What has my compiler done for me lately��

unSeegmentat Speech)

Agenda

1. Actual shellcode attacks.
2. Stack/Heap based exploits
   a. W^X memory.
3. Return Oriented Pro
   a. Stack Cookies
   b. Shadow Call Stack
4. Indirect control flow & c++ vtable attack
   a. CFI

Shellcode Attacks

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- The encoded instructions that are interpreted by the CPU.

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```

- Managed code (Javascript):
  - Sandboxed. Can only access very specific things.
  - All interaction managed by interpreter.
- Shellcode:
  - Full access to the system. Run directly on hardware.
- Two different attack types:

Shellcode Attack Types

- Remote attacks?

Shellcode Attack Types

- Remote attacks.
  - We have no ability to run unmanaged code.
  - Goal?

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- Local attacks?

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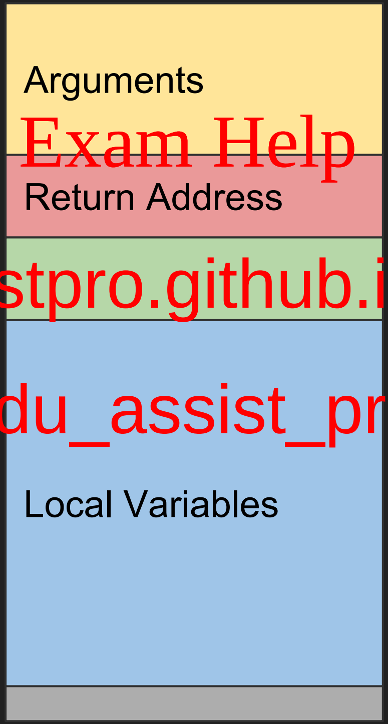
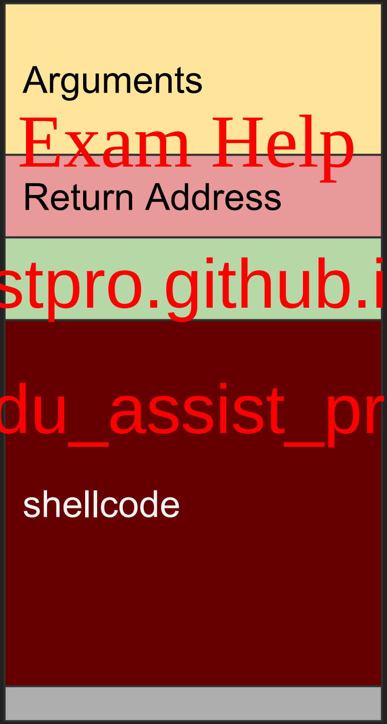
- Local attacks.
    - We have shellcode access on the machine.
    - Goal?
        - Privilege escalation.
    - Targets?
        - Kernel, hypervisor, any process running as a different user/group.

Stack based exploits



Stack based exploits

1. Overwrite the local variables
    a. Buffer overflow
    b. Use after return
    c. Use after scope



Stack based exploits

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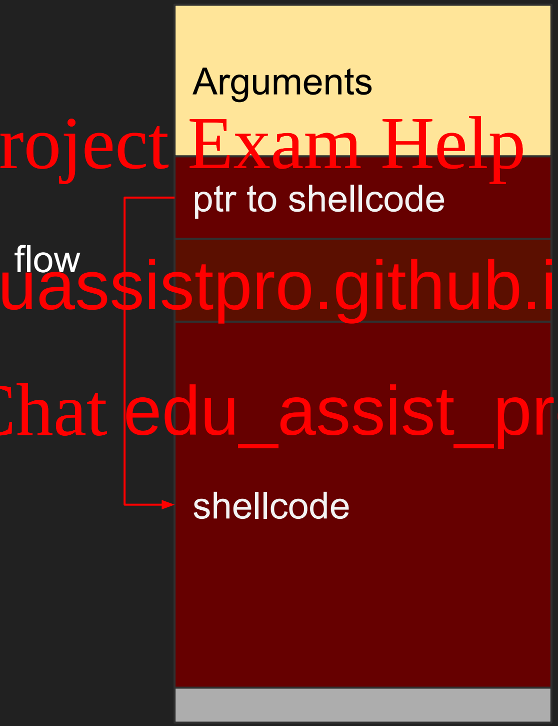
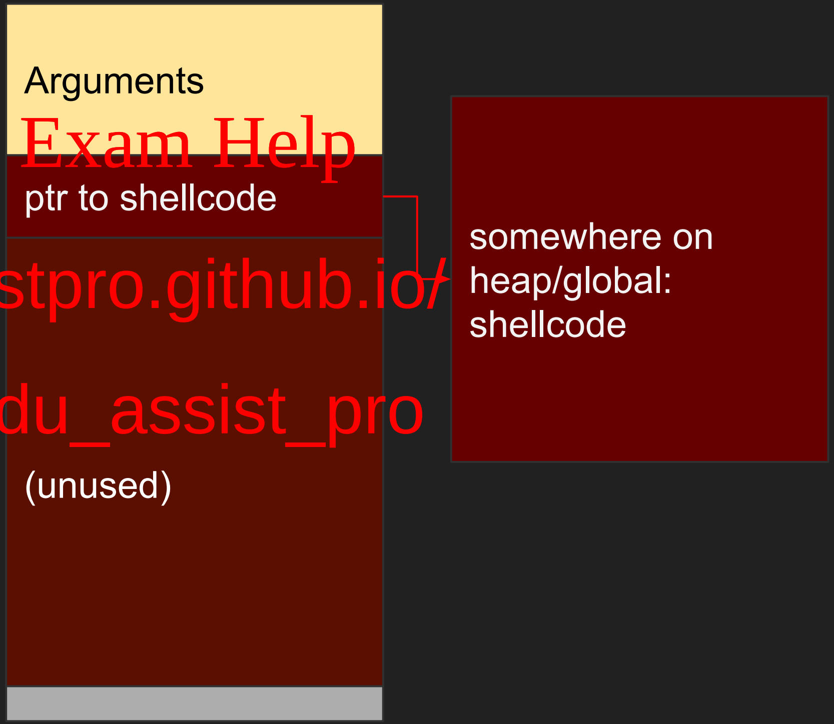
2. Overwrite the return



