Power Contracts:

Provably Complete Leakage Models for Processors

Roderick Bloem, Barbara Gigerl, Marc Gourjon, Vedad Hadžić, Stefan Mangard, Robert Primas

TU Graz

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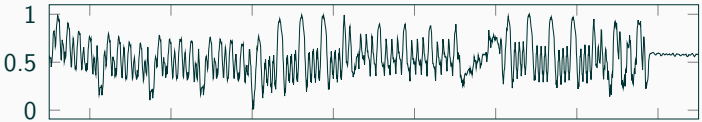
NXP

Motivation: Power Analysis Attacks

- Processors leak information about processed data through power side channels:



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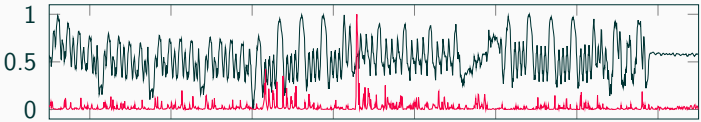

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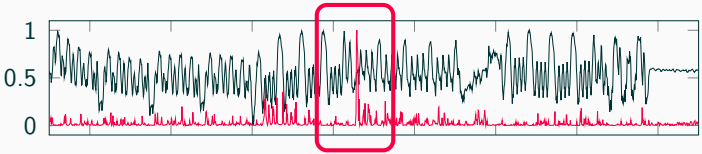

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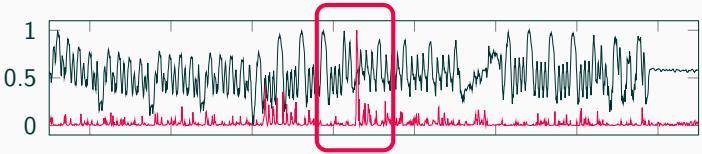

- Masking is a side-channel countermeasure
  - Splits secrets into uniformly random shares, e.g.,

$$s = s_1 \oplus s_2$$

Motivation: Masking Verification (Models)

