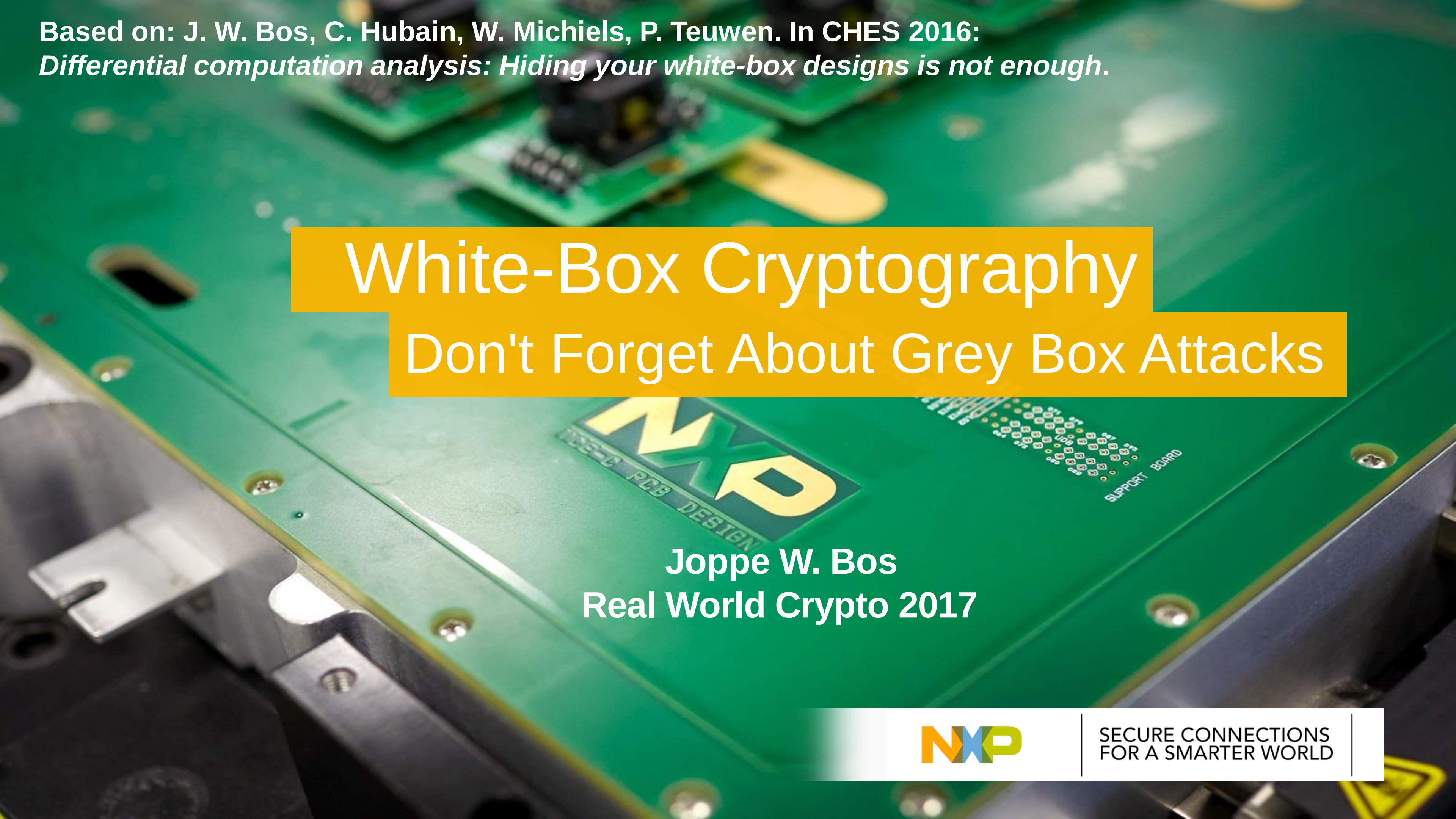
Based on: J. W. Bos, C. Hubain, W. Michiels, P. Teuwen. In CHES 2016: *Differential computation analysis: Hiding your white-box designs is not enough*.

White-Box Cryptography

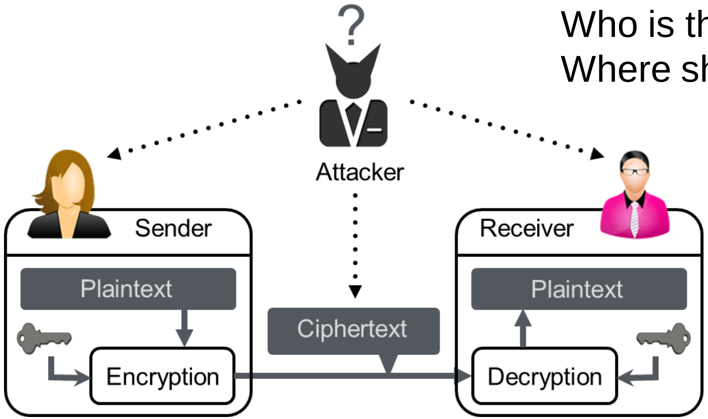
Don't Forget About Grey Box Attacks



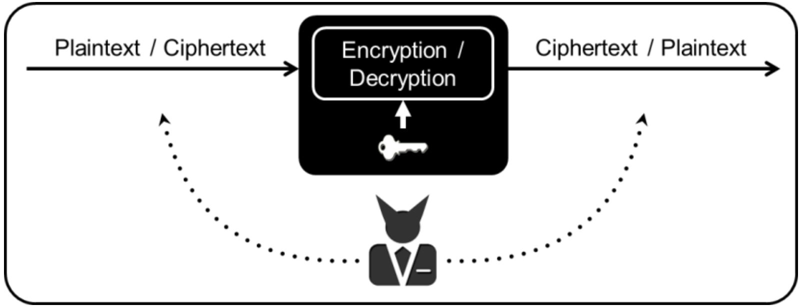
Joppe W. Bos

Real World Crypto 2017

SECURE CONNECTIONS FOR A SMARTER WORLD



Who is the attacker? External adversary, user, virus?
Where should we assume the attacker to be? What is realistic?



