Using a Vulnerability Assessment Methodology to build and improve Countermeasures against Multi-Fault Injection

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Plan

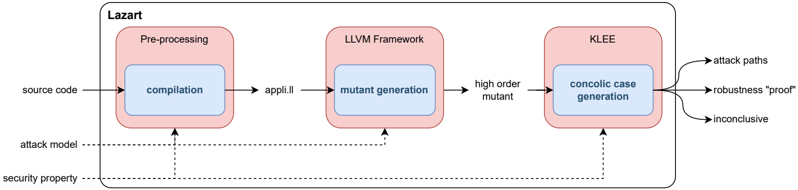
1. Overview of the Methodology

2. Case Study: Protecting Control-Flow against Multiple Faults

3. Proposing the CFIStack

4. Conclusion and Perspectives

Recalls on Lazart



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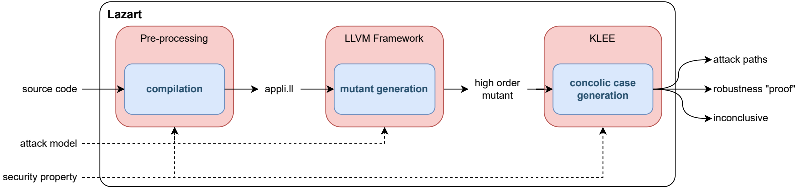

Multi-fault Analysis

- pre-defined fault models:
  - data load mutation (**DL**)
  - test inversion (**TI**)
  - switch call (**SC**)
  - no call (**NC**)

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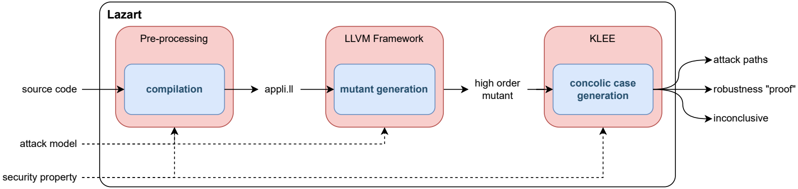

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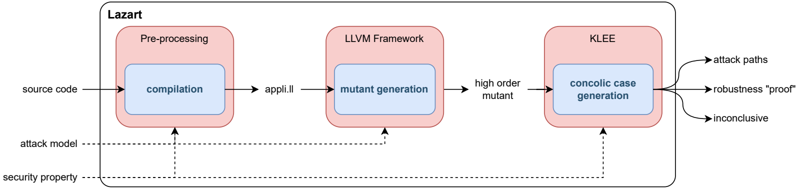

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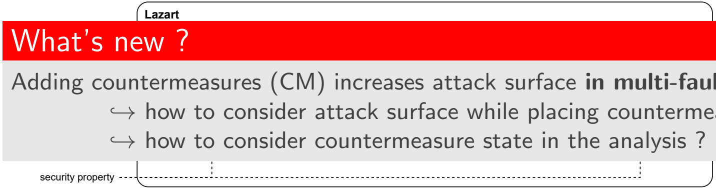

What's new ?

Adding countermeasures (CM) increases attack surface **in multi-fault**. . .

↪ how to consider attack surface while placing countermeasures ?

↪ how to consider countermeasure state in the analysis ?

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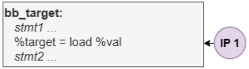
Protecting Sensitive Schemes

Sensitive Scheme



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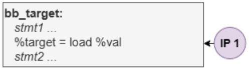

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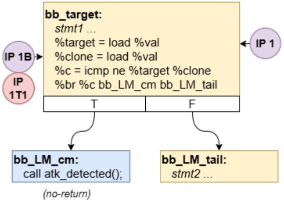

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  %target = load %val
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  %c = icmp ne %target %clone
  %br %c bb_LM_cm bb_LM_tail
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bb_LM_cm:
  call atk_detected();
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(no-return)

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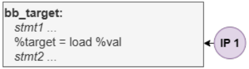

