Implementation Security In Cryptography

Lecture 01: Welcome!!

What to Expect from this Course

- Upon successful completion, you become…

A “mathematically and physically oriented” thief.

A person who know how to and (how not to) do practical cryptography

What *__not__* to Expect from this Course

Traditional mathematical cryptanalysis

Traditional (reduction-based) cryptographic proofs (except for a few cases…)

Prerequisites

A criminal mind — just joking

A bit of Boolean logic knowledge— gates, flip-flops etc

A bit of effort from your side to self-study and try a few things

A bit of courage to write C/C++/Python codes

What I Expect…

Please ask questions…

I will be more than happy if you are interested to do some advanced project — not as a part of these course though

You teach me — things that you have learnt and you thing you can use here — e.g. machine learning, formal methods, crypto

Plan Ahead...

Programming Assignments	30% (best two among 3 will be considered)
Mid,End Semester	40%
Quiz	30%

Jokes Apart: What to Expect from this Course

- Some basics of cryptographic algorithms
- Some basics on cryptographic hardware/software design
  - coding assignment
- Some exciting practical attacks
  - With hands-on
  - Attacks have theory — so there will be maths and stats…

Points to Remember

- Please take class notes — even if there are slides and online materials
- Please stop me — when I am going too fast
- Please stop me — when you have any question

Lecture Formats

- Traditional
- Some components will be math heavy at the beginning — so pay attention
- Later part of the course will have components directly from papers
    - So, if you think video lectures/ uploaded slides will save you, you are wrong.
- In the later part of the course, you will be given some papers to read
    - You have to present them in groups
    - Be prepared to do some Google search to understand them.
    - Not all papers are equally hard
        - We shall take care :)

Home Rules

- No cheating please!! — it will be reported
- No open-screen during lecture
- Group activity needed

Website and TAs

Course Details

Lecture Slot	6
Lecture Venue	CC 101
Lecture Schedule	Wednesday and Friday, 11:05 AM – 12:30 PM
Piazza	Course Piazza Page
Piazza Access Code	`cs6102`
Instructor Office Hours	After class or by prior email appointment
Teaching Assistants	**Shoaib Ahamed** (24m2102 [at] iitb.ac.in) **Aritra Belel** (24m0814 [at] iitb.ac.in) *Please use Piazza for general course-related queries.*

Implementation Security: Why?

- Let's start from stories…

IoT Goes Nuclear:
Creating a ZigBee Chain Reaction

Eyal Ronen(✉)*, Colin O'Flynn†, Adi Shamir* and Achi-Or Weingarten*
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†Dalhousie University, Halifax, Canada
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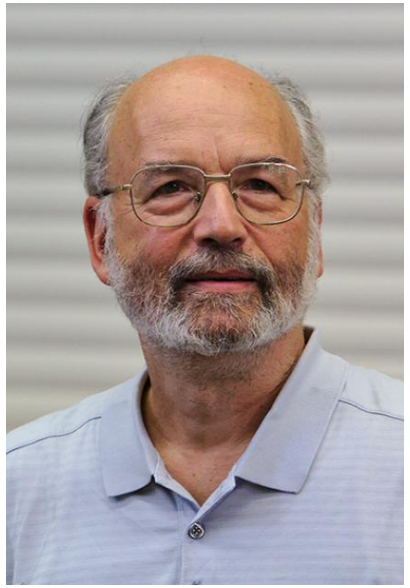
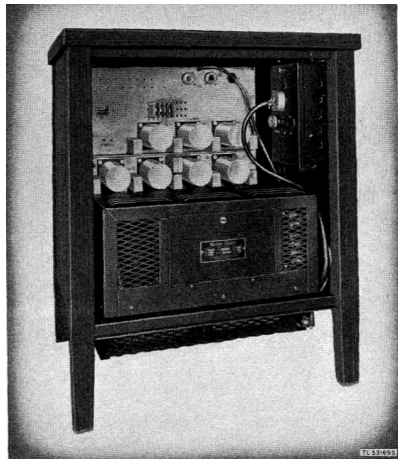


Figure 9. ZigBee warflying scenario



Serious Security: Rowhammer returns to gaslight your computer

Gaslights produce a telltale flicker when nearby lamps are lit; DRAM values do something similar when nearby memory cells are accessed.

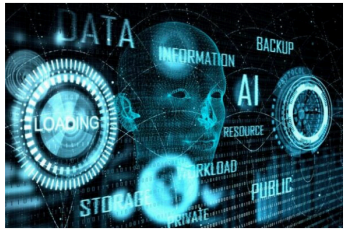
Written by Paul Ducklin

JULY 10, 2023

NAKED SECURITY | DATA LEAKAGE | ROWHAMMER | SERIOUS SECURITY

You're probably familiar with the word *gaslighting*, used to refer to people with the odious habit of lying not merely to cover up their own wrongdoing, but also to make it look as though someone else is at fault, even to the point of getting the other person to doubt their own memory, decency and sanity.

