SECURE-IC
THE SECURITY SCIENCE COMPANY

Accurate fault detection & classification based on embedded machine learning algorithms

Smart Monitor

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Presentation Outline

General introduction on trends in embedded systems security

Innovative product 1: Digital sensor v2

Innovative product 2: Smart monitor

Conclusions

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It is *machine* against *machine*

Attackers get smart:

- **Automatic** generation of specialized fault attacks
- **Machine learning** assisted pattern recognition in traces
- **Deep learning** in side-channel analysis

In response, protections must be smart

- Rich information . . . . **big data**
- Clever analysis . . . . **artificial intelligence**

Similar situation in IT security

ARTIFICIAL INTELLIGENCE FOR CYBER-SECURITY

INTRODUCTION

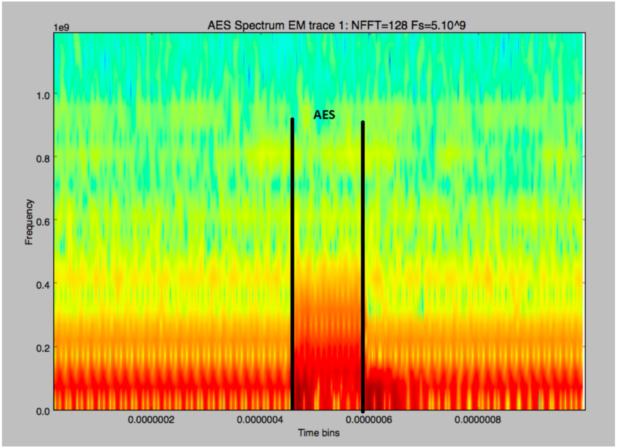
- Cyberspace: Are humans thrown on scrapheap?

DARPA's Cyber Grand Challenge: World's first automated network defence tournament

Source: http://archive.darpa.mil/cybergrandchallenge/.

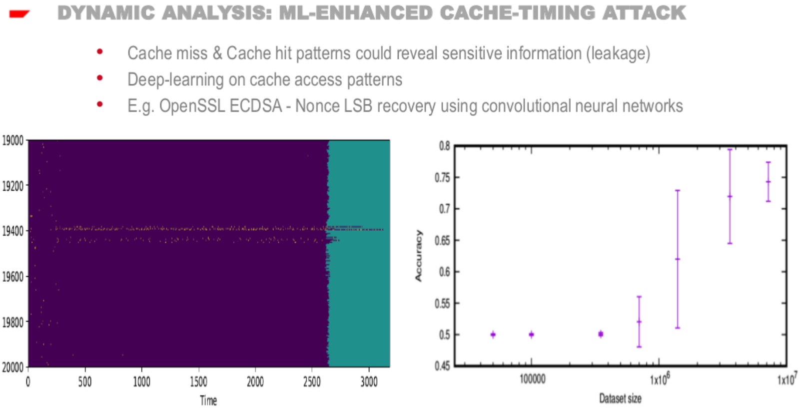
Noisy EM analysis

Side-channel analysis and machine learning: A practical perspective (IJCNN 2017 [PHJ+17])



Microarchitectural Analysis

Cachyzr (tool in CTZ)



DYNAMIC ANALYSIS: ML-ENHANCED CACHE-TIMING ATTACK

- Cache miss & Cache hit patterns could reveal sensitive information (leakage)
- Deep-learning on cache access patterns
- E.g. OpenSSL ECDSA - Nonce LSB recovery using convolutional neural networks

How we handle smart attacks?

