Detecting Similar Code Segments through Side Channel Leakage in Microcontrollers

Peter Samarin[1,2] and Kerstin Lemke-Rust[1]

Bonn-Rhein-Sieg University of Applied Sciences[1]
Ruhr-Universität Bochum[2]
Germany

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Bonn-Rhein-Sieg
University of Applied Sciences

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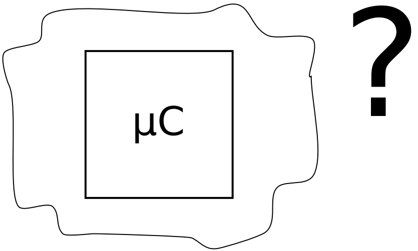
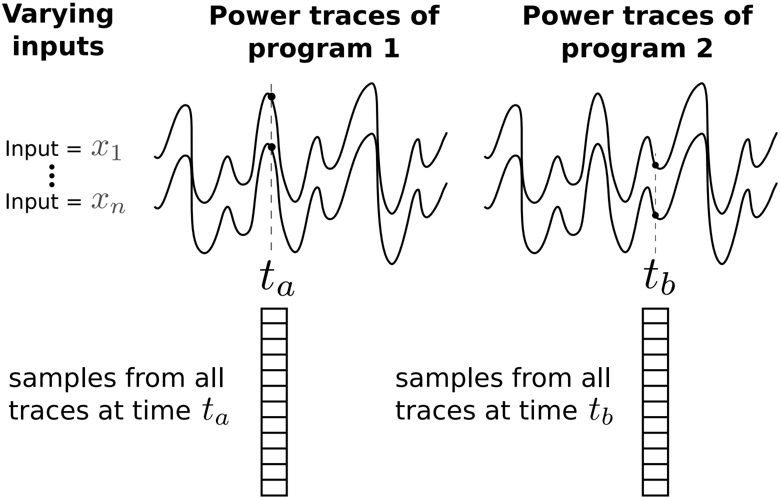
Motivation: Software Plagiarism in Microcontrollers

- A product comes to the market with the same capabilities
- *Does the system contain our intellectual property?*



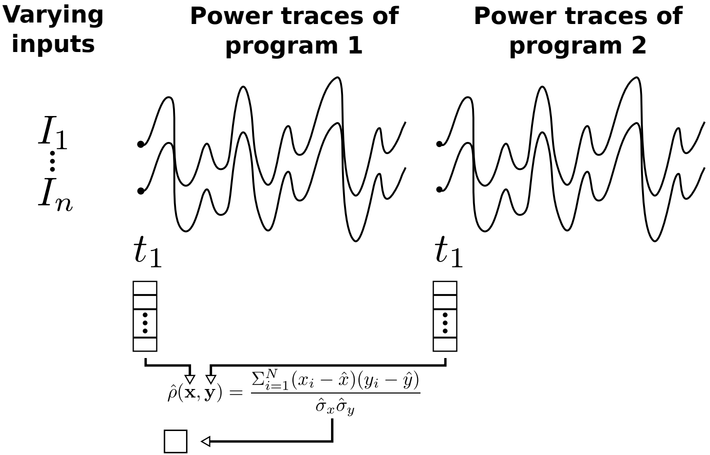
- Adversary takes our binary
- Effective read-out protection
- Comparison of code binaries not possible
- *Our solution*: compare power side channel leakage of the two implementations

Observations about the Power Side Channel



- high correlation when same data is processed
- low correlation when different data is processed

Our Approach



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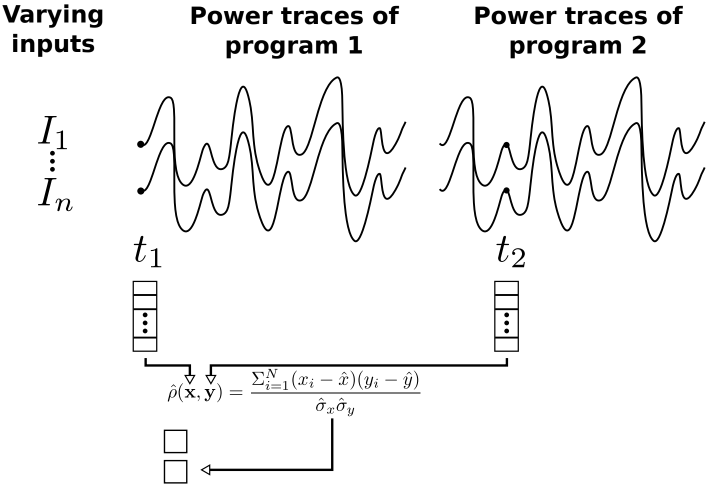

