It's a TRaP: Table Randomization and Protection against Function-Reuse Attacks

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Goals

- Preventing Function-Reuse Attacks: COOP and RILC

  → Prevent disclosure of function pointers

  → Hide code layout

Adversary Model

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+ W^X
+ X-only
+ JIT-cache protection

Outline

- Extended COOP
- Dynamic Linking
- PLT Randomization
- Vtable Randomization
- Implementation
- Performance
- Security Evaluation

Extended COOP

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- Regular main loop gadget (ML-G):
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  - iterate over container of objects
- Alternative ML-Gs:
  - Recursive: REC-G
  - Unrolled: UNR-G

Extended COOP: REC-G

```
class X {
public:
    virtual ~X();
};

class Y {
public:
    virtual void unref();
};
```

```
class Z {
public:
    X* objA;
    Y* objB;

    virtual ~Z() {
        delete objA;
        objB->unref();
    }
};
```

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```

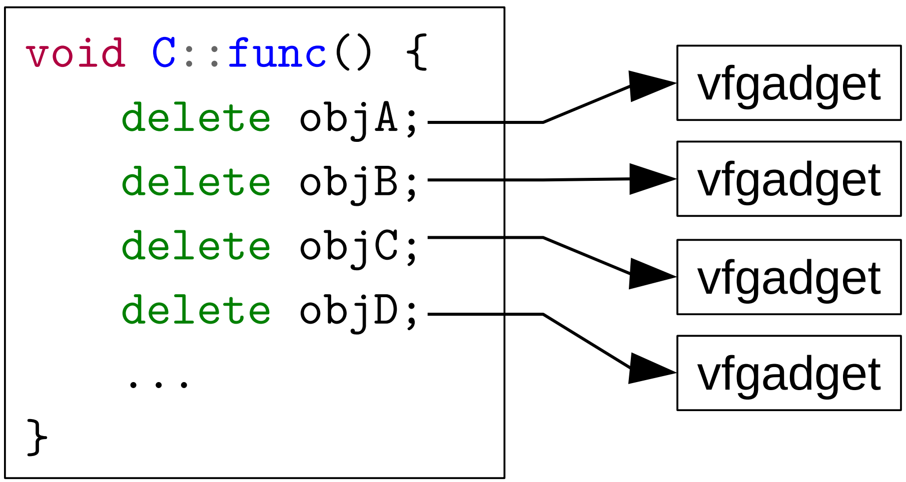
arbitrary vfgadget

recursion

Extended COOP: UNR-G

```
void C::func() {
    delete objA;
    delete objB;
    delete objC;
    delete objD;
    ...
}
```

Extended COOP: UNR-G



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  - Addresses of symbols not known at compile time

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- Libraries can be loaded at runtime
  - Addresses of symbols not known at compile time
- Global Offset Table & Procedure Linkage Table are used to resolve addresses at runtime

Dynamic Linking:
Global Offset Table

some_lib.h:

```c
extern int foo;
```

```c
#include "some_lib.h"

...
foo = 3;
...
```

some_lib.so:

foo

Dynamic Linking: Global Offset Table

some_lib.h:

```
extern int foo;
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```
#include "some_lib.h"


...
foo = 3;
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```