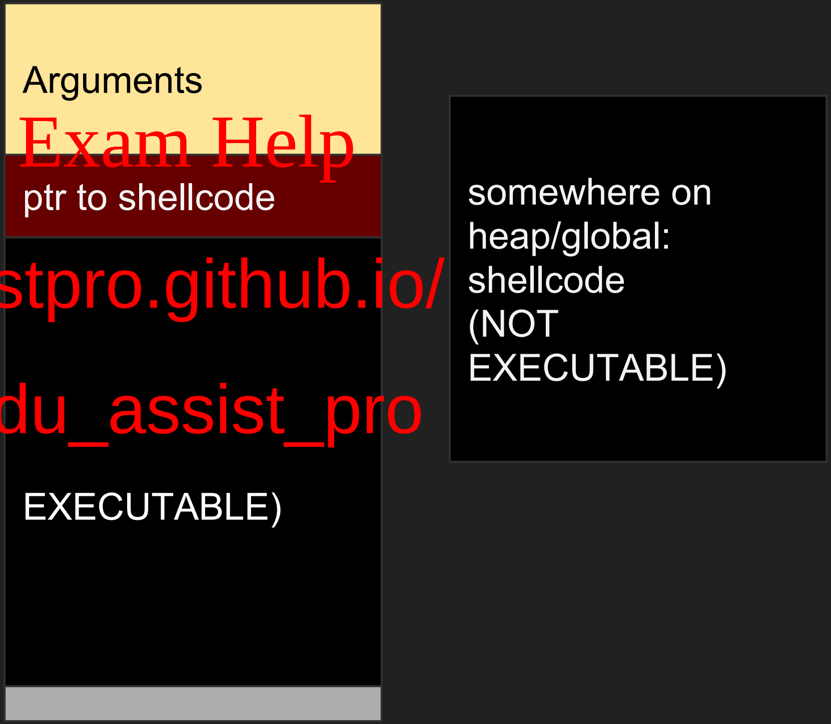
Heap based exploits

1. Add shellcode to heap:
   a. Heap buffer overflow
   b. Use after free
   c. Global buffer overflo
   d. Initialization order b
2. Overwrite the return



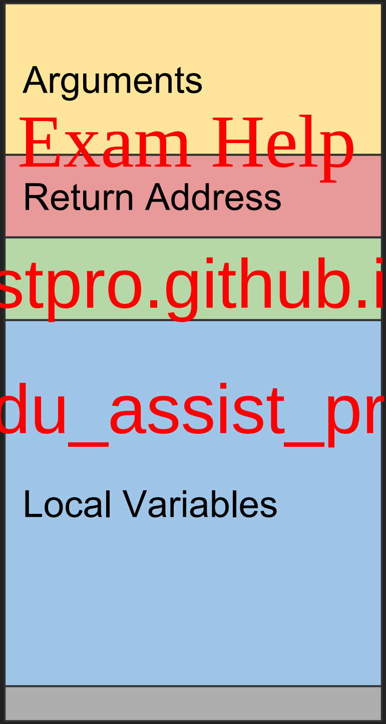
W^X Memory

- Write XOR Execute
- Can still write shellcode.
- Can't execute shellcode.
- Compiler sets sectio stack, heap, etc) me no-execute.
- Done by default on all compilers.
- Problem solved, right…?
  - Chrome still RWX v8 pages.



Return Oriented Programming

- Chains together “gadgets”, which is a sequence of a few instructions followed by ‘ret’.
- Smash stack with lo to gadgets.



Return Oriented Programming

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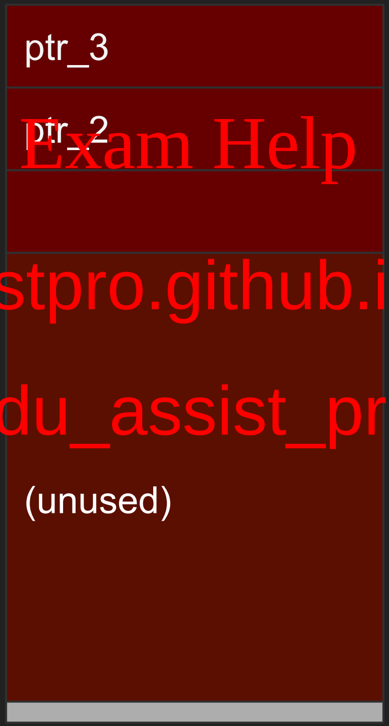
- Choose gadgets to execute shellcode we want.