Endpoints are trusted parties
Attacker “observes” data being transferred

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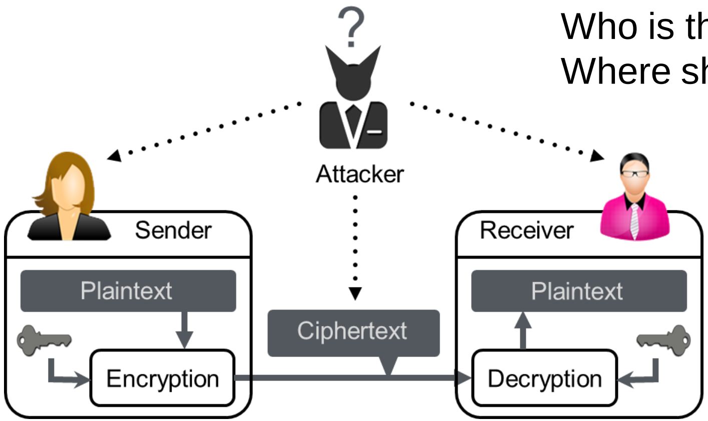

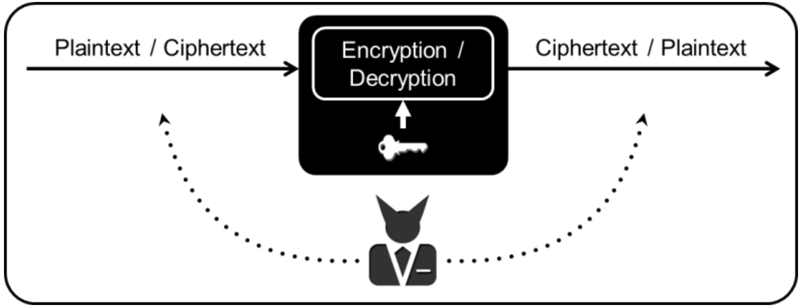

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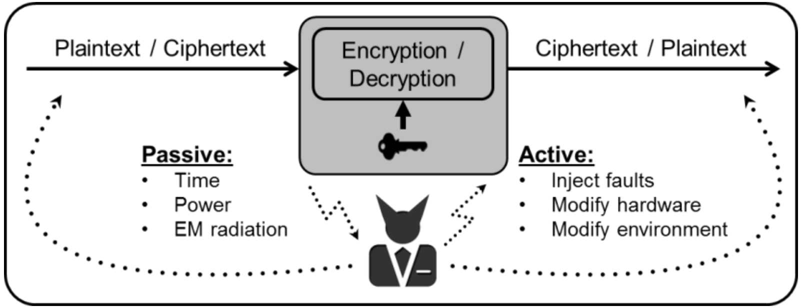


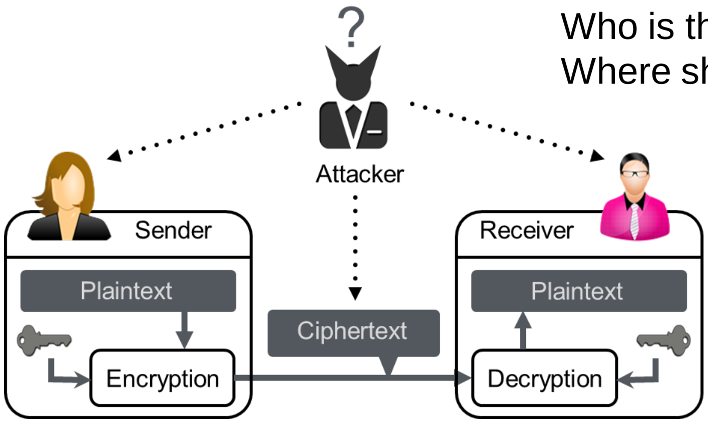
Passive:

- Time
- Power
- EM radiation

Active:

- Inject faults
- Modify hardware
- Modify environment

Hardware implementations tend to leak key-correlated information



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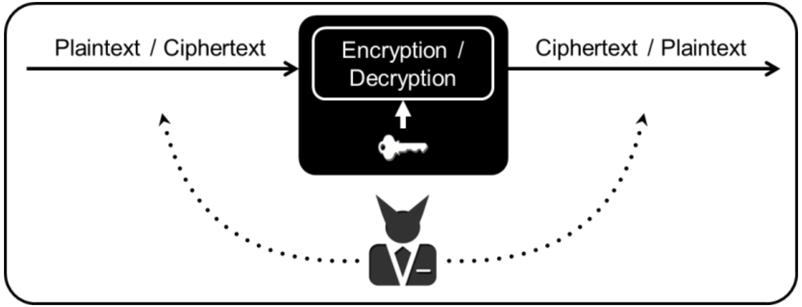

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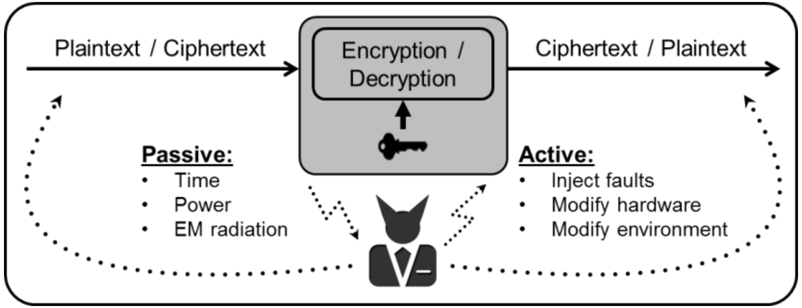

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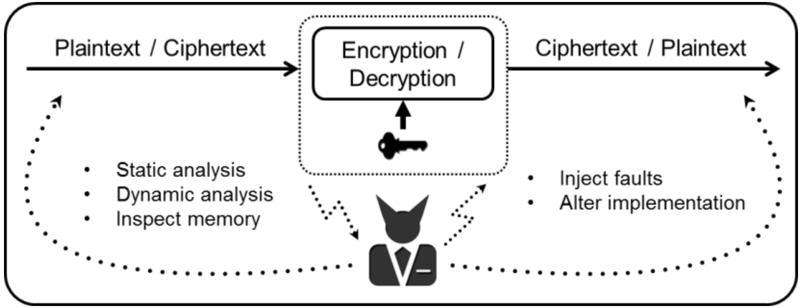

Adversary owns the device running the software.

Where is this used in practice?

Original use-case for white-box crypto is *digital right management*.