You might not know, however, that the term comes from a 1930s psychological thriller play called *Gas Light* (spoiler alert) in which a manipulative and murderous husband pretends to spend his evenings out on the town



AI power analysis breaks post-quantum security algorithm

Technology News | February 19, 2023

By Nick Flaherty

AUTHENTICATION & ENCRYPTION

Crypto Keys Could Be Compromised by Intel and AMD 'Hertzbleed' Chip Vulnerability

2 mins

By Martin Young

Updated by Geraint Price
15 June 2022, 07:40 GMT+0000

TRENDING: Maingear MG-1 AMD PC Build | GeForce RTX 4070 | Radeon RX 7900 XTX | Ryzen 7 7800X3D | Alienw

HOME | NEWS

AMD And Intel CPUs Rocked By New Speculative Execution Attack With A Huge Performance Hit

by Zak Killian — Wednesday, July 13, 2022, 05:08 PM EDT

0 Comments

BECOME A PATRON

Intel ups protection against physical chip attacks in Alder Lake

Repurposes logic originally used for spotting variations in voltage, timing in older circuits to help performance

Dan Robinson

Fri 12 Aug 2022 | 15:00 UTC

BLACK HAT Intel has disclosed how it may be able to protect systems against some physical threats by repurposing circuitry originally designed to counter variations in voltage and timing that may occur as silicon circuits age.

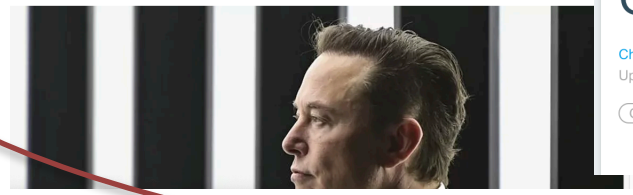
The research was presented by Intel at the Black Hat USA 2022 cybersecurity conference this week, and details logic inside the system chipset that is intended to complement existing software mitigations for fault injection attacks, the chipmaker said.

It makes use of a Tunable Replica Circuit (TRC), logic developed at Intel Labs to monitor variations such as voltage droop, temperature, and aging in circuits to improve

Technology

Using just a $25 device a researcher hacked into Elon Musk's Starlink system

What will the technology mogul have to say about this?



This NXP side-channel attack can clone Google Titan 2FA keys

Charlie Osborne 12 January 2021 at 13:28 UTC
Updated: 30 June 2021 at 16:34 UTC

Google | Hardware | 2FA

Who Cares...?


