Software Fault Isolation using the CompCert compiler

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Flash vulnerable plugin

Do you know this logo?

Flash is famous for its multiple
vulnerabilities
→ consequences on Flash
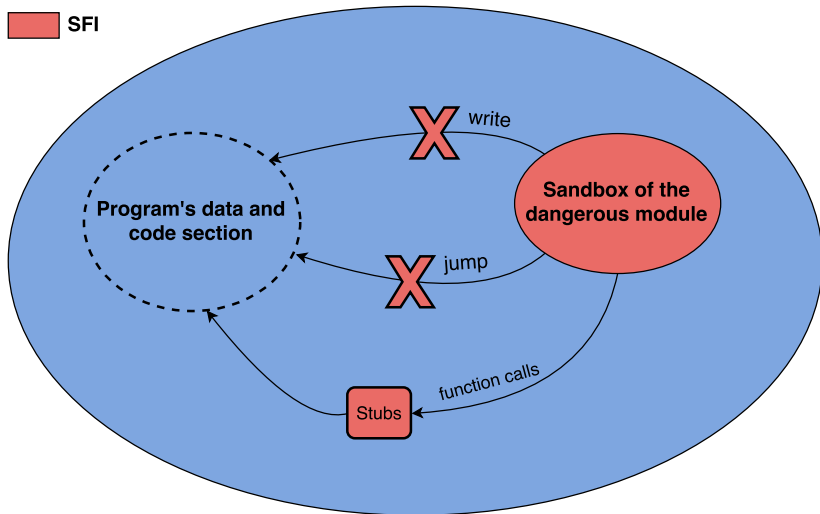→ but ALSO endangers your
browser

Goals of Software Fault Isolation (SFI) [4]

- SFI aims to allow a protected program to execute dangerous modules in its own memory space without dangers.

- SFI confines the execution of the dangerous modules in a reserved memory space called sandbox
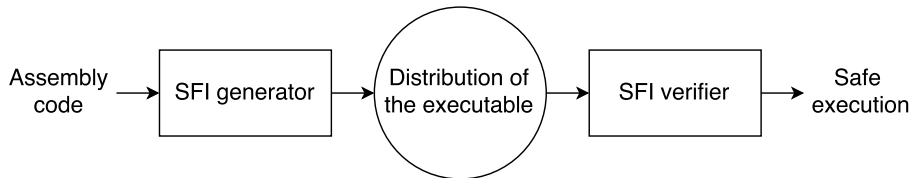
Goals of SFI

Overview of SFI

SFI chain is composed of two elements:

- the **generator** transforms the assembly code of the dangerous modules in order to confine the modules in their sandbox
- the **verifier** checks that the SFI transformations are present and valid before loading the code in memory

Problematics of SFI

We want to prevent attackers from using vulnerable modules to compromise our system

- ▶ SFI gives us a way to face such issue
- ▶ However SFI is currently lacking against Returned Oriented Programing attacks (ROP)
- ▶ ROP attacks focus function return addresses to execute malicious code they injected
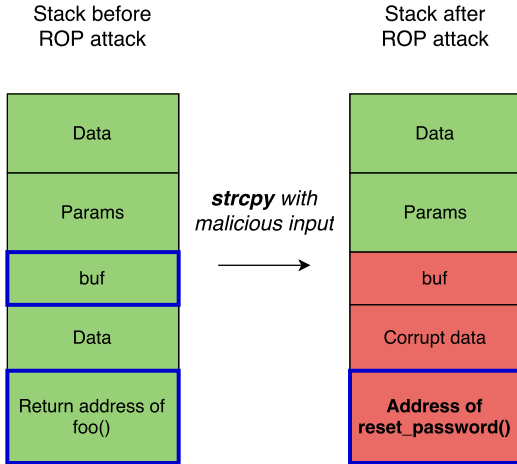
Contributions

- An approach inspired from SFI protecting return addresses against ROP attacks

- An implementation of our approach with the compiler CompCert for the x86-32 architecture

ROP attack example (1/2)

```
1  void reset_password() {
2    ... reset password ...          //Sensitive code
3  }
4
5  void foo(char* input){
6    char buf[1];
7    ... code ...
8    strcpy(buf, input);             //Vulnerability
9    ... code ...
10 }
```

ROP attack example (2/2)