(Option 1) Verify using some leakage model:

```
xor  x3, x1, x2 ; leaks x1 ⊕ x2
and  x7, x4, x3 ; leaks x4 & x3
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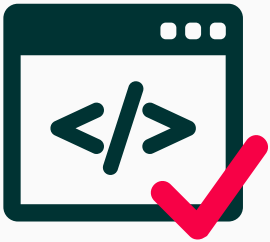

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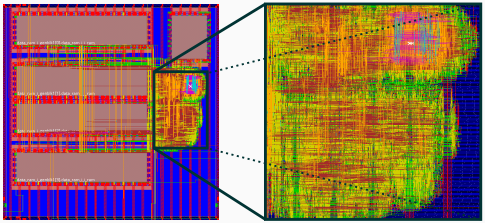

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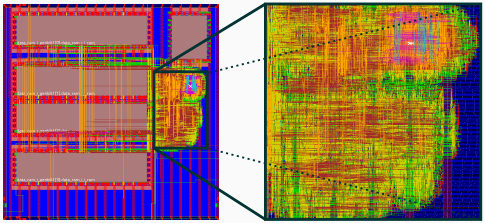

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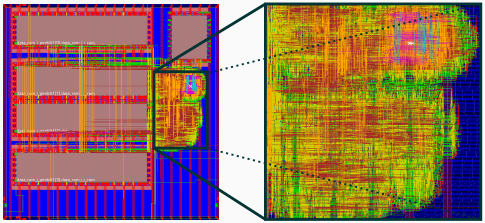

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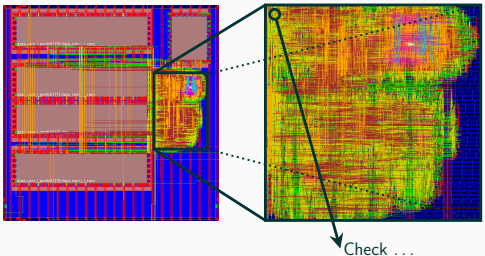

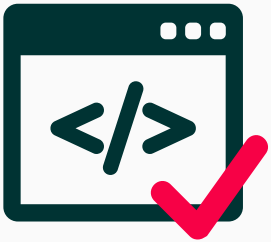

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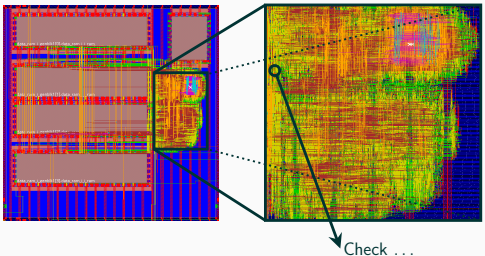

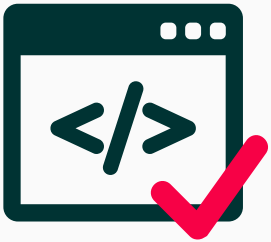

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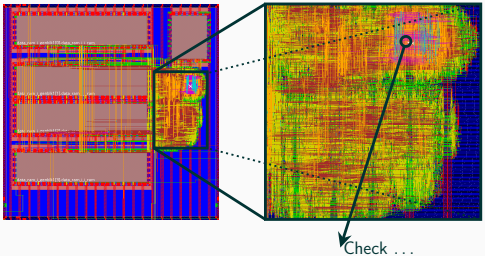

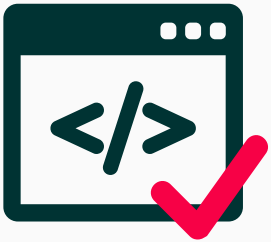

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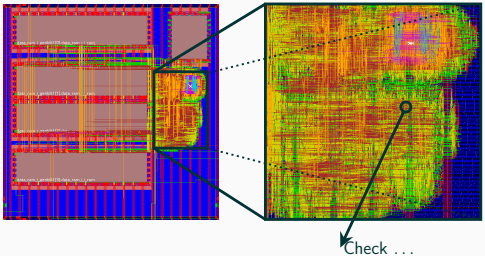

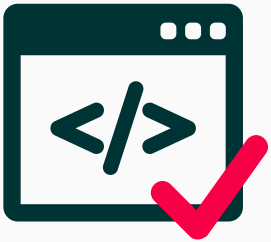

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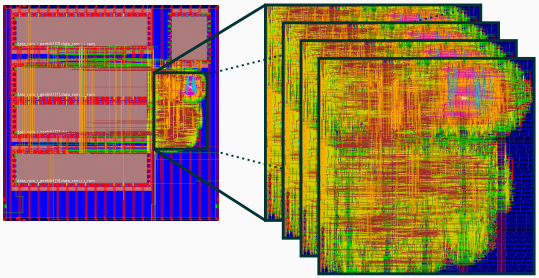

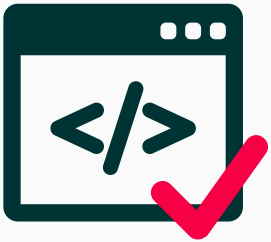

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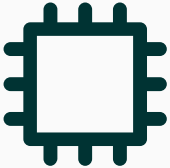
program



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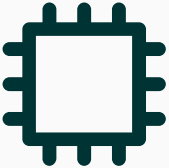

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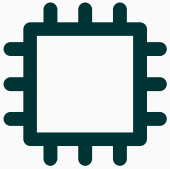

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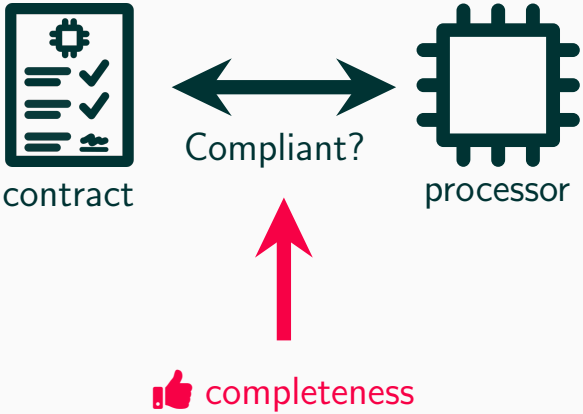

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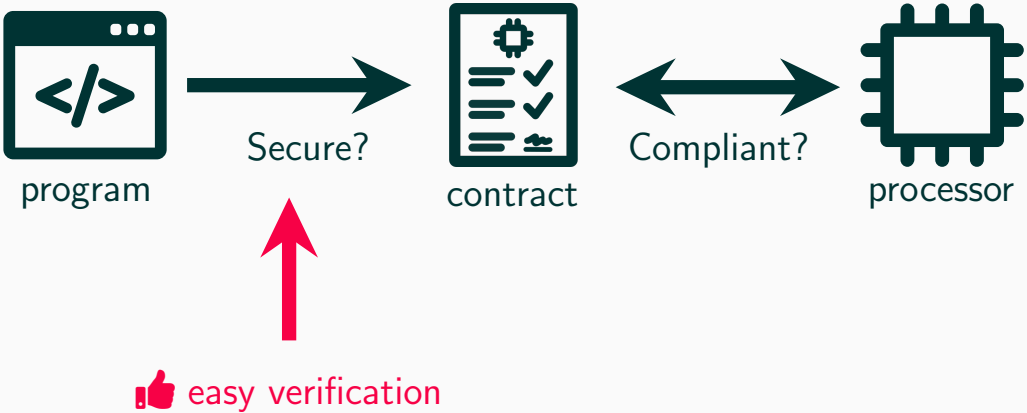