ECRYPT

AGENCE NATIONALE DE LA SÉCURITÉ DES SYSTÈMES D'INFORMATION
ANSSI


riscure


intel


NIST
National Institute of
Standards and Technology


Payatu


NVIDIA


NXP


AMD


Rambus


SEAGATE


LEDGER

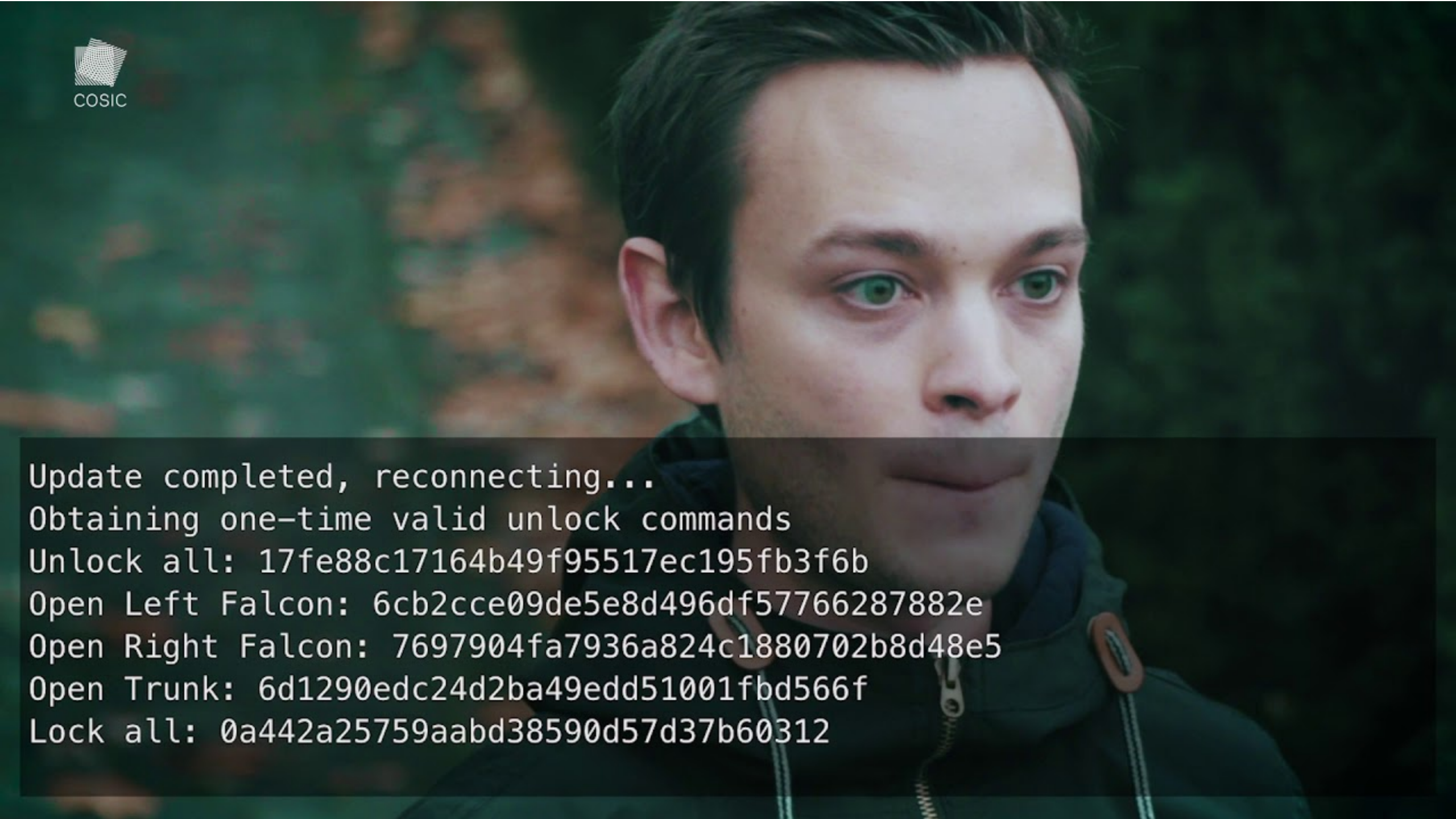

SECURE-IC
THE SECURITY SCIENCE COMPANY


SYNOPSYS®


CRYPTOEXPERTS
WE INNOVATE TO SECURE YOUR BUSINESS


B M W


THALES


COSIC
Update completed, reconnecting...
Obtaining one-time valid unlock commands
Unlock all: 17fe88c17164b49f95517ec195fb3f6b
Open Left Falcon: 6cb2cce09de5e8d496df57766287882e
Open Right Falcon: 7697904fa7936a824c1880702b8d48e5
Open Trunk: 6d1290edc24d2ba49edd51001fbd566f
Lock all: 0a442a25759aabd38590d57d37b60312

Why Crypto??

- Hacking chips is a fashion now…
- But where is crypto here?? I came here to learn some crypto!!!
    - Every device in this room is running some crypto

Cryptology

- Objectives: Aims at design and analysis of algorithms to ensure:
  - Confidentiality — No one reads your message
  - Integrity — No one modifies your message
  - Availability — Your system must not get too slow
- All of these can be ensured in a mathematically grounded way.
- Recent days there has been humongous advancement in cryptology.
- New primitives developed giving us additional capabilities:
  - Performing operations on encrypted databased in cloud.
  - Post-quantum Cryptography
  - Homomorphic encryption, multi-party computatio





- Embedded/IoT devices
- Typically in-order pipeline; limited memory (SRAM/Flash)
- Not typically multi-user
- **Physical Access**


- Modern high end processors; Intel, AMD, Apple
- Co-processors, e.g. GPUs
- **Remote Access**

Software Crypto

Implementation	FIPS 140-2 mode	FIPS 140-2 validated	FIPS 140-3 validated
Botan	No	No	No
Bouncy Castle	Yes	Yes[30]	In process[31]
BSAFE	Yes	Yes[32][33]	Yes[34]
cryptlib	Yes	No	No
Crypto++	No	No[a]	No
GnuTLS	No	Yes[35][b]	In process[36]
Java's default JCA/JCE providers	No	No[37][c]	No
Libgcrypt	Yes	Yes[38][d]	In process[36]
libsodium	No	No	No
Mbed TLS	No	No	No
NaCl	No	No	No
Nettle	No	No	No
Network Security Services (NSS)	Yes	Yes[39][e]	In process[36]
OpenSSL	Yes	Yes[40][f]	In process[36]
wolfCrypt	Yes	Yes[41]	Yes[42]

GitHub
https://github.com

mupq/pqm4: Post-quantum crypto library for the ARM ...

The **pqm4** build system is designed to make it very easy to add new schemes and implementations, if these implementations follow the NIST/SUPERCOP/PQClean API.

Cryptology ePrint Archive
https://eprint.iacr.org

pqm4: Benchmarking NIST Additional Post-Quantum ...

by MJ Kannwischer · 2024 · Cited by 15 — In this paper, we study the suitability and performance of said candidates on the popular Arm Cortex-M4microcontroller. We integrate the ...

National Institute of Standards and Technology (.gov)
https://csrc.nist.gov PDF

pqm4: Testing and Benchmarking NIST PQC on ARM Cortex-M4

by MJ Kannwischer · Cited by 132 — The **pqm4** framework investigates the feasibility and performance of the proposed PQC solutions on microcontrollers by focusing on a specific ...

