FROM RESEARCH TO INDUSTRY

cea tech

COGITO: Runtime Code Generation to Secure Devices

8emes rencontres de la communauté française de compilation – Nice

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COGITO

www.cea.fr

leti & list

Domain

Runtime code generation

. . . for security purposes in embedded systems, mainly against physical attacks

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Problem: program code is invariant

Code polymorphism (thanks to runtime code generation) could improve this:

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Motivation pitch

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- physical attacks

Objectives: explore the use of runtime code generation as a means to secure embedded systems against physical attacks

How? `deGoal`:

- runtime code generation and code optimizations
- suitable for constrained embedded systems:
  - fast code generation
  - within tiny memory footprints: works on TI's Launchpad MSP430 (512 B RAM)

Outline

This talk is about:

1. An overview of security issues – aka physical security of embedded systems for dummies

   . . . and how code polymorphism is likely to bring new solutions
2. A practical solution to achieve code polymorphism for security: `deGoal`
   - overview of `deGoal`
   - modification for security purposes
   - demo time

COGITO – ANR INS 2013

- Project coordination
- Bringing the `deGoal` framework
- Compilation & runtime code generation

- Scientific coordination
- Security analysis
- Physical attacks and software countermeasures
- JavaCards

- Security analysis
- Physical attacks, HW/SW countermeasures
- Experimental validation

Public website

www.cogito-anr.fr

Outline

Physical attacks

An attack is usually split between:

1. a **first step** attack:
   - global inspection of the target
   - identification of the security components involved (HW/SW)
   - identification of weaknesses
2. a **second step** attack:
   - focused attack
   - on an identified potential weakness

Approx. typology of physical attacks

- **Reverse engineering**
  - HW inspection: decapsulation, abrasion, chemical etching, memory extraction, etc.
  - SW inspection: debug, memory dumps, code analysis, etc.
- **Side channel attacks**: SPA (Simple Power Analysis), DPA (Differential –), CPA (Correlation –)...
  - Electromagnetic analysis
  - Power analysis
  - Acoustic analysis
  - Timing attacks
- **Fault injection attacks**
  - under/over voltage drops
  - iom / laser beam, optical illumination
  - glitch attacks
  - ...

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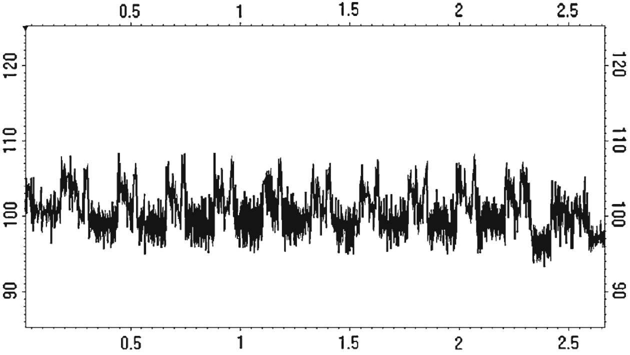
SPA on AES [Kocher, 2011]:



the AES rounds are "clearly" visible

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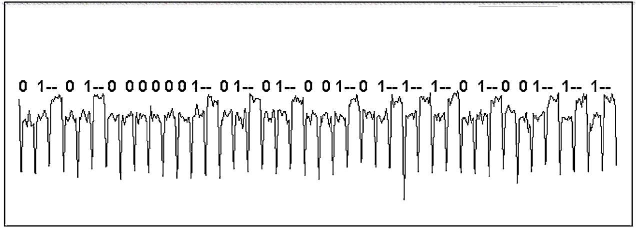
SPA on RSA [Kocher, 2011]:

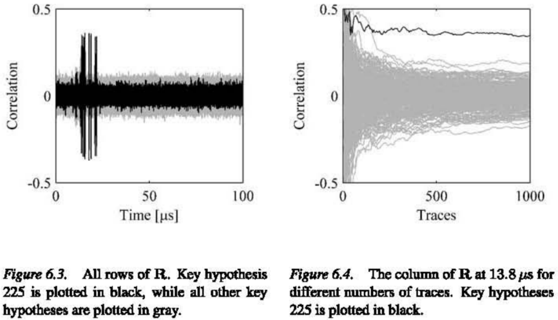


Direct access to key's contents:

- bits 0 = square
- bits 1 = square + mul

Approx. typology of physical attacks

- DPA on AES:
  1. get *n* traces from the target, using selected clear inputs
  2. compute intermediate values for each input, for each possible key values
  3. compute {power/EM/timing...} estimation from the intermediate values
  4. correlate with the measurement traces



