

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



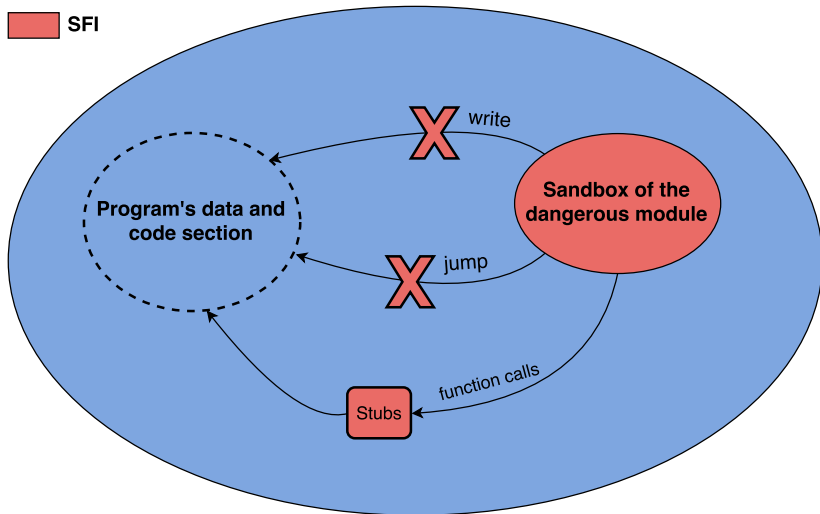
Goals of Software Fault Isolation (SFI) [4]

- ▶ 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

 Memory of the protected program

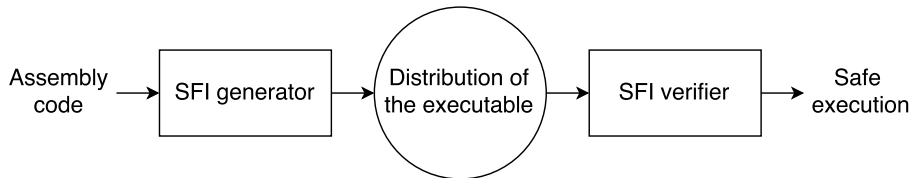
 SFI



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

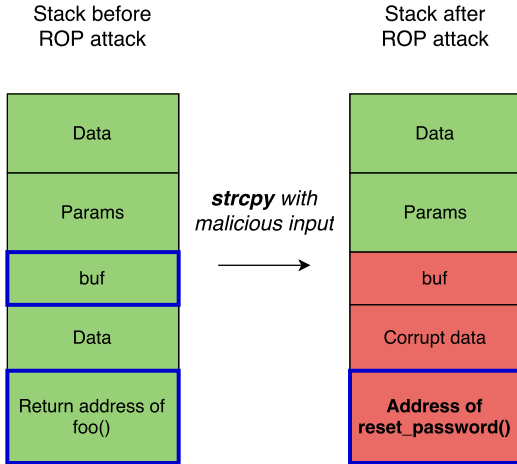
Contributions

- ▶ 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)



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”, 2005¹*

*“Apple Mail buffer
overflow vulnerability”, 2006*

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

¹From 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?

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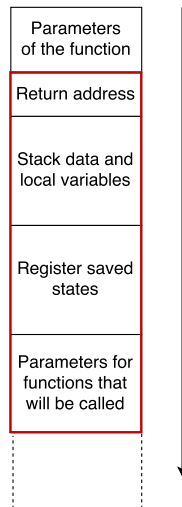
⇒ Modify the memory structure to have an easy way to distinguish return addresses locations

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

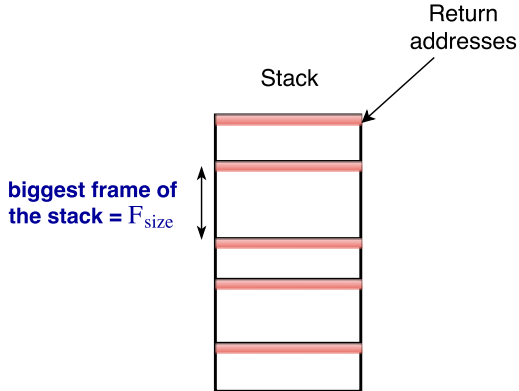


Stack transformation objective

- ▶ We want a stack structure with a property on the return addresses locations
- ▶ Every return addresses location a verifies the equality $a \bmod n = 0$
- ▶ The transformation is composed of two steps:
 1. Constant frames size
 2. Stack alignment