For example: streaming content, protecting DVD’s etc

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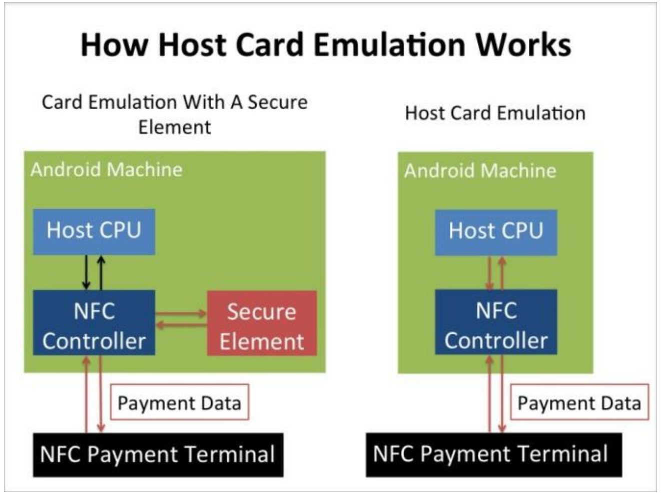


Source: Business Insider

Recent trend

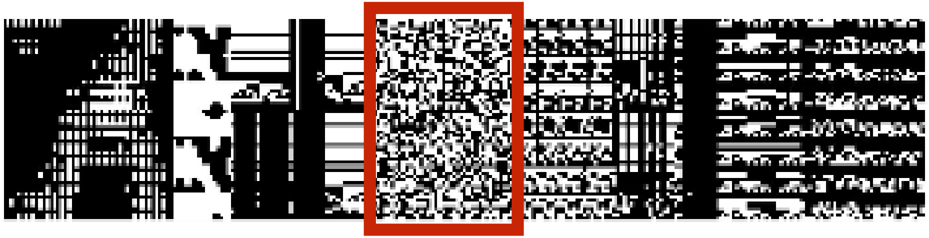
Use *Host Card Emulation* (HCE) to communicate using *Near Field Communication* (NFC)
→ Replace the secure element with software.

Protection of the cryptographic key? How?
White-box implementation!

Huge demand for practical + secure white-box

- 2014: VISA + Mastercard support HCE
- [Berg Insight]: **86%** of the Point of Sale devices in North America and **78%** in Europe will support NFC by 2017.
- [IHS research]: By 2018, 2/3 of all shipped phones will support NFC.
- → the deployed protocols use (and store!) AES / DES keys
  → need for secure **white-box cryptography**.

Why not use “normal” crypto software code?



■ 0-bit □ 1-bit

- **Entropy attack**
  - Locate the unusual high entropy of the cryptographic key in a memory dump using sliding windows for example.

Shamir, van Someren: *Playing "Hide and Seek" with Stored Keys*. Financial Cryptography 1999

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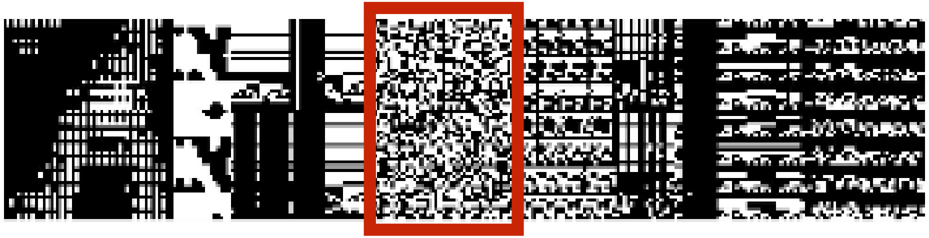

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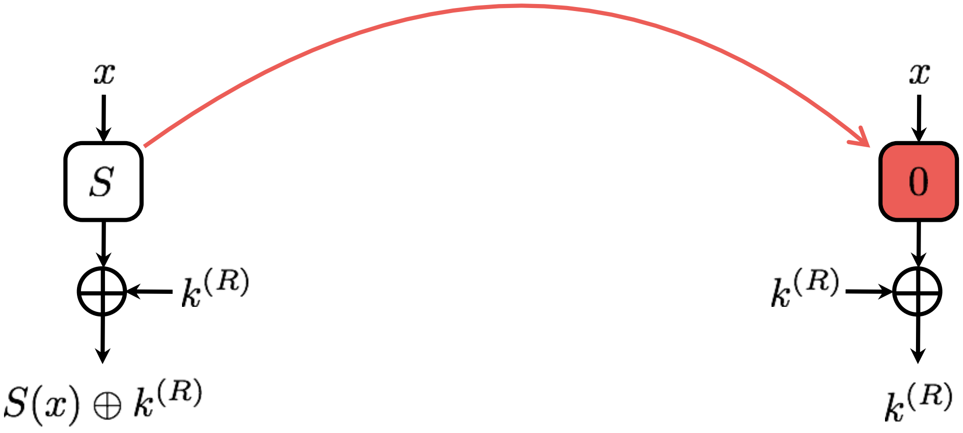


- **S-box blanking attack**
  - Locate the publicly defined S-boxes in the binary and overwrite it with all zeros such that *S*(*x*)=0 for any *x*.

Kerins, Kursawe: *A cautionary note on weak implementations of block ciphers*. *WISSec*, 2006

White-Box in Practice

White-Box theoretically Impossible?

No! “Ideal” WB AES implementation

One big lookup table

→ 2^{92} TB storage required

In practice

Network of smaller tables:

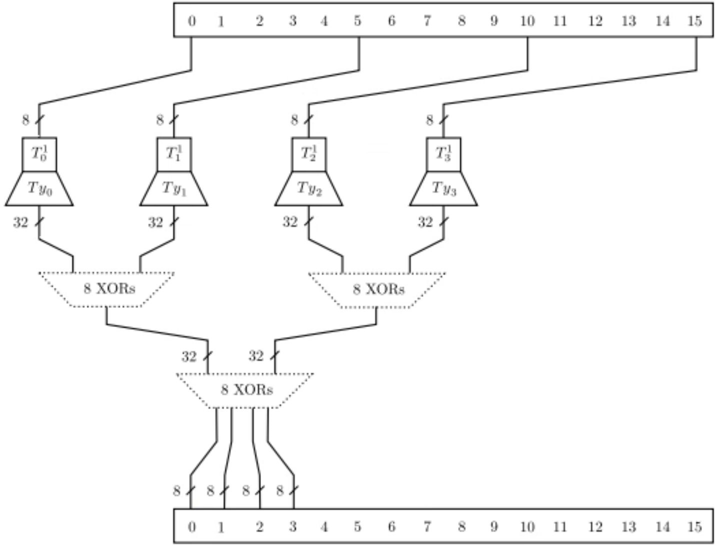
≈ 700 kB

Encoding on intermediate values using ideas by Chow

Chow, P. A. Eisen, H. Johnson, and P. C. van Oorschot. White-box cryptography and an AES implementation, in SAC 2002.