22 pages

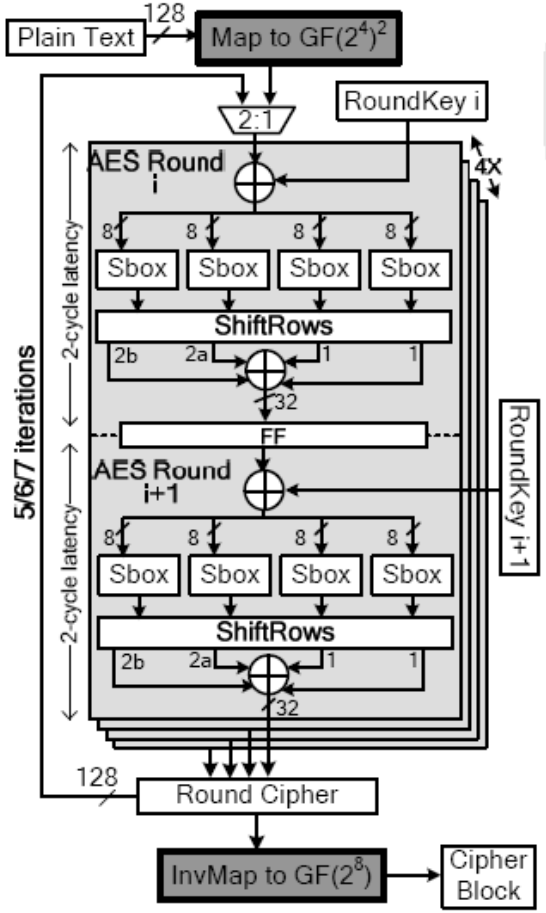
Need for Speed…

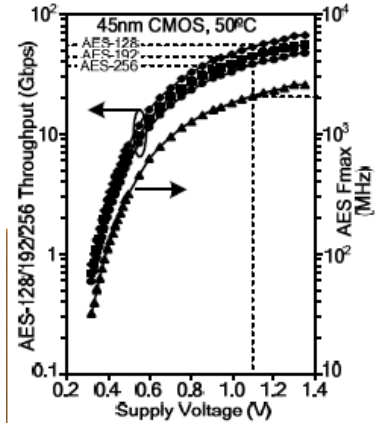
- Hardware vs Software speeds:
  - Sensitive operations in the internet is becoming very important aspect of web applications.
  - E-commerce and net-banking require transfer of sensitive information and are protected by Secure Socket Layer (SSL) and Transport Layer Security (TLS) protocols.
  - Open SSL is an open source implementation of SSL and TLS, and accompanying cryptographic algorithms.
- OpenSSL has implementations of symmetric ciphers, asymmetric ciphers, hash functions, etc.
  - However, they are time consuming in software!

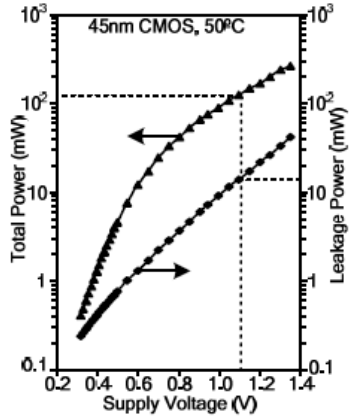
Cryptographic Co-processors

- Cryptographic algorithms can be accelerated by providing customized instruction in the processor Instruction Set Architecture (ISA):
  - AES-NI: Special Instruction in Intel ISA for performing AES operations.
  - PCLMULQDQ: Special Instruction in Intel ISA for carry less multiplication of 2 64-bit operands.
  - Every STM32 processor these days have a crypto accelerator
- Advantages:
  - Speed: Hardware offers speed, dedicated processing, parallelism.
  - Security: Can rule out many attacks which are possible on pure software. — this is a sweeping statement to some extent

Intel's AES-NI: Instruction for AES Operations







Reference: S. Mathew, *53Gbps Native GF(2^4)^2 Composite Field AES-Encrypt/Decrypt Accelerator for Content Protection in 45nm High Performance Microprocessors*, VTS 2010

Ok…But So What…

- Ok, crypto is some sort of math-heavy algorithm, that people sometimes implement in hardware…but then?

