Software Fault Isolation using the CompCert compiler

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Flash vulnerable plugin

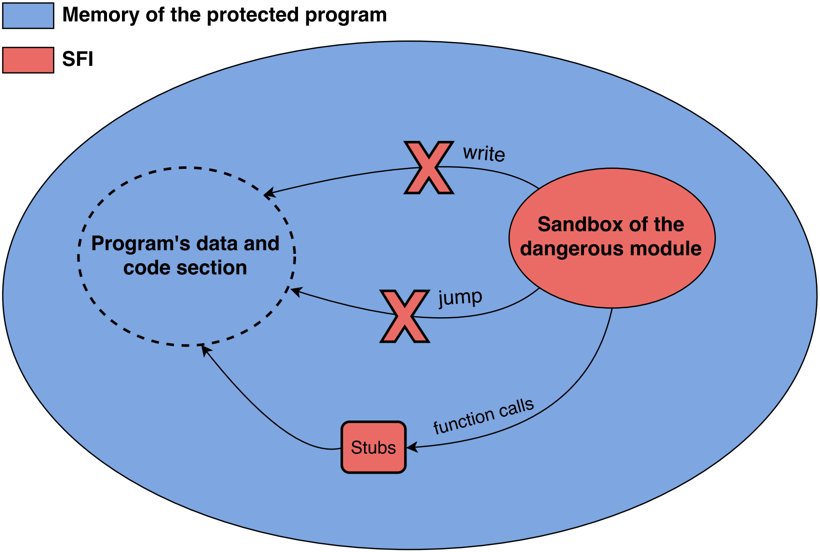
Do you know this logo?

Flash is famous for its multiple vulnerabilities
$\rightarrow$ consequences on Flash
$\rightarrow$ but ALSO endangers your browser

Goals of Software Fault Isolation (SFI)

- 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 area called sandbox
- `jump` and `write` instructions are protected by runtime checks
- function calls to the protected programs are controlled by SFI

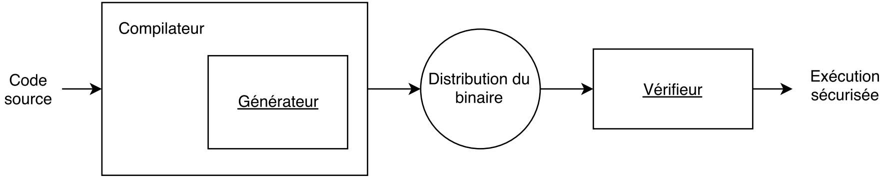
Goals of SFI


Memory of the protected program
SFI
write
jump
Program's data and code section
Sandbox of the dangerous module
function calls
Stubs

Overview of SFI

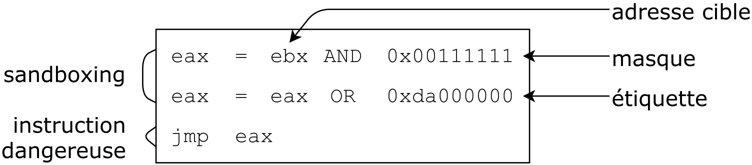
SFI chain is composed of two elements:

- 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



Sandboxing

Sandbox are continuous area identified by a tag.
For example the sandbox [`0xda000000` - `0xdaffffff`] has the tag `0xda`:



Implementations

- First implementations for RISC architecture
- NativeClient, SFI for Google Chrome x86-32, x86-64 and ARM
  - Most complete implementation of SFI
- Portable Software Fault Isolation, implementation with the certified compiler CompCert
  - Take advantages of the correctness of CompCert
  - CompCert is the compiler used for our work

Pros and cons of SFI

- Pros
  - Trusted Computing Base reduced to the verifier only
  - Faster than protection by process separation
- Cons
  - Architecture dependant
  - Slows down the modified modules (between 5% and 21% depending on the implementation)

Problematics of SFI

- SFI has difficulties to deal with indirect jump through return addresses
- SFI is still vulnerable to Return Oriented Programing (ROP) attacks
- ROP attacks are one of the most common attacks in the industry
- We propose a solution to solve this issue