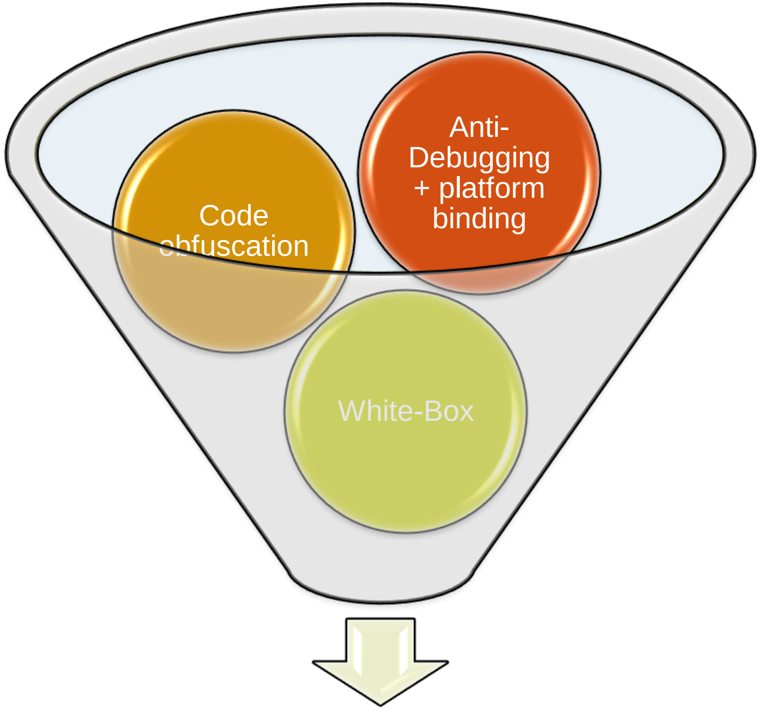
Generic idea.

Transform a cipher into a network of randomized key-instantiated **look-up tables**



J. A. Muir. A tutorial on white-box AES. In Advances in Network Analysis and its Applications, 2013

White box crypto - practice



White-Boxed implementation

In practice the white box is the most essential but a **small part** of the entire software implementation

- Strong code obfuscation
- Binary is “glued” to the environment
    - Prevent code-lifting
- Support for traitor tracing
- Mechanism for frequent updating

More details see the invited talk at EC 2016 *Engineering Code Obfuscation* by Christian Collberg

Effort and expertise required

Previous effort

Previous WB attacks were WB specific which means knowing

- the *encodings*
- which *cipher operations* are implemented by
- which (network of) *lookup tables*

Attack

1. time-consuming reverse-engineering of the code
2. identify which WB scheme is used + target the correct LUTs
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Our approach

Assess the security of a WB implementation

- ✓ Automatically and very simply (see CHES challenge)
- ✓ Without knowledge of any implementation choices
  → only the algorithm itself
- ✓ Ignores all (attempts) at code-obfuscation

Tracing binaries

- Academic attacks are on open design
- In practice: what you get is a binary blob

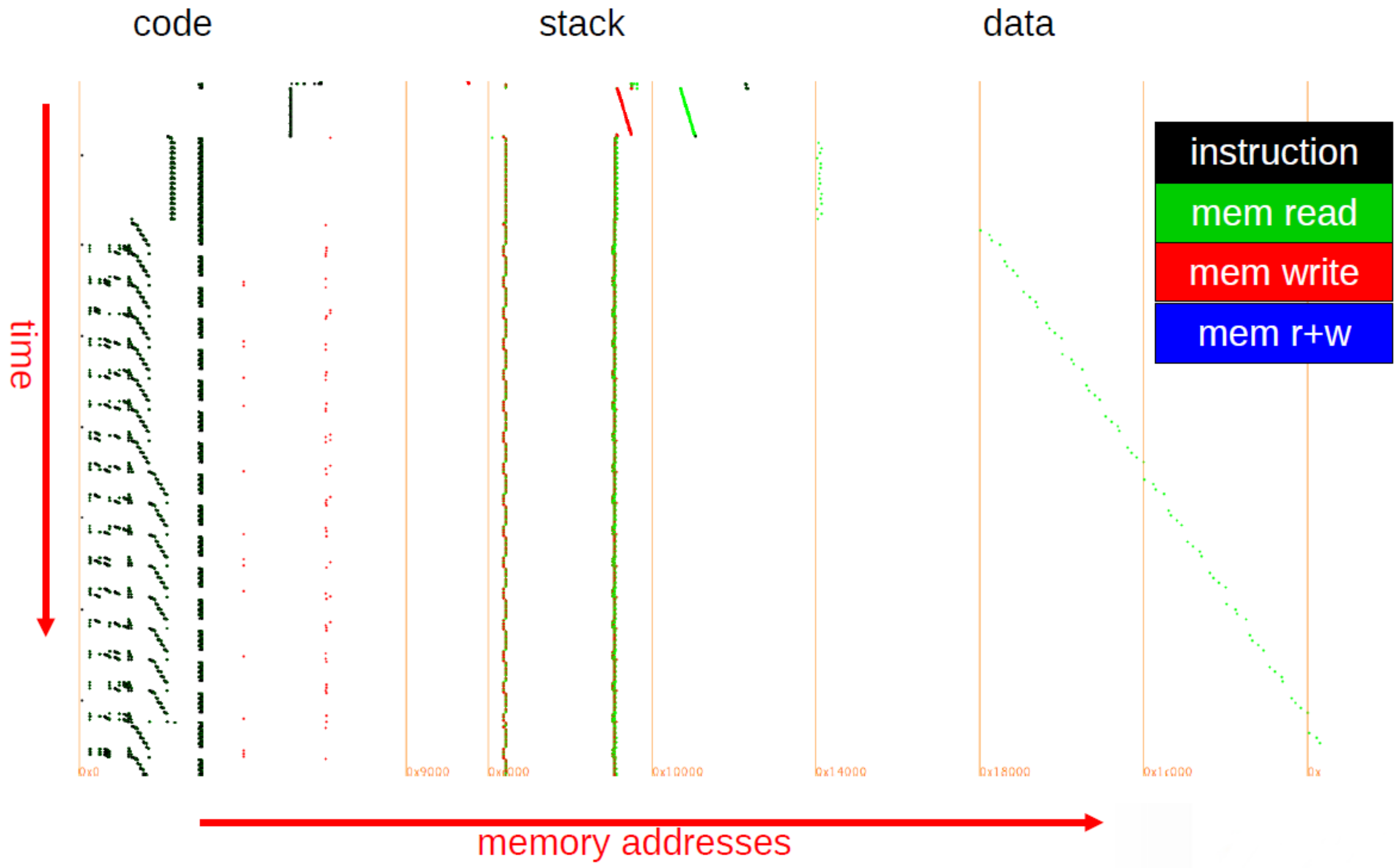
Idea: collect information using using *dynamic binary instrumentation* tools (→ visual representation → use traces to find correlation)

- Record all instructions and memory accesses.