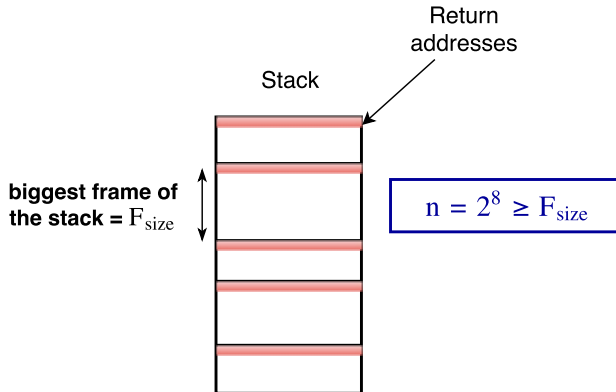
Stack transformation (1/6)

Find the biggest frames size



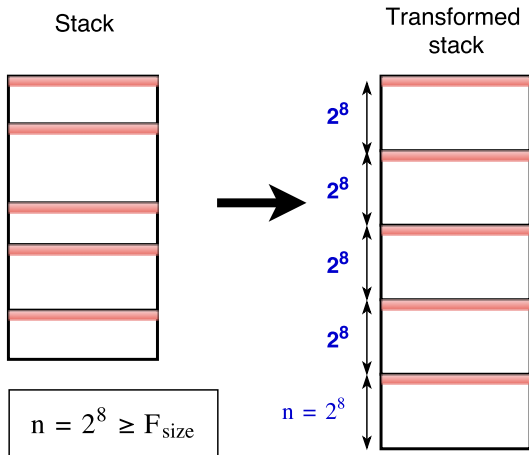
Stack transformation (2/6)

Calculate the new frames size



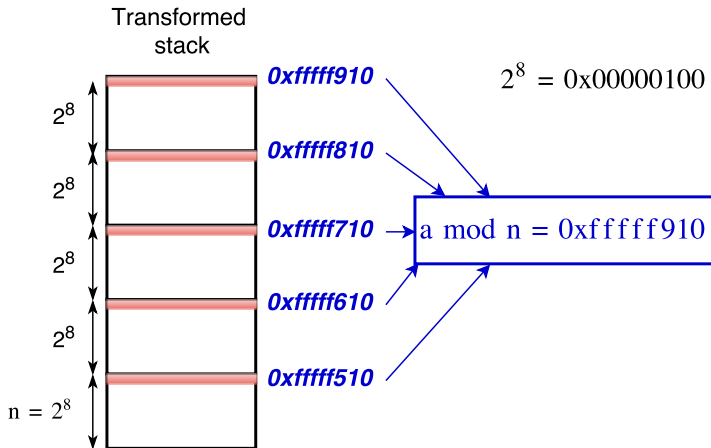
Stack transformation (3/6)

Fix the size of the frames



Stack transformation (4/6)

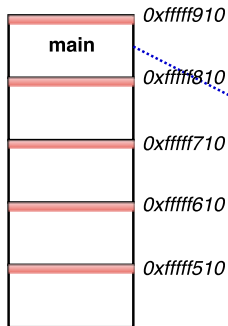
Return addresses locations



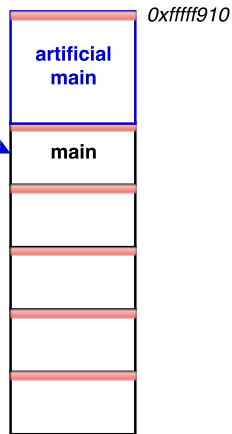
Stack transformation (5/6)