ROP attack example (1/3)

```
void evil_code() {
  printf("Argh, we got hacked!\n");
}

void foo(char* input){
  char buf[1];
  ... code ...
  strcpy(buf, input);
  ... code ...
}
```

ROP attack example (2/3)

terminal$ ./buffer $(python -c 'print 13*"a" + "\x7b\x84\x04\x08"')

Address of evil_code = 0x0804847b

Stack before:

0xf7712000

0xff957998

0xf7593d26

0xf7712d60

0x0804868c

0xff957978

0xf7593d00

0xf7713dc0

0xf77828f8

0xff957998

0x08048510 //Return address of *foo*

ROP attack example (3/3)

Stack after :
0xff958161
0xff957998
0xf7593d26
0xf7712d60
0x0804868c
0xff957978 //Buffer overflow
0x61593d00 //“a”
0x61616161 //“aaaa”
0x61616161 //“aaaa”
0x61616161 //“aaaa”
0x0804847b //"\x7b\x84\x04\x08", *evil_code* address
Argh, we got hacked! //Success! *evil_code* was executed
Segmentation fault (core dumped)

Modern ROP attacks

- ROP attacks are a common kind of attack in the industry
- Modern ROP attacks are much more complicated
- *Return-to-libc* attacks uses code from the *glibc* library to construct malicious code and uses return addresses to execute it

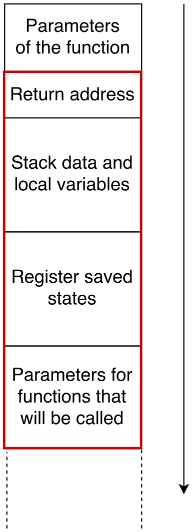
Goals of our approach

We want to have a way to protect return addresses at runtime.

- Modifications of the memory layout in order to have an easy way to know return addresses location
- Code transformations which add runtime checks on the dangerous instruction in order to forbid any illegal `write` on the return addresses locations

CompCert stack

- 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



Transformations of the stack layout

All the return addresses locations a verify the equality $a \ mod \ n = 0$, with n a constant offset between the return addresses locations.

1. Set a constant offset n between all the return addresses
2. Align the stack

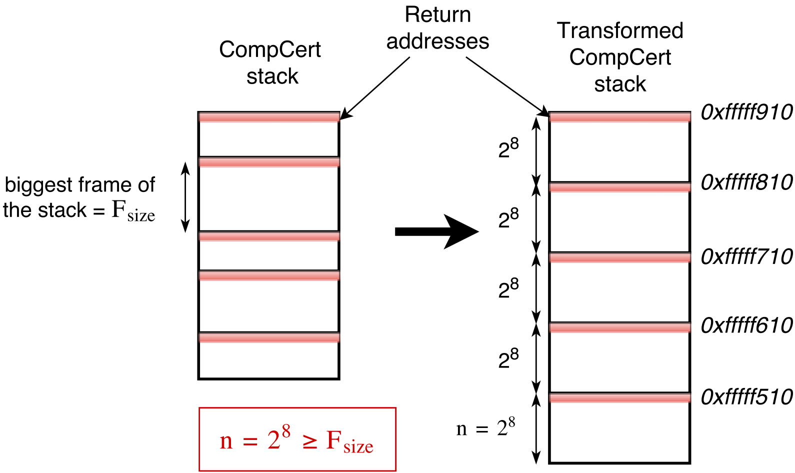
Constant offset n between return addresses (1/2)

Constant offset n between return addresses locations

- Fix frames size to n
- Pick n as the biggest frame size of the previous stack
- Pick n as a power of two

With this we have $a \ mod \ n = c$, with c the location of the first return address in the stack

Constant offset *n* between return addresses (2/2)