Security by design

- Formal models of protection rationale
- Validation by VTZ tool (Virtualyzr [DGN+17]), throughout the design flow
- Evaluation in rich platform

Machine learning (ML)

- Sensors fusion
- Embedded ML
- Nice byproduct: allows to tolerate noise, e.g., technology dispersion

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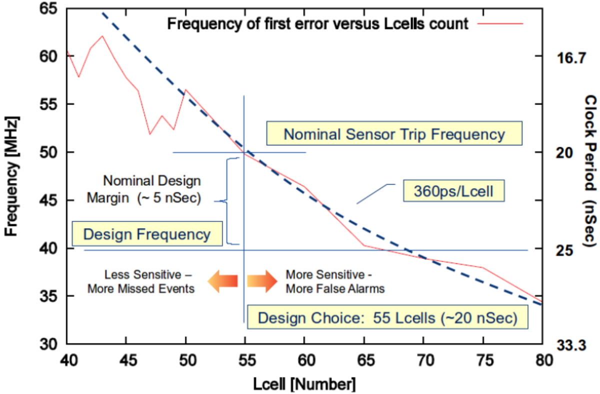
Digital sensor V2 [GP17]

New features:

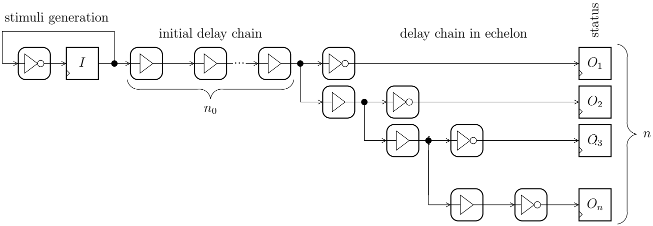
- Centered status: can see as well speed decrease as speed increase
- More fine: delta temperature/bit, etc.
- History (internal oscilloscope)
- Spatial efficiency (= smart monitor)

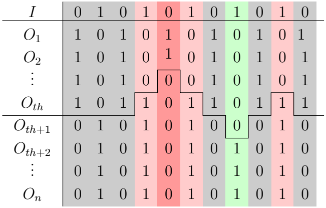
New feature: finer resolution (illustration)



Objective: by proper selection of buffers, make the slope more steep.

New features: history (illustration)





I	0	1	0	1	0	1	0	1	0	1	0
O_1	1	0	1	0	1	0	1	0	1	0	1
O_2	1	0	1	0	1	0	1	0	1	0	1
⋮	1	0	1	0	0	0	1	0	1	0	1
O_{th}	1	0	1	1	0	1	1	0	1	1	1
O_{th+1}	0	1	0	1	0	1	0	0	0	1	0
O_{th+2}	0	1	0	1	0	1	0	1	0	1	0
⋮	0	1	0	1	0	1	0	1	0	1	0
O_n	0	1	0	1	0	1	0	1	0	1	0

A unique signature:
Fig. 14, page 189, of [SBGD11]

The Digital Sensor V2: new usages

- As always: **fully digital**, i.e., using precharacterized standard cells from the PDK
  - Can replace analog sensors (see below)
  - Less costly than analog sensors for small technological nodes (7 nm, 5 nm, etc.)

- **One *single* instance** is sufficient for:
  - low clock frequency: have n_0 set to a large value
  - high clock frequency: have n_0 set to 0
  - low / high temperature: increase n / decrease n_0 (*see slide 19*)
  - better voltage (higher than nominal): increase n beyond 32 bits (*see slide 20*)
- ***Multiple* instances** are needed for local attacks, such as:
  - EM pulse injection attack
  - laser injection attack
  - Number and location of sensors: spread by supply net of P/G network, close to sensitive registers

Experimental results

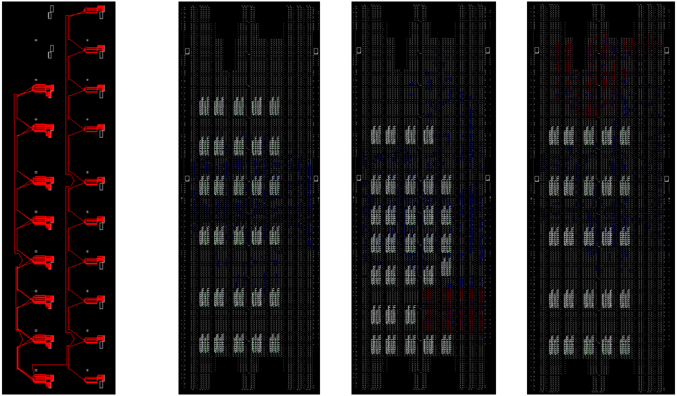
Dimensioning on SAKURA G, SPARTAN 6 FPGA:

- FIFO depth: **40**
- Status: **16** to **32** — chain length: n_0=**70** + **16-32**
- Number of instances: ≈ **50**
- Sensitivity (see next slides):
  - **0.04 bit/°C**
  - **0.18 bit/mV**
- Without and with crypto running in parallel (AES core)

Big data: **64000** bits ready to be analyzed at each clock cycle.

