Counterfeit Object-oriented Programming

Felix Schuster, Thomas Tendyck, Christopher Liebchen, Lucas Davi, Ahmad-Reza Sadeghi, and Thorsten Holz (S&P '15)

Jaemin Hong 20203698

Fake

Fabricate

Mimic

Counterfeit Object-oriented Programming

Simulate

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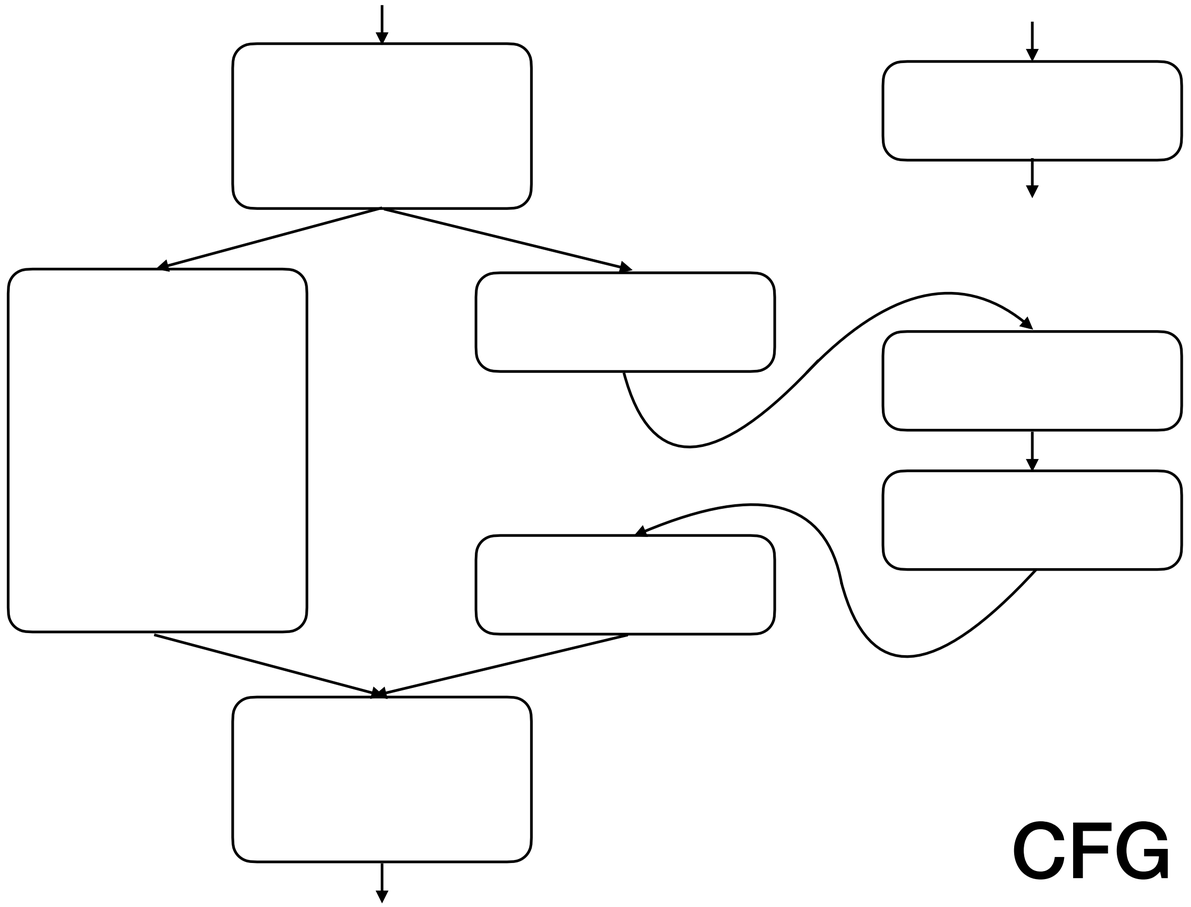
CFI uses an approximated CFG to detect spurious function calls at runtime.



CFG

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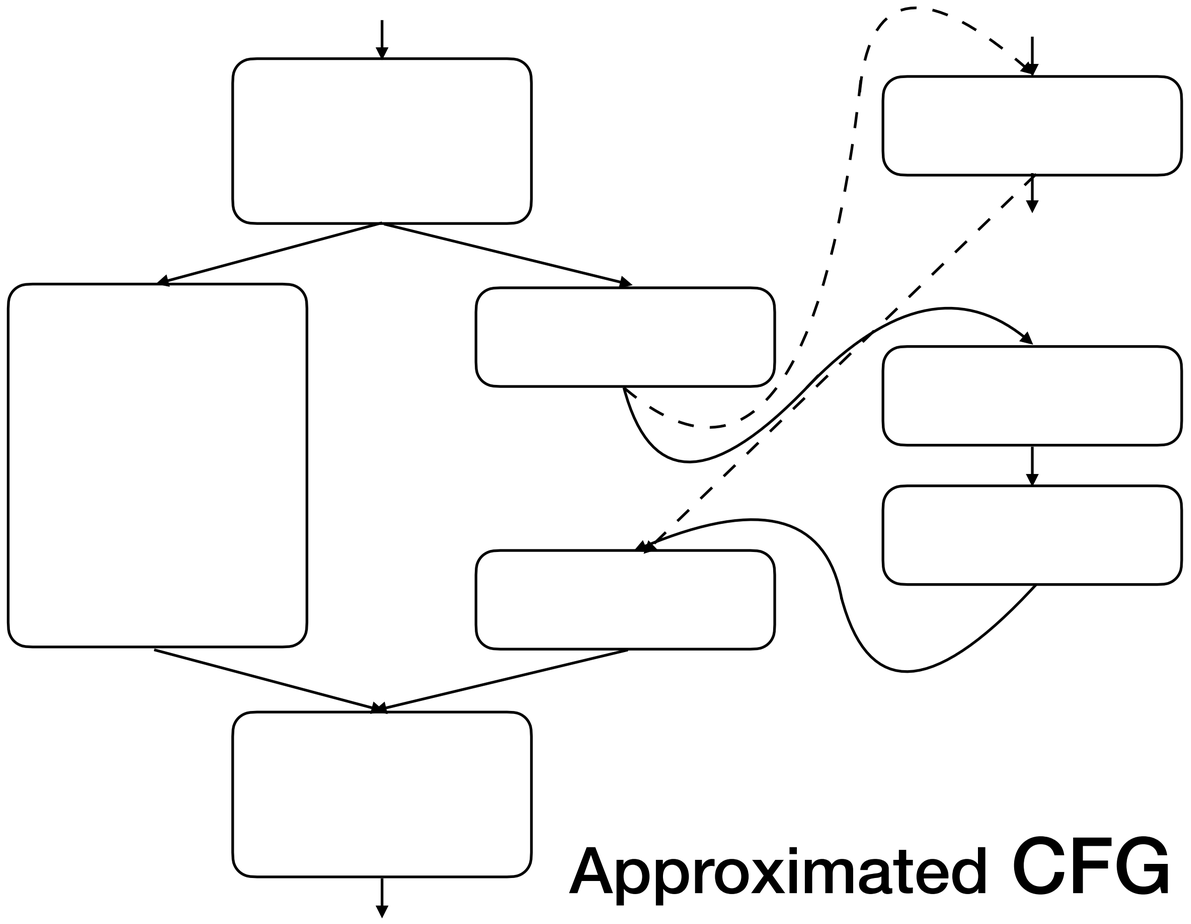

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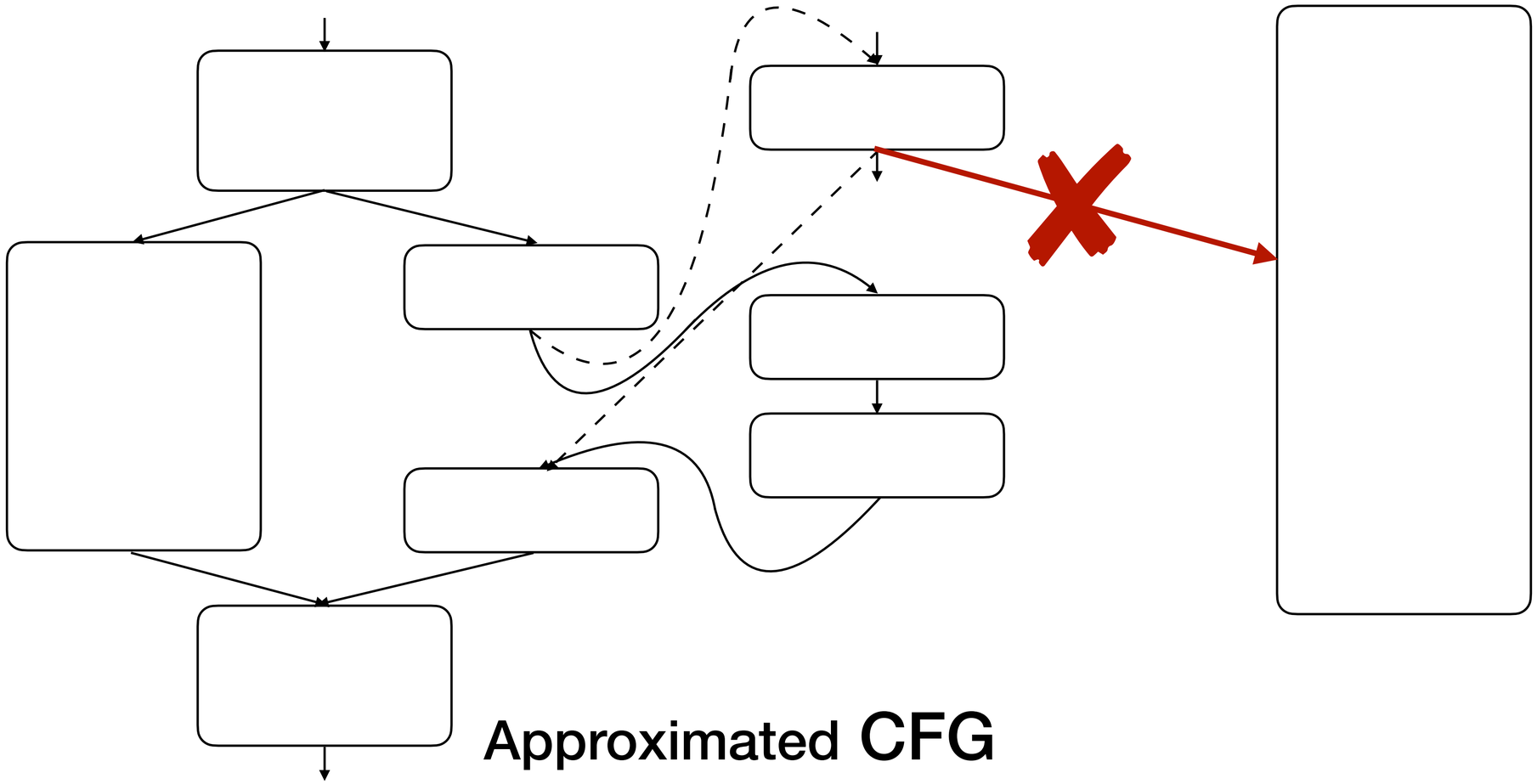