Examples of the tools we extended / modified

- Intel PIN (x86, x86-64, Linux, Windows, Wine/Linux)
- Valgrind (idem+ARM, Android)

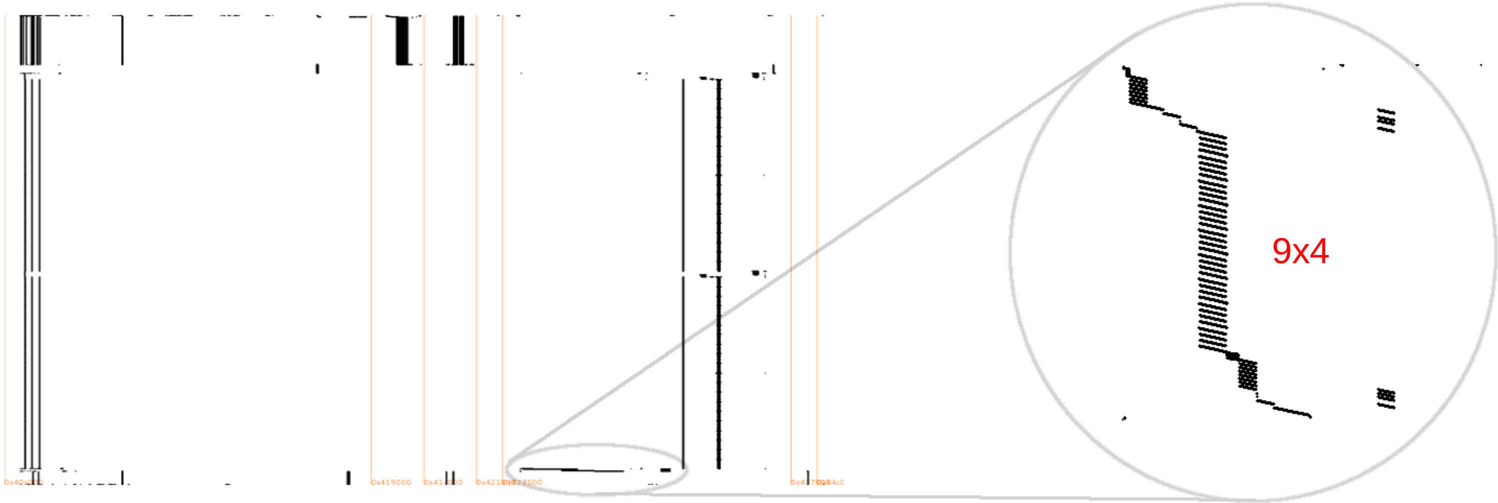
Trace visualization



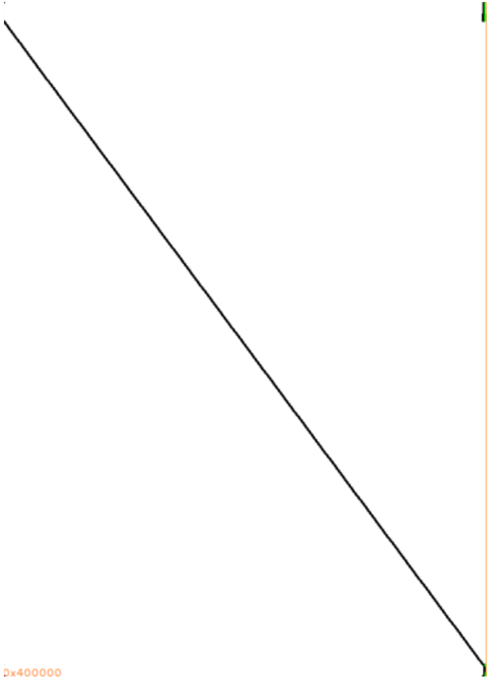
instruction
mem read
mem write
mem r+w

Based on Ptra, an unreleased Quarkslab tool presented at SSTIC 2014