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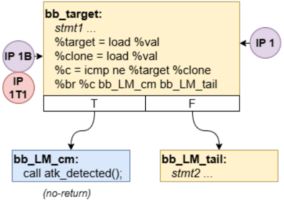

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```
klee_make_symbolic(&val);
Load_Dupl(val, &target);
oracle(!(target == val));
```

Oracle for load duplication

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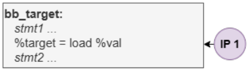

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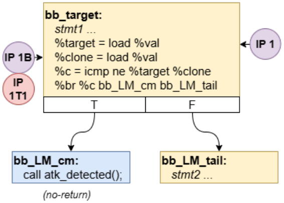

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Analysis Principle

- consider only **nominal behavior** of sensitive scheme (*i.e.* injection points IP) ↪ not of program P
- either preserve nominal, or detect attack

Studying Counter-Measures in Isolation

Robustness levels

Use **symbolic execution** to compute a **robustness level** (*rl*) against **multi-fault attacks**.

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	Test inversion		Load modification		Combination	
Countermeasure	*rl*	*Vuln*	*rl*	*Vuln*	*rl*	*Vuln*
Test duplication	1	2	-	-	1	2
Load duplication	-	-	1	1	1	2
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Robustness levels of countermeasure schemes (for `max_order=4`)

Vuln: number of attack paths found with **rl + 1** faults

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↪ **automatic placement of counter-measures against multi-fault**

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Minimal Working Example

```
bool is_authentified = false;

void authentify() {
    is_authentified = true;
}

void try_authentify() {
    if (check_password()) {
        authentify();
    }
}

void caller() {
    try_authentify();
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Requirements

- ensure **control-flow integrity**

  ↪ both forward and backward edges

  ⇒ check both call and return addresses
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Minimal Working Example

```
bool is_authentified = false;

void authentify() {
    is_authentified = true;
}

void try_authentify() {
    if (!check_password()) { //TI
        authentify();
    }
}

void caller() {
    try_authentify();
}
```

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Protecting Both Directions with CFIStack

Main Idea

- store **function signature** and **return address** (inspired from **SecSwift** and **shadow stacks**)

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```
void try_authentify (addr ret_caller) {
    peek_and_check(sig_try_authentify);
    pop();
    ... // function body
    peek_and_check(ret_caller);
    return;
}

void caller() {
    int mem_current = current;
    push(ret_caller);
    push(sig_try_authentify);
    try_authentify(ret_caller);
ret_caller:
    pop();
    check_current(mem_current);
    ... // remaining code
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```

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<u>Oracle for CFIStack Nominal Behavior:</u>

```
old_cfi_current == cfi_current &&
cmp(cfi_stack, old_cfi_stack, STACK_SIZE)
```

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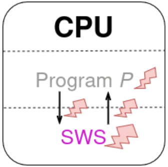
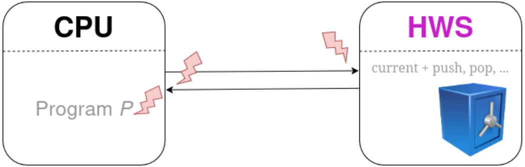
Proposing SWS *vs.* HWS

- **SWS** (soft): primitives (`push`, . . .) **logic** are vulnerable (*e.g.* TI, DL)
- **HWS** (hard): primitives logic (+ `current`) are considered secure

↪ just change the `Lazart` setup (mainly, IPs for **TI** and **DL**)





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SWS	SC		2	1
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HWS	SC		2	1
	SC + DL		4	1

SWS: Software CFIStack / **HWS**: Hardware CFIStack

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PSWS	SC		2	1
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PSWS: Protected SWS (with our methodo.)
↪ add **load-** and **test-duplication** to SWS

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- **but can we do better ?**

Feedback and Distribution

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Try it yourself !