Insertion of a new artificial main

Fixed frames size
stack

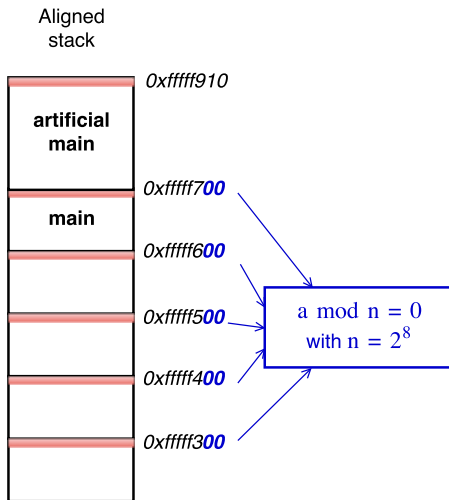


Aligned
stack



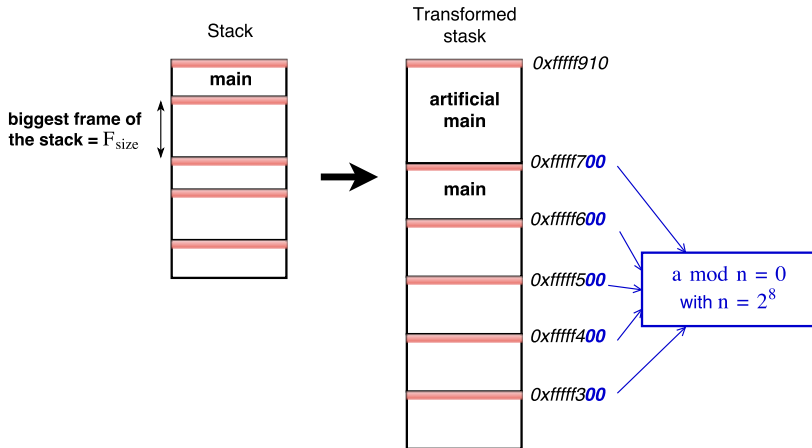
Stack transformation (6/6)

Return addresses locations



Stack transformation

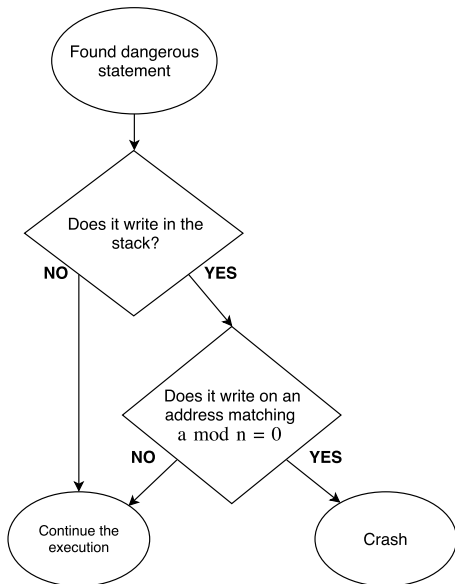
Summary



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

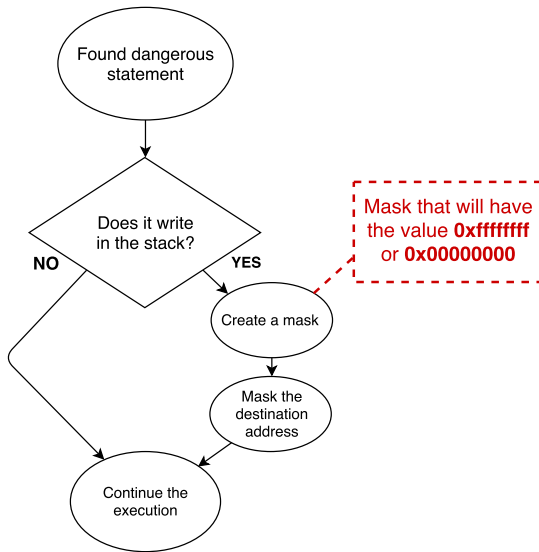
Runtime check



- ▶ The protection mechanism might be executed numerous times
- ▶ To improve performance we want to have this runtime check as fast as possible

Branchless check

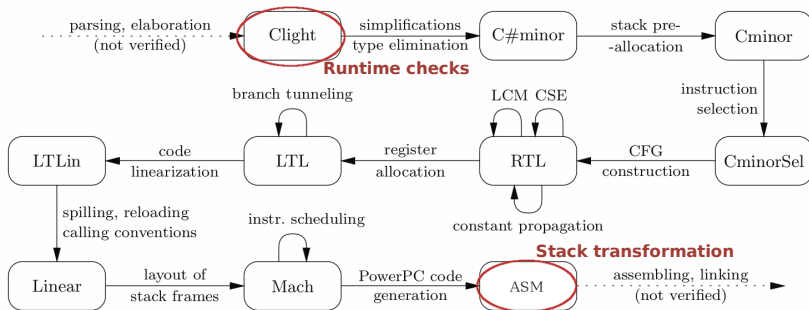
- ▶ Uses only a single *if...then...else* instruction
- ▶ In certain situation has shown better performance