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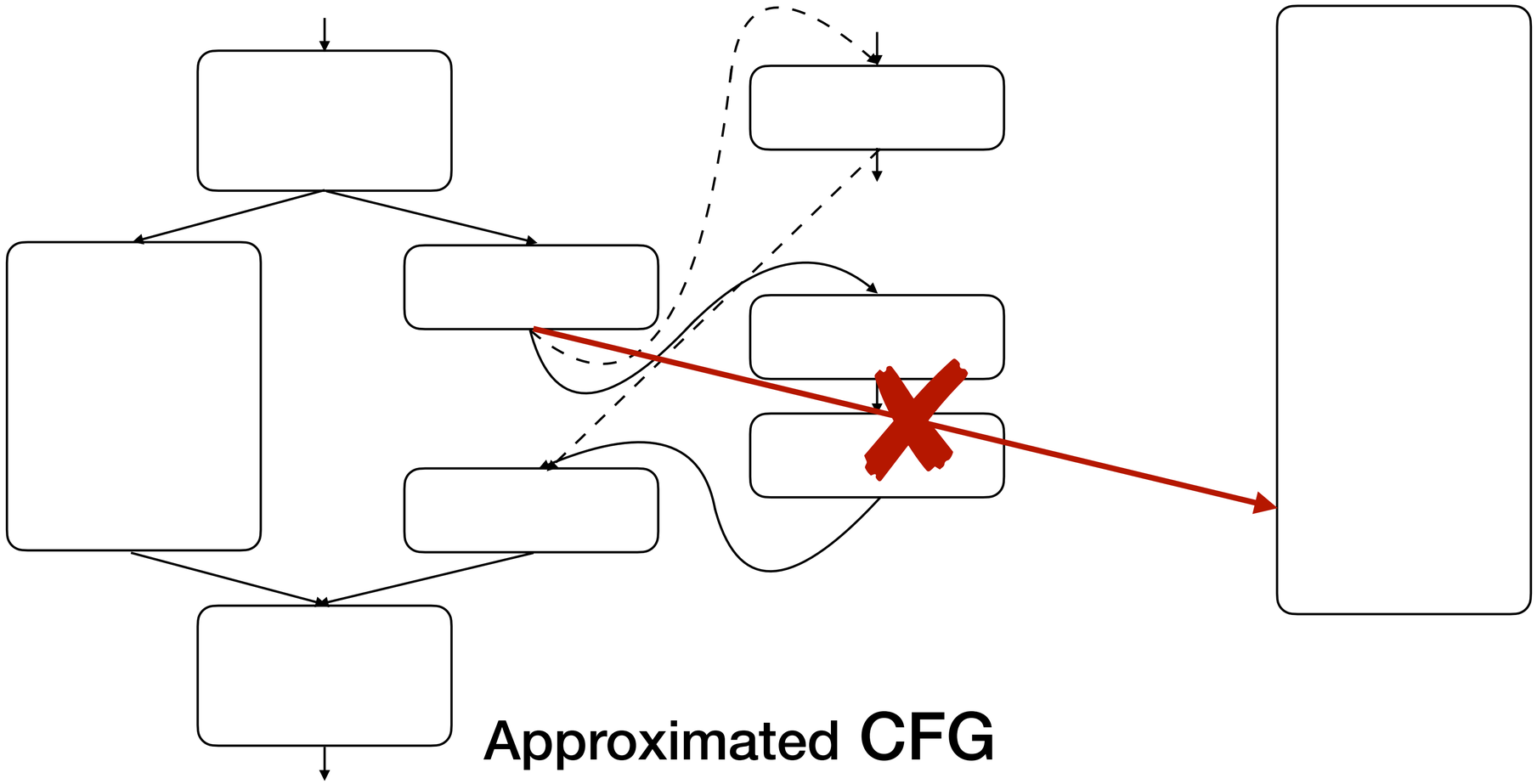

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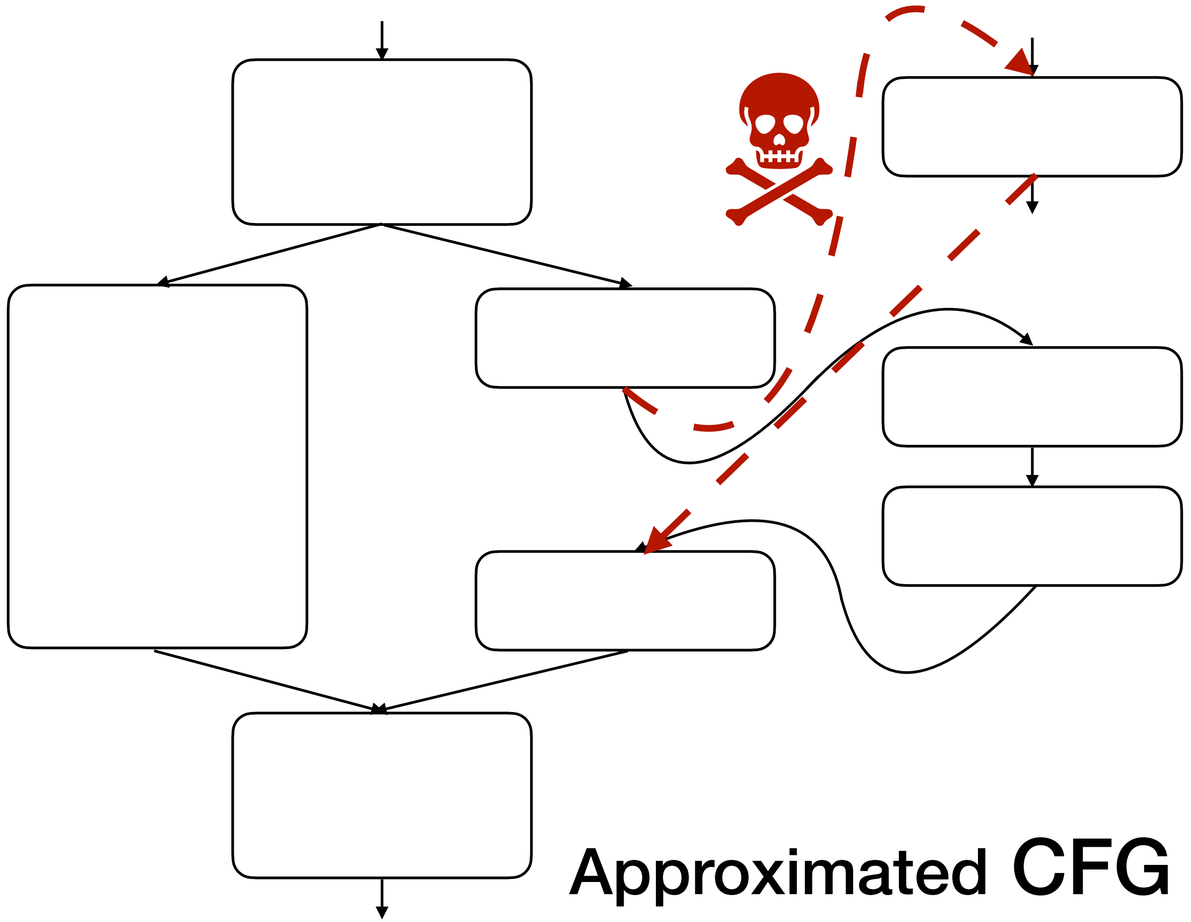

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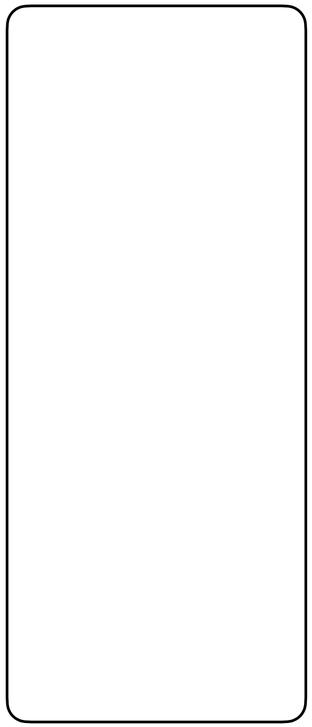

A class inherits methods from its parents.

```
class A {
  virtual int f() { return 0; }
};

class B : public A {

};
```

```
A *a = new A();
a->f();  // 0



B *b = new B();
b->f();  // 0
```

A class can override methods from its parents.

```
class A {
  virtual int f() { return 0; }
};

class B : public A {
  virtual int f() { return 1; }
};
```

```
A *a = new A();
a->f();  // 0


B *b = new B();
b->f();  // 1
```

Virtual methods allow dynamic dispatch.

```
class A {
  virtual int f() { return 0; }
};

class B : public A {
  virtual int f() { return 1; }
};
```

```
A *a = new A();
a->f();  // 0


A *b = (A *) new B();
b->f();  // 1
```

Virtual methods are implemented via `vtable`s.

```
class A {
  virtual int f() { return 0; }
  virtual int g() { return 2; }
};

class B : public A {
  virtual int f() { return 1; }
};
```

```
A::f():
    return 0

A::g():
    return 2

B::f():
    return 1
```