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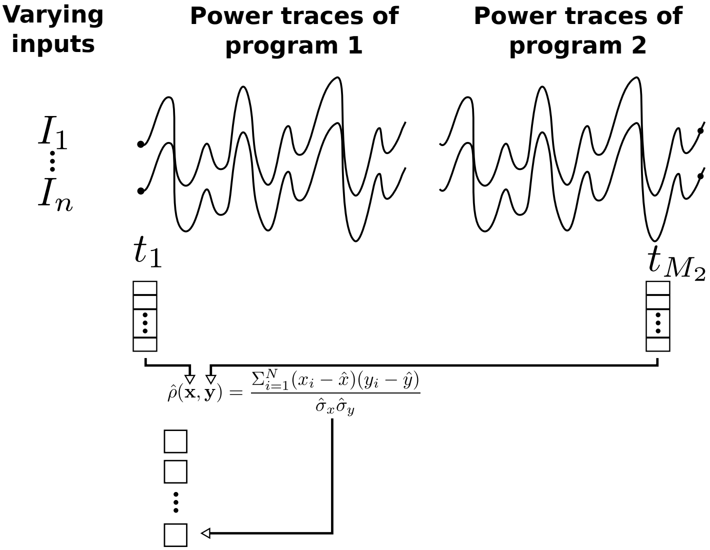

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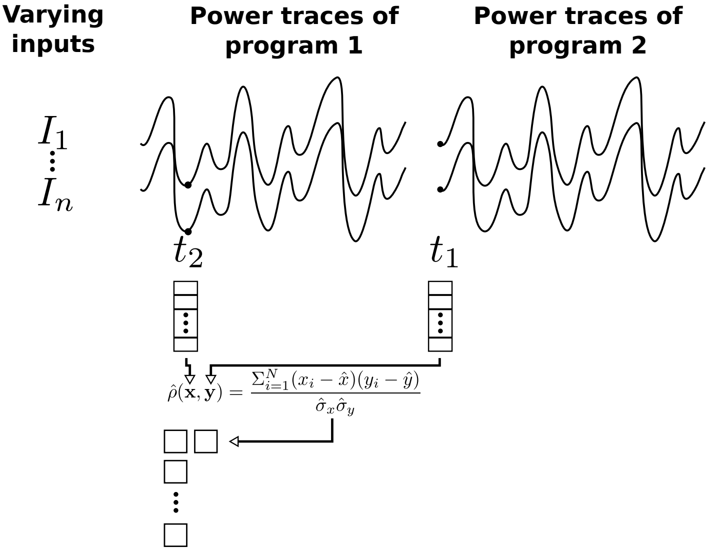

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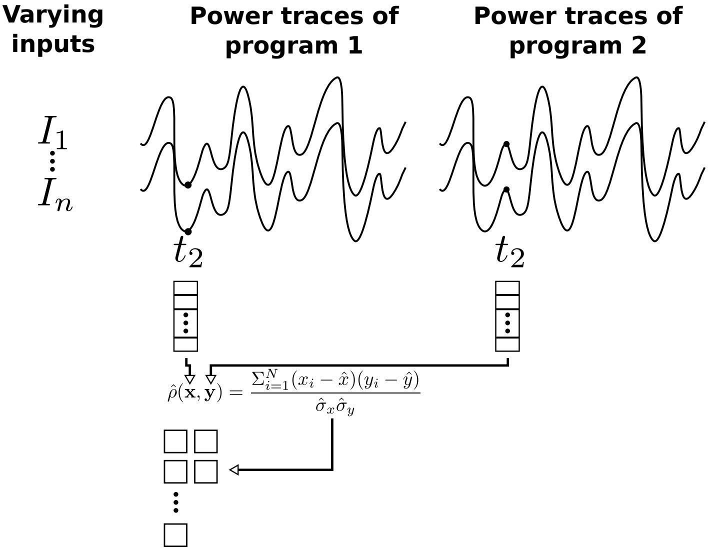