```


...
6d4: movl    $0x3, 0x20095a(%rip)
...
```

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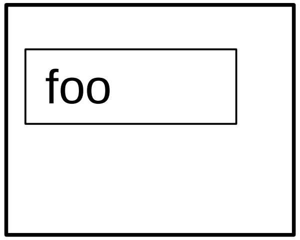

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```
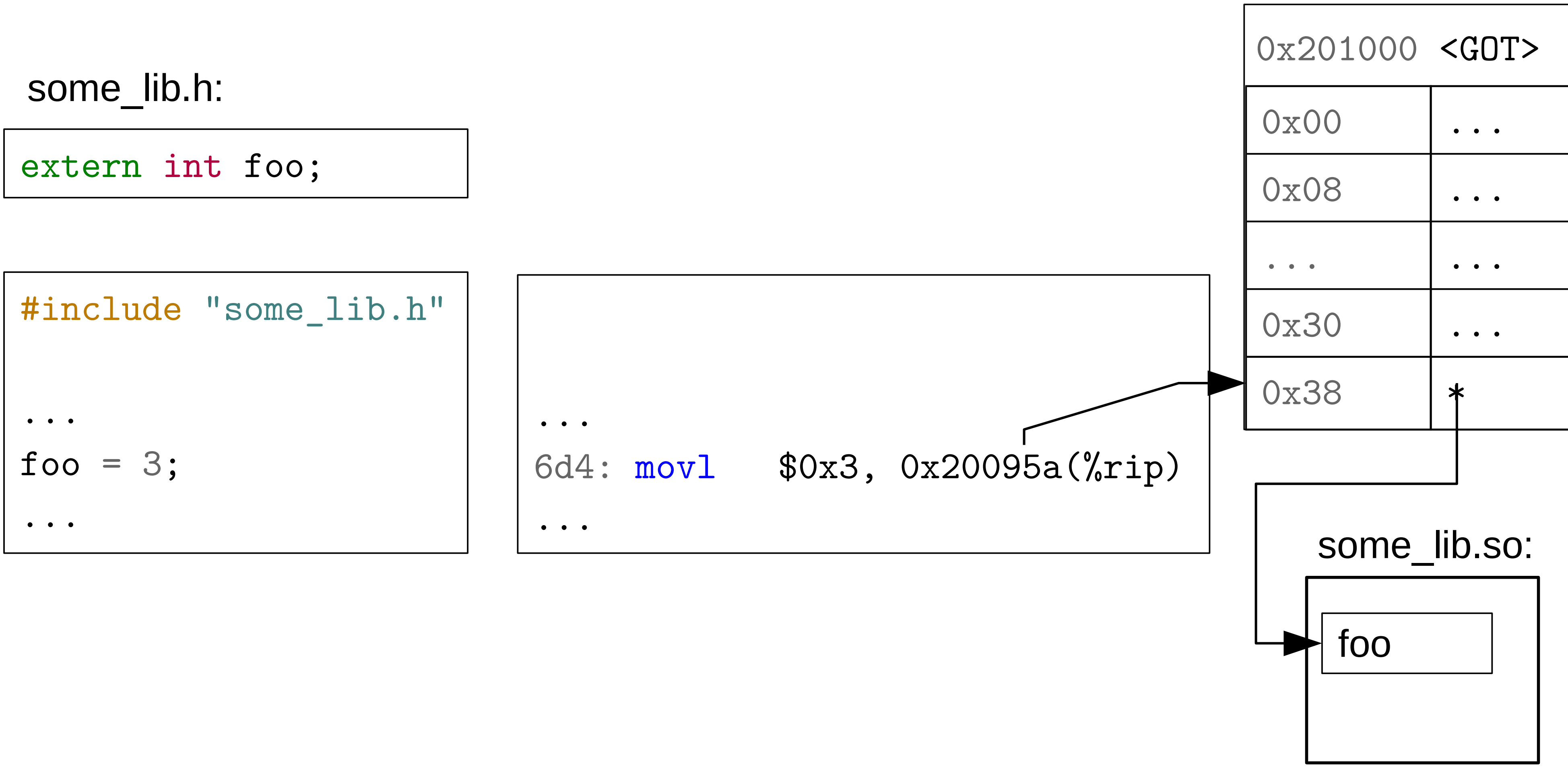

0x201000 <GOT>	
0x00	...
0x08	...
...	...
0x30	...
0x38	*

some_lib.so:

foo

Dynamic Linking: Global Offset Table



Dynamic Linking: Procedure Linkage Table

some_lib.h:

```
void fun(void);
void fun2(void);
```

```
#include "some_lib.h"