Virtual methods are implemented via `vtable`s.

```
class A {
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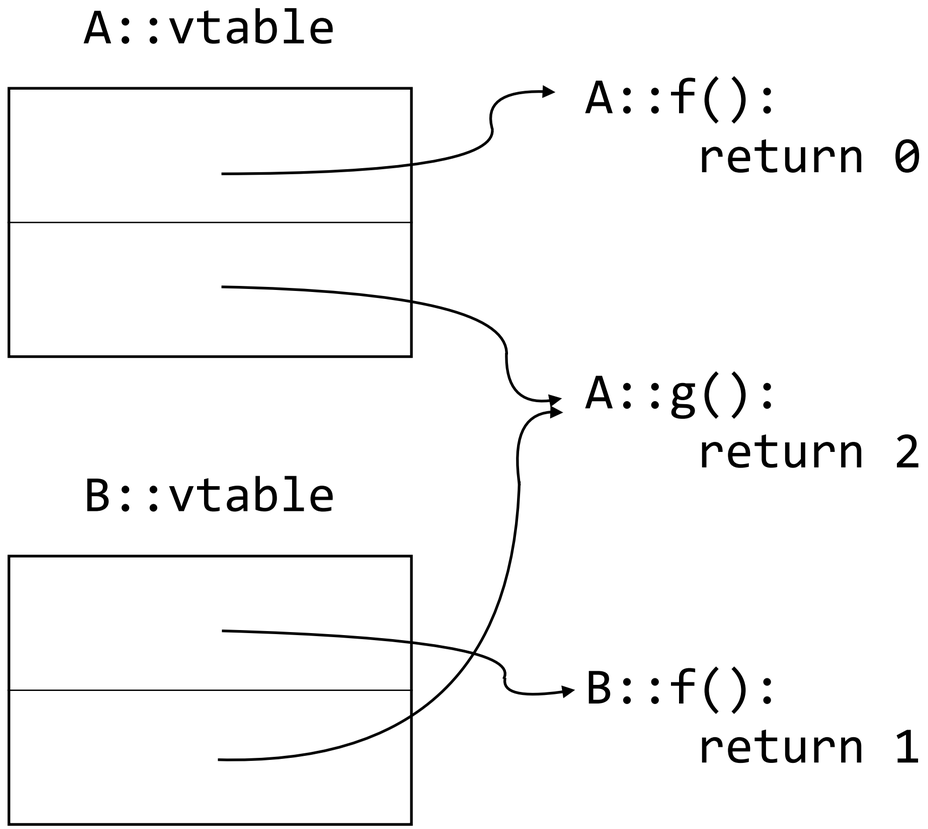
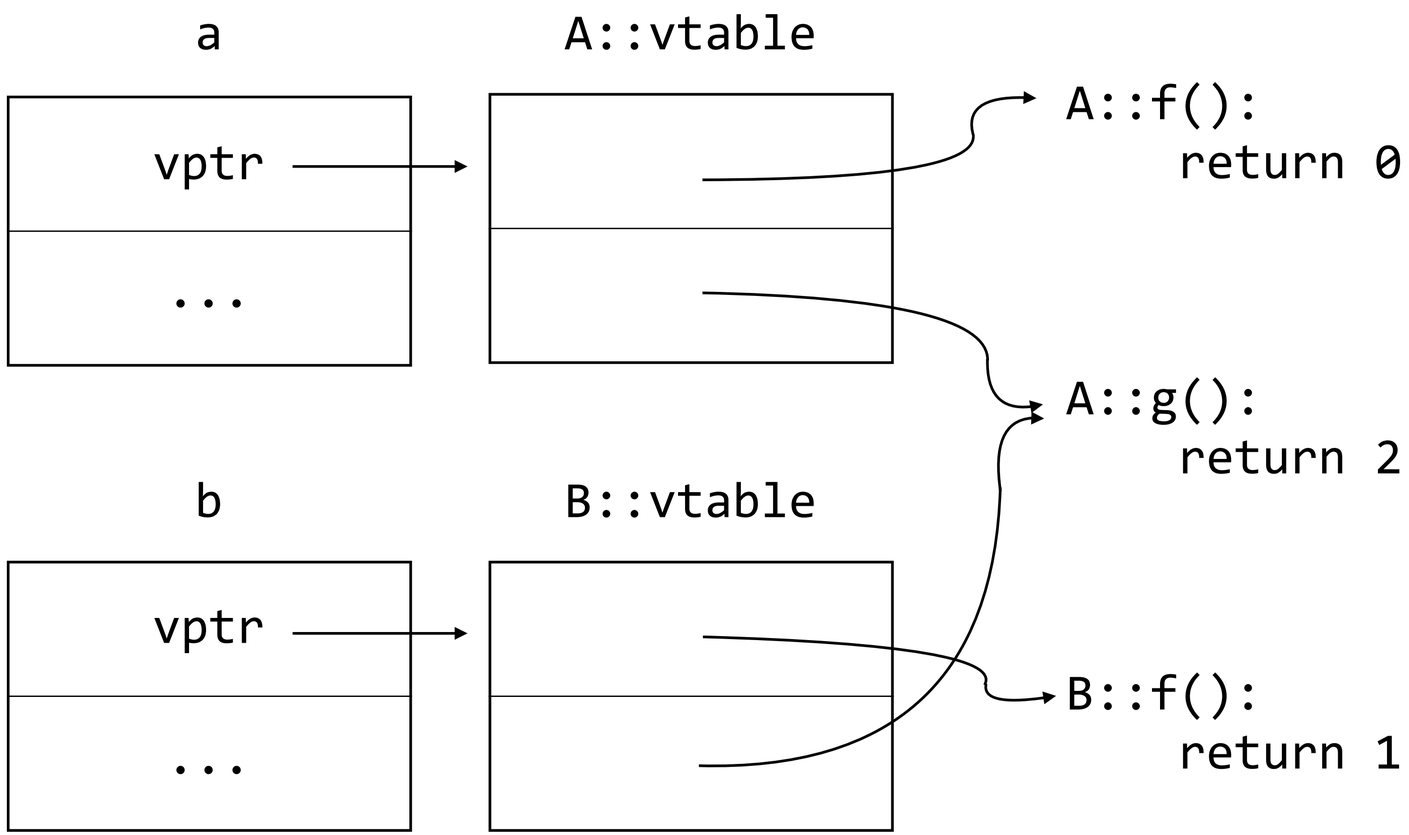


Virtual methods are implemented via `vtable`s.

```
A *a = new A();

A *b = (A *) new B();
```



Virtual methods are implemented via `vtable`s.

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a->f();  // 0
a->g();  // 2


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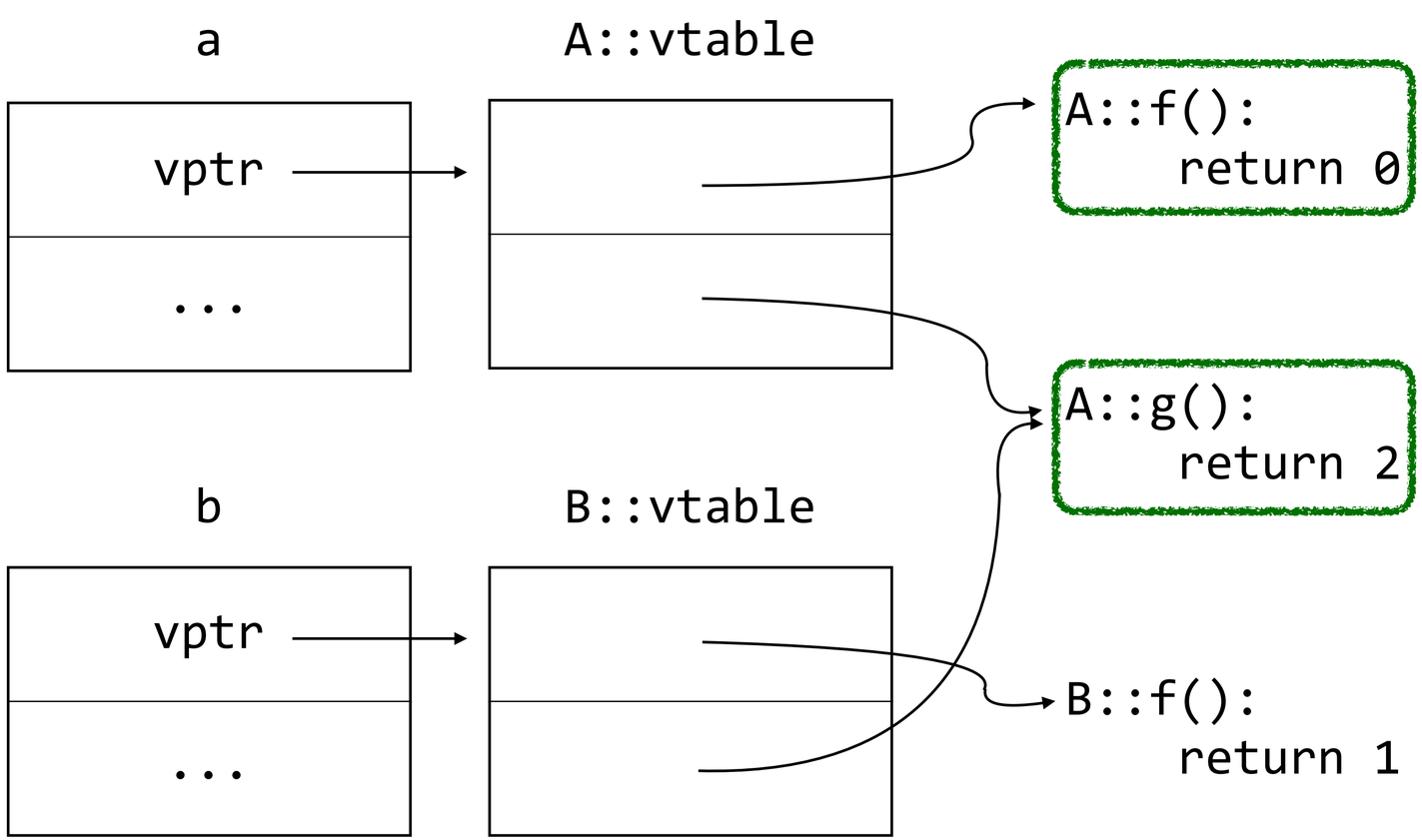
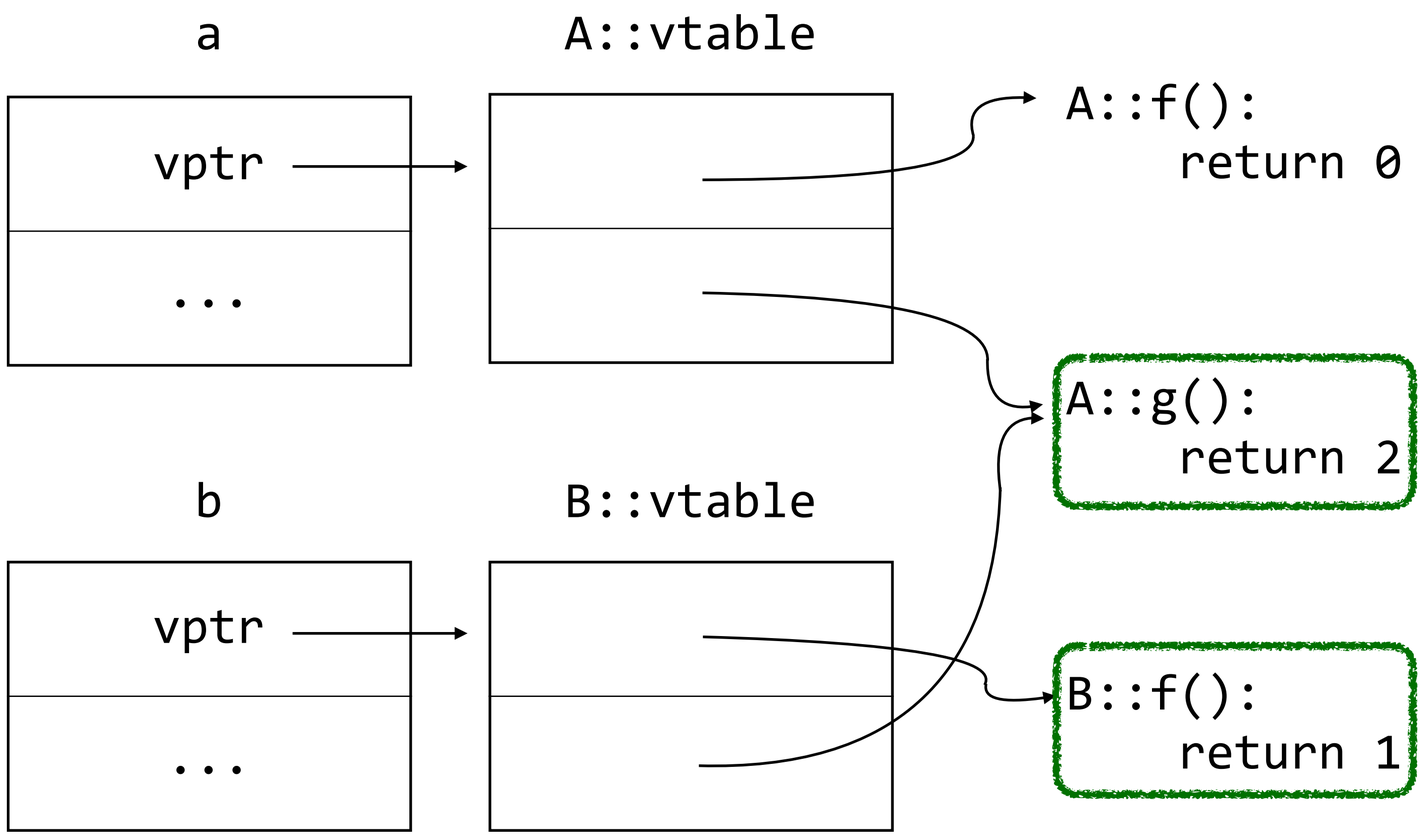
```



Virtual methods are implemented via `vtable`s.