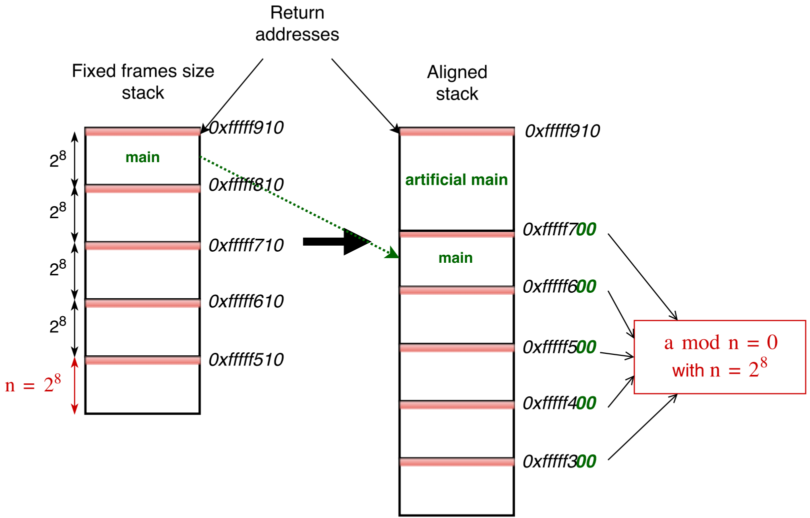
$$n = 2^8 \geq F_{size}$$

Stack alignment (1/2)

We currently have the equality $a \ mod \ n = c$ but we want $a \ mod \ n = 0$ with a any return address locations and c the first return address location in the stack.

- introduce an artificial function at the beginning of the program
- the function align the stack as we wanted
- the function then calls the *main* of the program

Stack alignment (2/2)



Injection of runtime checks

1. Check if the address is part of the stack
2. Check if the address verifies $a \ mod \ n = 0$

```
if (targeted_address > 0xff000000) {
  temp_var = targeted_address & (n-1);
  if (temp_var < 3) {
    Error behaviour
  }
}
*targeted_address = value;
Continue execution...
```

Branchless runtime checks

In certain cases branchless code shows much better performance

```
if (targeted_address > 0xff000000) {
    temp_var = targeted_address & (n-1);
    temp_var = temp_var - 3;
    temp_var = temp_var >> 31;
    temp_var = ~temp_var;
    targeted_address = temp_var &
        targeted_address;
}
*targeted_address = value;
Continue execution...
```

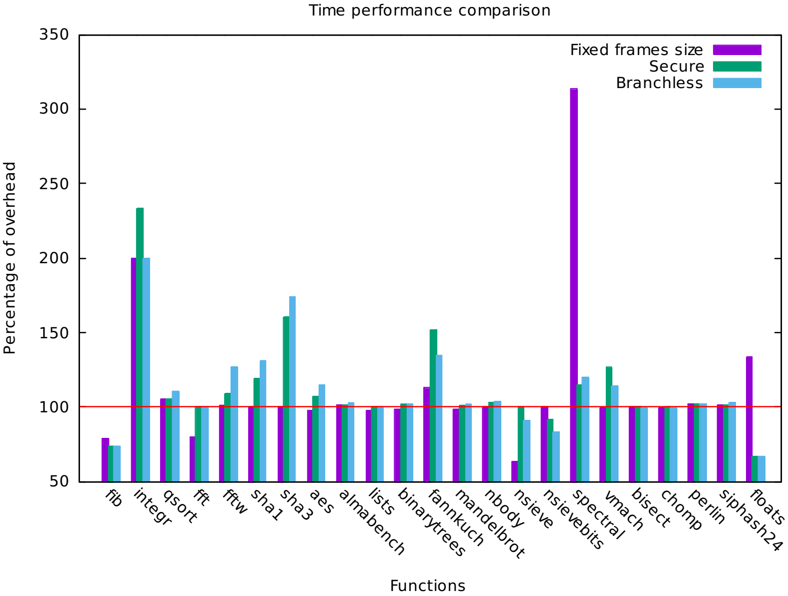
Conditions of our approach

- No modifications of the stack (inline assembly)

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

- Need to recompile extern libraries with the same frames size

Evaluation of performance (1/2)



Discussion

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