...
fun();
...
```

some_lib.so:

fun
fun2

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  690: pushq  0x200972(%rip)
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  69c: nopl   0x0(%rax)
6a0 <fun2@plt>:
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  6a6: pushq  $0x0
  6ab: jmpq   690 <.plt>
6b0 <fun@plt>:
  6b0: jmpq   *0x20096a(%rip)
  6b6: pushq  $0x1
  6bb: jmpq   690 <.plt>

...
819: callq  6b0 <fun@plt>
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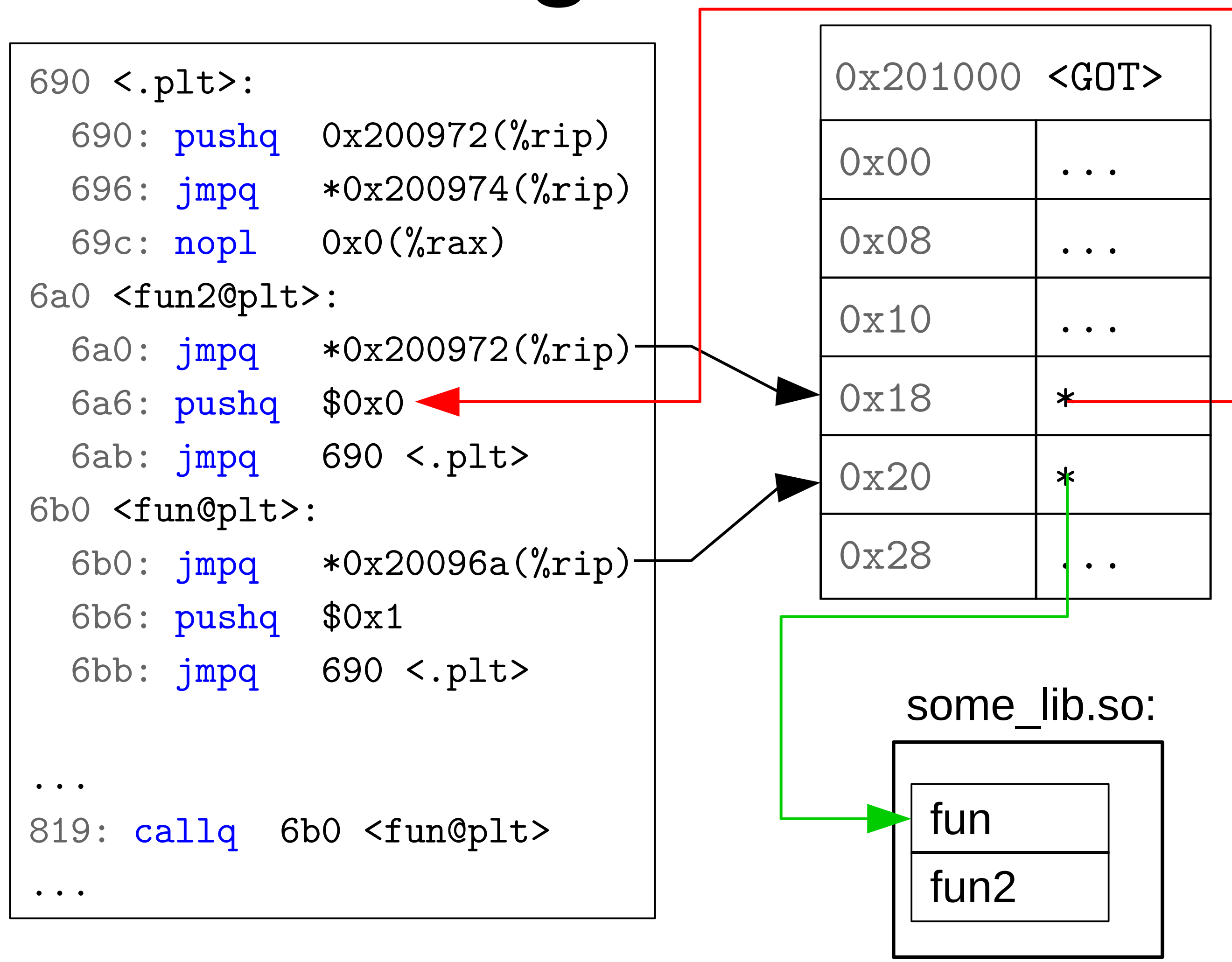

Problems with GOT and PLT

- Global Offset Table has to be stored in read-writable memory

    → Adversary can read code pointers and infer memory layout

PLT Randomization

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- Place PLT in X-only memory
- Eager binding (instead of lazy)
- Insert booby traps
- Randomize order of PLT entries
- Call using trampolines

Vtable Splitting

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class A {
public:
    virtual void funA();
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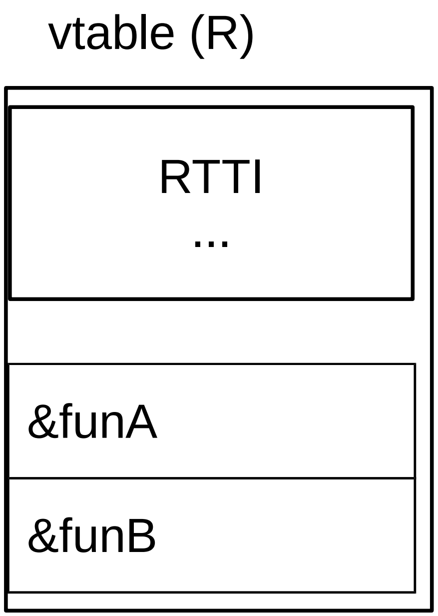
};
```