Return Oriented Programming

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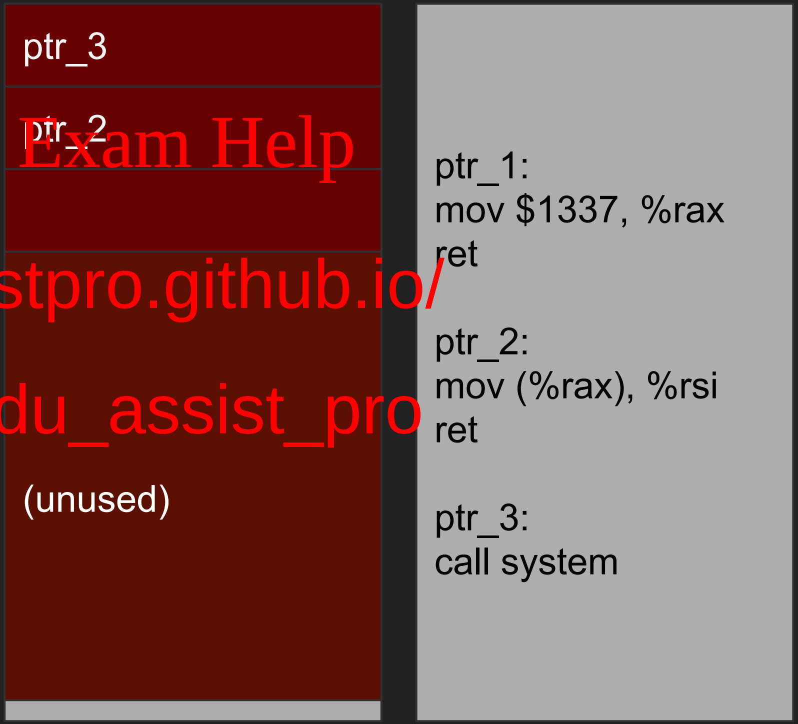
- If clever, we hide strings in other places we have write access to. Use the strings in the exploit.



ptr_3

ptr_2

(unused)

```
ptr_1:
mov $1337, %rax
ret

ptr_2:
mov (%rax), %rsi
ret

ptr_3:
call system
```

Return Oriented Programming

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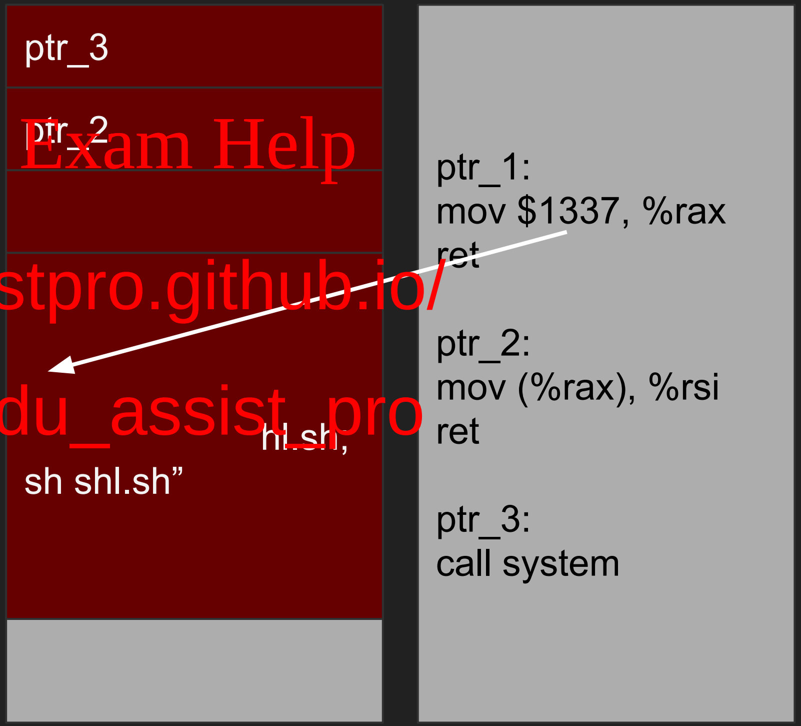

ptr_3

ptr_2

hl.sh;
sh shl.sh”

ptr_1:
mov $1337, %rax
ret

ptr_2:
mov (%rax), %rsi
ret

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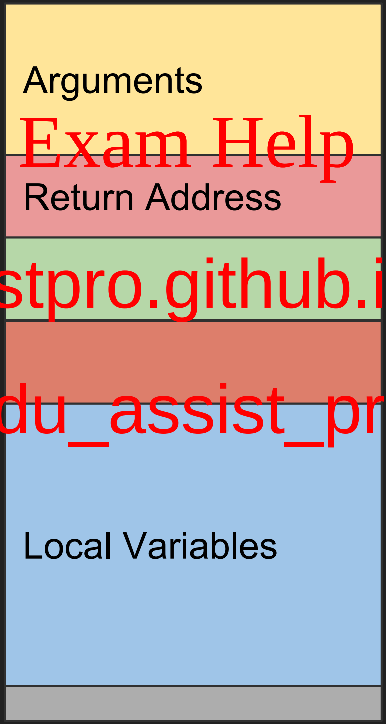
call system