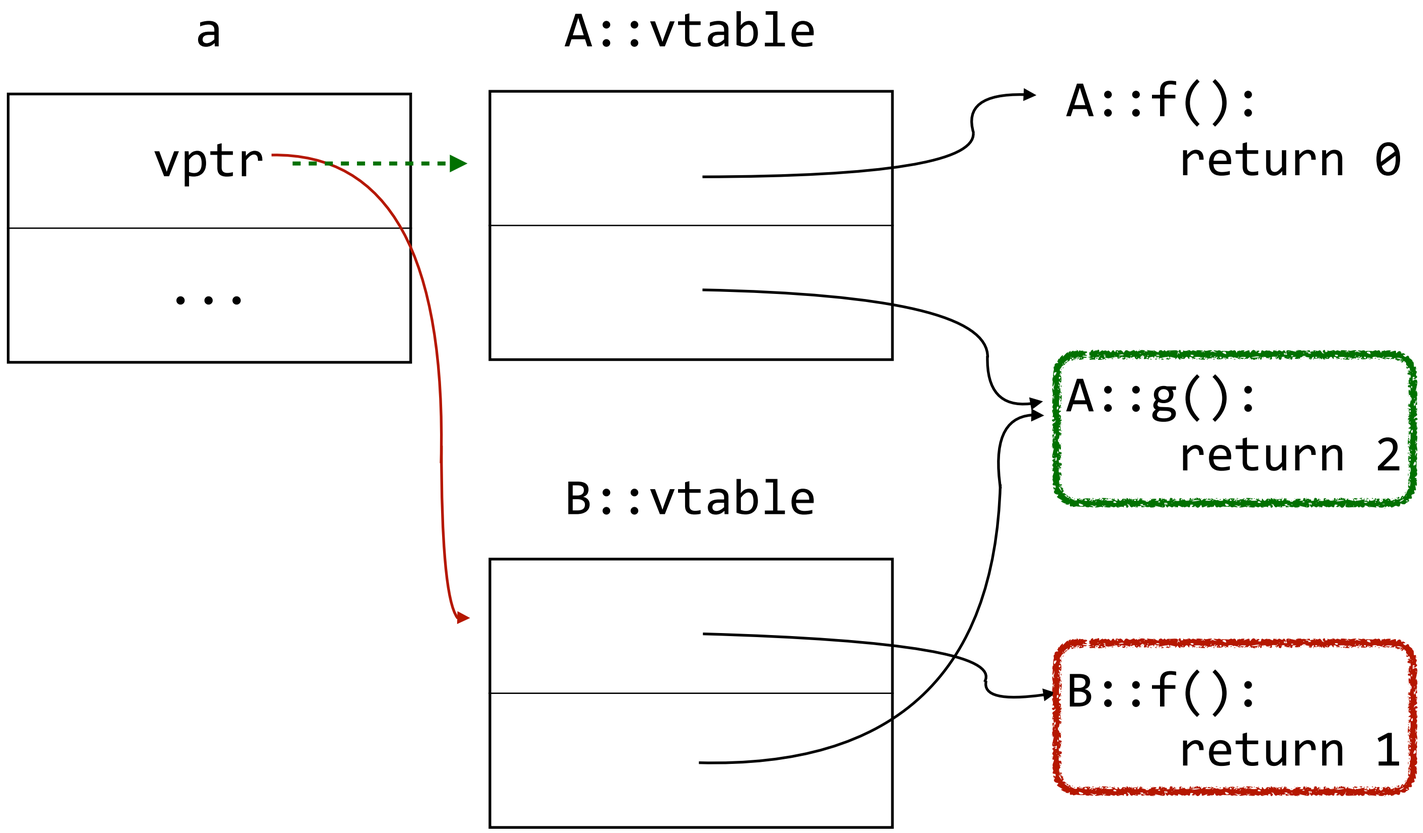
```
A *a = new A();
```

```
A *b = (A *) new B();
b->f();  // 1
b->g();  // 2
```



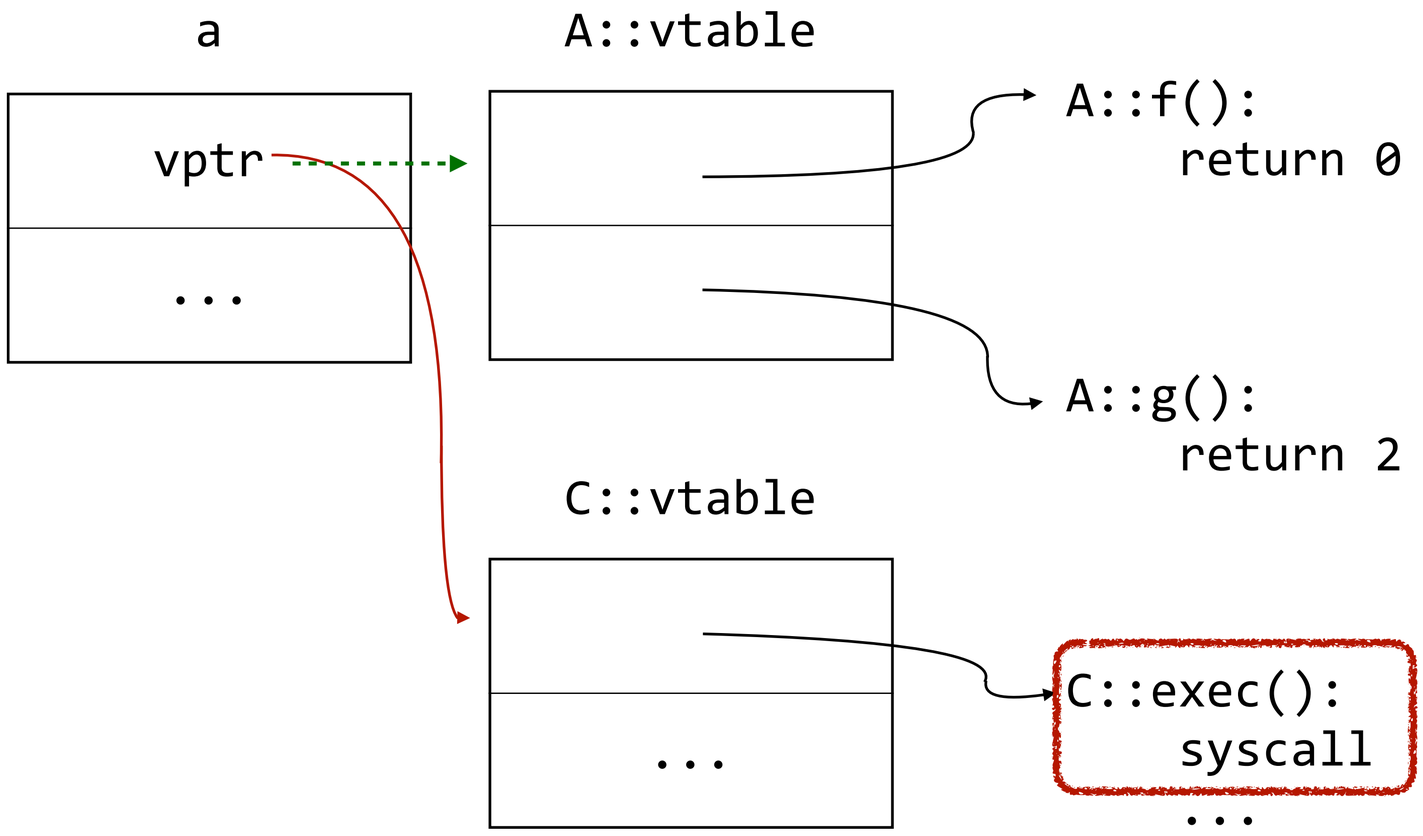
We can change the behavior of an object by changing `vptr` of the object.

```
A *a = new A();
a->f();  // 1
a->g();  // 2
```



We can change the behavior of an object by changing `vptr` of the object.

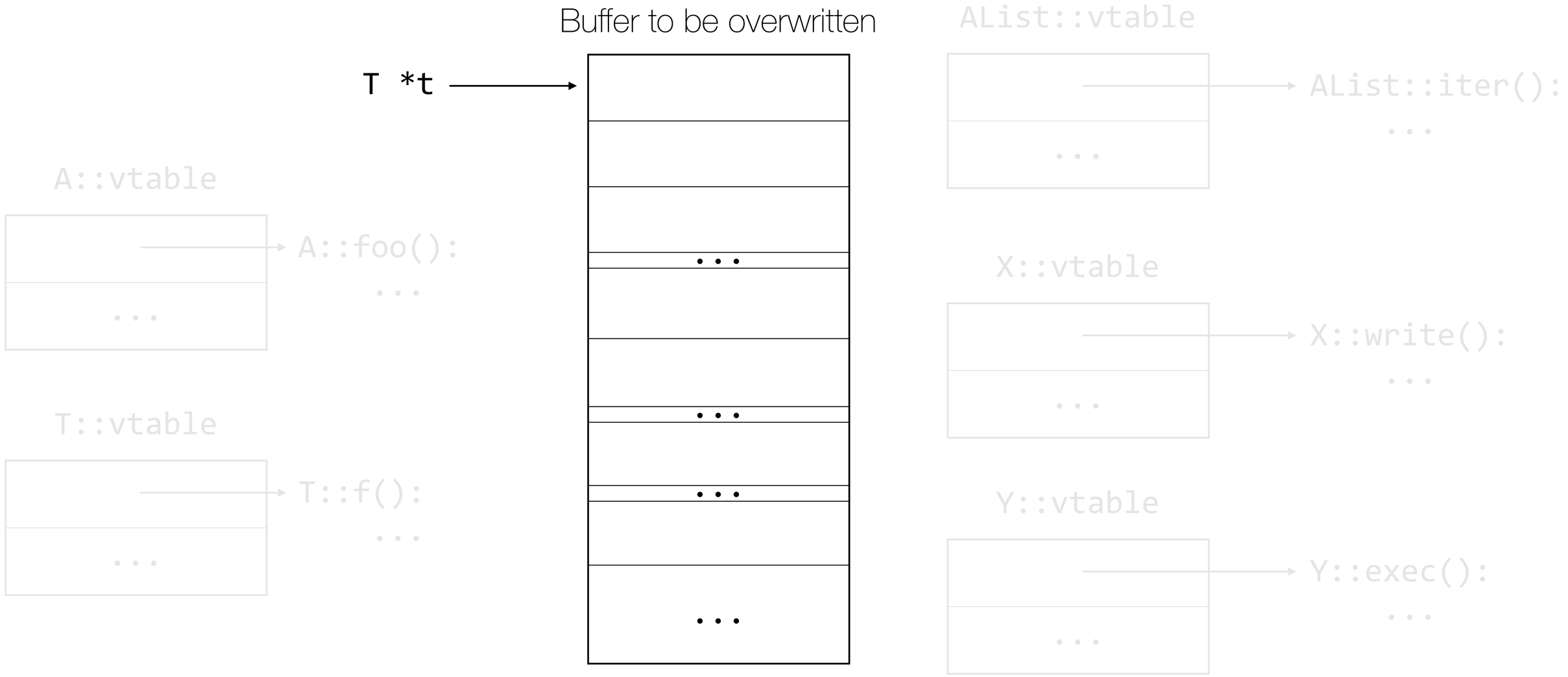
```
A *a = new A();
a->f();  // ???
a->g();  // ...
```



The main loop gadget allows invoking an arbitrary sequence of methods.

```
class AList {
    A **arr;
    int num;
    virtual void iter() {
        for (int i = 0; i < num; i++)
            arr[i]->foo();
    }
};
```

The main loop gadget allows invoking an arbitrary sequence of methods.