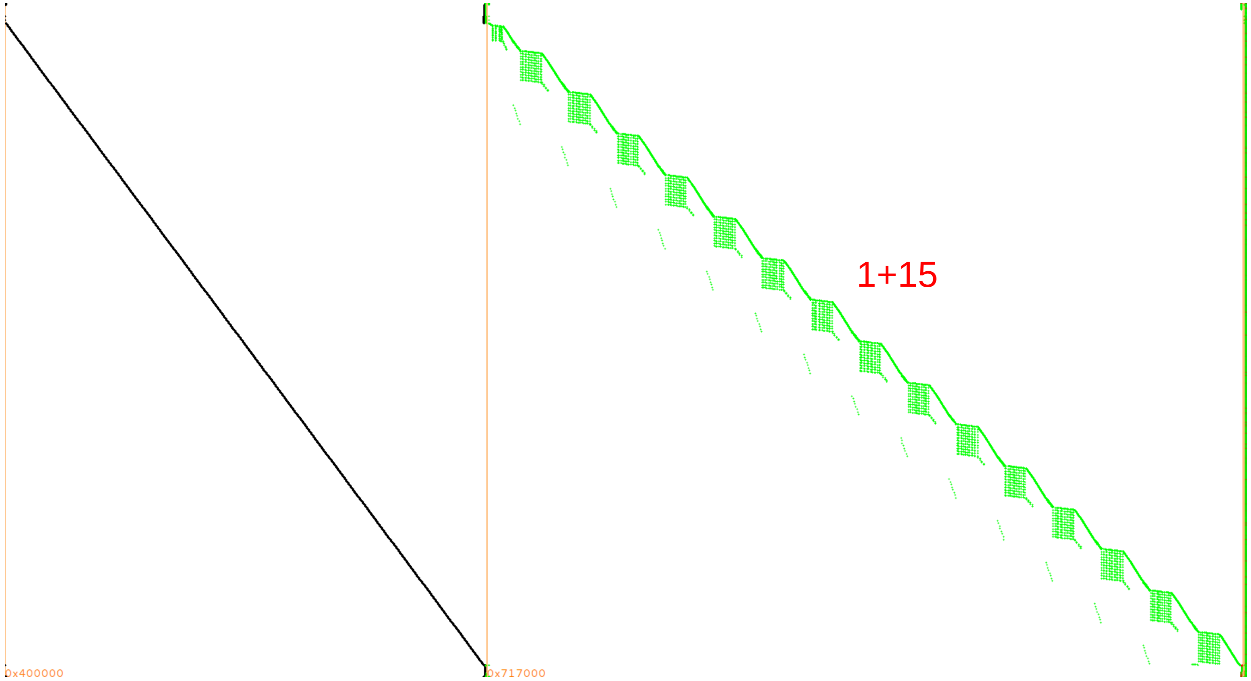
Visual crypto identification: code



Visual crypto identification: code?



Visual crypto identification: code? data!



1+15

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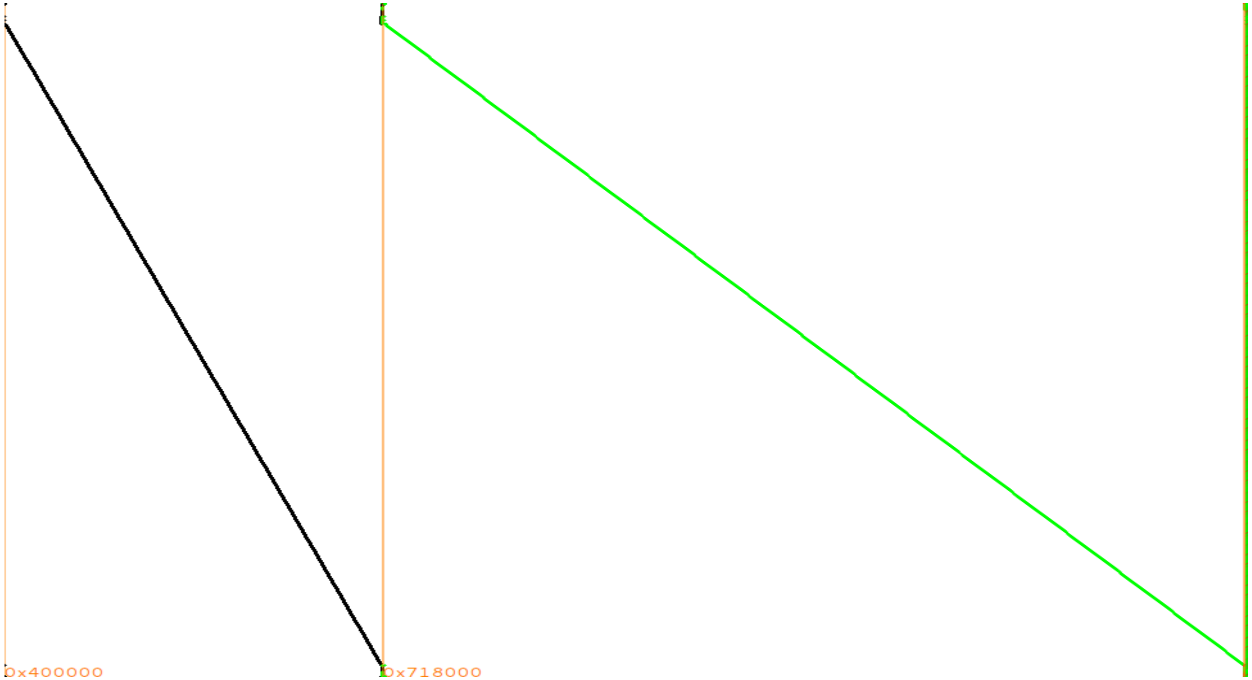
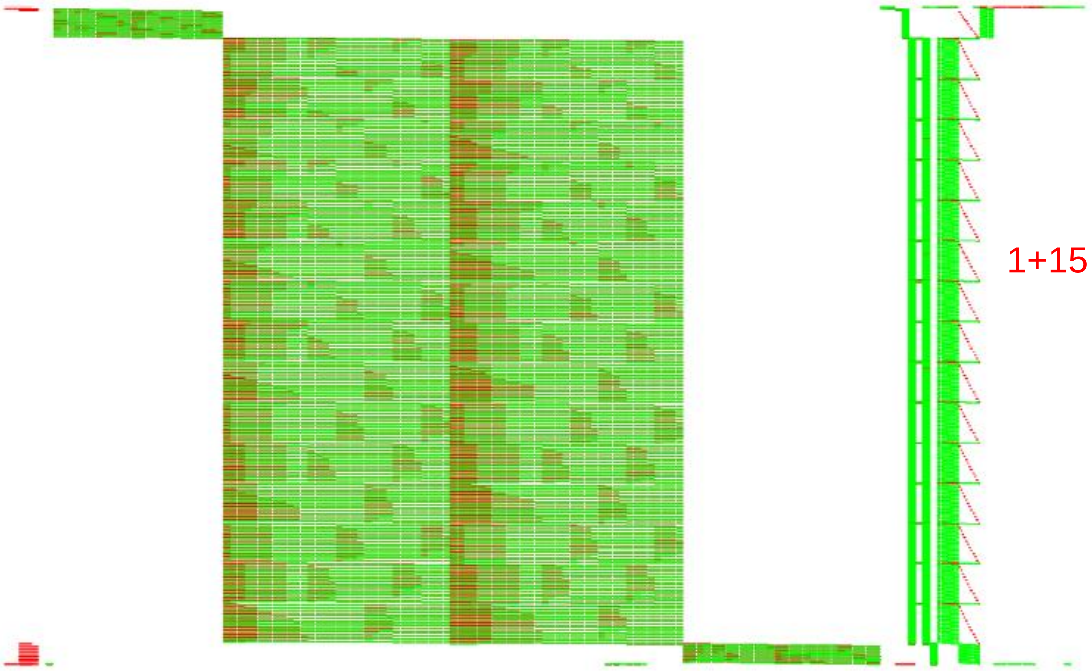


Visual crypto identification: stack!