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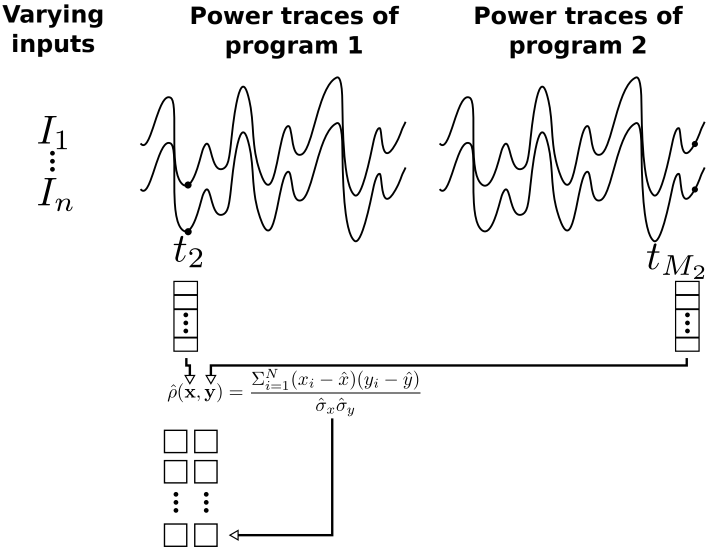

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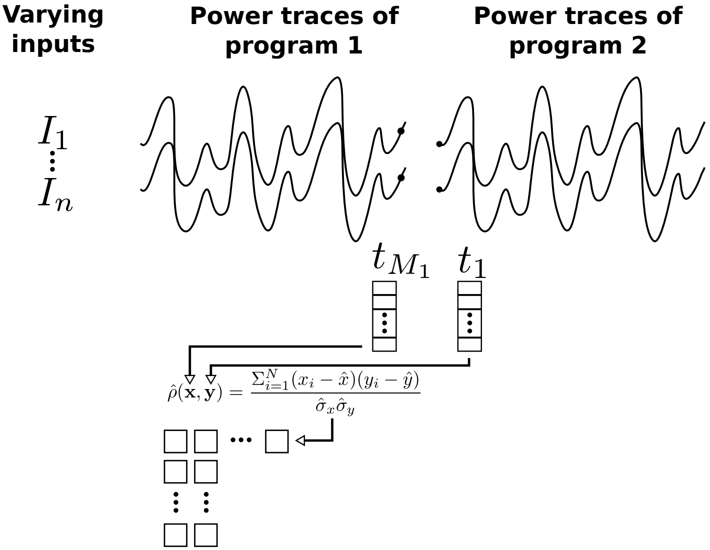

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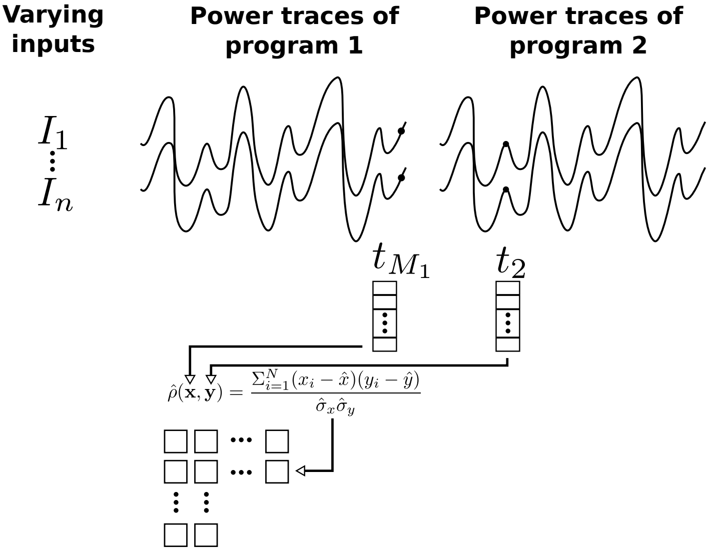
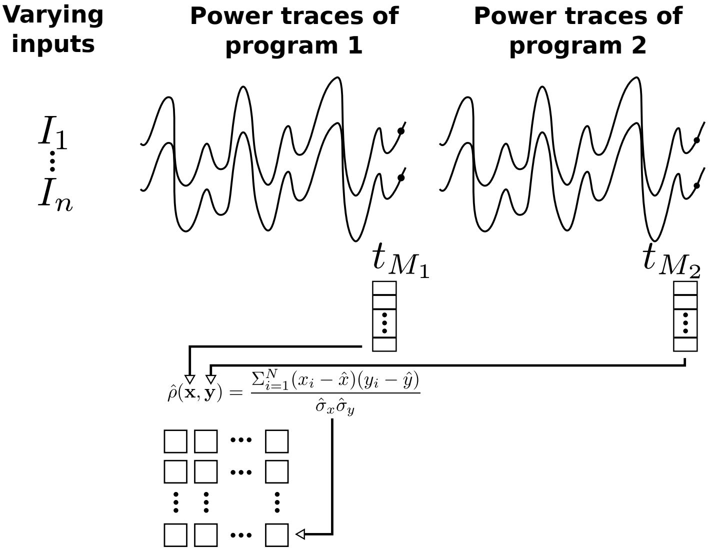
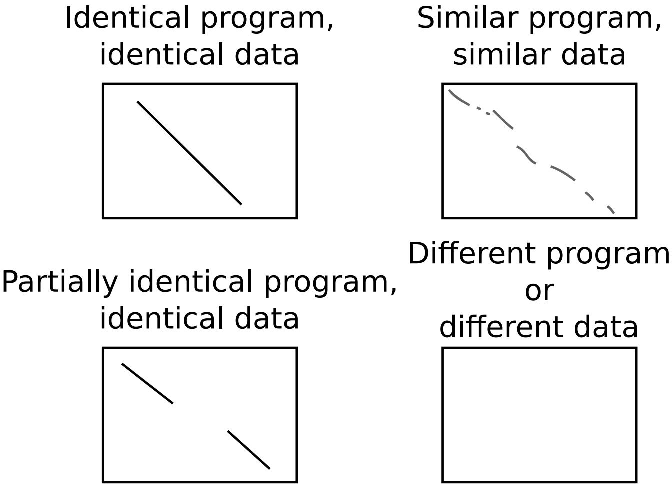