Crypto can be attacked…

IoT Goes Nuclear:
Creating a ZigBee Chain Reaction

Eyal Ronen(✉)*, Colin O'Flynn†, Adi Shamir* and Achi-Or Weingarten*
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coflynn@dal.ca

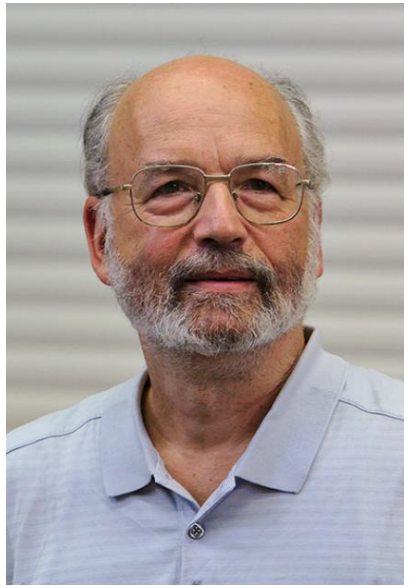


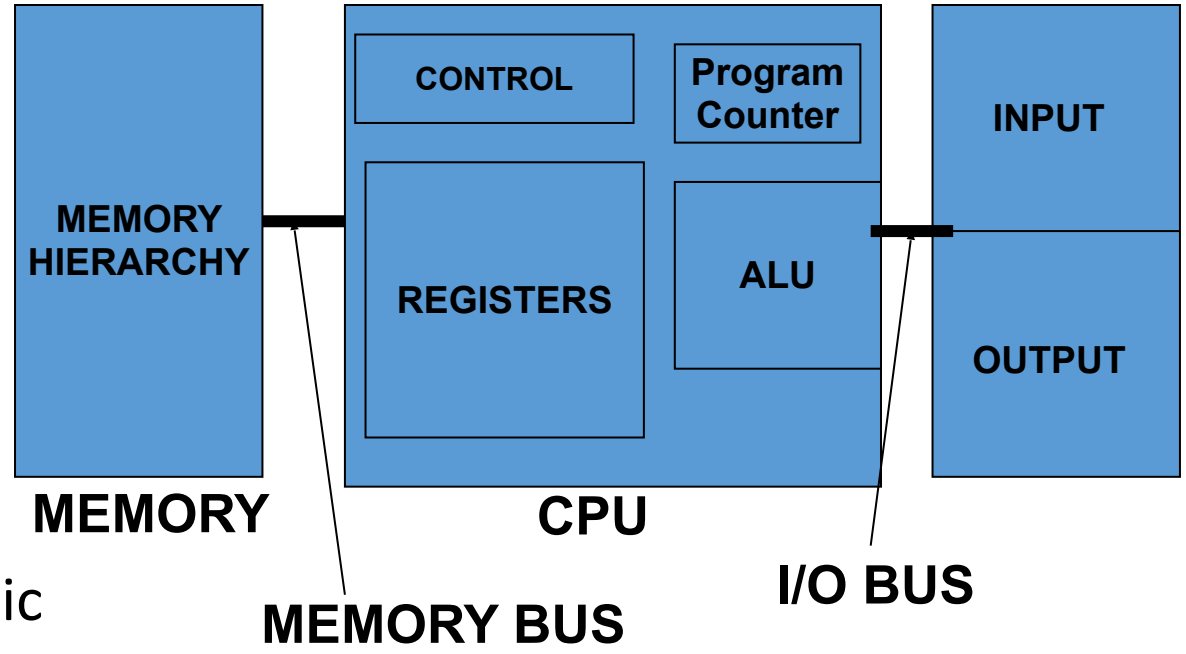
Figure 9. ZigBee warflying scenario

- “if you think your problem can be solved by cryptography, then you do not understand cryptography and you do not understand your problem”-[Bruce Schneier]

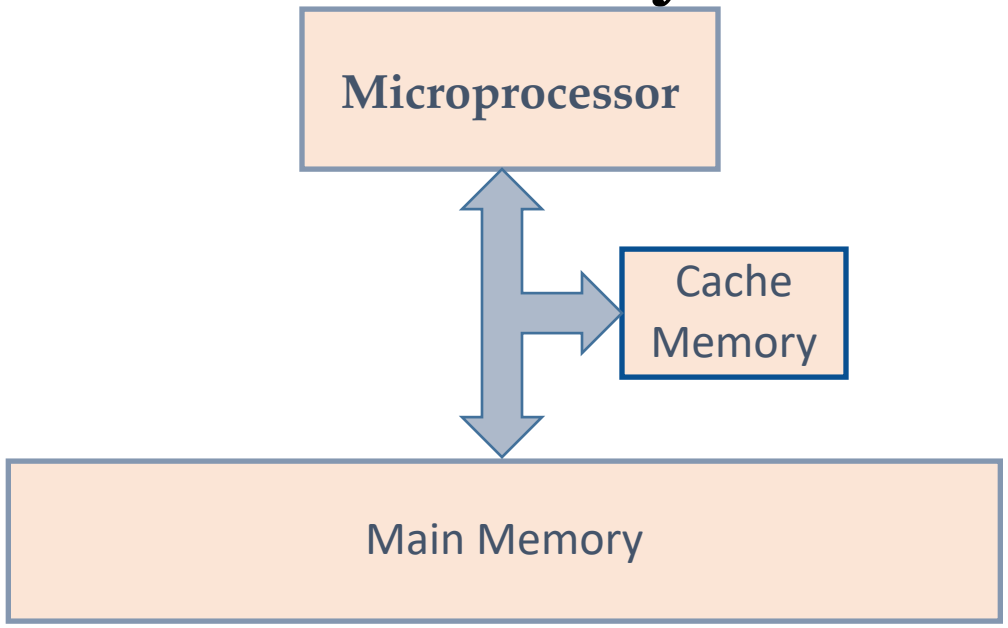
Crypto and Attacks

- Software Attacks: Present day computing systems are naturally vulnerable.