Stack before
ROP attack

Stack after
ROP attack

strcpy *with*
malicious input

→

| Data |
| Params |
| buf |
| Data |
| Return address of foo() |

| Data |
| Params |
| buf |
| Corrupt data |
| **Address of reset_password()** |

Modern ROP attacks

- ROP attacks are a common kind of attack in the industry
- Modern ROP attacks are much more complicated [1]

*"Skype URI handling
routine contains a buffer overflow"*, 2005[1]

*"Apple Mail buffer
overflow vulnerability "*, 2006

*"glibc vulnerable to stack buffer
overflow in DNS resolver "*, 2016

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[1]From CERT vulnerability database

Problematic

We want to add additional checks at runtime to protect the return addresses.

How do we know the return addresses locations in the memory?

Problematic

We want to add additional checks at runtime to protect the return addresses.

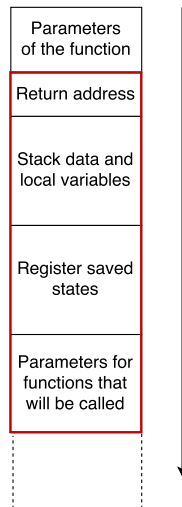## How do we know the return addresses locations in the memory?

⇒ Modify the memory structure to have an easy way to distinguish return addresses locations

Presentation of our approach

1. Presentation of the stack

2. Transformation of the stack structure

3. Insertion of runtime checks in the protected code

4. Evaluation of the approach

Stack structure

- Programs memory is separated into multiple area like the heap, the stack or the code section
- Return addresses are solely located in the stack
- The stack is composed of piled up frames each related to a function being executed
- Frames store data of their respective function

| Parameters of the function |
| Return address |
| Stack data and local variables |
| Register saved states |
| Parameters for functions that will be called |

Stack transformation objective

▶ We want a stack structure with a property on the return addresses locations

▶ Every return addresses location *a* verifies the equality
  <u>*a mod n* = 0</u>

▶ The transformation is composed of two steps:
  1. Constant frames size
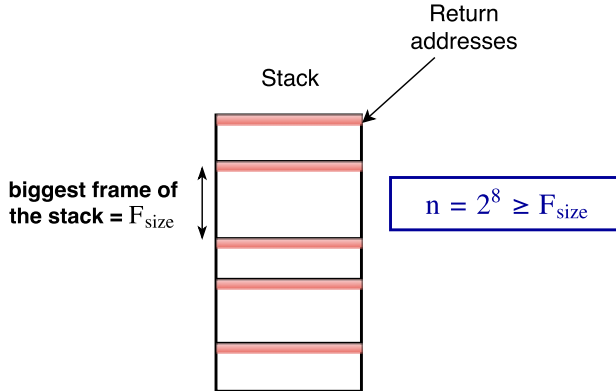 2. Stack alignment
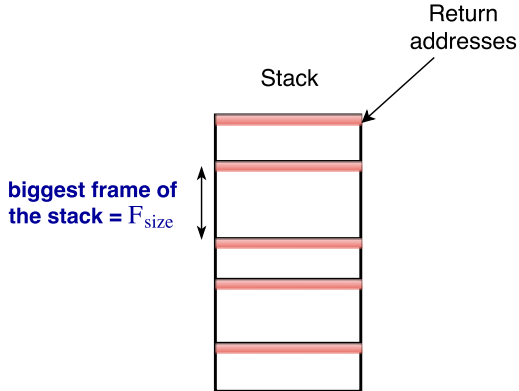
Calculate the new frames size