Our Approach: Correlate at all Times

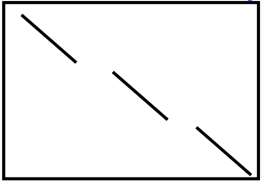


Expectations about the Similarity Matrix

- The similarity matrix shows at what time similar computations happen



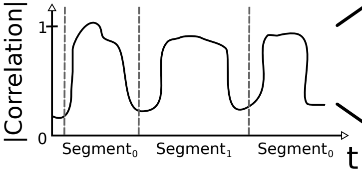
Our Approach: Similarity measure



Suspicious program

Genuine program

abs(max(col_i))



$$\rho_{col} = \frac{1}{M_1}\sum_{i=1}^{M_1} p_{col_i}$$

Global similarity measure

$$\rho_{Seg_0} = \frac{1}{|Seg_0| * N_0}\sum_{i}^{|Seg_0|*N_0} p_{col_i}$$

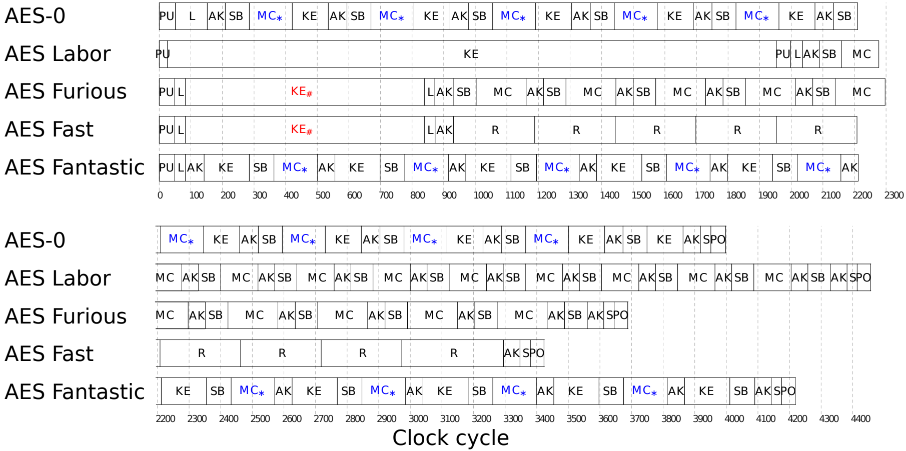
$$\rho_{Seg_1} = \frac{1}{|Seg_1| * N_1}\sum_{i}^{|Seg_1|*N_1} p_{col_i}$$

Local similarity measure

Experimental Setup

- Smartcards with ATMega163 microcontroller
  - 8-bit μC, running at 4MHz
- Measure using a digital oscilloscope (PicoScope 6402C)
  - sampling rate is 375 MHz