- Von Neumann (1903-1957)
- Contributed to give a very basic model, often referred to as Von Neumann model



Attacks due to Memory Wall

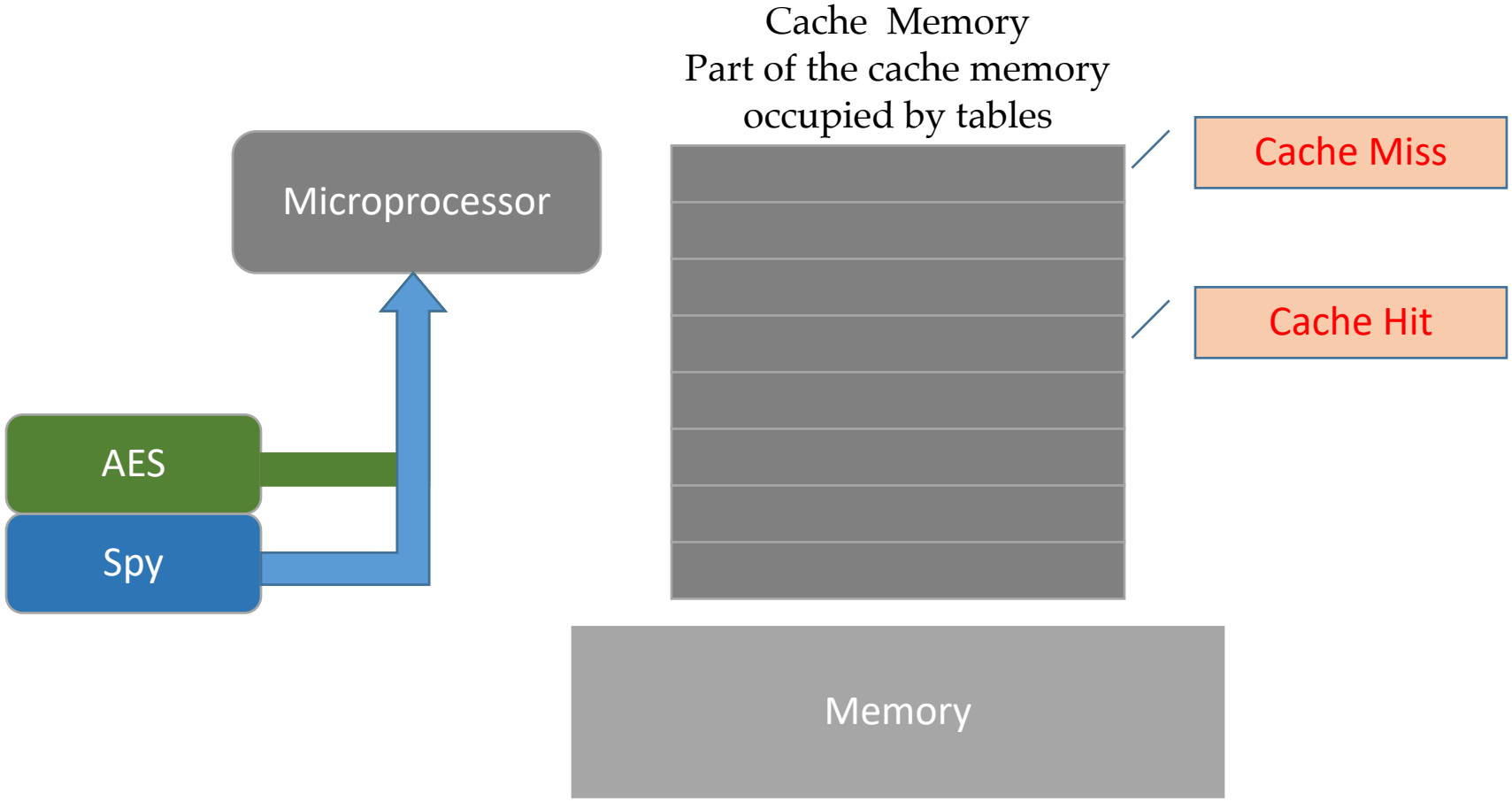


- If there is a *Cache Hit*
  - Access time is less
  - Power Consumption is less

- If there is a *Cache Miss*
  - Access time is more
  - Power Consumption is more

Timing Attacks due to Cache Memory

- Uses a spy program to determine cache behavior



Micro-architectural Attacks: Design for Security

Computer Architecture has been designed with performance as a primary design criteria.

Security has been an after thought.

