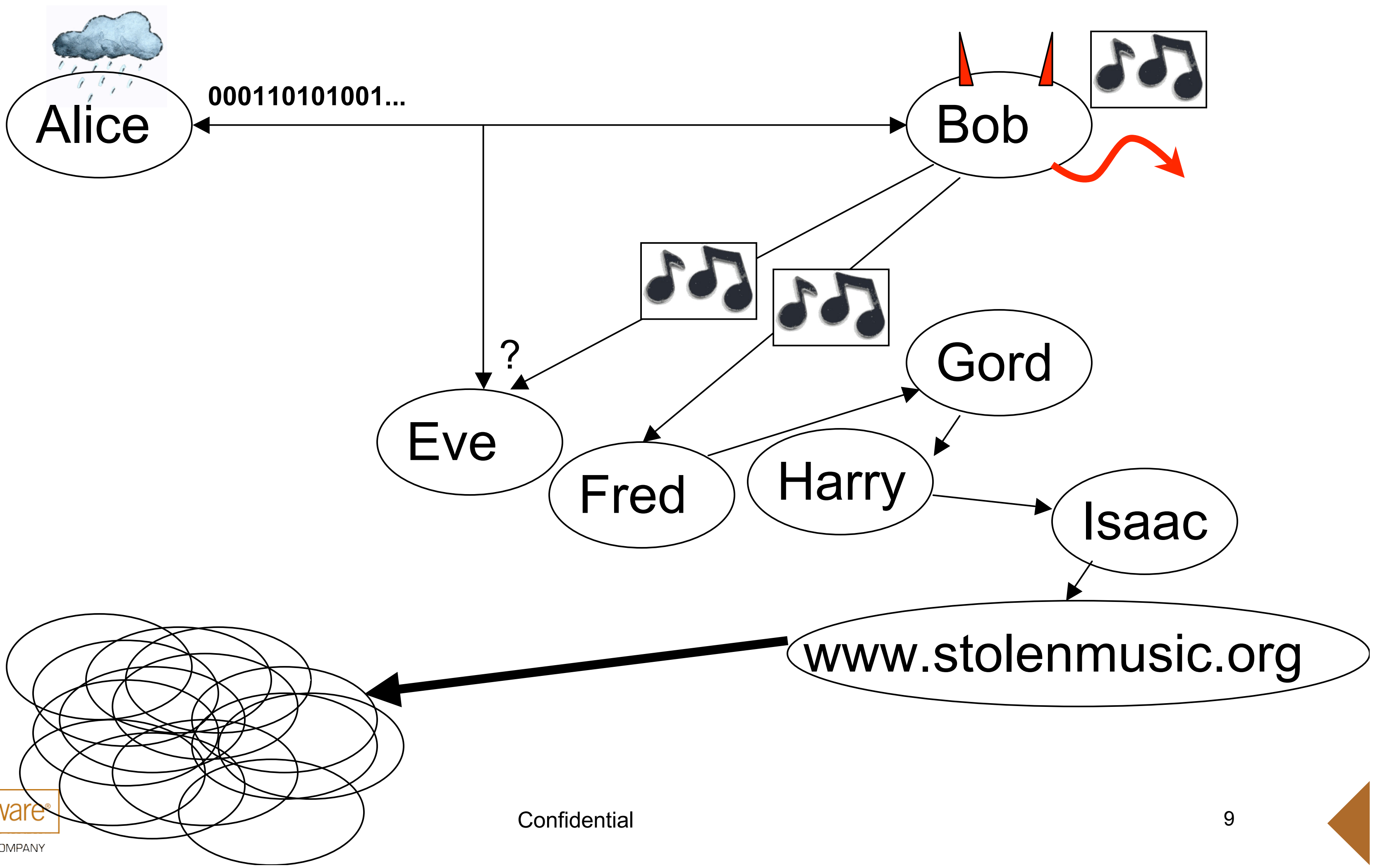
> Overall, these factors outweigh the security considerations

Times Have Changed (2)

- 1977 – DES
  - Optimized for hardware implementations
  - Standard did not allow for software implementations until 1988
- 2000 – AES
  - Evaluation criteria explicitly discussed performance in software
  - Hardware performance was not considered until the 2nd round
- We live in a software world

Times Have Changed (3)

> Who's the attacker?



White-Box Attacks

- Let's visit this new attack context
  - Software implementations
  - Environment is untrusted
  - Attacker has direct access to the machine while it's running
- What's meant by direct access? The attacker can
  - Trace every program instruction
  - View the contents of memory and cache at any granularity
  - Stop execution at any point and run an off-line process
    - Reduced round attacks are no longer theoretical
  - Alter code or memory at will
    - Fault attacks are real and trivial to execute
  - and can do all this for as long as they want, whenever they want, in collusion with as many other people as they can find

White-Box Attacks (2)