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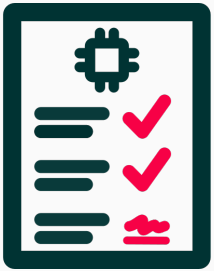
Contracts formally describe a processor.



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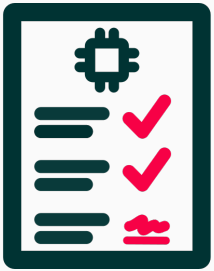

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- Functional (ISA) specification :
  - architectural registers, e.g., `pc`, `x1`, `x2`, ...
  - what instructions compute, e.g.,

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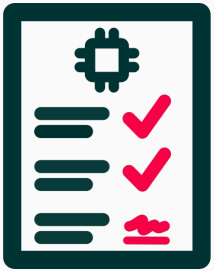

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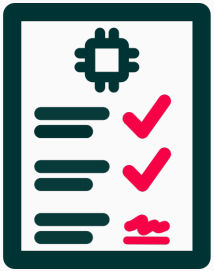
- Leakage specification:
  - microarchitectural elements, e.g., `rf_pA`
  - what is leaked, e.g., `leak(x1, x2, rf_pA)`

Power Contract Example



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5
6
7
8
9    X(rd) = result;                 // write result
10   pc = pc + 4;                    // update pc
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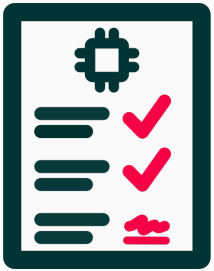

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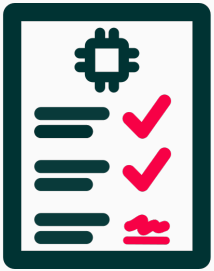

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10   pc = pc + 4;             // update pc
11   rf_pA = rs1_val;         // update RF A port
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A processor complies with a contract if:

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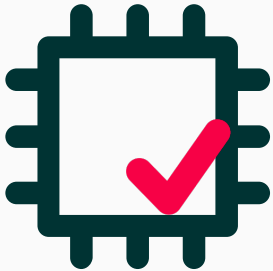

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- `leak(x1 + x2)` and `leak(x1 & x2)`
- any other function g(`x1, x2`)

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1. $\forall$ j, i : $j \simeq i \Rightarrow j+k \simeq i+1$