For example:

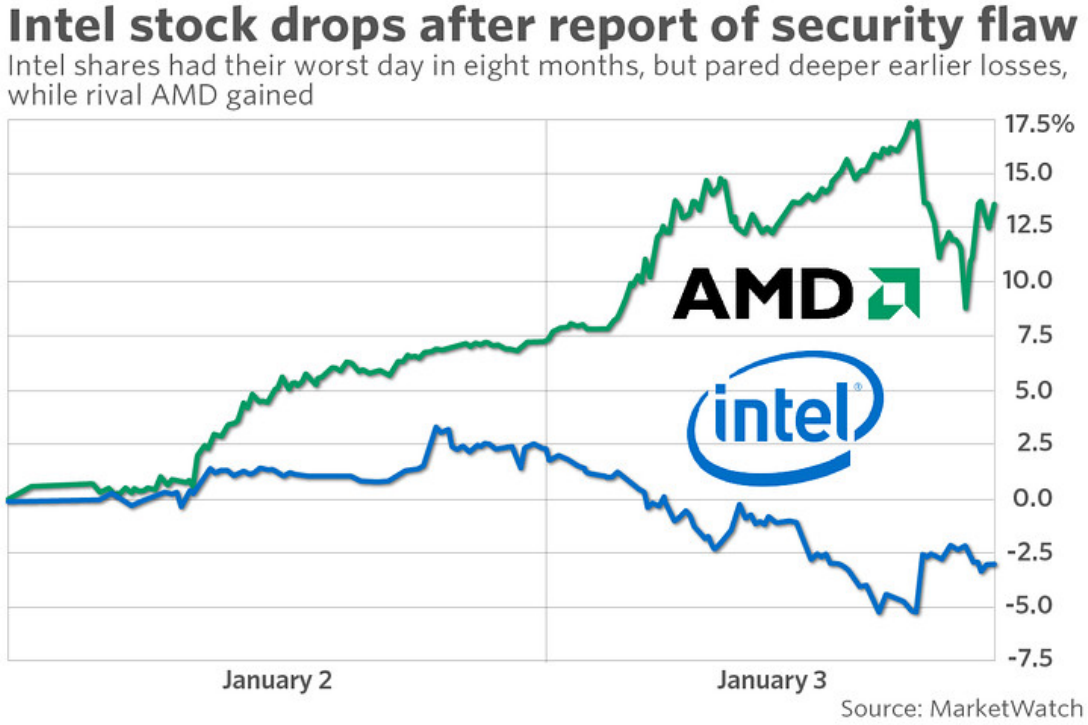
Speculative execution is an optimization technique where a computer system performs some task that may not be needed.

This has been the basis of the recently discovered attacks: Spectre and Meltdown.

To quote Bruce Schneier, "**Fixing them either requires a patch that results in a major performance hit, or is impossible and requires a re-architecture of conditional execution in future CPU chips.** It shouldn't be surprising given that microprocessor designers have been building insecure hardware for 20 years. What's surprising is that it took 20 years to discover it."

Reference: *Spectre and Meltdown,* Daniel Gruss, Moritz Lipp, Yuval Yarom, Paul Kocher, Daniel Genkin, Michael Schwarz, Mike Hamburg, Stefan Mangard, Thomas Prescher and Werner Haas, Google Ground Zero Project

Security can be a game changer



Although the vulnerabilities, called **Meltdown** and **Spectre**, affected leading processors in many devices, **Intel** is bearing most of the fallout **after** rival AMD distanced itself from the bulk of the issues. **Intel shares** were down nearly 5 percent, around $43 apiece, **after** posting a 3 percent decline on Wednesday.

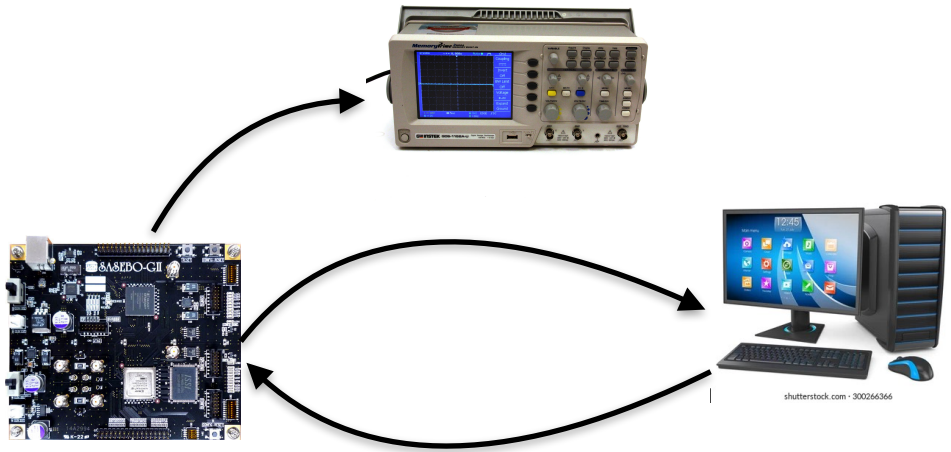
Reference: https://www.cnbc.com/2018/01/04/intel-stock-down-intc-could-meltdown-spectre-exploit-benefit-amd.html