$$n = 2^8 \geq F_{size}$$

Fix the size of the frames
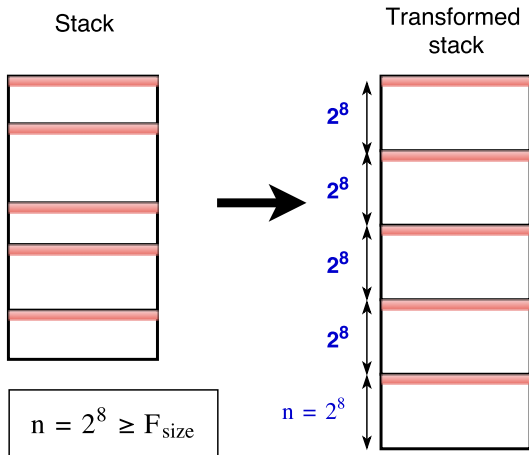
Return addresses locations
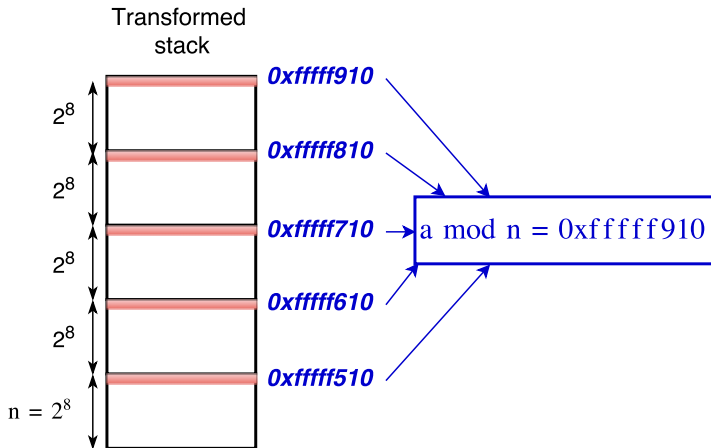
Stack transformation (5/6)

Insertion of a new artificial main
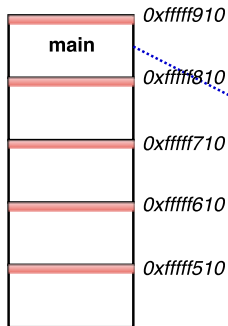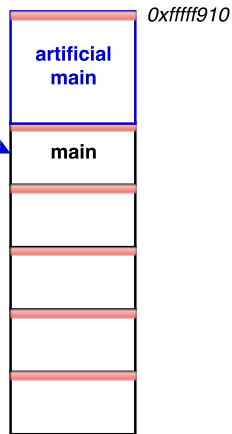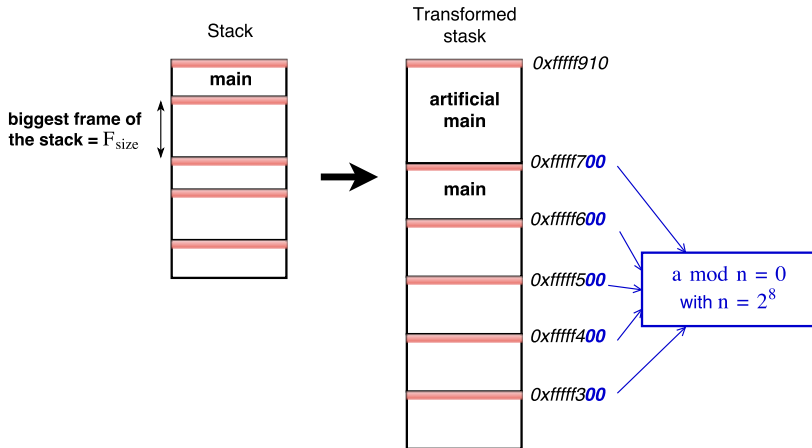
Return addresses locations
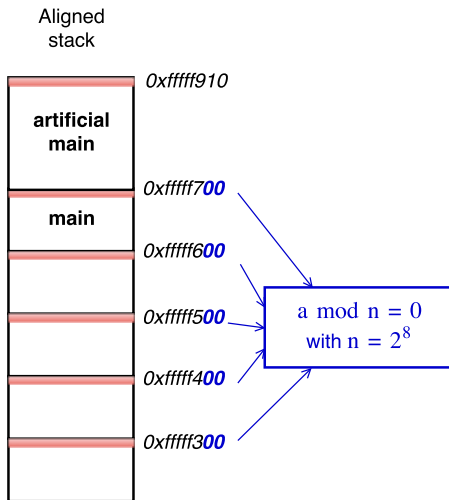
Stack transformation
Summary

Code transformation

- We have now an easy way to differentiate return addresses locations with $a \bmod n = 0$

- We need to insert additional runtime check to protect these locations from being overwritten illegally