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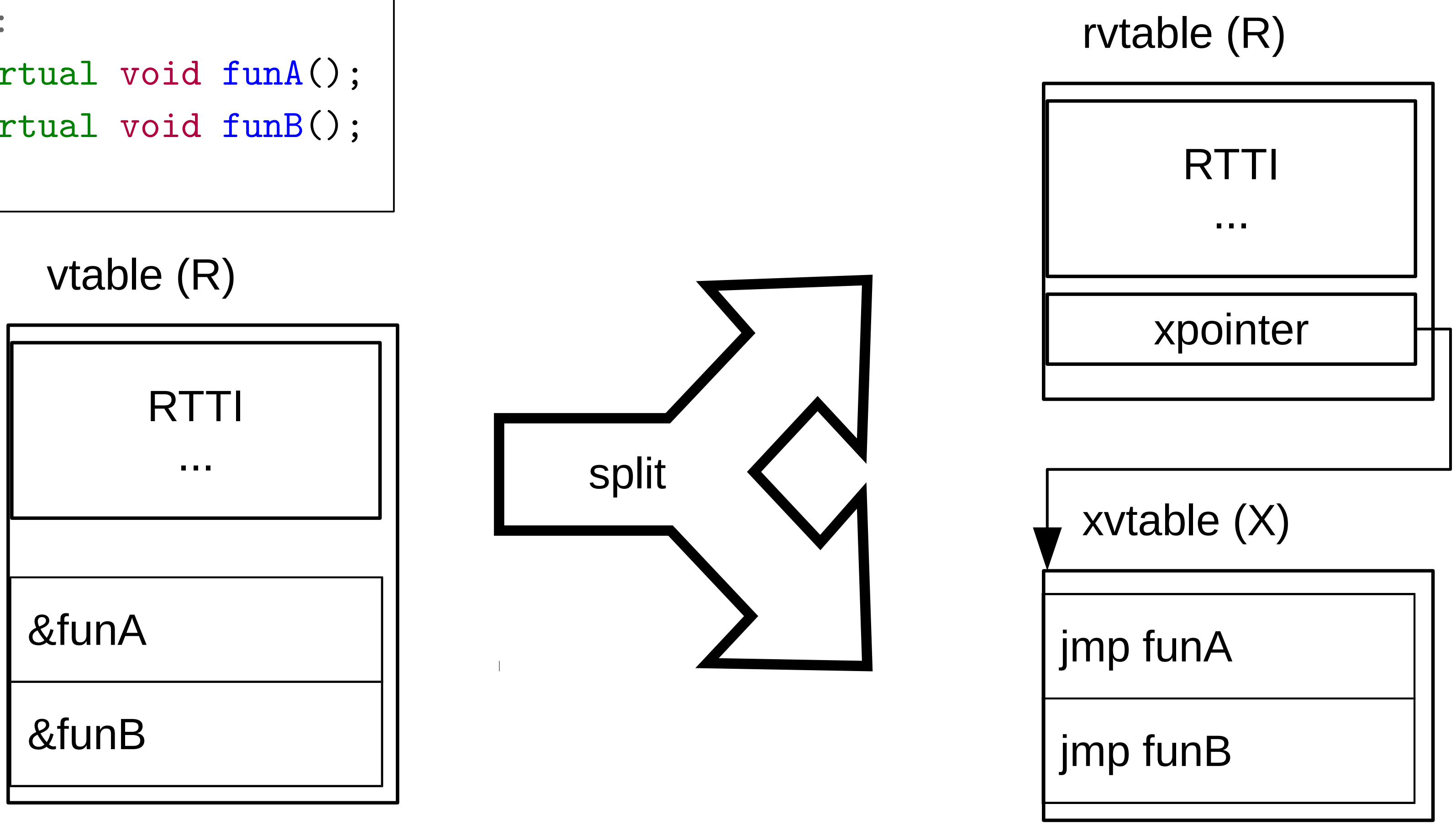

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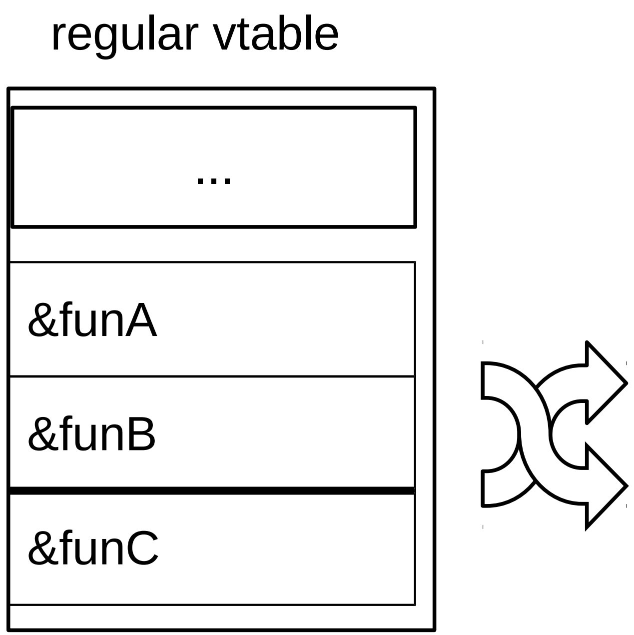