Differential Computation Analysis

Naive approach: Port the white-box to a smartcard and measure power consumption

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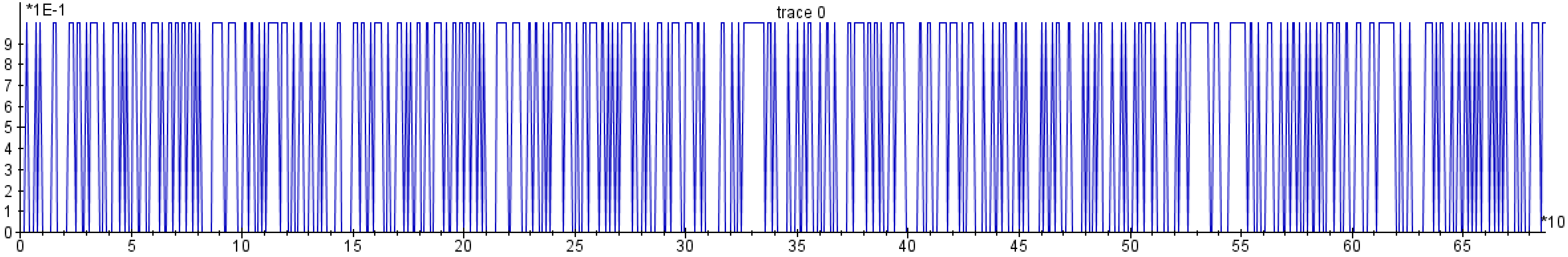
Better approach: each bit is equally important

→ Serialize bytes in a succession of bits



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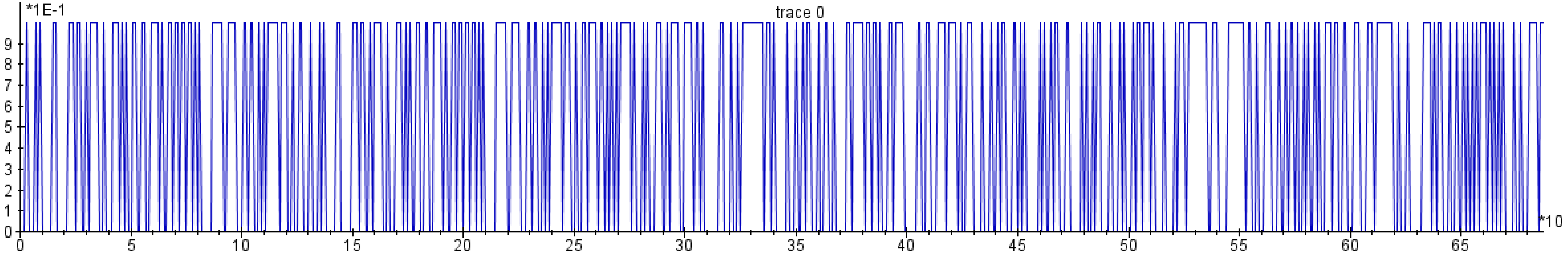


Visual challenge: try to identify the rounds
(Hint: auto-correlation can reveal them!)

DCA: DPA on software traces

HW analogy: this is like probing each bus-line individually ***without any error***

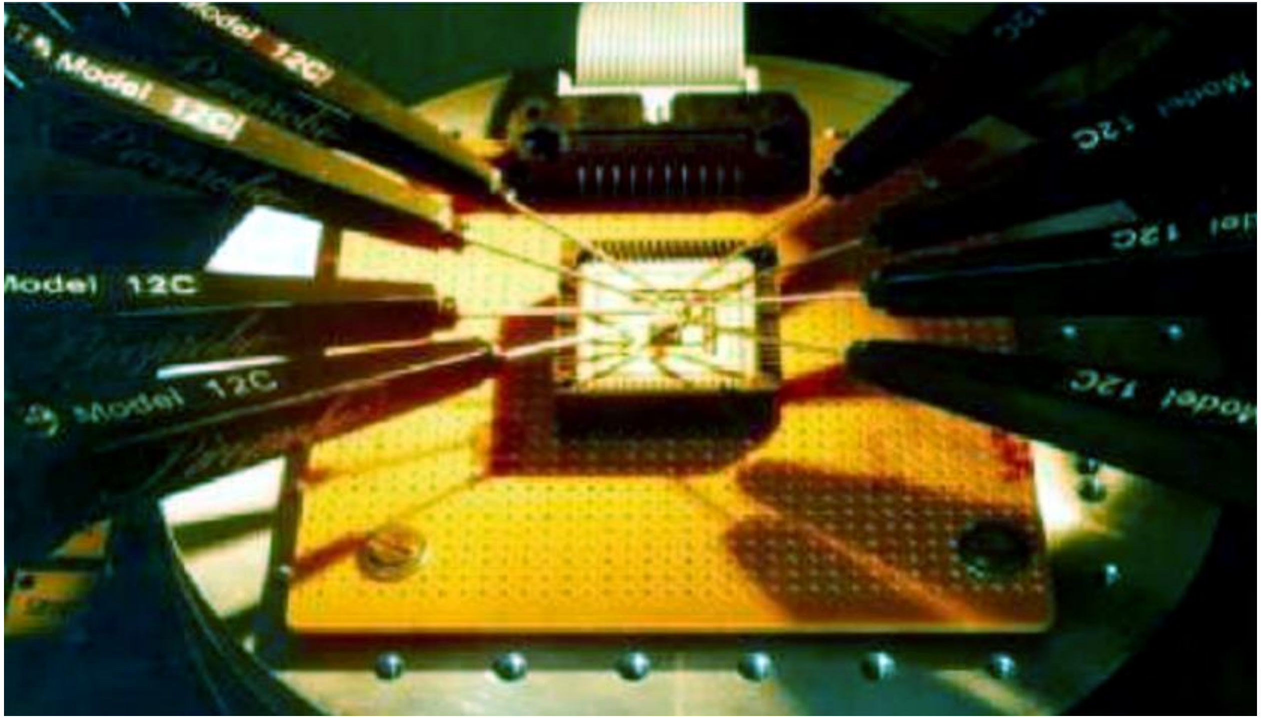


Image source: Brightsight

Results

WB implementations should not leak any side-channel information (by definition of the WB attack model): let’s check!

WB implementation	Algorithm	#traces
Wyseur challenge, 2007	DES (Chow+)	65
Hack.lu challenge, 2009	AES (Chow)	16 (no encodings)
SSTIC challenge, 2012	DES	16 (no encodings)
Klinec implementation, 2013	AES (Karroumi, dual ciphers)	2000 → 500

Intuition why this works:
Encodings do not sufficiently hide correlations when the correct key is used.

