Step aside! A fuzzy trip down side-channel lane

Side-channel assisted fuzzing in embedded systems

Master thesis, Master Computing Science
a.k.a. TRU/e Master in Cyber Security (`true-security.nl`)

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"Zoom etiquette"

- During the presentation ($\pm$ 30 minutes):
  - Disable audio transmission.
  - Question? Announce it in chat.
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Outline

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Assessing the security of embedded systems:

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This thesis combines three topics:

- Fuzzers
- Side-channels
- *Embedded system:* Smartcards

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Two fuzzers used in this thesis

- AFL, *American Fuzzy Lop*[1] (mutational, evolutionary)
- DifFuzz[3][1] (differential, based on AFL)

[1] Not part of this presentation

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2. *Constant-time* (under certain conditions)

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      - information on branches taken
      - exit codes indicating valid/invalid input, length, etc.

Preliminaries — Smartcards

Example of a smartcard (banking card, public domain)

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  - *Contact* vs. *contactless* cards
  - Personalization or provisioning
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- Standardized through ISO7816[2]
  - *Application Protocol Data Unit* (APDU), "message"
  - Status words
- Java Card
  - Programming language: subset of Java
  - Not limited to one hardware platform
  - Implements ISO7816

Research questions

1. *What fuzzers are already using side-channels?*
2. *How can we safely interface a Java Card smartcard with the fuzzer AFL?*
3. *How can we provide the fuzzer AFL with side-channel information?*

Case studies

Case study I: *PasswordEq*

- Custom Java Card applet
- Fixed password of 10 bytes
- Two password compare instructions:
  1. *Unsafe* with regards to timing
  2. *Safe* with regards to timing
- Status words report *Incorrect length*, *Correct/incorrect password*

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Case study II: Unprovisioned SIM card

- Instruction set discovery using status words

Experiments

Highlighting two of the six experiments:

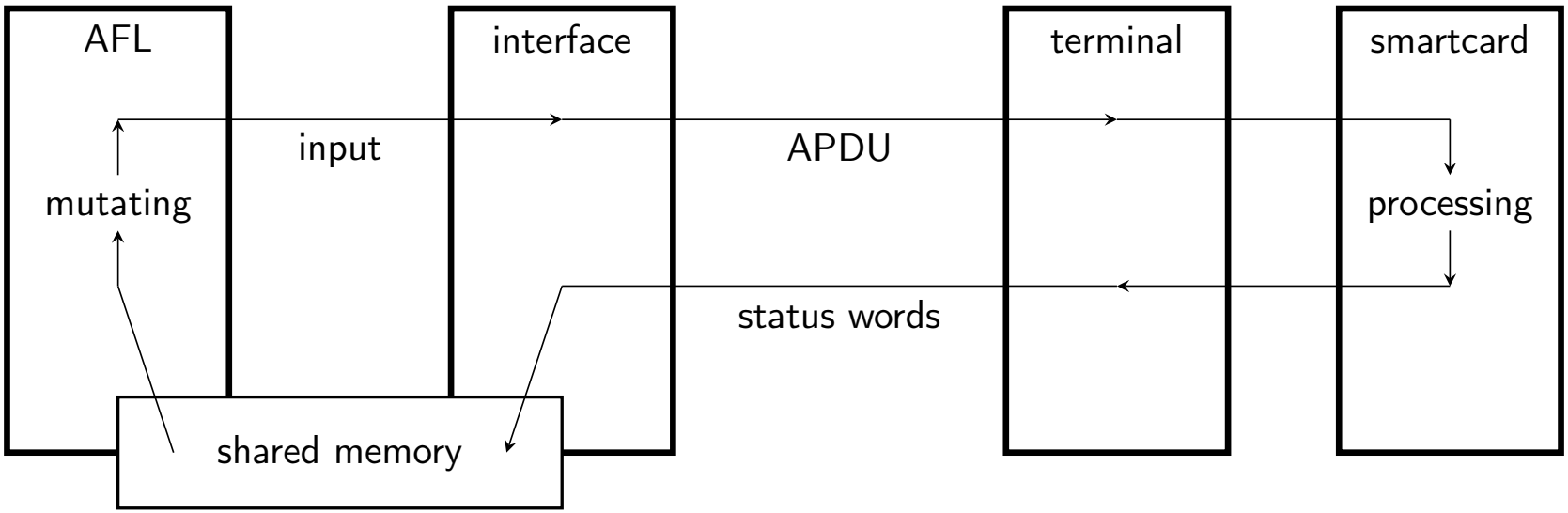
1. Smartcard instruction set discovery using status words
2. `PasswordEq` password extraction using status words and timing