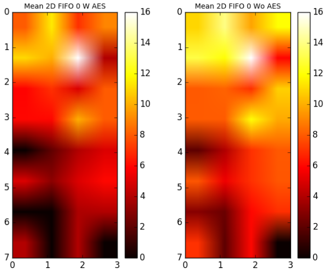
Layouts

Various experimental setups

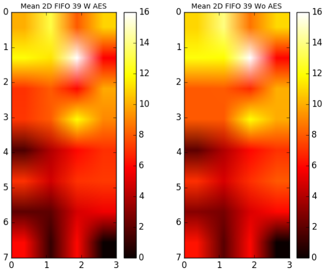


1 60 64 50

Natural variability



Time sample #0

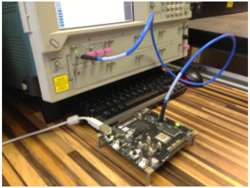


Time sample #39

- In a threshold-based approach, the threshold is not easy to set
- Depends on the location, depends on the internal activity

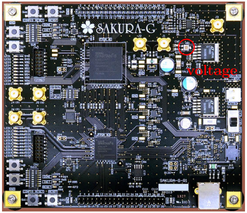
Characterization & attack means (LBZ)

Clock



Temperature

Power



EM field

Experiments at Rennes SSF

Security Science Factory

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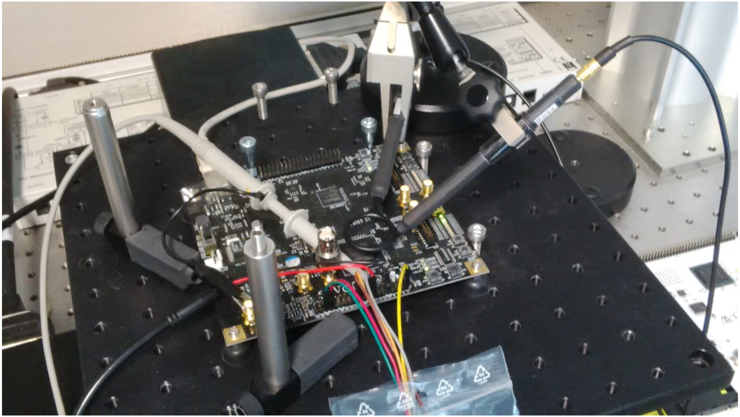
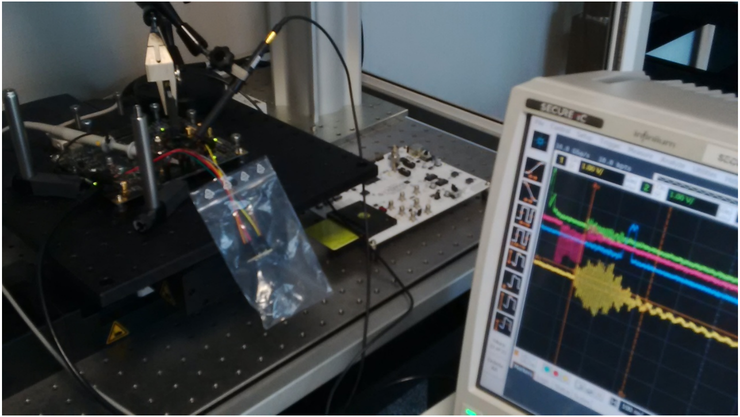