Implementation environment

CompCert the certified compiler [2]

- ▶ CompCert has been proven with the proof assistant Coq
- ▶ CompCert has performance similar to gcc -O1



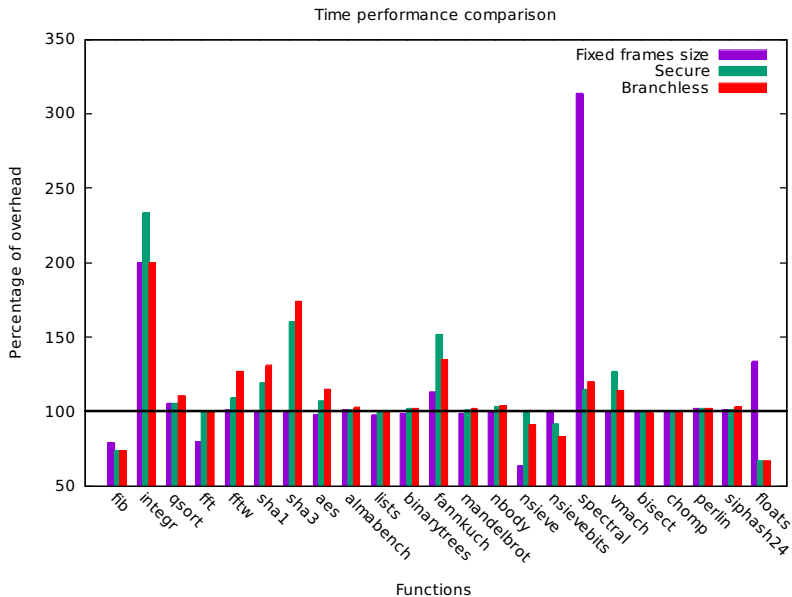
Requirements

- ▶ No modifications of the stack (inline assembly)

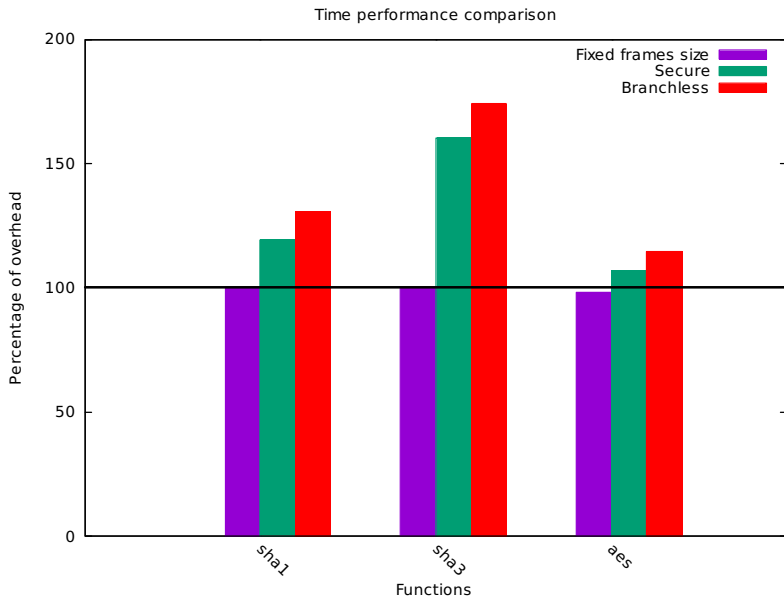
```
1  int foo(int a) {  
2  asm( '\ $sub 50, \ %esp ' );  
3  printf( "Hello world!" );  
4  }
```

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

Evaluation of performance



Evaluation of performance



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...
```

$$n = 2^8 = 0x00000100$$

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

Values

addr = 0xfffff718

mask = 0x00000000

Branchless example

Legal execution

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if (addr > 0xff000000) {  
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addr = 0xfffff718

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$$n = 2^8 = 0x00000100$$

Forbidden write destination
the program should crash

Values

addr = 0xfffff700

mask = 0x00000000

Branchless example

Illegal execution

```
if (addr > 0xff000000) {  
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