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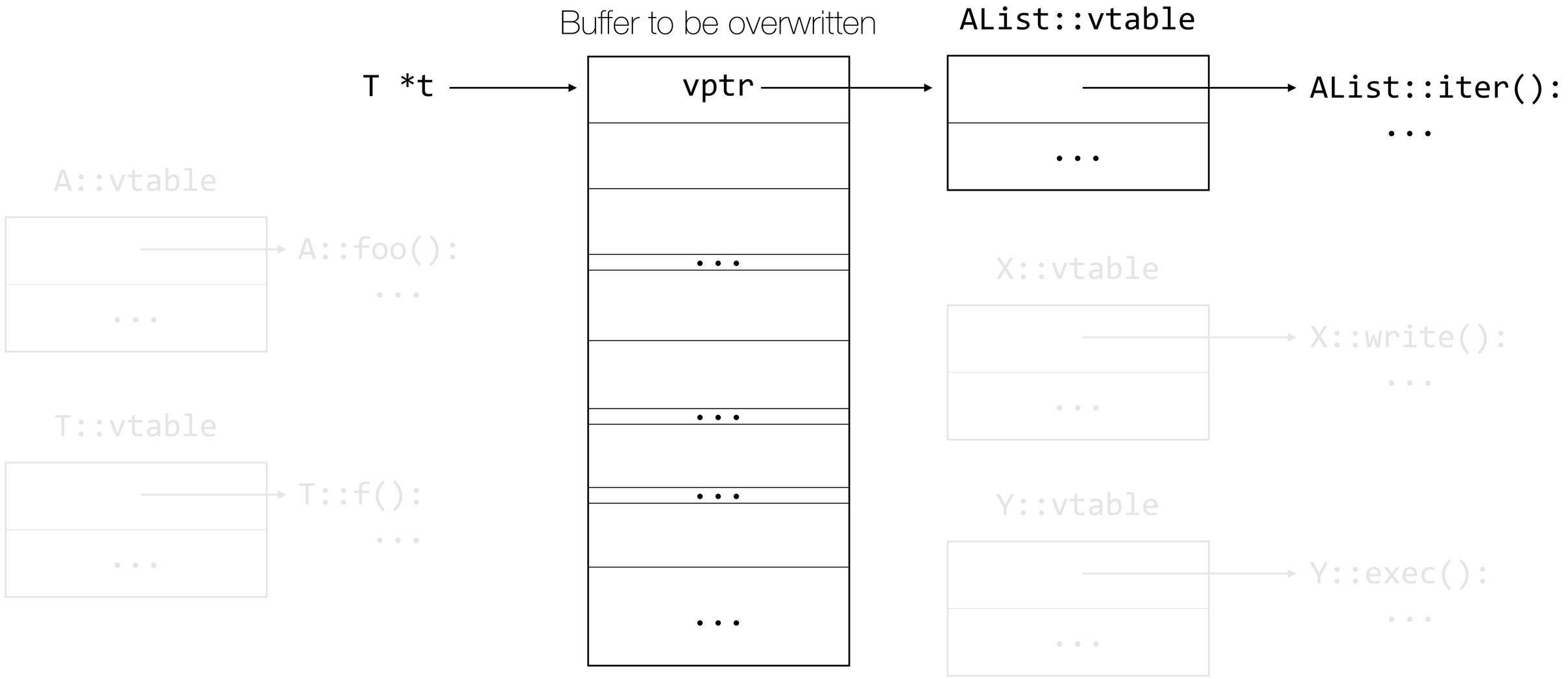

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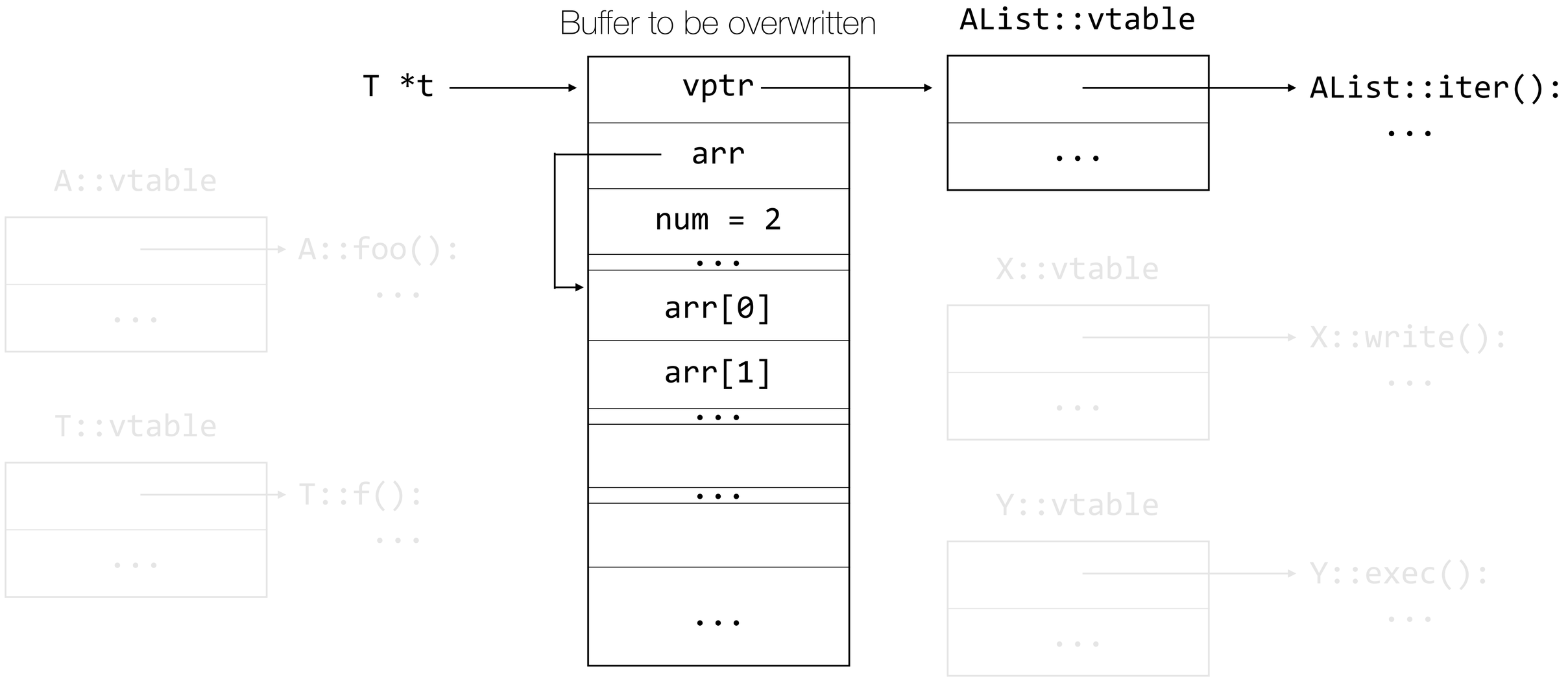

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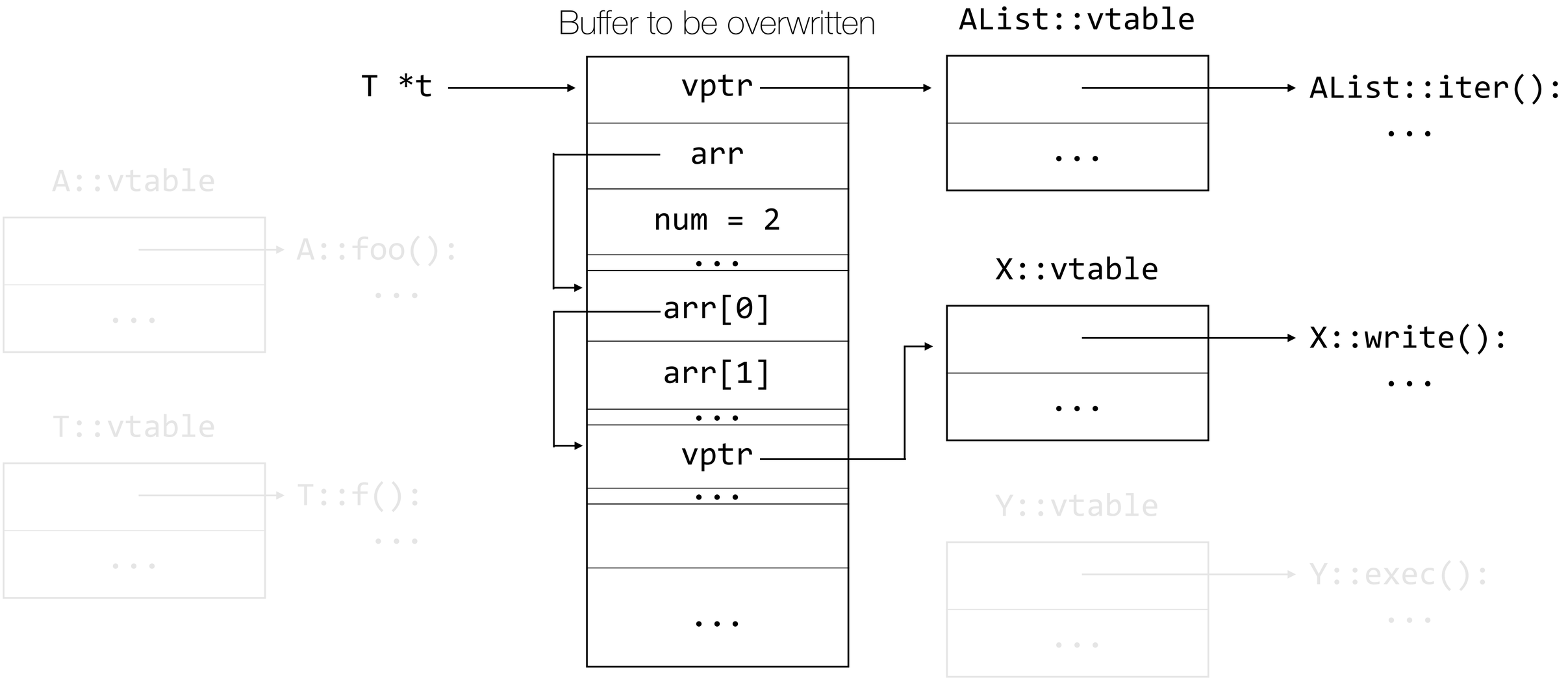

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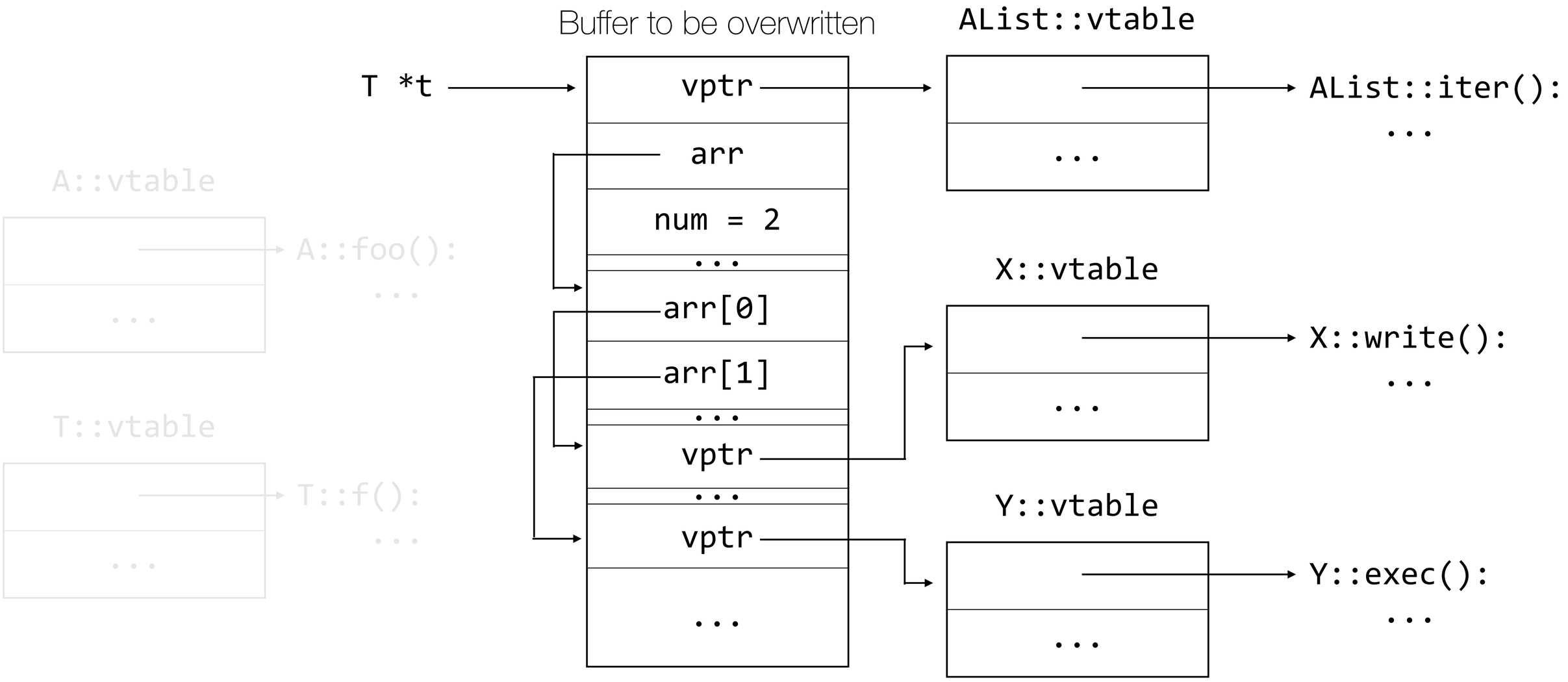