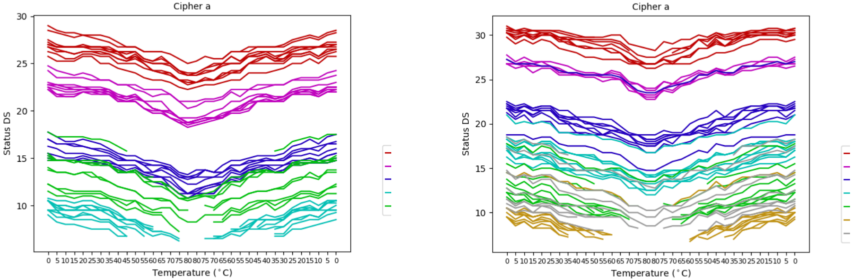
Experiments at Rennes SSF

Security Science Factory



Variability is by techno dispersion, not P&R

Automatic routing | Manual routing

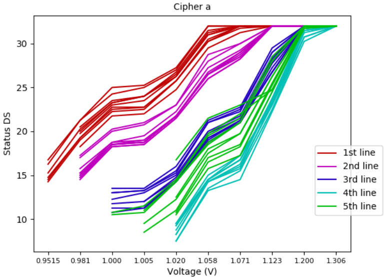


Characterization: **0.04 bit/°C**

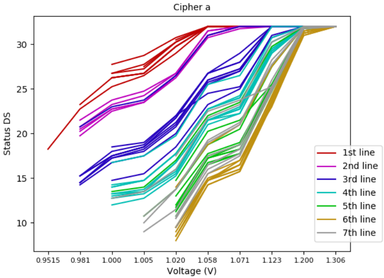
- Saturation at ≤ 32 can be leveraged by increasing n
- Saturation at ≥ 0 can be leveraged by decreasing n_0

Variability is by techno dispersion, not P&R

Automatic routing



Manual routing



Characterization: **0.18 bit/mV**

- Saturation at ≤ 32 can be leveraged by increasing n

Innovative product 1: Digital sensor v2

Summary

Security feature innovation ("*big data*" allowing "*analytics*"):

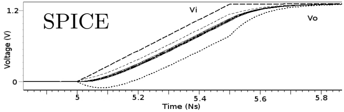
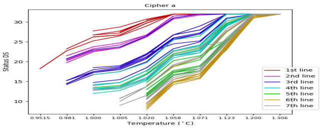
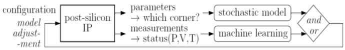
- Captures complete waveforms
- Monitors when conditions get worse but also when they unexpectedly get more favorable
- Increased environmental condition sampling resolution

Demonstration / proof of maturity:

- Show-case of an FPGA board with a matrix of DS V2
- Illustration of sensitivity even to internal activity change
- Illustration of sensitivity when external conditions change

Robust design-for-security and -for-yield approach

DfS and DfY for the DS V2

1. Mathematics stochastic model	$$T = n \times C(P,V,T) \times T_0$$ $$C(P,V,T) = \alpha P + \beta V + \gamma T$$
2. Simulation parameters characterization	
3. Emulation parameters validation	
4. Post-silicon release *in situ* configuration	

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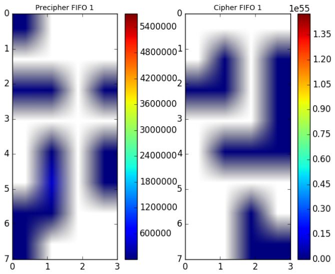
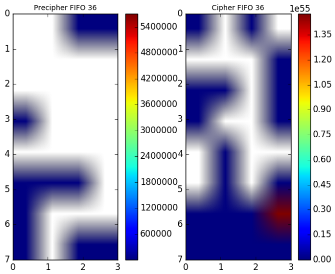
Distinguishing internal activity, with T-Test [Wel47]

Time sample #1

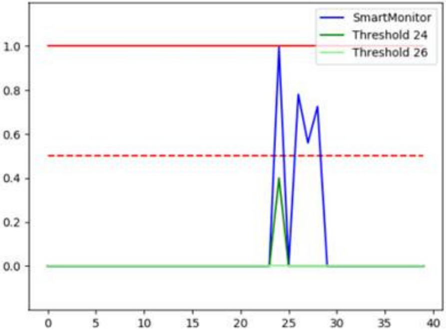


Time sample #36 (EM inj)