Both methodology and example documented in `Lazart` wiki:
https://gricad-gitlab.univ-grenoble-alpes.fr/securitytools/lazart/-/wikis/Countermeasure-hardening-tutorial

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BACKUPS

Please don't be mean

Need to Preserve the Whole Stack ?

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void try_authentify() {
    if (check_password()) {
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void caller() {
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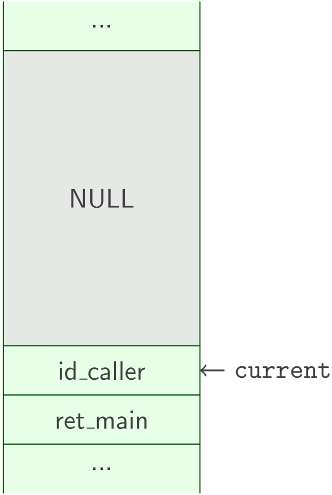

...

NULL

id_caller ← current

ret_main

...

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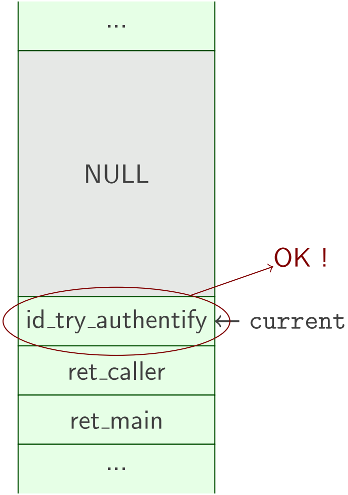


...

NULL

OK !

id_try_authentify ← current

ret_caller

ret_main

...

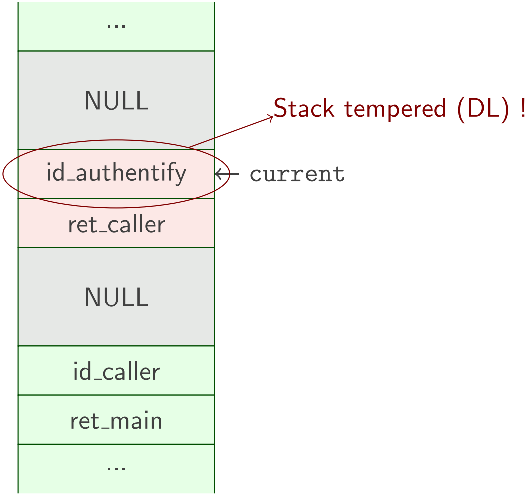
Need to Preserve the Whole Stack ?

```
bool is_authentified = false;

void authentify() {
    is_authentified = true;
}

void try_authentify() {
    if (check_password()) {
        authentify();
    }
}

void caller() {
    try_authentify();
}
```



...

NULL

id_authentify

ret_caller

NULL

id_caller

ret_main

...

Stack tempered (DL) !

current

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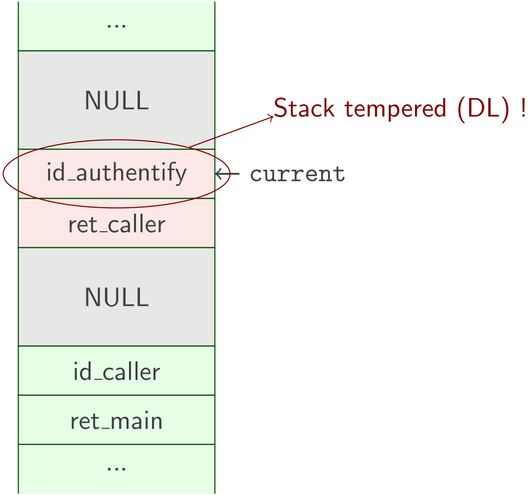

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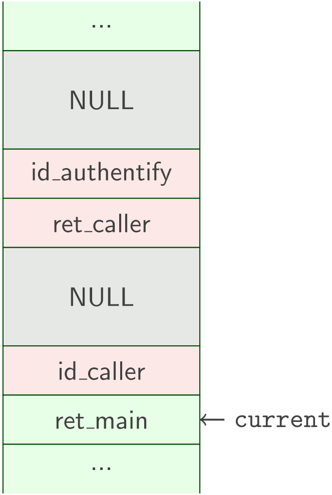
...