Stack Cookies

- -fstack-protector
- Adds “cookie” or “canary” to stack on function entry.
- Checks it on functio
- If the cookie fails, kil

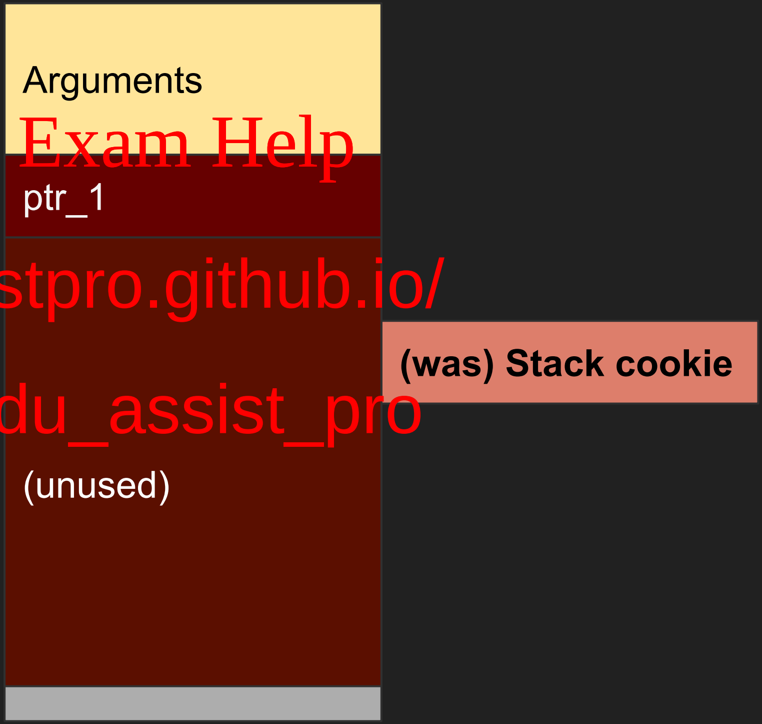


Stack Cookies

```
movq %fs:40, %rax      ; grab cookie
movq %rax, -8(%rbp)   ; save to stack
xorl %rax, %rax          ; hide the cookie

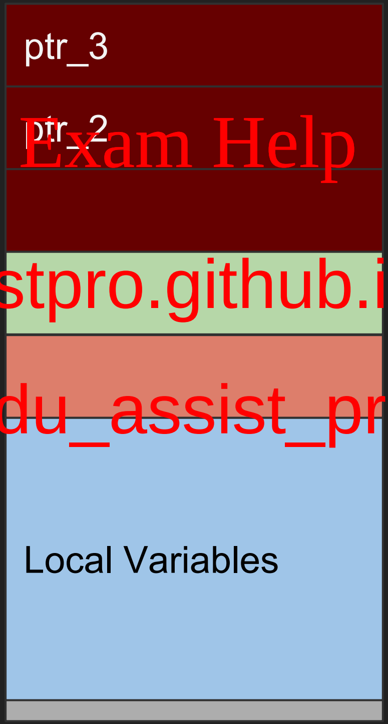
<normal function code>


movq -8(%rbp), %rax   ; get from stack
xorq %fs:40, %rax       ; compare
jnz __stack_chk_fail
ret
```