Test Programs: Implementations of AES in Assembly



PU - push registers
PO - pop registers
*,# - identical code

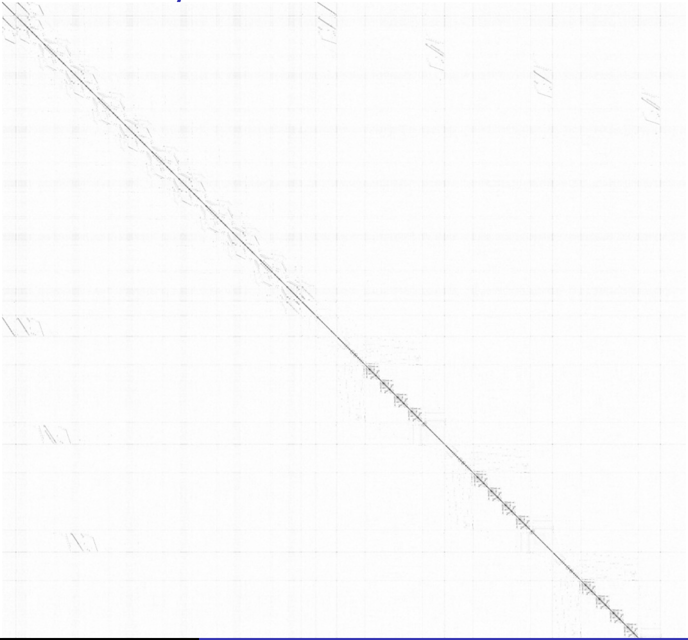
L - load key/plaintext
S - store ciphertext

KE - key expansion
AK - add round key

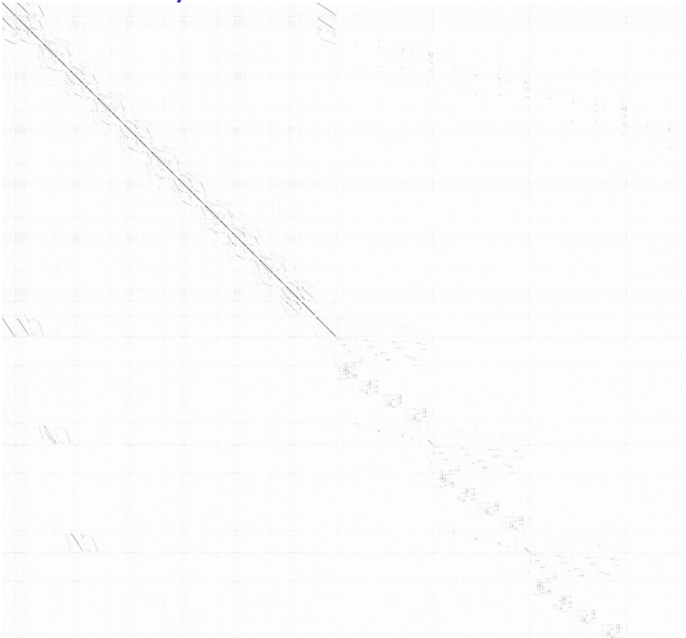
SB - shift rows and subbytes
MC - mix columns
R - one AES round in *Fast*

- 10k traces were recorded for each implementation

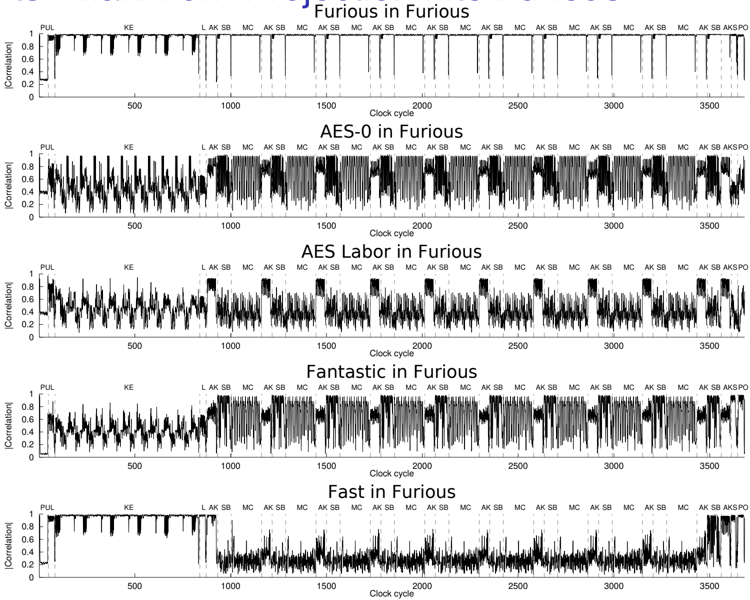
Results: Similarity Matrix of Furious vs. Furious