- Thus we transform the code adequately during the compilation phase

Runtime check
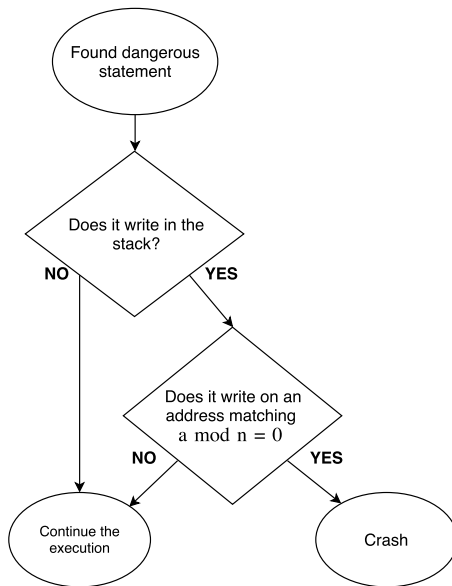
Branchless check
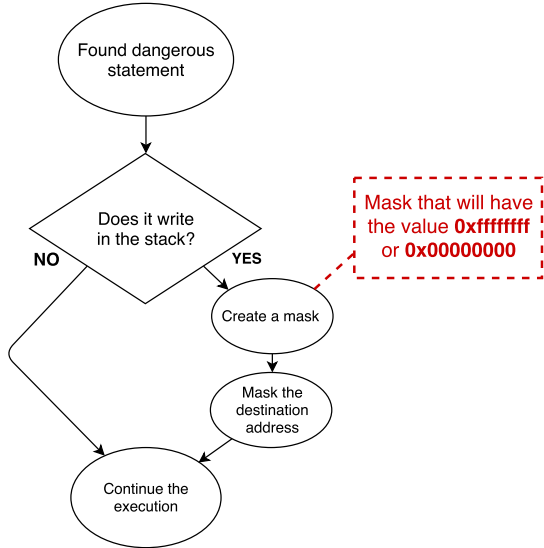
Implementation environment
CompCert the certified compiler [2]

- CompCert has been proven with the proof assistant Coq
- CompCert has performance similar to `gcc -01`
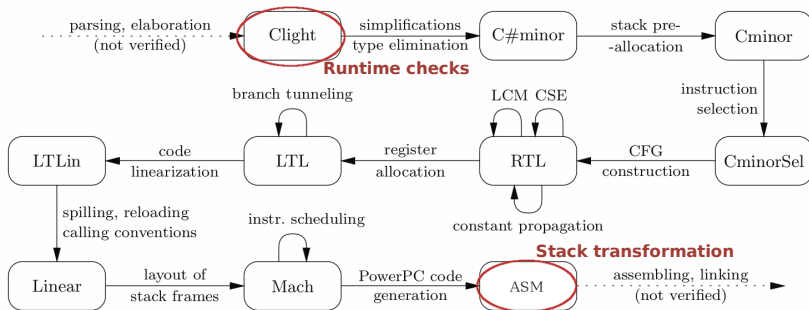
Requirements

- No modifications of the stack (inline assembly)

```
1  int foo(int a) {
2  asm(''\$sub 50, \%esp'');
3  printf("Hello world!");
4  }
```

- No function pointers to protect our runtime checks
- Need to recompile external libraries with the same frames size