- Normalized difference between *with* and *without* EM injection
- Those figures require *multiple* measures to be computed

Distinguishing internal activity, with ML [Vap98]

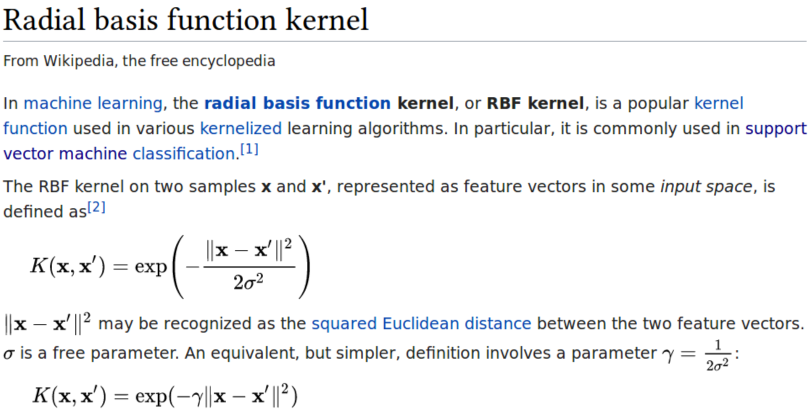


Description of the results

- 100% (±1) detection by Smart-Monitor
- 40% (±1) detection by one DS V2
- Others are completely blind

- **Blue:** 32 DS V2, using 3 samples, instantaneous reaction, and accurate damping
- **Green:** threshold at each DS V2, equal to: normalized mean(with EM) - mean(w/o EM).

Radial Basis Function (RBF) kernel



Radial basis function kernel

From Wikipedia, the free encyclopedia

In machine learning, the **radial basis function kernel**, or **RBF kernel**, is a popular kernel function used in various kernelized learning algorithms. In particular, it is commonly used in support vector machine classification.[1]

The RBF kernel on two samples **x** and **x'**, represented as feature vectors in some *input space*, is defined as[2]

$$K(\mathbf{x},\mathbf{x'}) = \exp\left(-\frac{\|\mathbf{x}-\mathbf{x'}\|^2}{2\sigma^2}\right)$$

$\|\mathbf{x}-\mathbf{x'}\|^2$ may be recognized as the squared Euclidean distance between the two feature vectors. σ is a free parameter. An equivalent, but simpler, definition involves a parameter $\gamma = \frac{1}{2\sigma^2}$:

$$K(\mathbf{x},\mathbf{x'}) = \exp(-\gamma\|\mathbf{x}-\mathbf{x'}\|^2)$$

Our best fit is for $\gamma \approx \frac{1}{4}$.

Innovative product 2: Smart monitor

Summary

Security feature innovation:

- Can be fed by DS V2, but also other sensors, incl. CyberEU
- Robust benign / malicious observation classification

Demonstration / proof of maturity:

- Detection before the AES is faulted
- Model robustness w.r.t. device architecture

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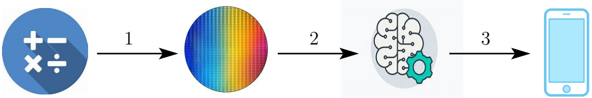
Flow for Smart-Monitor management of chip fabrication uncertainties

Mathematics: for the modelization of delays
Simulation: for validation of the model
Emulation: for cross validation of simulations with real data
⟹ dimensioned architecture, RTL

Deployment



Netlist, GDSII
⟹ **Tapeout**
⟹ **Samples back**

Characterization of the engineering samples:
- nominal *vs* EM
- nominal *vs* underfeed, overclock, etc.

Off-chip learning phase:
⟹ support vectors (SVs) generated by SVM algorithm

Programmation of SVs in mass production:
⟹ countermeasure is armed

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Analyzing security breaches of countermeasures throughout the refinement process in hardware design flow.
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[GP17] Sylvain Guilley and Thibault Porteboeuf.
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