Results: Similarity Matrix of Fast vs. Furious



Results: Maximum Projection into Furious



PU - push registers
PO - pop registers
L - load key/plaintext
S - store ciphertext
KE - key expansion
AK - add round key
SB - shift rows and subbytes
MC - mix columns

Results: Maximum Projection, Global Similarity

	AES-0	AES Labor	Furious	Fast	Fantastic
AES-0	**0.97**	0.41	0.63	0.33	0.53
AES Labor	0.42	**0.91**	0.46	0.29	0.39
Furious	0.61	0.44	**0.96**	0.45	0.54
Fast	0.35	0.32	0.46	**0.96**	0.29
Fantastic	0.58	0.40	0.62	0.30	**0.93**

Results: Maximum Projection of Code Segments

	AK	SB	MC	KE
AES-0	**0.96**	**0.97**	**0.98**	**0.97**
AES Labor	0.64	0.33	0.36	0.43
Furious	0.68	0.65	0.73	0.46
Fast	0.45	0.31	0.26	0.44
Fantastic	0.64	0.58	0.75	0.41

(a) →*AES-0*

	AK	SB	MC	KE
AES-0	0.68	0.31	0.38	0.40
AES Labor	**0.96**	**0.97**	**0.96**	**0.88**
Furious	0.73	0.38	0.40	0.41
Fast	0.48	0.24	0.19	0.39
Fantastic	0.62	0.31	0.37	0.43

(b) →*AES Labor*

	AK	SB	MC	KE
AES-0	0.71	0.65	0.71	0.46
AES Labor	0.75	0.40	0.37	0.45
Furious	**0.95**	**0.98**	**0.98**	**0.96**
Fast	0.47	0.31	0.27	0.95
Fantastic	0.65	0.72	0.68	0.41

(c) →*Furious*

	AK	KE	R
AES-0	0.69	0.46	0.28
AES Labor	0.73	0.45	0.23
Furious	0.85	**0.95**	0.27
Fast	**0.97**	**0.95**	**0.98**
Fantastic	0.64	0.40	0.25

(d) →*Fast*

	AK	SB	MC	KE
AES-0	0.66	0.57	0.75	0.33
AES Labor	0.62	0.32	0.35	0.40
Furious	0.62	0.71	0.70	0.32
Fast	0.43	0.27	0.25	0.31
Fantastic	**0.96**	**0.96**	**0.97**	**0.90**

(e) →*Fantastic*

Experiment Set #2: Furious vs. Modified Furious

- addr: change register and data addresses
- swap: change the order of instruction execution
- addr+swap
- dummy: add 792 NOP instruction randomly
- dummy smart: add 792 leakage-generating instructions
- dummy smart+addr+swap

Dummy Smart Explanation

- Assembly language macros applied to state registers randomly throughout the code

1

```
INC \reg
DEC \reg
```

2

```
NEG \reg
NEG \reg
```

3

```
ROL \reg
ROR \reg
```

4

```
PUSH \tmp
LDI  \tmp, \c
EOR  \reg, \tmp
POP  \tmp
```

5

```
LDI ZL, 0x00
LPM \tmp, Z
```

6

```
EOR \tmp, \tmp
```

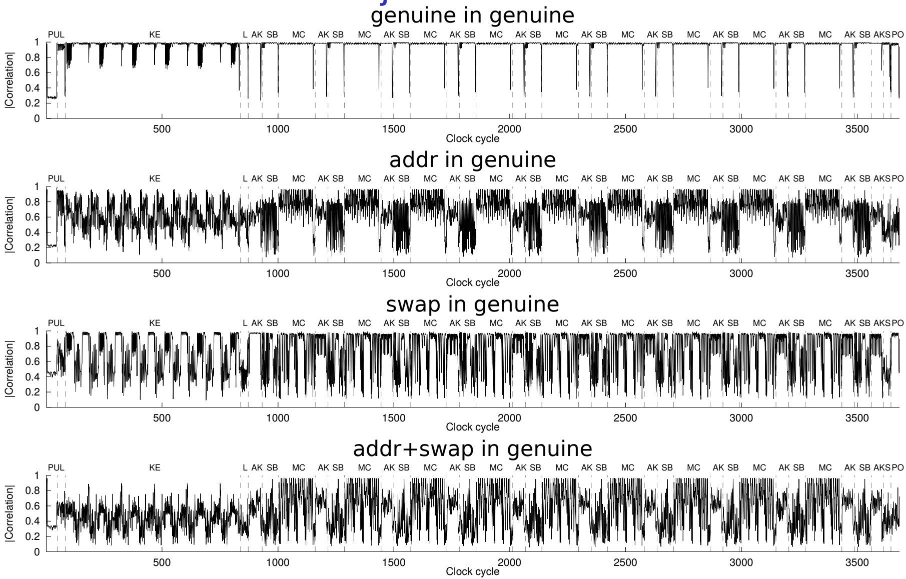
7

```
PUSH \reg1
PUSH \reg2
PUSH \reg3
EOR  \reg1, \reg2
EOR  \reg2, \reg3
EOR  \reg3, \reg1
POP  \reg3
POP  \reg2
POP  \reg1
```