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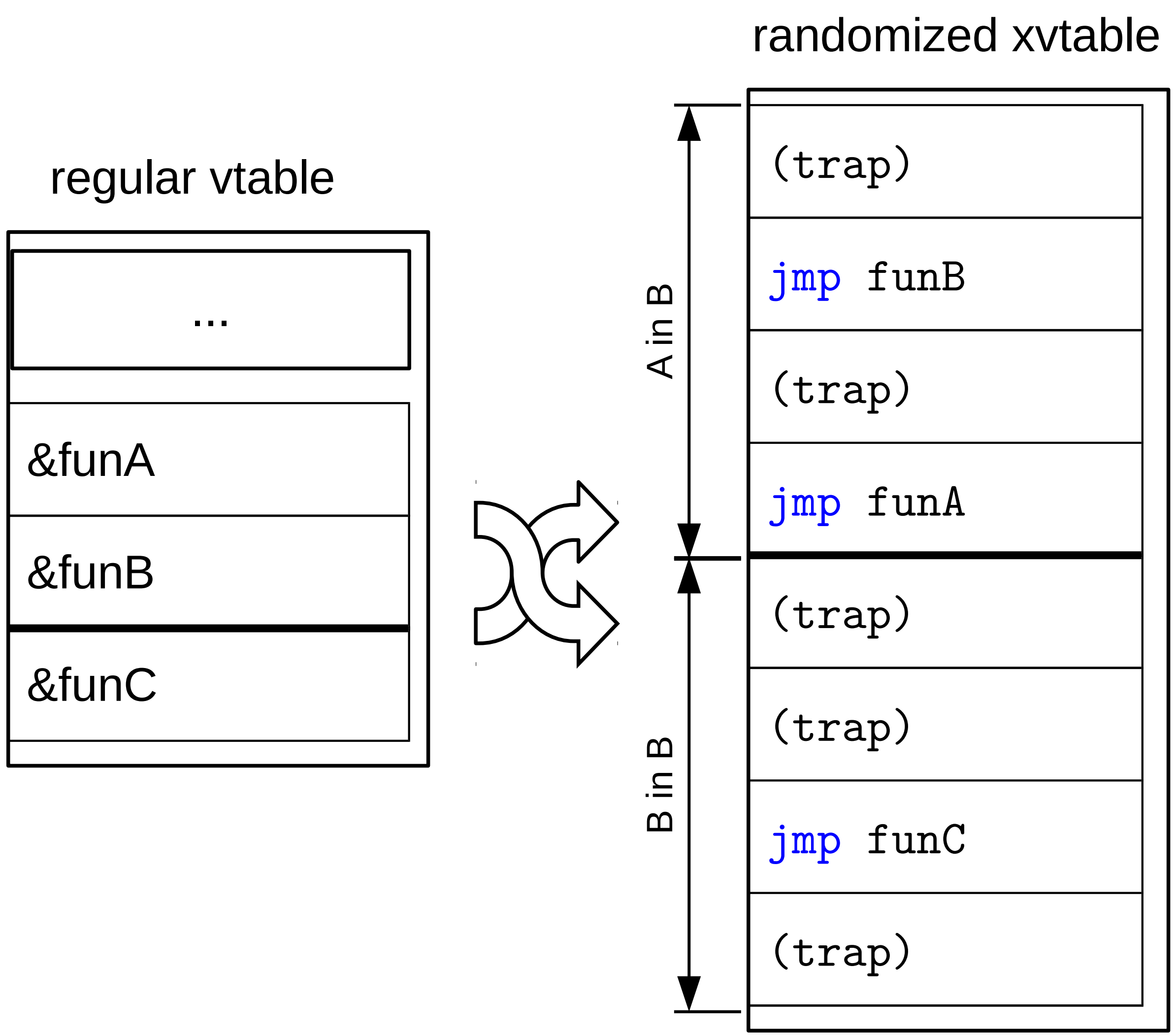

Vtable Randomization: Virtual Function Call

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void example(void) {
    A* x = ...;
    x->funA();
}
```

xvtable (X)

```
(trap)
jmp funB
(trap)
jmp funA
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Vtable Randomization: Virtual Function Call

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void example(void) {
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}
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```
example:
    jmp <trampoline0>
return_site0:
    ...
```