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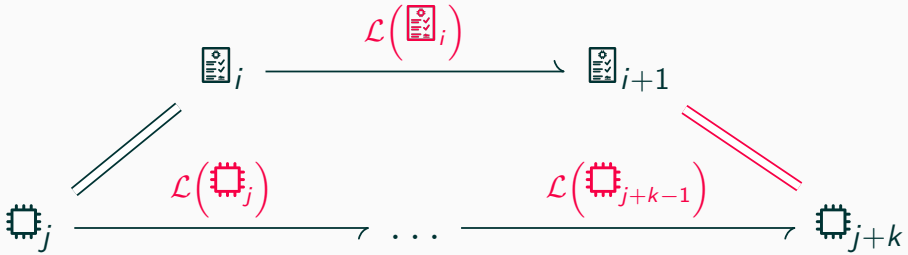

1. $\forall\ \square_j, \blacksquare_i : \square_j \simeq \blacksquare_i \Rightarrow \square_{j+k} \simeq \blacksquare_{i+1}$
2. $\exists\ f_\lambda : \forall\ \square_j, \blacksquare_i : \square_j \simeq \blacksquare_i \Rightarrow f_\lambda \circ \lambda\left(\blacksquare_i\right) = \lambda_g\left(\square_{l-1}, \square_l\right)$

Main Verification Trick

We need to show λ is stronger than λ_g:

$$\exists\ f_\lambda : \forall\ \square_j, \square_i :$$
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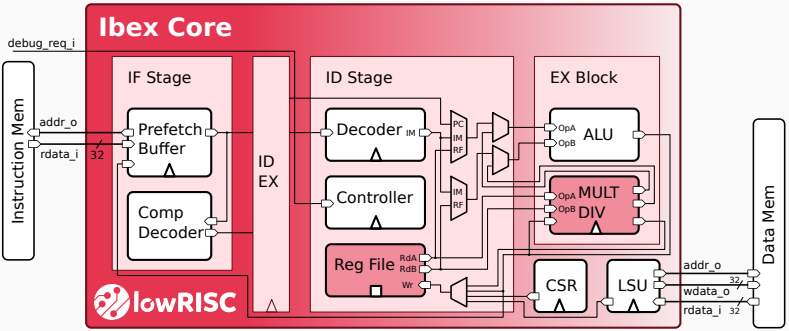
We show it implicitly through congruence:

$$\forall\ \square_j, \square'_j, \blacksquare_i, \blacksquare'_i :$$
$$\square_j \simeq \blacksquare_i \wedge \square'_j \simeq \blacksquare'_i \wedge \lambda\left(\blacksquare_i\right) = \lambda\left(\blacksquare'_i\right) \Rightarrow$$
$$\lambda_g\left(\square_{l-1}, \square_l\right) = \lambda_g\left(\square'_{l-1}, \square'_l\right)$$

Case Study: Target

We have created a contract for IBEX:



Case Study: Leaks

Almost all instructions have the same leakage:

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Additionally, the writeback stage leaks:

```
leak(x1_val, x1_nval);
leak(x2_val, x2_nval); //...
```

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- Changed ∼1k lines of RISC-V spec
- Configuration requires ∼400 lines
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Gadget	# Instr.	# Clear.	Verification time	
			Contract	Netlist
`AND`	62	10	< 1 s ✓	284.63 s ✓
`Refresh`	19	0	< 1 s ✓	32.85 s ✓
`XOR`	16	1	< 1 s ✓	50.79 s ✓
`NOT`	5	0	< 1 s ✓	63.32 s ✓

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