NULL

id_authentify

ret_caller

NULL

id_caller

ret_main ← current

...

Need to Preserve the Whole Stack ?

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void authentify() {
    is_authentified = true;
}
```

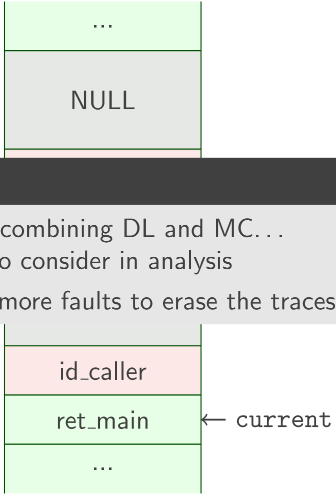
Why do we need such a strong oracle ?

In a multi-fault context, we might temper the stack by combining DL and MC...
↪ could lead to erroneous control-flow, that we need to consider in analysis

↪ by checking the whole stack, it would require twice more faults to erase the traces

```
}

void caller() {
    try_authentify();
}
```



Need to Preserve the Whole Stack ?

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void authentify() {
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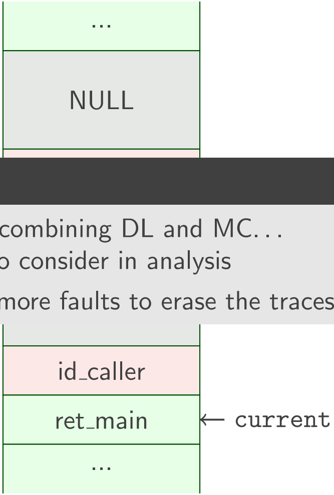

Considered Fault Models for CFIStack Analysis

Variant	Fault model	Target	Function
SWS	SC/NC	try_authentify push pop check_current	caller()
		peek_and_check pop	try_authentify()

	TI	-	pop()
			push()
			peek_and_check()

	DL	mem_current sig_try_authentify	caller()
		sig_authentify	authentify()

		current	pop()
			push()

Variant	Fault model	Target	Function
HWS	SC/NC	try_authentify check_current pop	caller()
	TI	-	-
	DL	mem_current sig_try_authentify	caller()
		sig_authentify	authentify()

Comparing Robustness Levels with NC and SC

Version	Fault model	#attacks 1F	#attacks 2F	Robustness level
SWS	SC		2	1
	SC + DL	132+		**0**
	SC + TI	3		**0**
	SC + DL + TI	135+		**0**
	NC		1	1
	NC + DL	72+		**0**
	NC + TI	3		**0**
	NC + DL + TI	75+		**0**
Protected SWS	SC		2	1
	SC + DL		7+	1
	SC + TI		7+	1
	SC + DL + TI		10+	1
	NC		1	1
	NC + DL		5+	1
	NC + TI		5+	1
	NC + DL + TI		10+	1

Version	Fault model	#attacks 1F	#attacks 2F	Robustness level
HWS	SC		2	1
	SC + DL		4	1
	NC		1	1
	NC + DL		2	1

Toward n-Robustness

Version	Fault model	#IP to protect for 2-robustness
HWS	NC	1
	NC + DL	1
	SC	3
	SC + DL	3
PSWS	NC	1
	NC + DL	3
	NC + TI	4
	NC + TI + DL	6
	SC	3
	SC + DL	5
	SC + TI	6
	SC + TI + DL	8

Insights from the methodology

- which IP to protect ?
- which CM to use ?
- try to **minimize** the protection while **ensuring robustness**

Some feedback to harden using CFIStack variants