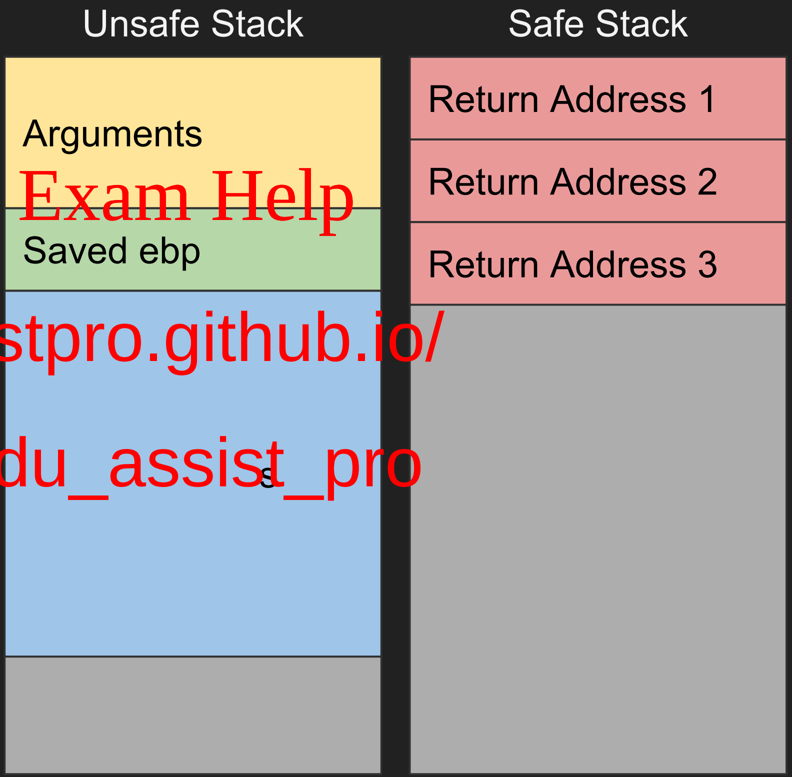
Stack Cookies

1. Overflowing the return address must write over stack cookie.
2. Cookie is hidden outside of normal memory.
3. 5.4210 * 10^(-20) ch guessing correct cookie.
4. Stops sequential write bugs, what about arbitrary write?



Shadow Call Stack

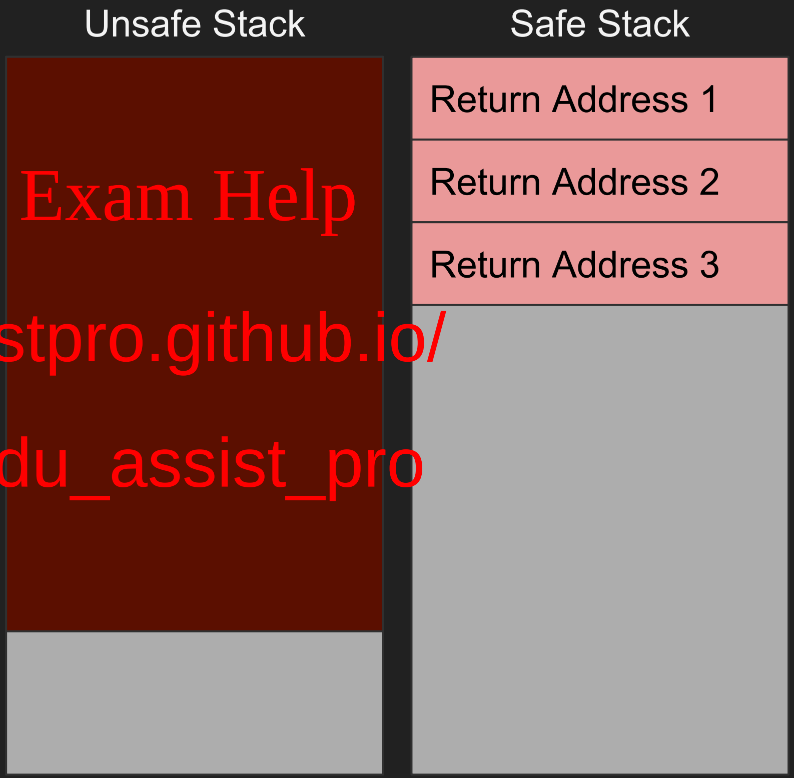
- -fsanitize=shadow-call-stack
- Another ROP defense
- Separate stacks into *safe* and *unsafe*.
- Safe contains return
- Unsafe contains everything else.



Shadow Call Stack

- Arbitrary writes are still safe as long as safe stack pointer is secret.
- Safe stack pointer is hidden:
  - Reserved register (x
  - Reserved segment (

flow



TOCTOU Vulnerabilities

- Time of Check to Time of Use (TOCTOU)
- Thread-based security race between call and pr finishing.
- Prologue #3, save return address into register at top of function entry.
- Requires stack location disclosure.

ShadowCallStack Prologue:

1. Normal function entry.
2. Allocate space on shadow stack.

shadow stack.

S k Epilogue:

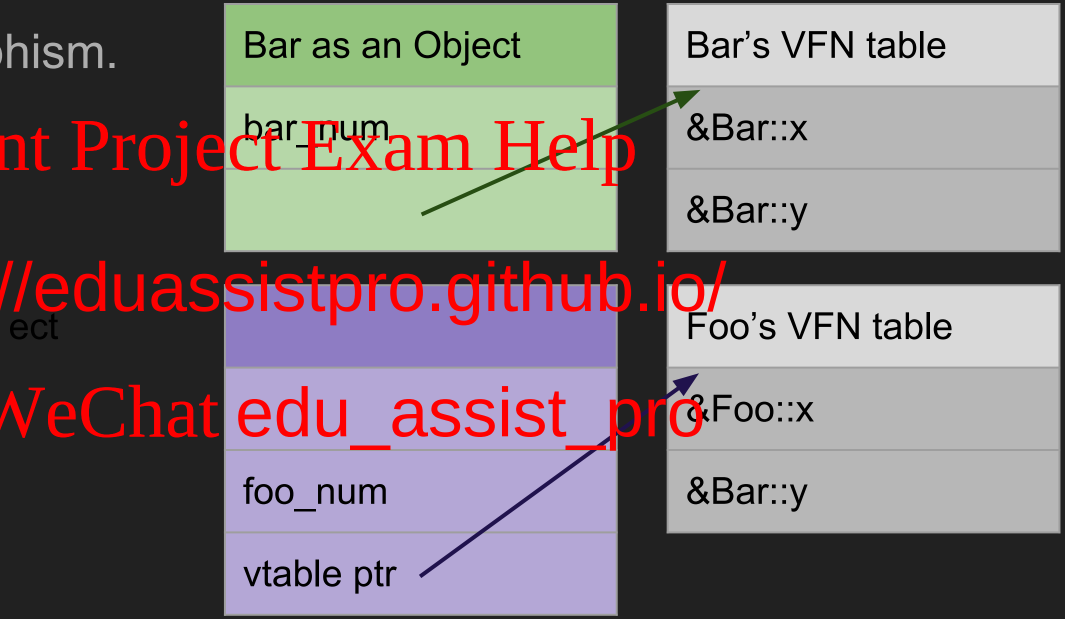
1. Pop from shadow stack.
2. Compare to return address off regular stack.
3. Fail if return address has been compromised.