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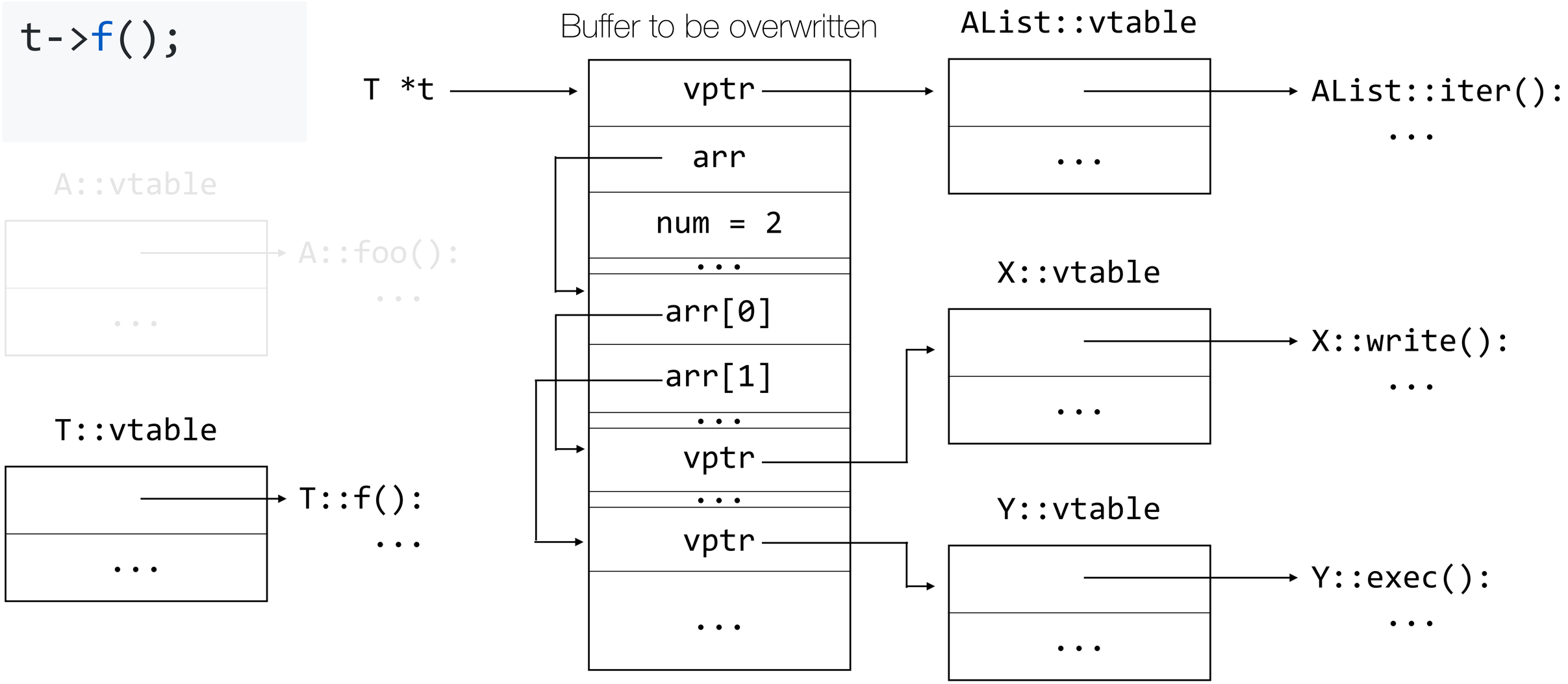
```
t->f();
```



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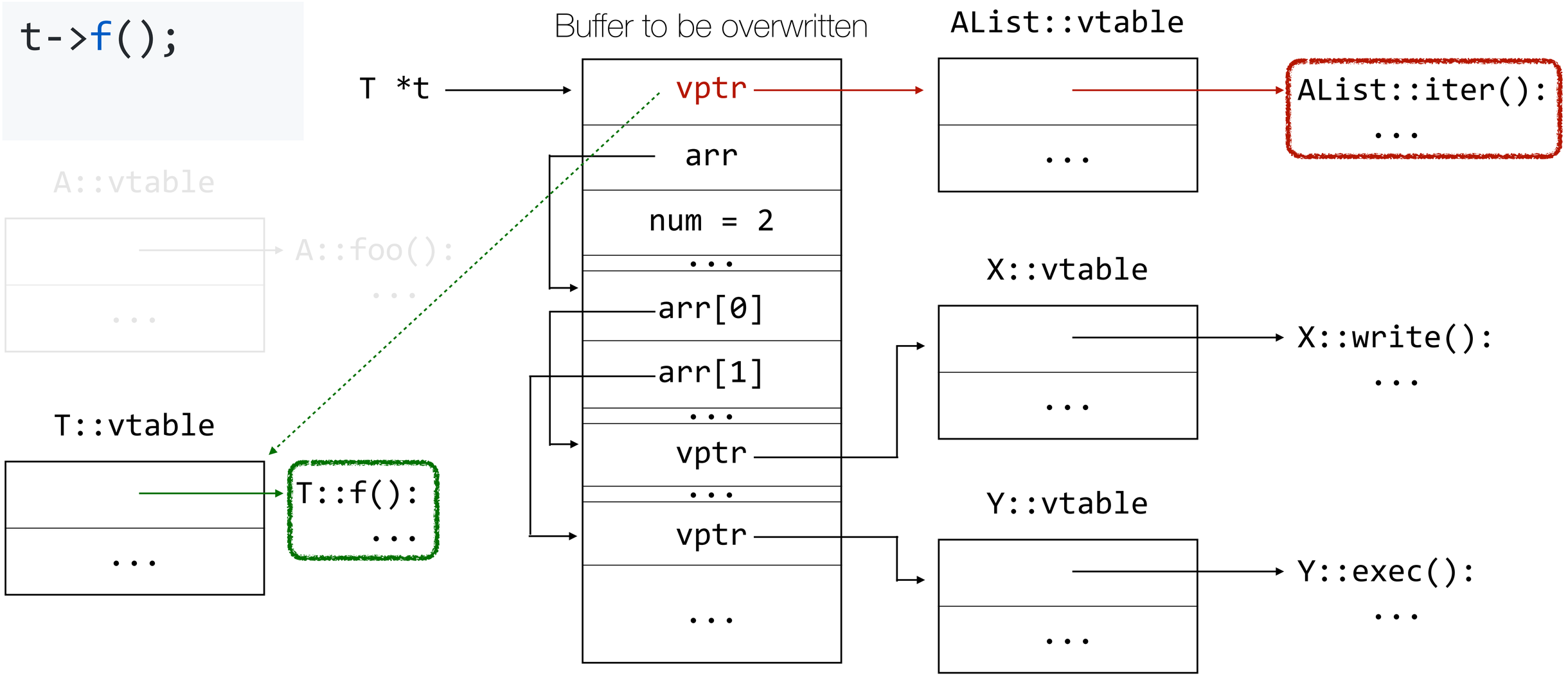

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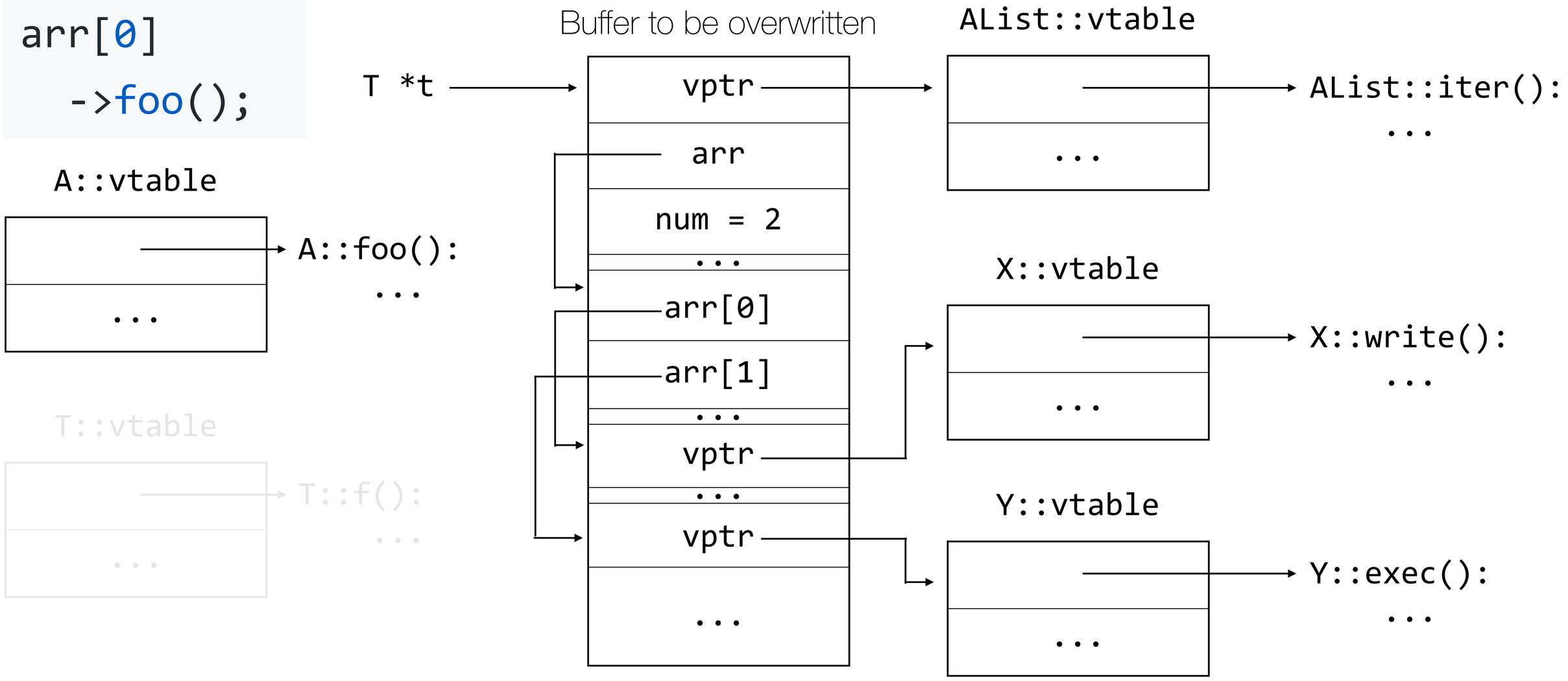
```
arr[0]
  ->foo();
```