8

```
MOV \tmp, \reg ;; save register
LDI ZH, hi8(hd_temp)
LDI ZL, lo8(hd_temp)
LD  \reg, z
MOV \reg, \tmp ;; restore register
```

Results: Maximum Projection



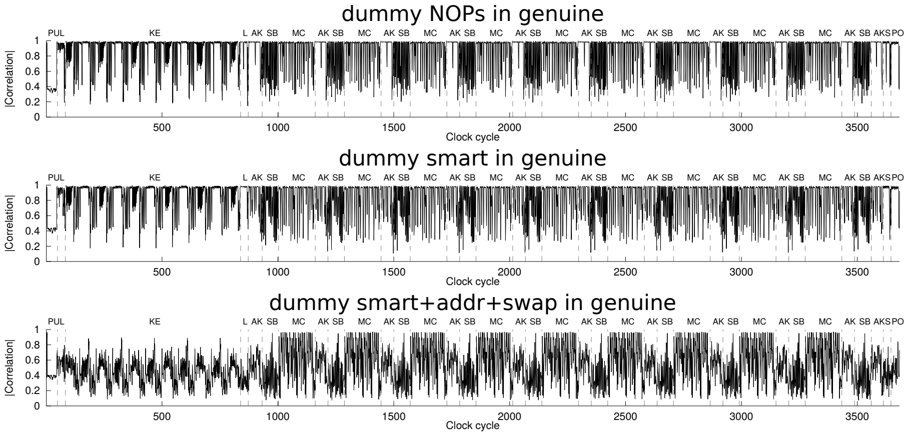
PU - push registers
PO - pop registers

L - load key/plaintext
S - store ciphertext

KE - key expansion
AK - add round key

SB - shift rows and subbytes
MC - mix columns

Results: Maximum Projection Contd.



PU - push registers
PO - pop registers

L - load key/plaintext
S - store ciphertext

KE - key expansion
AK - add round key

SB - shift rows and subbytes
MC - mix columns

Results: Detection of Similar Code Segments

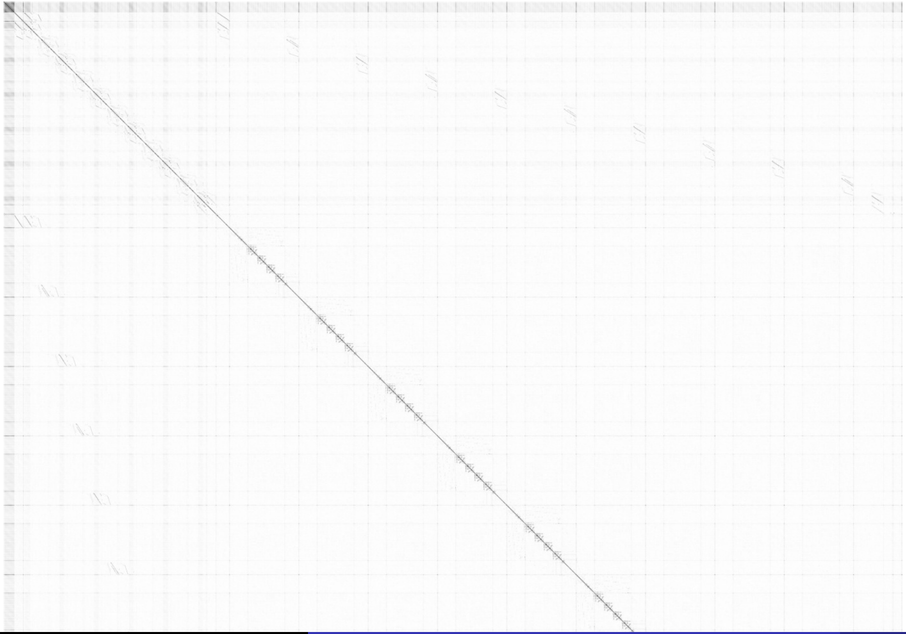
	genuine
genuine	**0.96**
addr	0.64
swap	0.73
addr+swap	0.52
dummy NOPs	0.84
dummy smart	0.83
dummy smart+addr+swap	0.51