C++ Virtual Function Tables

- Used to implement polymorphism.

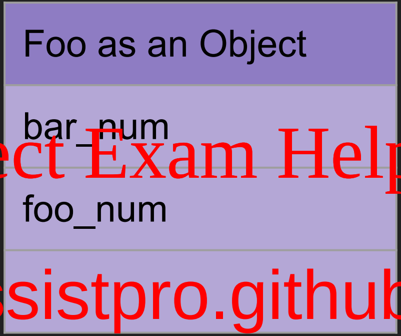
```
struct Bar {
    virtual void x() { … }
    virtual void y() { … }
    int bar_num = 0;
}

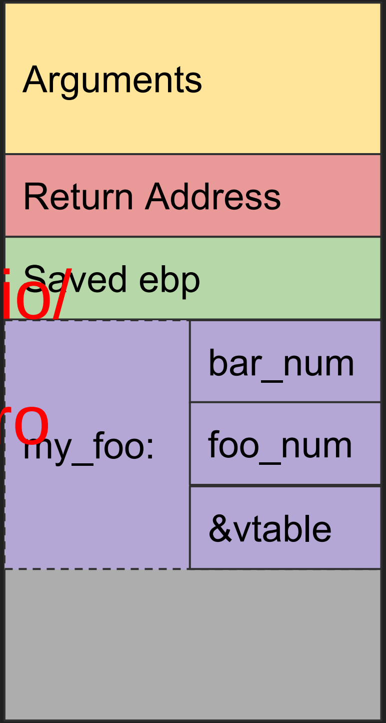
class Foo : Bar {
    void x() override { … }
    int foo_num = 0;
}
```



C++ Virtual Function Tables

```
int x() {
        Foo my_foo;
        foo.x();
}
```

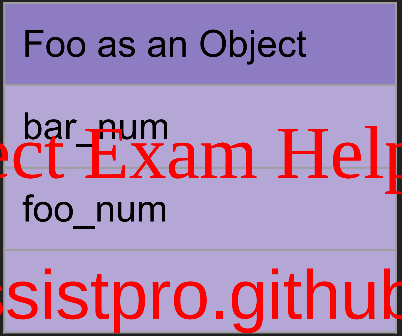




C++ Virtual Function Tables

```
int x() {
        Foo my_foo;
        foo.x();
}

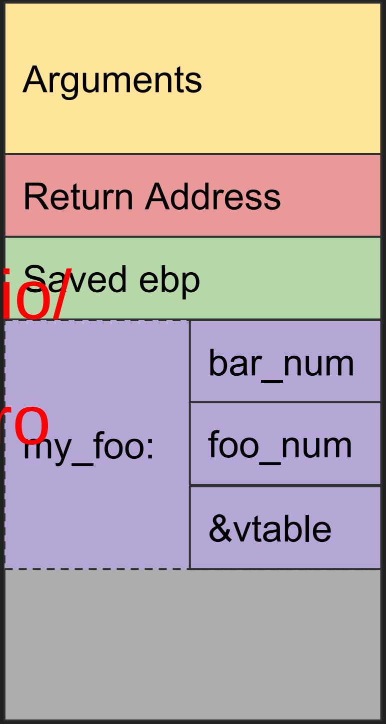

x:
<create my_foo on stack>
movq -8(%rsp), %rdi     ; get vtable ptr
movq $0, %rsi           ; index of &Foo:x
movq %rsi(%rdi), %rdi   ; get &Foo:x
callq *(%rdi)           ; call &Foo:x
```



Foo as an Object

bar_num

foo_num



Arguments

Return Address

Saved ebp

my_foo:

bar_num

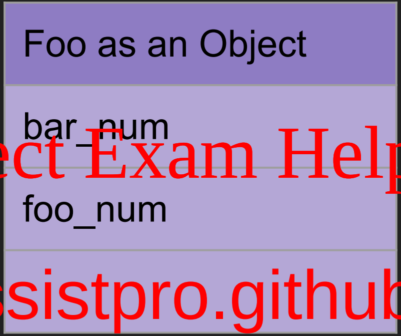
foo_num

&vtable

C++ Virtual Function Tables

- Add some dangerous code and...

```
int x() {
    Foo my_foo;
    char buffer[255];
    fgets("%s", buffer);
    foo.x();
}
```