See also: P. Sasdrich, A. Moradi, and T. Güneysu. White-box cryptography in the gray box - a hardware implementation and its side channels. In FSE 2016.

A lot of potential for follow-up work!

Use the extended research results from the grey box world

Countermeasures

- Use random masks / delays → white-box model allows to disable entropy source
- Use static random data within the white-box itself?
- Use ideas from threshold implementation? [TI]
- Better DBI framework detection mechanisms
- DCA might fail when using large encodings → larger LUTs → algebraic attacks still work

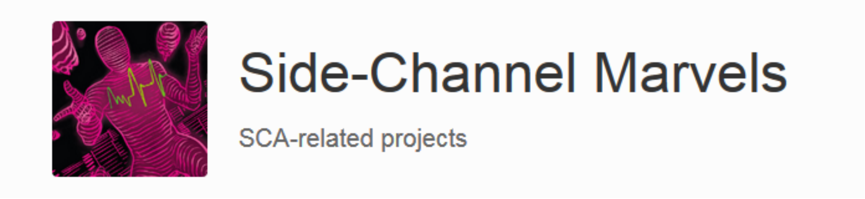
[TI] S. Nikova, C. Rechberger, and V. Rijmen. Threshold implementations against side-channel attacks and glitches. In Information and Communications Security, 2006.

Other attacks

Riscure has proven software fault attacks (DFA) work too [RISCURE].

Once there are countermeasures against DCA and DFA, can we use any of the other known advanced SCA in this setting?

[RISCURE] E. S. Gonzalez, C. Mune, Job de Haas: Unboxing the White-Box: Practical Attacks Against Obfuscated Ciphers. Black Hat Europe 2015.

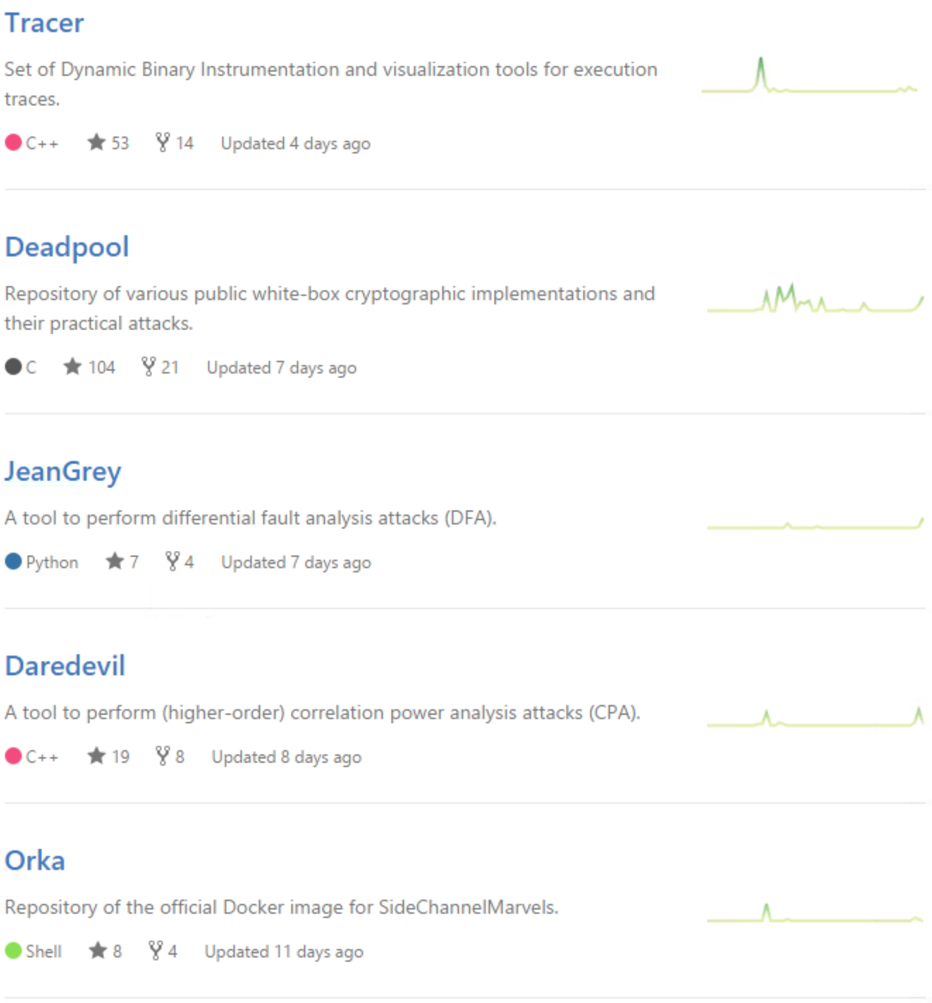


Side-Channel Marvels

SCA-related projects

https://github.com/SideChannelMarvels

Any help to complete our collection of open whitebox challenges and attacks or to improve our tools is highly appreciated!



Tracer

Set of Dynamic Binary Instrumentation and visualization tools for execution traces.

● C++ ★ 53 ⑂ 14 Updated 4 days ago

Deadpool

Repository of various public white-box cryptographic implementations and their practical attacks.

● C ★ 104 ⑂ 21 Updated 7 days ago

JeanGrey

A tool to perform differential fault analysis attacks (DFA).

● Python ★ 7 ⑂ 4 Updated 7 days ago

Daredevil

A tool to perform (higher-order) correlation power analysis attacks (CPA).

● C++ ★ 19 ⑂ 8 Updated 8 days ago

Orka

Repository of the official Docker image for SideChannelMarvels.

● Shell ★ 8 ⑂ 4 Updated 11 days ago

Conclusions

- Software-only solutions are becoming more popular
  - Relies heavily on white-box crypto
  - Traditional (DRM) and new use-cases HCE (payment, transit, …)
- DCA is an automated attack → no expertise needed
  - Counterpart of the DPA from the crypto HW community
- Level of security / maturity of many (all?) WB schemes is questionable
  - Open problem to construct asymmetric WB crypto
  - Industry keeps design secret
  - Need for way to measure the real security of such software solutions
- We will probably see more advanced countermeasures and attacks soon

What is the real security level of the deployed HCE solutions?

SECURE CONNECTIONS
FOR A SMARTER WORLD