(a) Global similarity

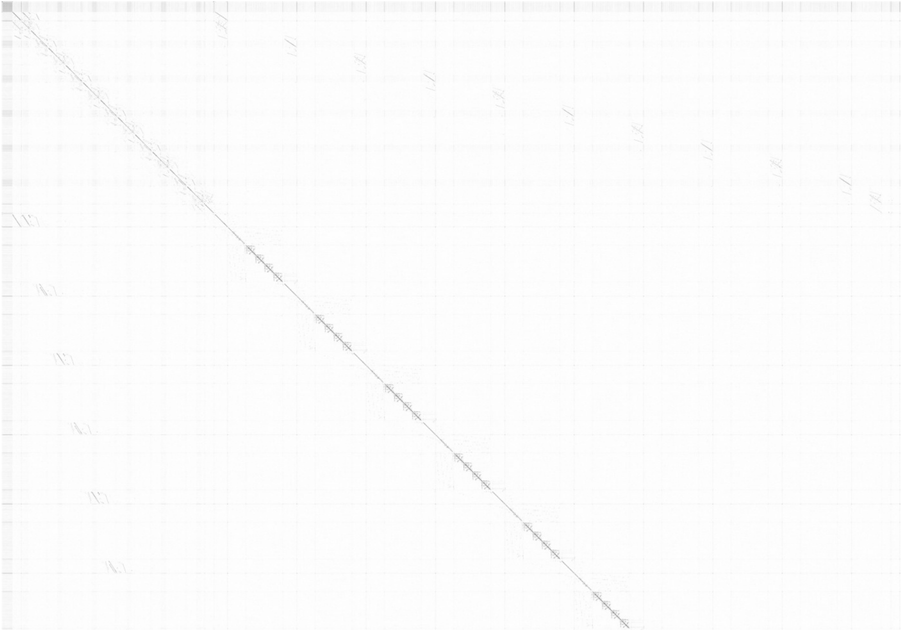
AK	SB	MC	KE
0.95	**0.98**	**0.98**	**0.96**
0.61	0.52	0.76	0.60
0.84	0.62	0.78	0.80
0.59	0.37	0.64	0.45
0.92	0.72	0.87	0.86
0.82	0.75	0.85	0.85
0.54	0.36	0.63	0.44

(b) Local similarity

Results: Similarity Matrix of genuine vs. genuine



Results: Similarity Matrix of addr vs. genuine



Related Work

- (Becker et al. 2011)
  - Detect Hamming weight of the instructions
  - Embed watermarks detectable in the side channel
  - Problem: not all microcontrollers leak the Hamming weight of the instruction
- (Strobel et al. 2015)
  - Side channel disassembler
  - Use electromagnetic emanation
  - Detect individual instructions
  - Problem: Only tested on one microcontroller
- (Durvaux et al. 2012)
  - Use power consumption as its own watermark
  - Horizontal correlation one two traces
  - Problem: sensitive to the dummy cycles

Conclusions and Future Work

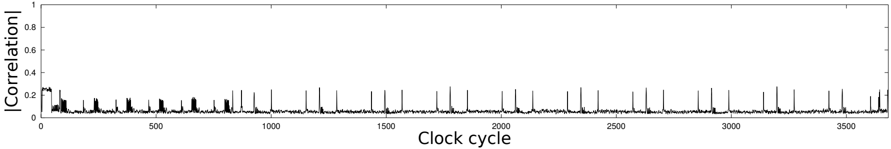
- Method for detecting similarity of programs using side channels
- We can detect identical code segments in the power consumption of a microcontroller
- Our method also works well with cases where many dummy cycles have been inserted
- Interesting application: detecting unlicensed implementations of patented technology

Future Work

- Combination of horizontal and vertical approaches
- Non-linear programs
  - dissect into data-dependent code paths
  - compute similarity for each code path
- Evaluation using different microcontrollers
- Dealing with random data

Questions?

Backup: Furious vs Furious Wrong Data



Backup: Visual Inspection