[Mangard, 2007]

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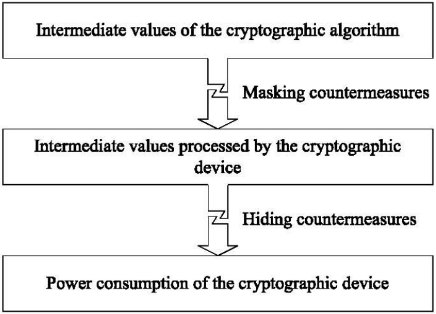
Software protections against physical attacks

Hiding and masking decorrelate data processing from power consumption



Hiding: remove the data dependency of the power consumption
Masking: randomize the intermediate values that are processed by the cryptographic device (vs. algorithmic intermediate values)

[Mangard, 2007]

Our proposal

Use **code polymorphism** to tackle the problem of **program contents** as an **invariant**

Code polymorphism

Definition

Regularly changing the behaviour of a (secured) component, at runtime, while maintaining unchanged its functional properties

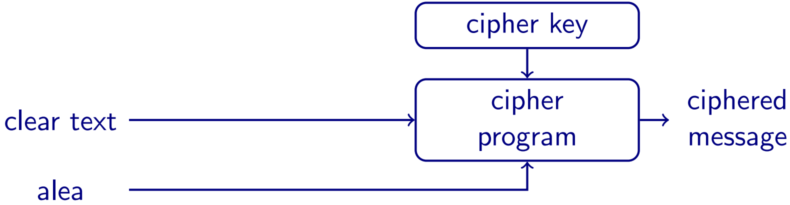
How?

- Generate secured (& polymorphic) functions at runtime
- . . . thanks to a code generator
- Generate a new morphing each time it is necessary
  - security factor ω

What for ?

- SW reverse: more difficult
  - the secured code is not available before runtime
  - the secured code regularly changes its form
  - meta-analysis of the code generator?
- polymorphism changes **the spatial and temporal properties** of the secured code: side channel attacks fault attacks
- combine usual SW protections against 2nd step attacks

COGITO sketched



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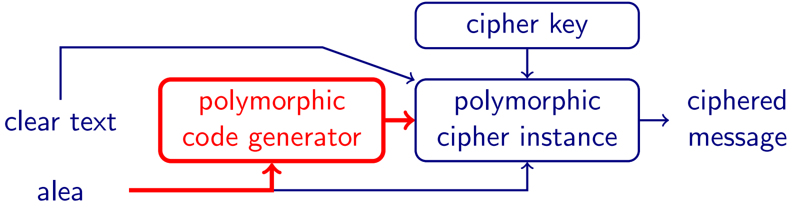

Outline

Overview of `deGoal`

1. Program performance: strong correlation to data
2. Static compilation: no (or almost no) knowledge about the data

- `deGoal` is a tool that allows to design **compilettes**
- A compilette is:
  - an *ad hoc* code generator that targets *one* kernel ($\neq$ application)
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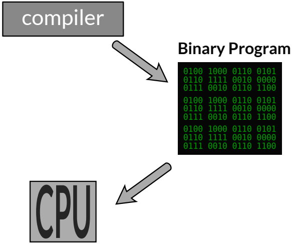

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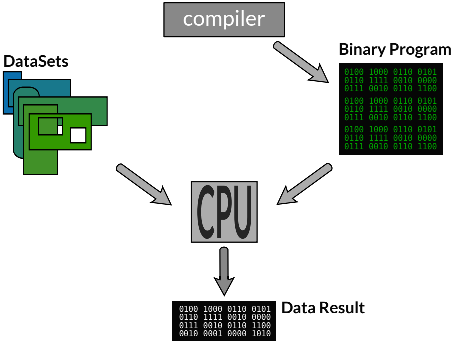

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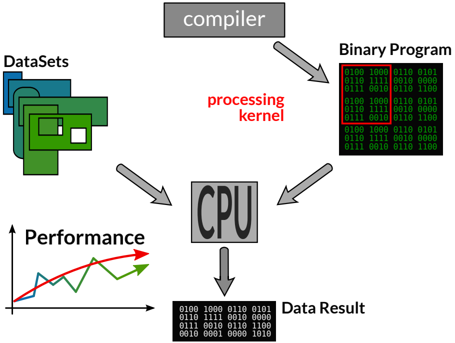