Evaluation of performance

Time performance comparison

Evaluation of performance
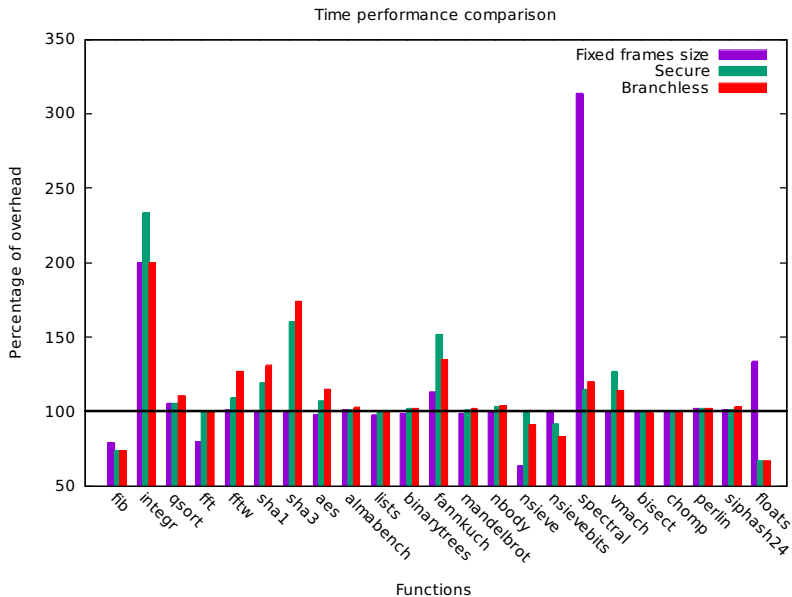
Time performance comparison
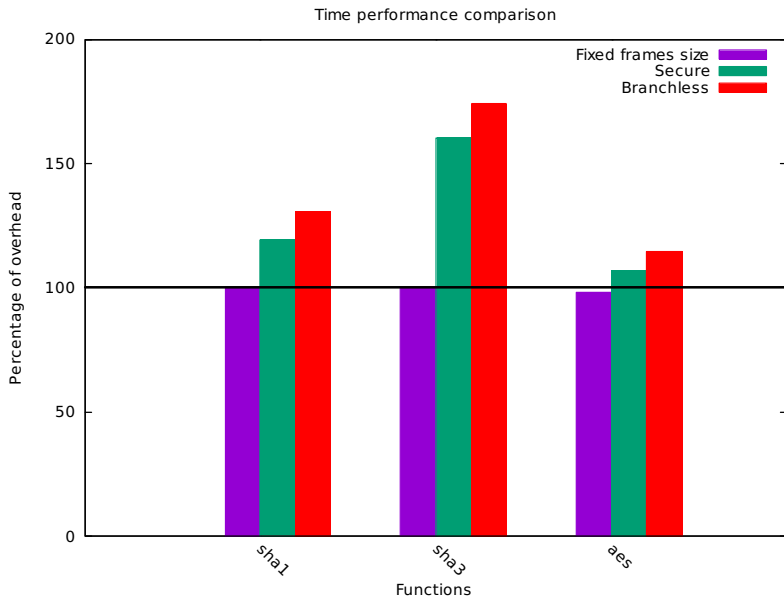
Conclusion

Prospectives

- ▶ Test our implementation against more complicated ROP attacks
- ▶ Reduce the number of runtime checks with static analysis [5]
- ▶ Improve the performance of the runtime checks with a super-optimizer
- ▶ See the impact of our approach on memory consumption
- ▶ Prove the security properties of our implementation

References

[1] Erik Buchanan, Ryan Roemer, Hovav Shacham, and Stefan Savage.
When good instructions go bad: Generalizing return-oriented programming to RISC.
In Paul Syverson and Somesh Jha, editors, *Proceedings of CCS 2008*, pages 27–38. ACM Press, October 2008.

[2] Xavier Leroy.
Formal verification of a realistic compiler.
Commun. ACM, 52(7):107–115, 2009.

[3] David Sehr, Robert Muth, Cliff Biffle, Victor Khimenko, Egor Pasko, Karl Schimpf, Bennet Yee, and Brad Chen.
Adapting software fault isolation to contemporary cpu architectures.
In *Proceedings of the 19th USENIX Conference on Security*, USENIX Security'10, pages 1–1. USENIX Association, 2010.

[4] Robert Wahbe, Steven Lucco, Thomas E. Anderson, and Susan L. Graham.
Efficient software-based fault isolation.
SIGOPS Oper. Syst. Rev., 27(5):203–216, 1993.

[5] Bin Zeng, Gang Tan, and Greg Morrisett.
Combining control-flow integrity and static analysis for efficient and validated data sandboxing.
In *Proceedings of the 18th ACM Conference on Computer and Communications Security*, CCS '11, pages 29–40. ACM, 2011.

Branchless example
Legal execution

```
if (addr > 0xff000000) {
    mask = addr & 0x000000ff;
    mask = mask - 3;
    mask = mask >> 31;
    mask = ~mask;
    addr = mask & addr;
}
*addr = value;
Continue execution...
```

addr is not a return address location, it should keep its value

Values
addr = 0xfffff718
mask = 0x00000000

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Continue execution...
```

Forbidden `write` destination
the program should crash

Values
`addr = 0xfffff700`
`mask = 0x00000000`

Branchless example
Illegal execution

```
if (addr > 0xff000000) {
  mask = addr & 0x000000ff;
  mask = mask - 3;
  mask = mask >> 31;
  mask = ~mask;
  addr = mask & addr;
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