```
trampoline0:
    call x->vtable->xvtable[3]
    jmp <return_site0>
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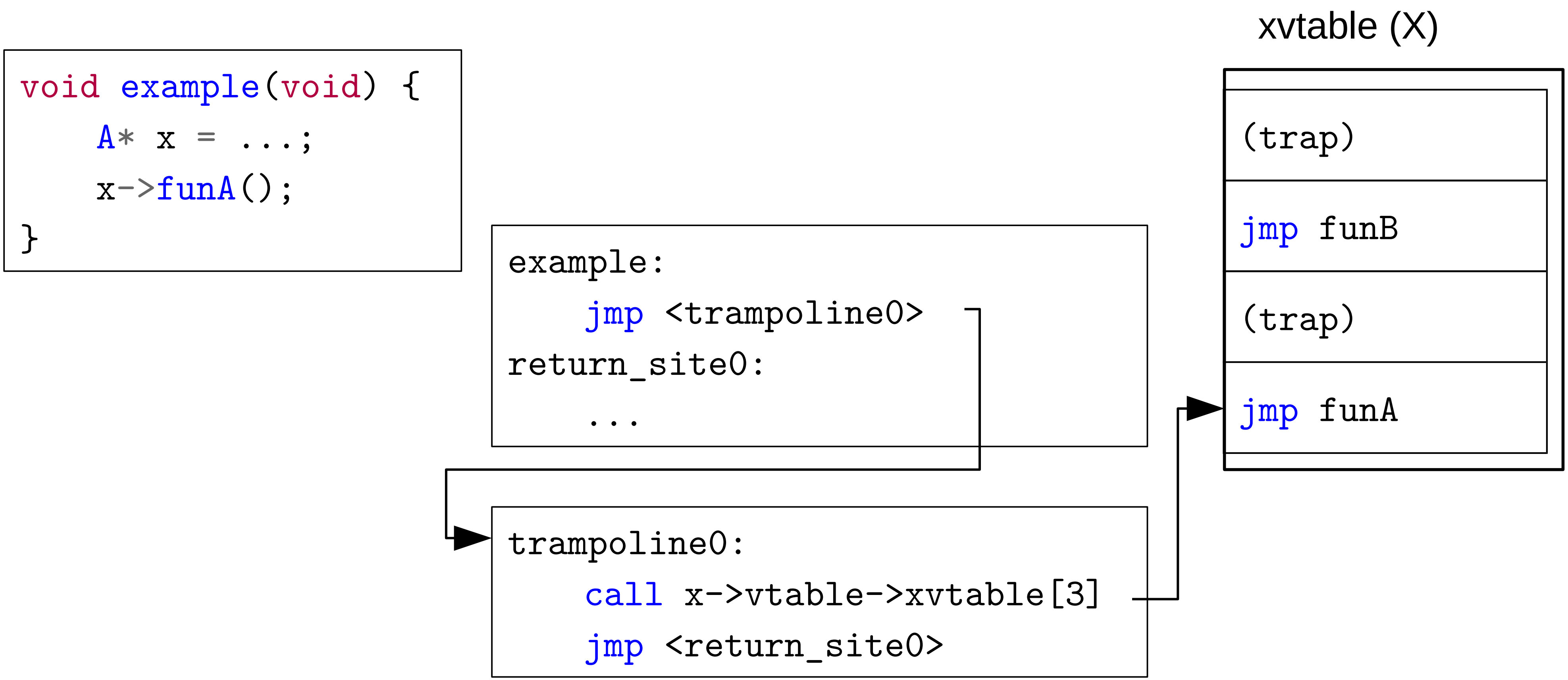

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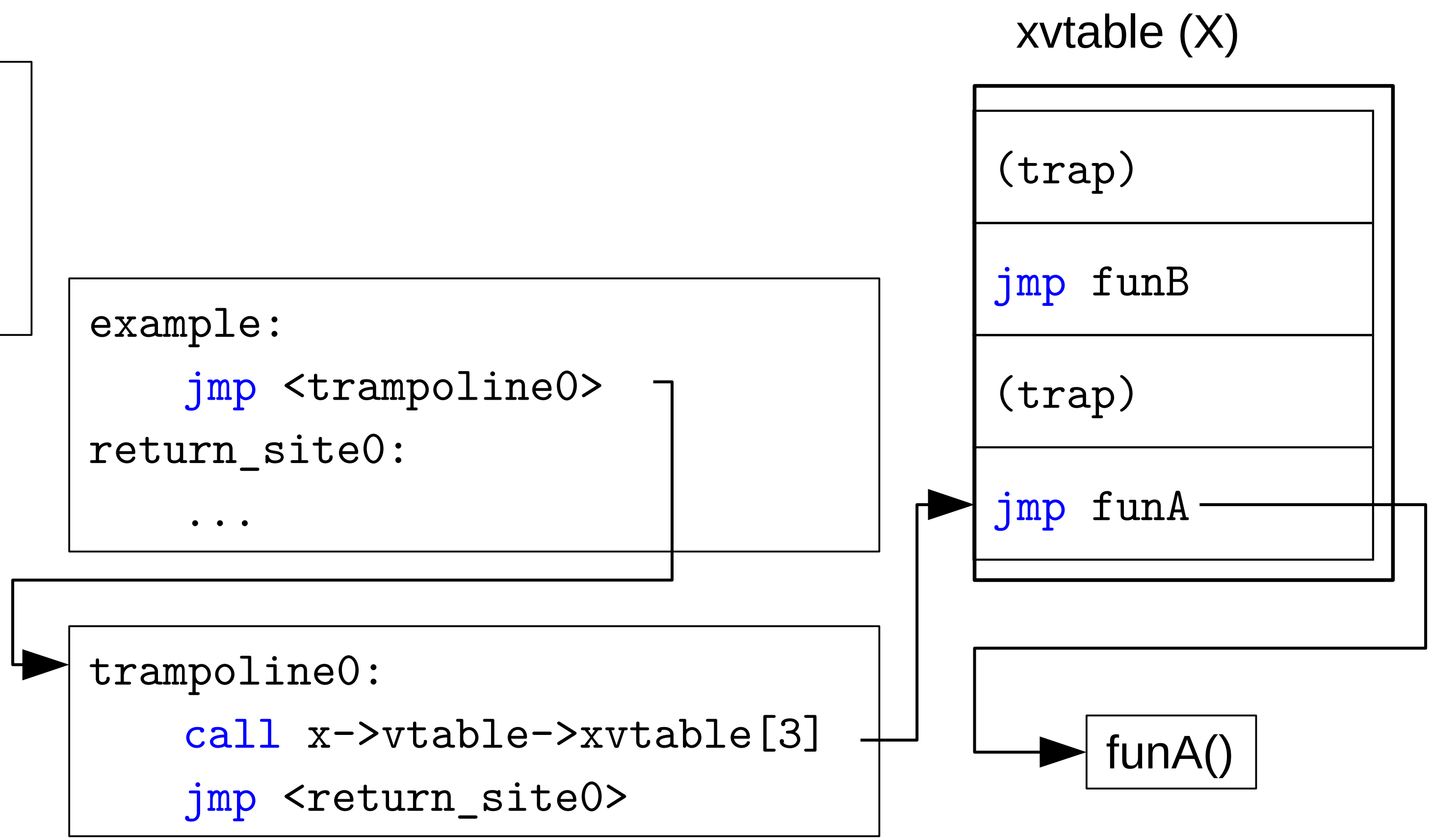