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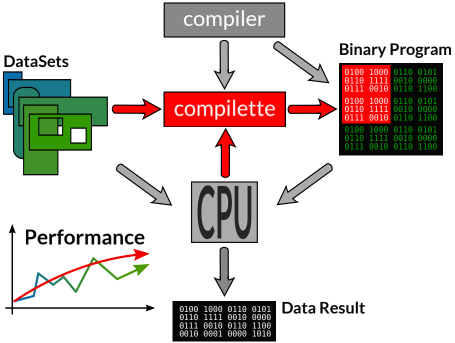

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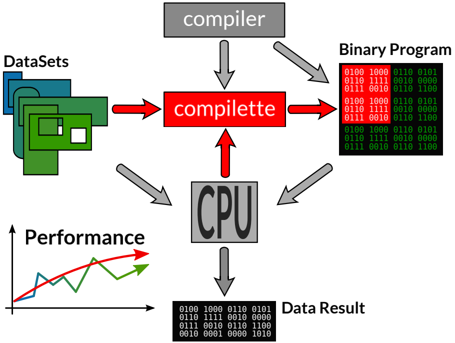


Properties of compilettes:

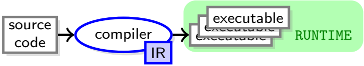
- low memory footprint
- high portability

Aim:

- Modify kernel's binary instructions
- according to the input data
- whenever needed at runtime

Approaches for code specialization

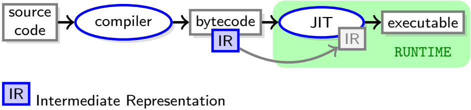
Static code versionning (e.g. C++ Templates)



- static compilation
- runtime: select executable
- memory footprint ++
- limited genericity
- runtime blindness

Dynamic compilation

(JITs, e.g. Java Hotspot)



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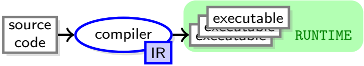

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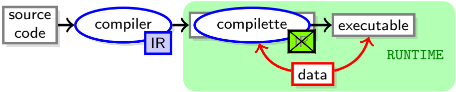
Runtime code generation, with deGoal

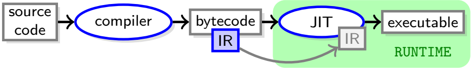
A *compilette* is an ad hoc code generator, targeting one executable



- fast code generation
- memory footprint −−
- **data-driven code generation**

Dynamic compilation

(JITs, e.g. Java Hotspot)



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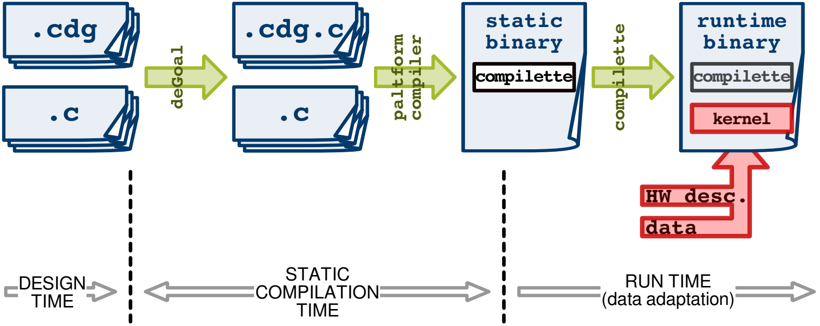
IR Intermediate Representation

Development flow using deGoal



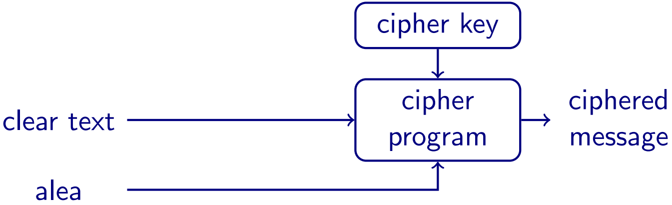
Supported architectures

- ARM 32-bits, Thumb 1 & 2 (including NEON, VFP)
  - Cortex-A8 (beagleBoard), Cortex-A9 (snowball), Cortex-M3 (STM32 discovery – 8 kB RAM)
  - gem5 + McPAT
- MSP430 from Texas Instruments
  - TI's Launchpad (512 bytes only!), Zolertia
- MIPS 32 bits
- VLIW architectures: STxP70 (ST-Microelectronics), other VLIWs under NDA
- Nvidia GPUs (Cuda PTX assembly language)