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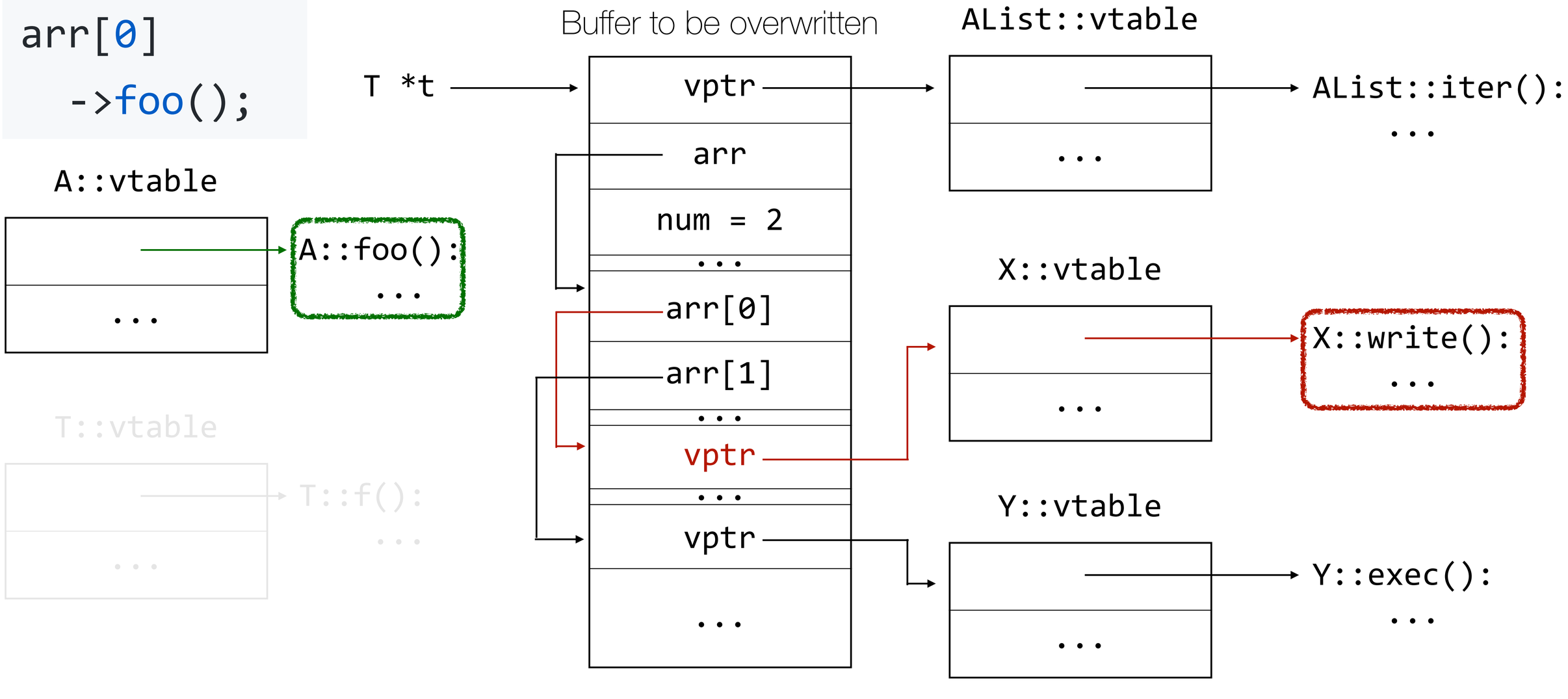
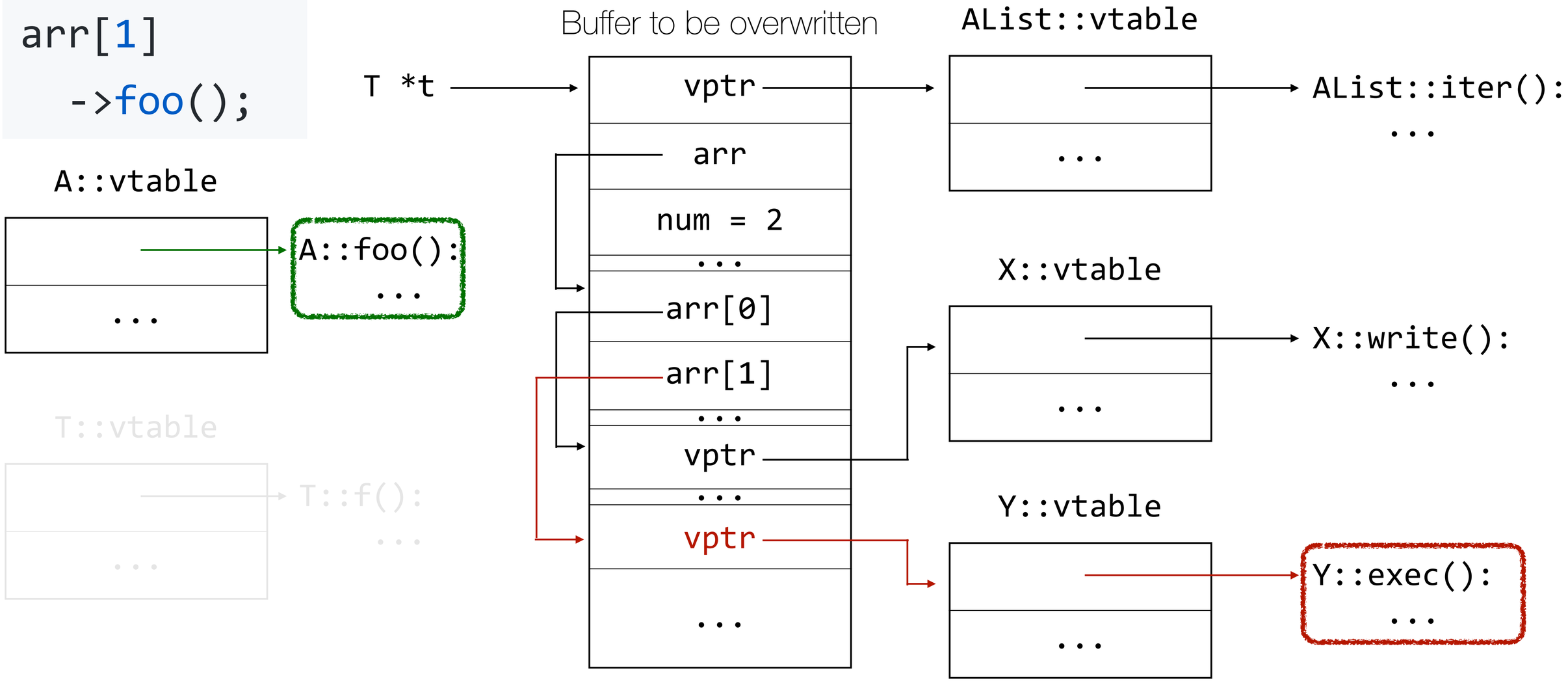


The main loop gadget allows invoking an arbitrary sequence of methods.

```
arr[1]
  ->foo();
```



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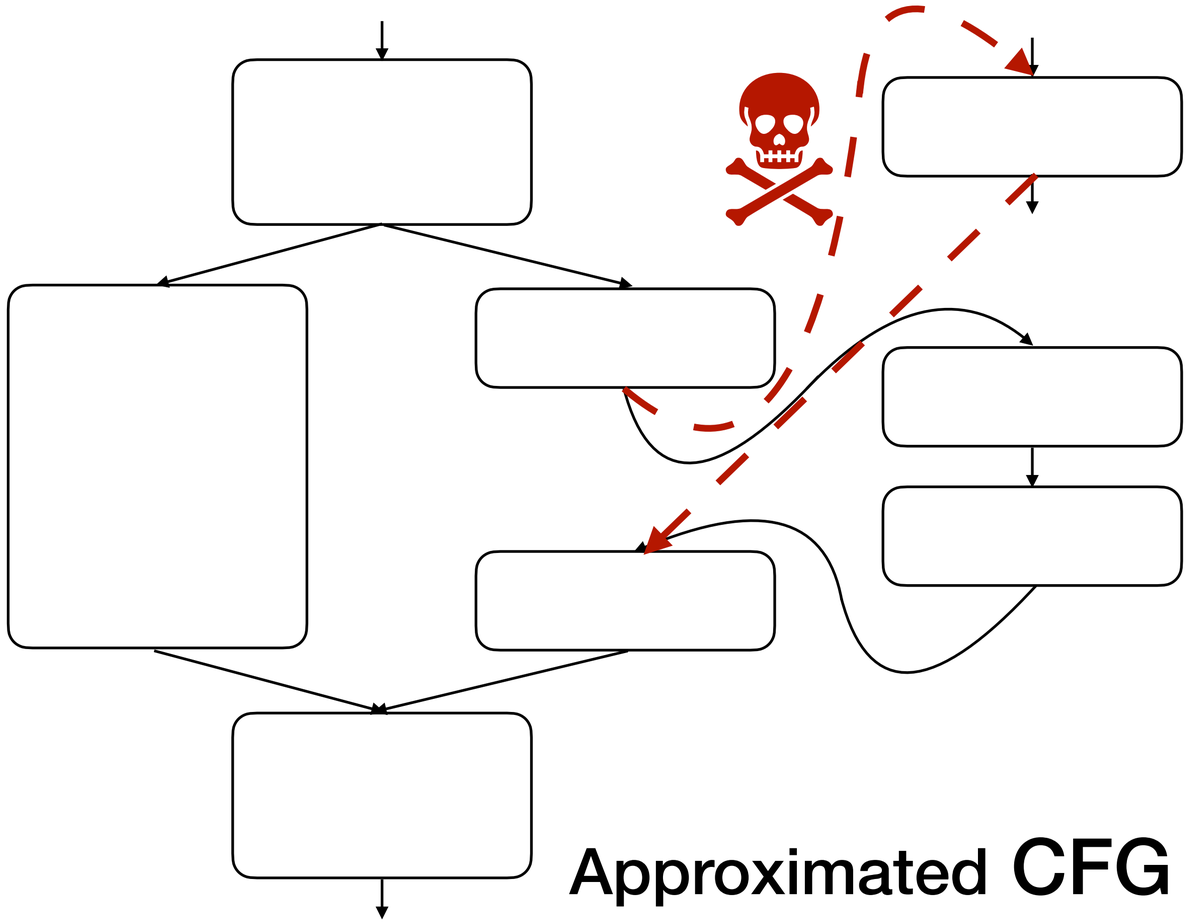
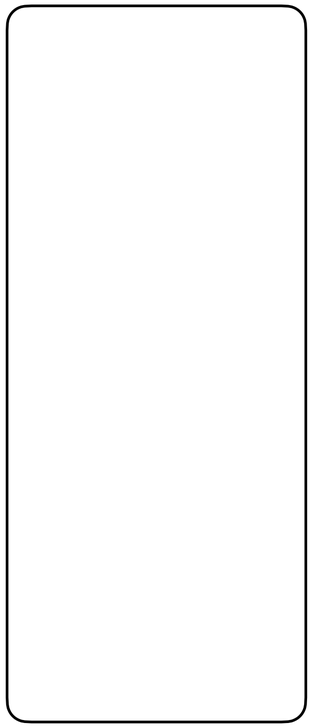