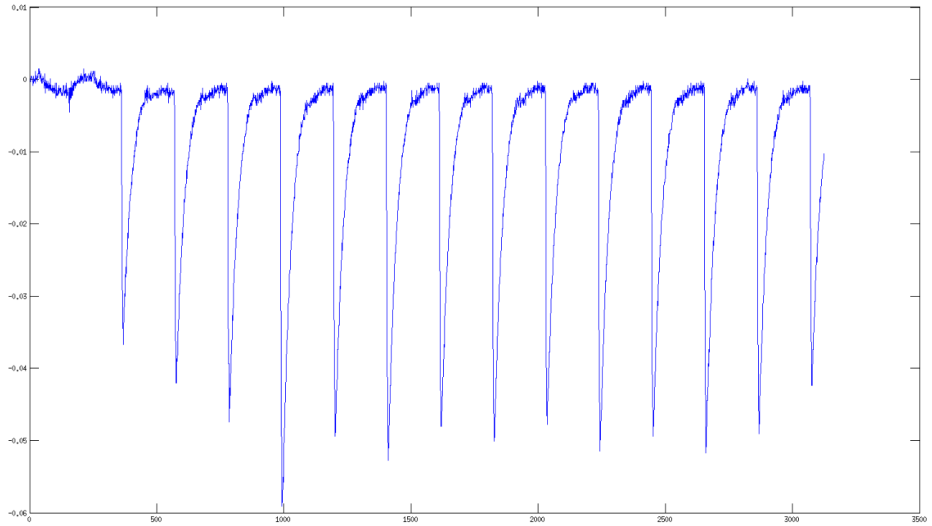
Ok…But So What…

- Ok, that was about crypto software…
- I will make hardware crypto…then?
- Also, my device is not multi-user

It is Impossible to Cheat Physics

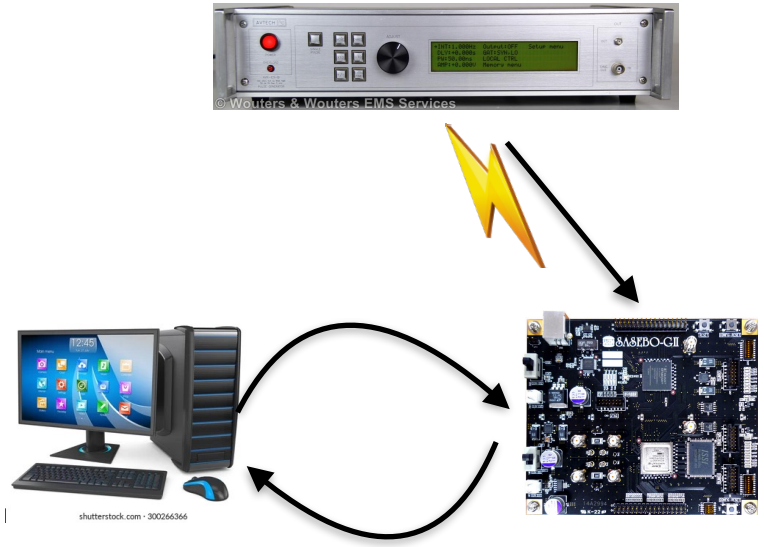
- The physical channels are correlated with the information being processed
- Let us consider the power consumption from a chip performing AES
- Fundamental cause: power consumption is correlated with switching of CMOS transistors (0->1, 1->0)
    - Typically it is assumed that power consumption is correlated with the Hamming Weight/Distance.
- If some internal state is exposed, the key of AES can be recovered in seconds.





Source: Testbed for Side Channel analysis and security evaluation

It is Impossible to Cheat Physics



- The computation can be disturbed with “faults”…
- Once again, you can break AES…

Ok…So Everything is Vulnerable

- What is the point of studying then…..Let’s go home and sleep.
  - The attacks are not straightforward…needs maths and “criminal mind”..
  - We shall learn these attacks here in this course….and some ways to prevent them….

Course Modules

- Module 1: Some Crypto Algorithms and Their Implementation
  - Intro to crypto concepts and some basic crypto building blocks.
  - Learning Objective: To understand how crypto math is ported to hardware/software efficiently
- Module 2: Power Attacks on Block Ciphers
  - The real fun begins here
  - Attacks on real power measurements
  - Learning Objective: How to attack crypto implementations
- Module 3: Power Attack Countermeasures
  - Theoretical
  - How to provably protect against power attacks.
  - Optional assignment — you may give a try if interested
  - Learning Objective: Doing attacks in practice and mathematically analyzing why they happen
- Module 4: Fault Attacks
  - Another source of fun
  - Python based attack codes
  - Learning Objective: How to exploit a fault mathematically