It is the only tool for dynamic code generation able to target very small processors, up to 8-bit microcontrollers

Demonstrated for the **16-bit MSP430** with only **512 bytes of RAM**: *Software Acceleration of Floating-point Multiplication using Runtime Code Generation. C. Aracil & D. Couroussé. ICEAC 2013*

A sketch of `deGoal` for COGITO



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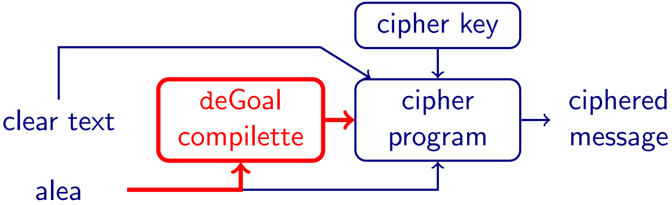

Overview of deGoal capabilities

deGoal runtime capabilities

Performed *in this order*:

1. register selection
2. instruction selection
3. instruction scheduling

What does it mean for COGITO:

- Portability to very small processors and secure elements
  - Limited memory consumption
  - Fast runtime code generation
- Ability to combine with hardware countermeasures
- Introduce alea during runtime code generation [1,2,3]
- Polymorphism: random generation of semantically equivalent sequences
  - random mapping to physical registers [1]
  - use of semantic equivalences [2]
  - instruction scheduling [3]
  - insertion of dummy operations [3]

Potential limitations and flaws

Requirement: **writable program memory**

- Current practice:
  - generate code in RAM (most frequent case)
  - or in ROM (flash)

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  - Lower the side effects of this issue:
    - obfuscate the code generator with encryption
    - ...
  - Hardware design of a dedicated block ...

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The **code generator** itself must be secured agains physical attacks

Out of the scope of this talk

Outline

Demo

Target : $[B] = \alpha \times [A]$

```c
typedef void (*fp)(int*);
int src[TABLE_LEN], dest[TABLE_LEN];

void vector_mul(int * A, int A_len, int alpha, int * B) {
    int i; for (i=0; i<A_len; i++) {
        B[i] = alpha * A[i];
    }
}

int main() {
    cdg_insn_t * code = CDGALLOC(ALLOC_LEN);
    compilette(code, src, vsize, alpha); /* code generation */

    fp kernel = (fp)code;
    kernel(dest);                        /* execution */

    PRINT("dest :");
    for (i = 0; i < vsize; ++i) { PRINT("%3d ", dest[i]); }
}
```

Demo

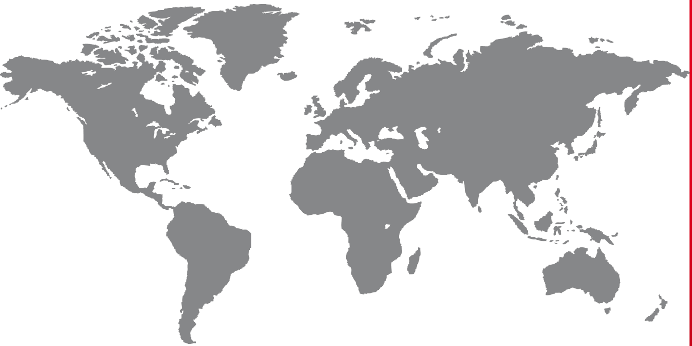
```
void compilette(cdg_insn_t* code, int * A_addr, int A_len, int alpha) {
  #[
  Begin code Prelude B_addr

  Type  ptr_t int 32
  Type  vint_t int 32 #(A_len)
  Alloc vint_t v
  Alloc ptr_t tmp

  mv tmp, #(A_addr)
  lw v, tmp
  mul v, v, #(alpha)
  sw B_addr, v
  rtn

  End
  ]#;
}
```

Demo

- non-polymorphic execution
- random register allocation
- instruction shuffling

Two positions opened !!

- Post-doc on COGITO
  keywords: security, code generation, [IoT]
- Embedded SW developper for MPSoCs
  keywords: embedded, runtime SW, code generation, parallelism



Thanks!

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Outline

1. The COGITO project
2. Code polymorphism as a proposal to improve physical security in embedded systems
3. `deGoal`
   - Introduction to `deGoal`
   - Secured runtime code generation with `deGoal`
   - Potential limitations
4. Demo