White-box

- Debuggers
- Emulators
- Other attack tools

Grey Box

- Timing analysis
- Power analysis
- Fault injection

Black-box

- Input / output

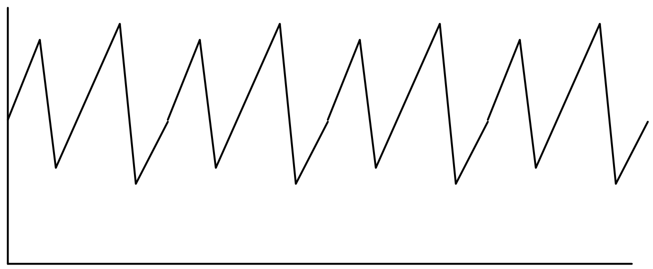
Interlude – Attacking ECC

- Recall the *always double and add* method described by Prof. Miri as a defence against side channel attacks on elliptic curve scalar multiplication

```
Input: d = d1d2...dn (the scalar), P (the elliptic curve point)
Output: Q = dP (another elliptic curve point)
Q = P
for i from 2 to n
          T1 = 2Q
          T2 = T1 + P
          if (di = 1)
                    Q = T2
          else
                    Q = T1
return Q
```

Attacking ECC (2)

- The black-box attacker sees only d, P and dP
  - Always double and add is overkill in this case
- The grey-box attacker sees



  - A consistent power trace leaks no information
- The white-box attacker sees

```
if (d_i = 1)
            Q = T2
else
            Q = T1
```

  - They can trace the execution and extract the key

White-Box Attacks (3)

- The security proofs from the black-box attack context simply don't carry over to the white-box context
  - NB: the proofs are not invalid, they just consider a different attack model
- We are now forced to consider a white-box attacker; they are strictly more powerful than our classic black-box attacker

White-Box Cryptography

- A short-form for cryptographic implementations that provide security against a white-box attacker
- Even more so than with side-channel attacks, the *implementation* becomes as important as the algorithm itself

White-Box Cryptography (2)

> This is still a relatively untapped field, with a lot of fundamental unanswered questions
  - What is a formal definition for the white-box attack context?
  - What's meant by "security" in a white-box attack context?
    - What are we trying to defend? For how long?
  - Is practical white-box cryptography possible?
    - This almost certainly depends on answers to the first two questions
  - Are existing algorithms, designed for the black-box attack context only, a good starting point, or should we start from scratch?

White-Box Cryptography and Obfuscation

> There are several models of obfuscation, but all involve the hiding of certain properties of a program
> The value of the key is one such (very important) property
> Thus, if we could create an obfuscator, we could apply it to cryptographic algorithms and increase security against white-box attackers

Some Results

- We do know that it's possible to implement a cipher in such a way that the best attack is a black-box attack
- Consider AES, with key K
  - It can be described as a function that takes a 128-bit input and produces a 128-bit output
  - Such a function can be "implemented" as a lookup table with 2^{128} entries
  - Such an implementation has no internals, so it can only be attacked as a black box
- Obviously, this isn't practical
- Open question: can we do any better?

Some Results (2)

- Barak et al – "On the (Im)possibility of Obfuscating Programs
  - Proposed a definition for an obfuscator, and showed that there existed contrived programs that could not be obfuscated under this model
  - No claims made regarding the obfuscatability of programs in general
  - Their result applies equally well to hardware implementations, so doesn't quite match the real world

Some Results (3)

- Other models for obfuscation:
  - Canetti et al (2008) showed that it is possible to obfuscate point functions under their model
  - Hohenberger et al (2007) were able to obfuscate re-encryption under a security-oriented model
  - Goldwasser et al (2008) introduced *best-possible obfuscation*, with various positive and negative results

Some Results (4)

- Proposed implementations of AES:
  - Chow et al (2002), “White-Box Cryptography and an AES Implementation”
    - Presented the first implementation of AES that took white-box attacks into account
  - Billet et al (2004), “Cryptanalysis of a White-Box AES Implementation”
    - An attack on the Chow et al implementation
  - Michiels et al (2008), “Cryptanalysis of White-Box Implementations”
    - Another attack

Some Results (5)

- Proposed implementations of DES:
  - Chow et al (2002), “A White-Box DES Implementation for DRM Applications”
    - The first implementation of DES that took white-box attacks into account
  - Jacob et al (2002), “Attacking an Obfuscated Cipher by Injecting Faults”
    - An attack on one variant of white-box DES proposed by Chow et al
  - Link et al (2005), “Clarifying Obfuscation: Improving the Security of White-Box DES”
    - An improved implementation
  - Goubin et al (2007), “Cryptanalysis of White-Box DES Implementations”
  - Wyseur et al (2007), “Cryptanalysis of White-Box DES Implementations with Arbitrary External Encodings”
    - Powerful attacks on the Chow et al and Link et al implementations

What's Next?

- A "white-box friendly" cipher design
  - Design a cipher from the ground up to be secure in a white-box attack context
  - This would require both a cipher design, with demonstrable black-box security properties, and a description of a white-box implementation

Conclusions

- The model we have used for analyzing ciphers needs updating
- Software implementations and legitimate users as attackers push us towards a white-box attack context
- The implementation of a cipher is as important as the cipher itself
- There is a ton of opportunity to do seminal work in white-box cryptography

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