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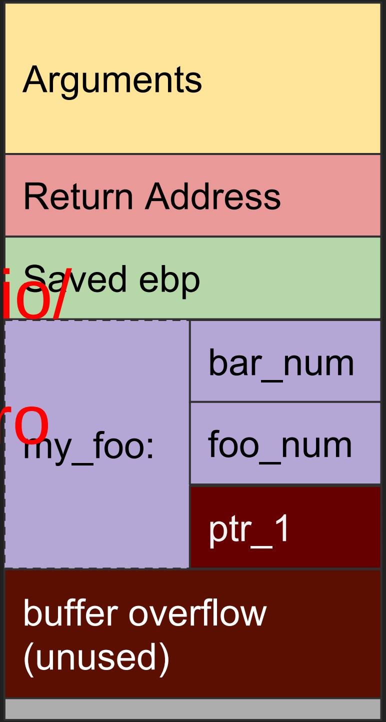


Arguments

Return Address

Saved ebp

my_foo:

bar_num

foo_num

ptr_1

buffer overflow (unused)

Control Flow Integrity (CFI)

- -fsanitize=cfi
- Adds checks to ensure correct vtable before call.
- Stops smashing vta stack/heap.
- Kills the program on sanity check failures.

```
movq -8(%rsp), %rsi    ; get vtable ptr
movq $0, %rsi          ; index of &Foo:x
call cfi_check
            %rsi
                       ; get &Foo:x
                       ; call &Foo:x

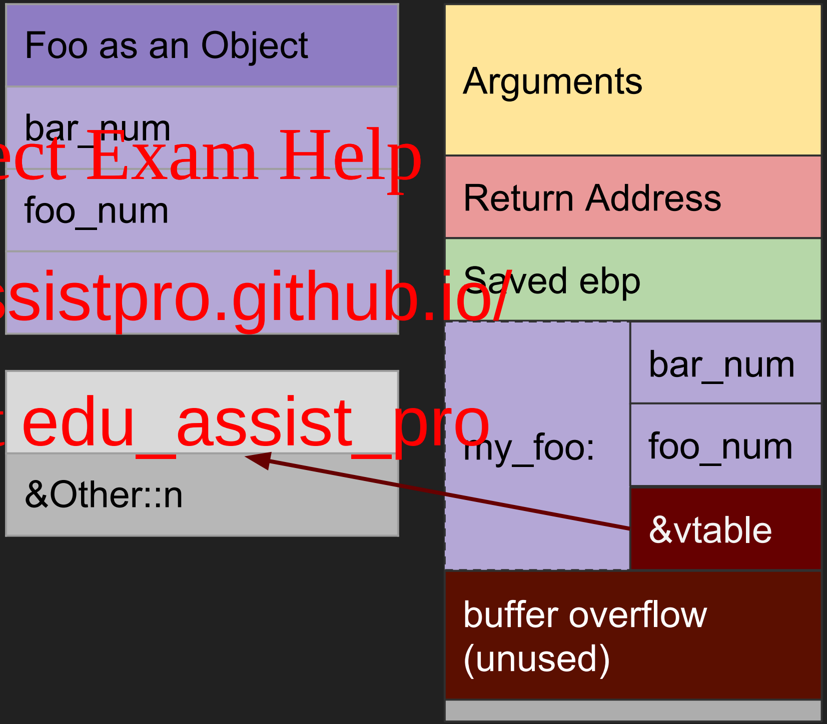
cf
; ensure table is in range and aligned
; ensure index (%rsi) is valid
```

CFI cont.

- More advanced attack: Run a different virtual function from a different class.

```
class Other {
    virtual void n();
}
```

- CFI protects against these as well.



Foo as an Object

bar_num

foo_num

&Other::n

Arguments

Return Address

Saved ebp

my_foo:

bar_num

foo_num

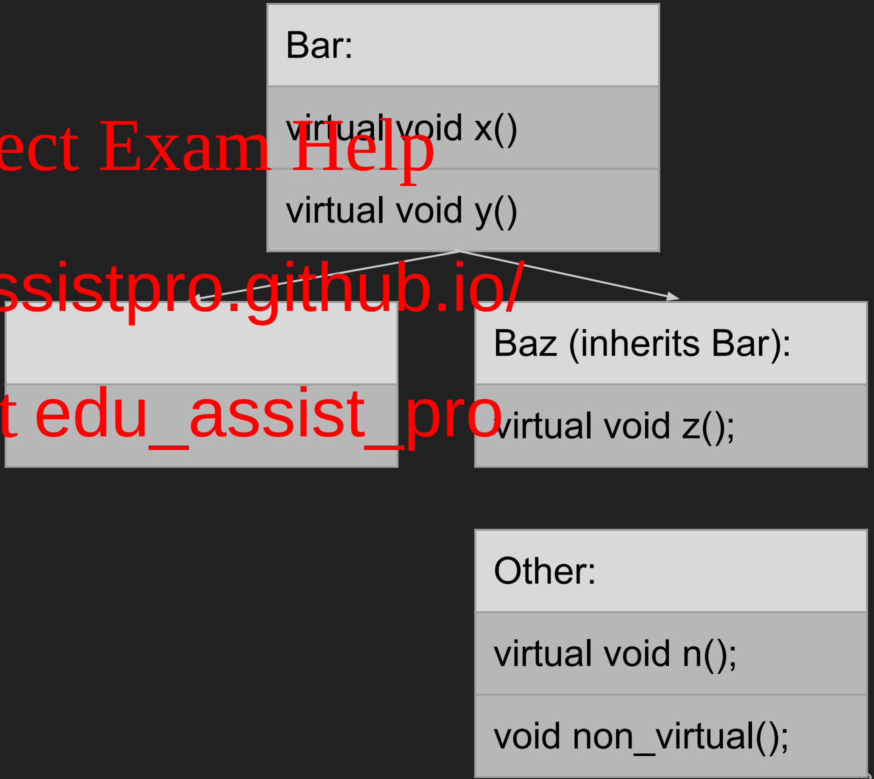
&vtable

buffer overflow (unused)

CFI Cast Checking

- CFI adds checks to all types of cast checking.

```
Baz* b1 = new Foo();
Baz* b2 = new Bar();
Bar* b3 = new Foo();           // OK
Baz* b4 = b3;                  // wrong
(Other* b3)->non_virtual(); // wrong
Bar* b6 = new Other();         // wrong
void* o = new Other();         // OK
(Bar* o)->y();                 // wrong
```

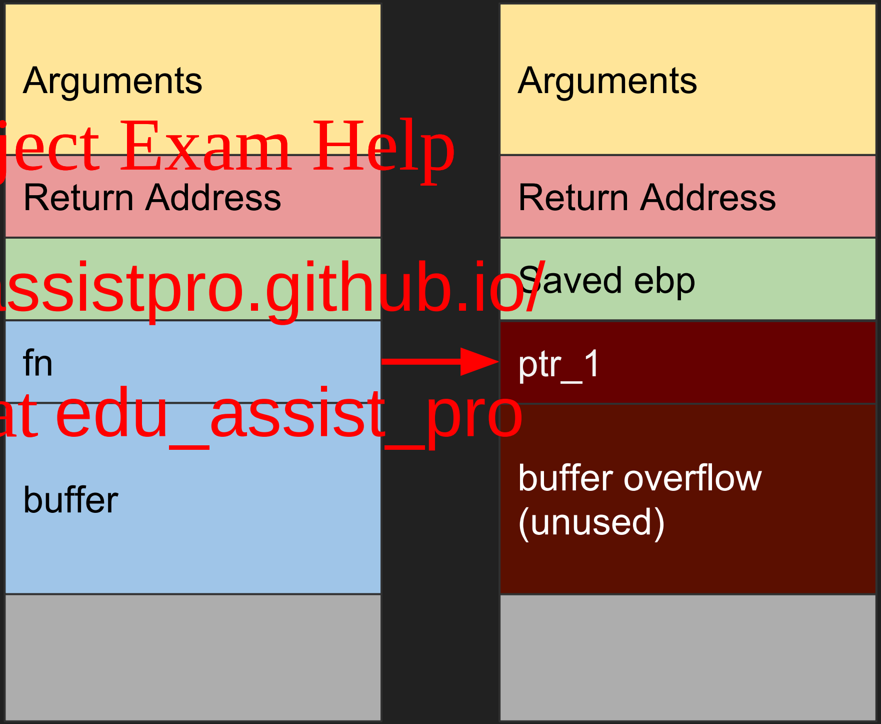


CFI Indirect Call

- Also protects against similar tomfoolery with indirect function calls.

```
void my_function() { … }

int main() {
        void (*fn_ptr)() = &my_function;
        char buffer[255];
        fgets("%s", buffer);
        fn_ptr();
}
```

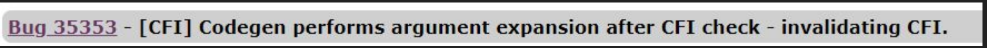


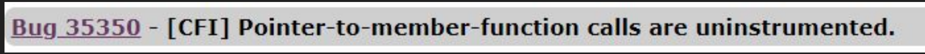
CFI Issues

- Only forward-edge protection.
  - rCFI is implemented, but very expensive and requires significant metadata.
- Cross-DSO is computationally expensive.
- Checks can get quit
  - e.g. Base class vcall

```
Derived::x() {
        return Base::x() + Base::y();
}
```

- also...


Bug 35353 - [CFI] Codegen performs argument expansion after CFI check - invalidating CFI.


Bug 35350 - [CFI] Pointer-to-member-function calls are uninstrumented.

Other CFI

- Microsoft Control Flow Guard (CFG)
    - Near-precise. Isn't perfect.
- Intel Control Enforcement Technology (CET)
    - Hardware enforced
    - Also ENDBRANCH,
- ARM Pointer Authe

cise.

Final Notes

- Protection mechanisms mentioned **do not fix the underlying bug**.
- Can still deny service by crashing process.
- No protection is holistic.
- Compilers can only
  - -fstack-protector (-fs
  - -fsanitize=cfi
  - -shadow-call-stack
- Compilers are made by humans. Any s ode should always be inspected by hand.