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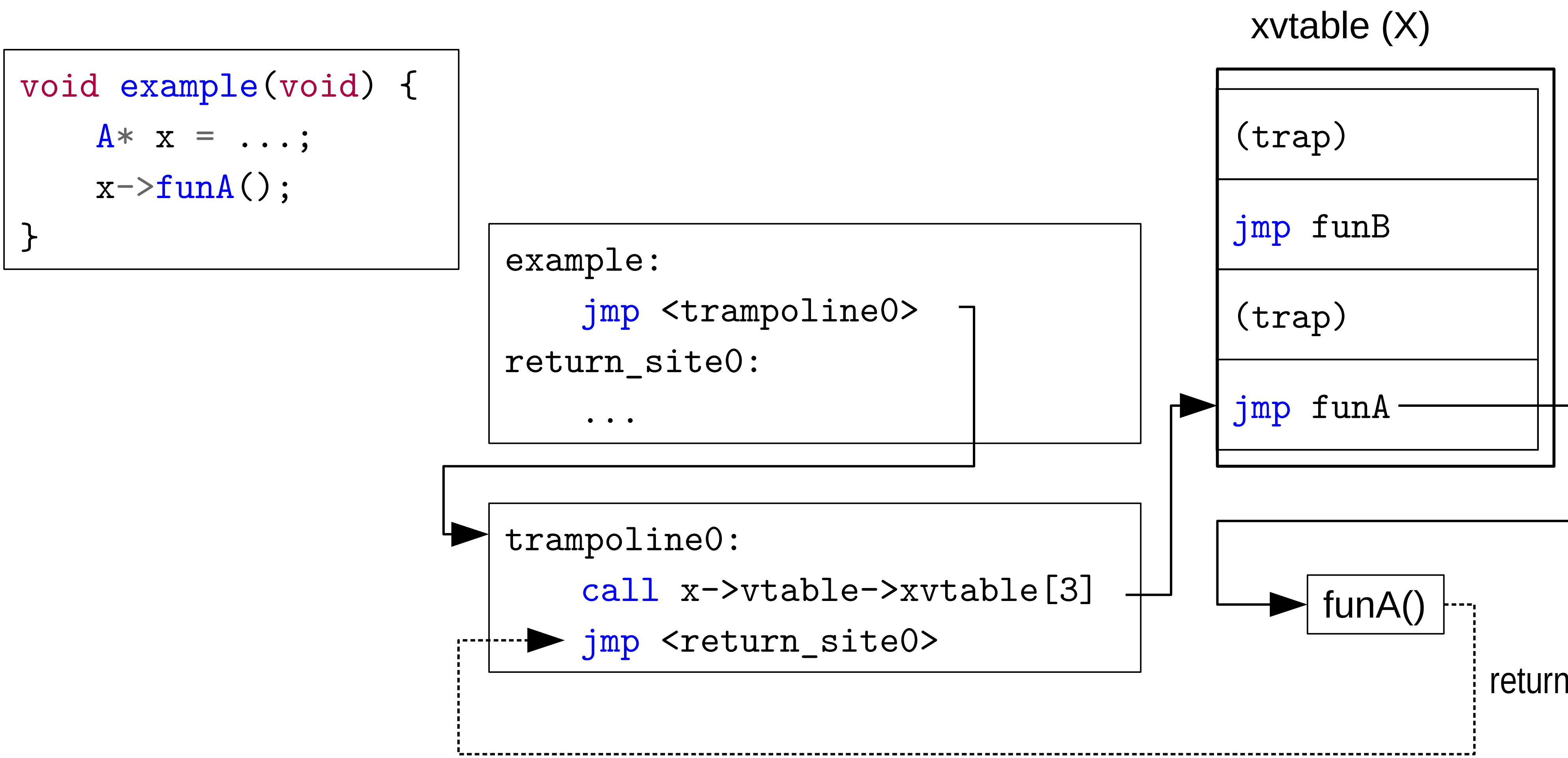