Materials used for these experiments:

- JavaCOS A40 Java Card smartcard / unprovisioned SIM card
- OmniKey CardMan 5121 smartcard terminal
- Laptop[3] running a Linux distribution
- Vanilla AFL
- Custom interface program
  - Translation layer between AFL and Java Card
  - Filtering of unwanted inputs
  - Logging

[3] i5-3320M @ 2.60GHz CPU, 16GB memory

Experiments — Setup



Schematic overview of the interaction between smartcard and AFL

Experiment I: smartcard instruction set discovery

- Unprovisioned / non-personalized SIM card
- Black-box approach
- *Pseudo* side-channel status words
- Looking for status words that indicate "an implemented instruction"
- Ideally faster than brute-force approach, due to feedback loop
- Fuzzing time: 30 minutes

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- 109 instructions found

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Conclusion:

- Fuzzing for finding a smartcard's instruction set works
- Using a fuzzer is *less* time-efficient than a brute-force approach

Experiment II: `PasswordEq` password extraction

Recap of the `PasswordEq` Java Card applet:

- Fixed password of 10 bytes
- Two password checking instructions:
  1. *Unsafe* with regards to timing
  2. *Safe* with regards to timing
- Status words report *Incorrect length*, *Correct/incorrect password*

Experiment II: `PasswordEq` password extraction

Approach:

1. Let AFL generate APDUs
2. Send APDUs to the Java Card smartcard
3. Record status words in AFL's shared memory
4. Record execution time in AFL's shared memory
5. Repeat

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- The timing side-channel reveals how many characters were correct
  - This reduces the search space from 256^{10} to $256 \cdot 10$, or linear search time rather than exponential
- Ideally, AFL zooms in on the *unsafe* password checking instruction
- Ideally, AFL finds the correct length, and the correct password, due to timing information

Experiment II: `PasswordEq` password extraction

Results, after fuzzing 1 hour and 40 minutes:

- AFL found *safe* and *unsafe* instructions
- AFL found the correct length *parameter*
- AFL *did not* find the correct password

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Conclusion

- Adding timing information did not result in finding the password
- Complexity of the stored password
- Discrepancy between length parameter and length of the supplied password
  - *Example:* Length parameter: 10, actual password length: 5
  - Applet: length correct, password incorrect

Future work

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- Feeding a power side-channel to AFL
- White-box instrumentation of Java Card applets

Wrapping up

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1. DifFuzz
2. Custom interface program
3. Store it in AFL's shared memory

Thanks for your attention!

Stay safe!

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References I

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Standard ISO/IEC 7816-4:2013, International Organization for Standardization, Geneva, CH, 2013.

Shirin Nilizadeh, Yannic Noller, and Corina S. Păsăreanu.
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In *Proceedings of the 41st International Conference on Software Engineering*, ICSE '19, pages 176–187, Piscataway, NJ, USA, 2019. IEEE Press.

List of experiments

1. DifFuzz paper
2. Exposing a timing side-channel in a Java Card applet
3. Using DifFuzz to fuzz a Java Card applet on a smartcard
4. Status words as pseudo side-channel information for AFL
5. Smartcard instruction set discovery using status words
6. Status words, timing, AFL, `PasswordEq`