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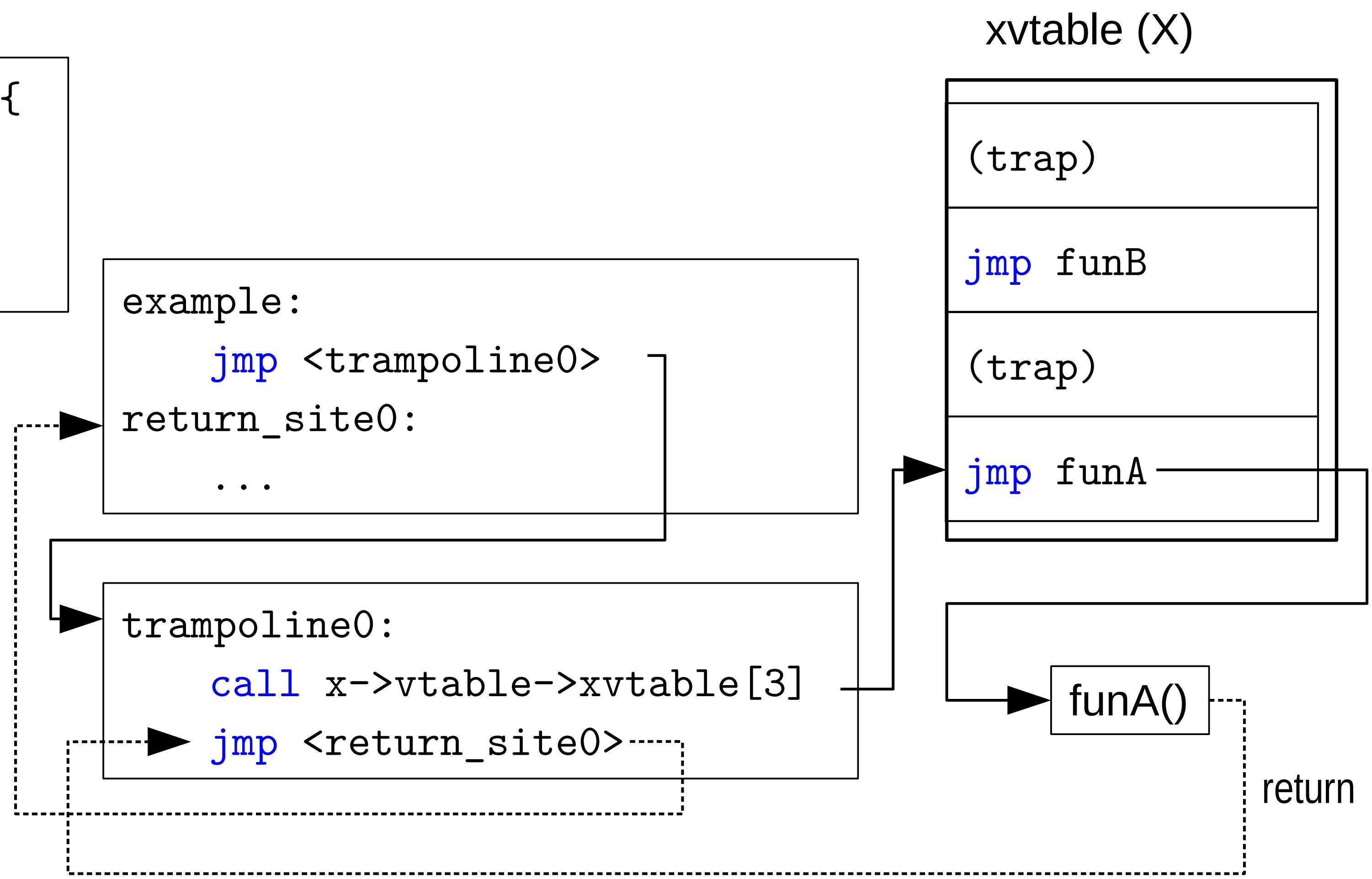

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- Extends Readactor (protects against ROP)
- Modified Clang:
  - Ensure separation of code and data
  - Collect *TRaP* information
- At program start: RandoLib
  - Perform randomization
  - Rewrite call-sites
  - Unloaded afterwards

Performance

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- Memory overhead negligible (?)

Security Evaluation

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(Ignoring side channels)

- Attacker can only disclose code pointers to trampolines
  - Cannot infer location of other functions from that
- Program-allocated function pointer tables are unprotected
- Probability of correctly guessing 3 vfgadgets $< (1/16)^3 \approx 0.024$ %

References

– Stephen Crane, Stijn Volckaert, Felix Schuster, Christopher Liebchen, Per Larsen, Lucas Davi, Ahmad-Reza Sadeghi, Thorsten Holz, Bjorn De Sutter, Michael Franz. *“It’s a TRaP: Table Randomization and Protection against Function-Reuse Attacks.”*

– Michael Matz, Jan Hubička, Andreas Jaeger, Mark Mitchell. *“System V Application Binary Interface AMD64 Architecture Processor Supplement Draft Version 0.99.6”*

Questions?