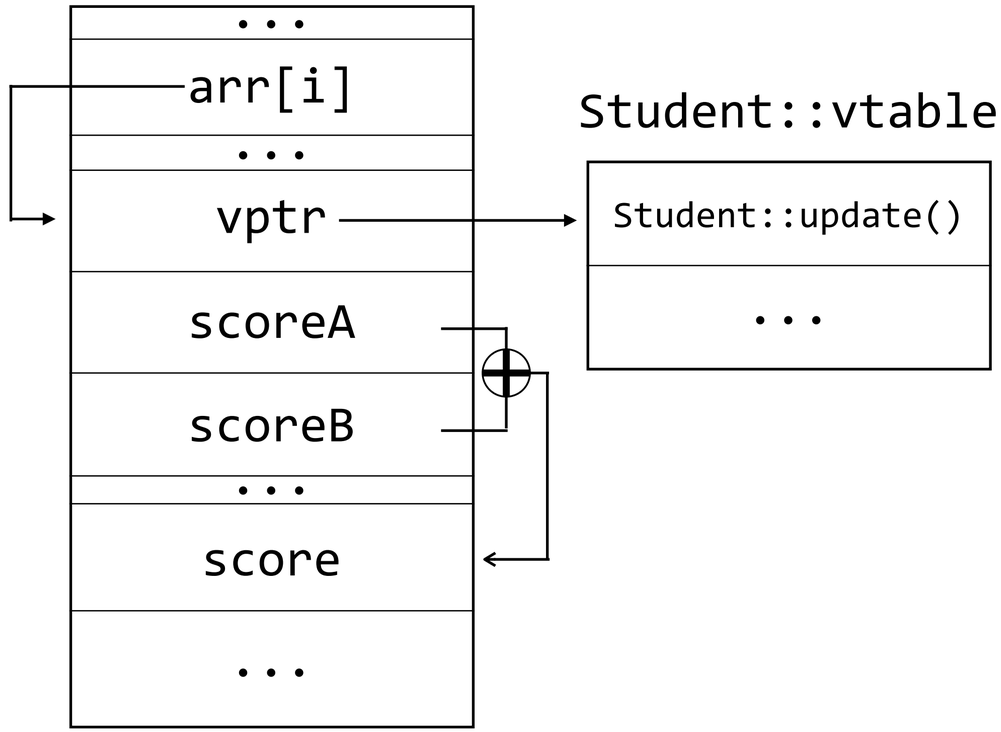
Approximated CFG



Arithmetic gadgets can be found easily.

```
class Student {
    int scoreA, scoreB;
    ...
    int score;

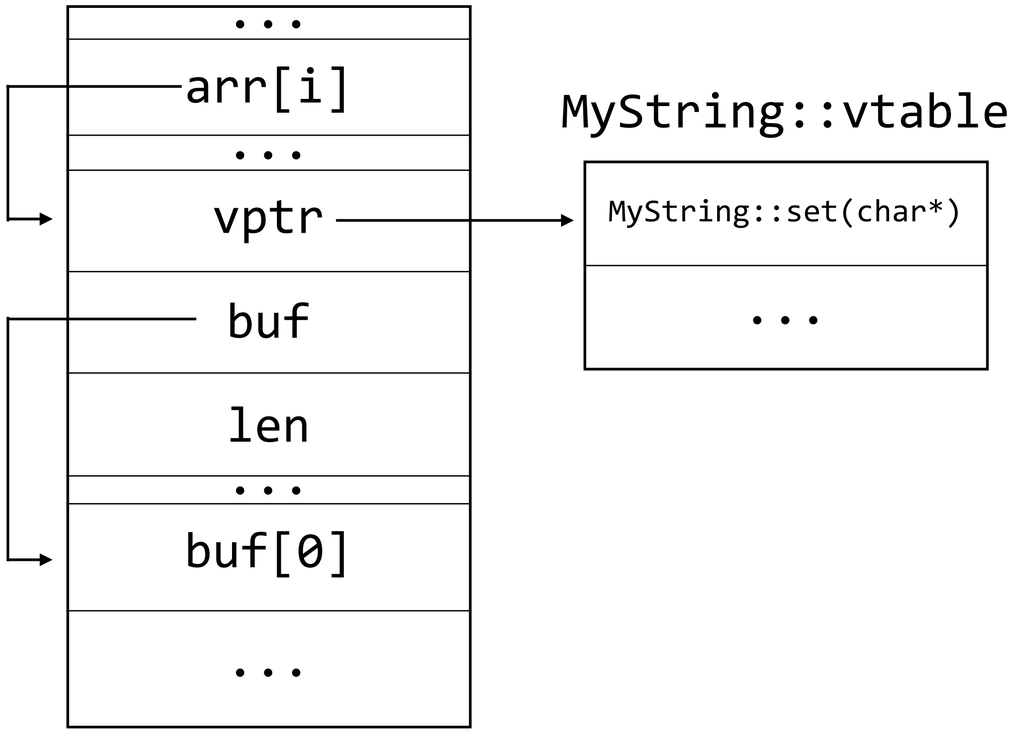
    virtual void update() {
        score = scoreA + scoreB;
    }
};
```



Read/write gadgets can be found easily.

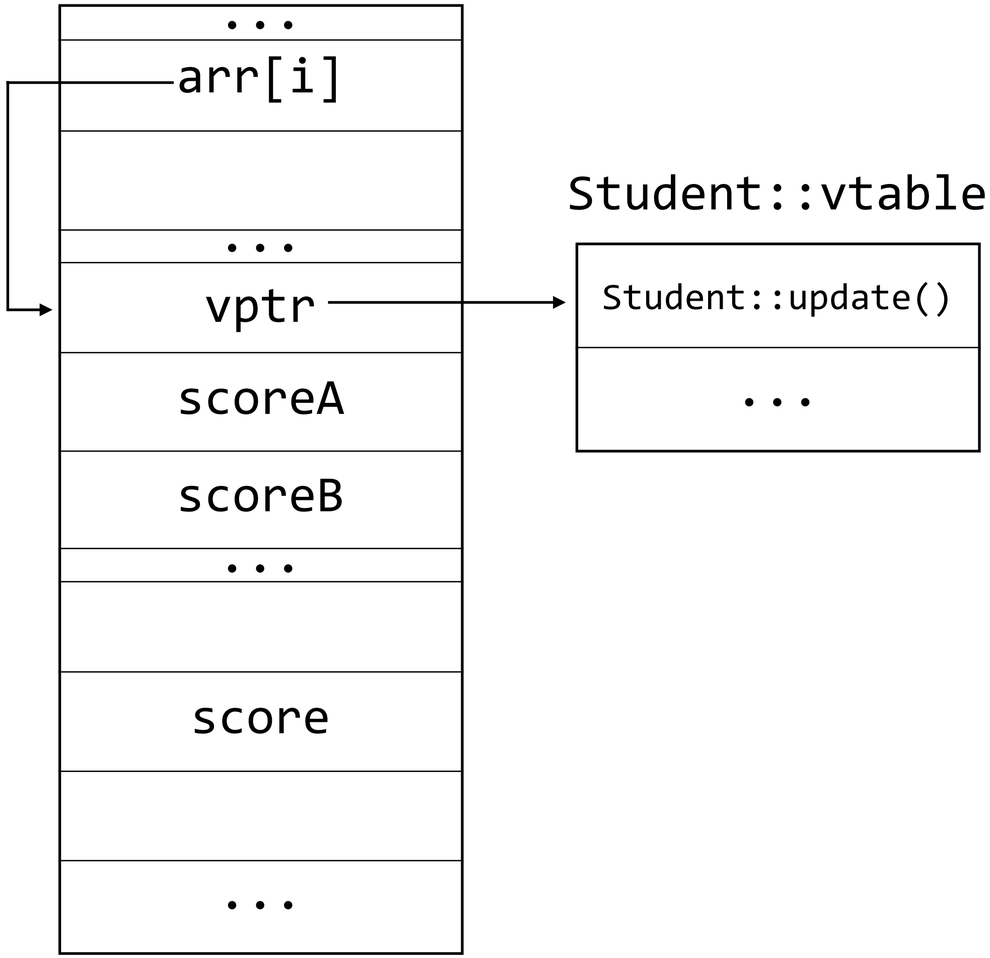
```
class MyString {
    char *buf;
    int len;

    virtual void set(char *src) {
        strncpy(buf, src, len);
    }
};
```



Overlapping objects allow arbitrary read/write.

```
class Student {
    int scoreA, scoreB, score;
    virtual void update() { .. }
};
class MyString {
    char *buf; int len;
    virtual void set(char *src)
    { .. }
};
```



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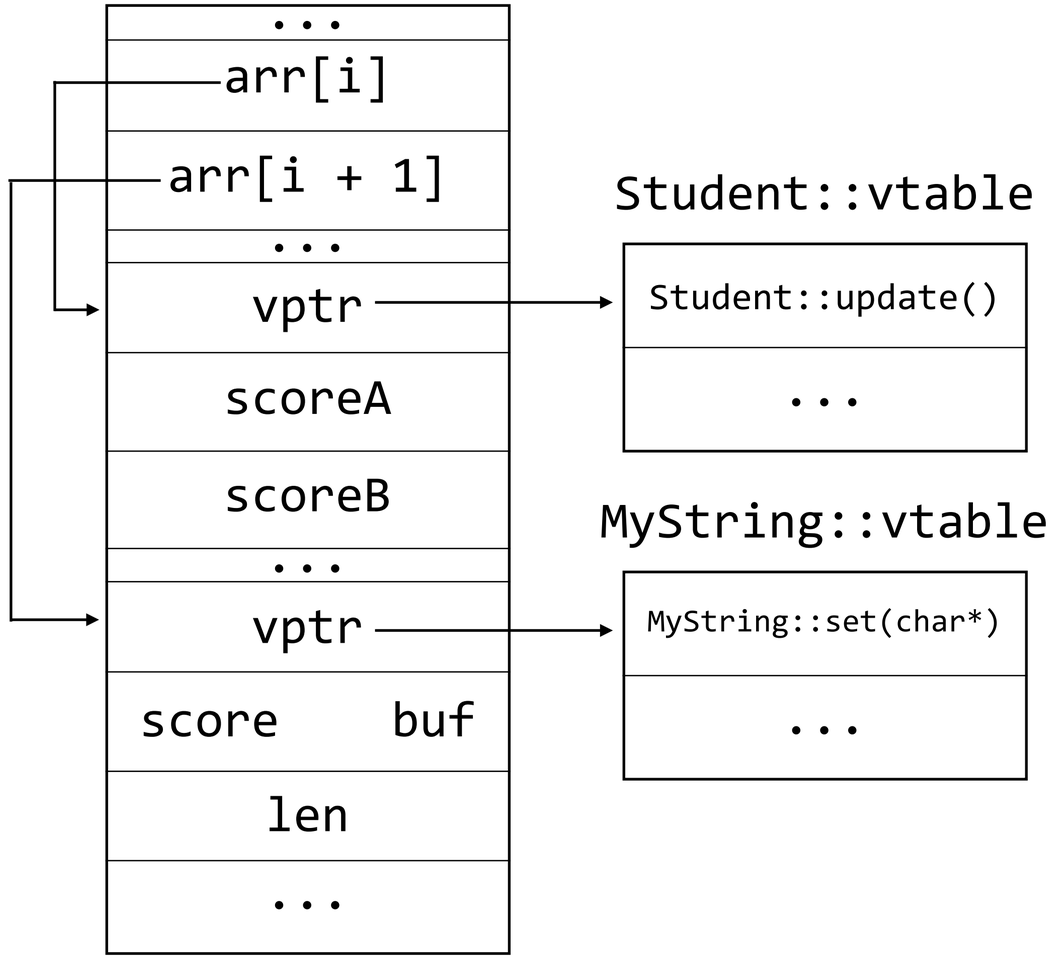

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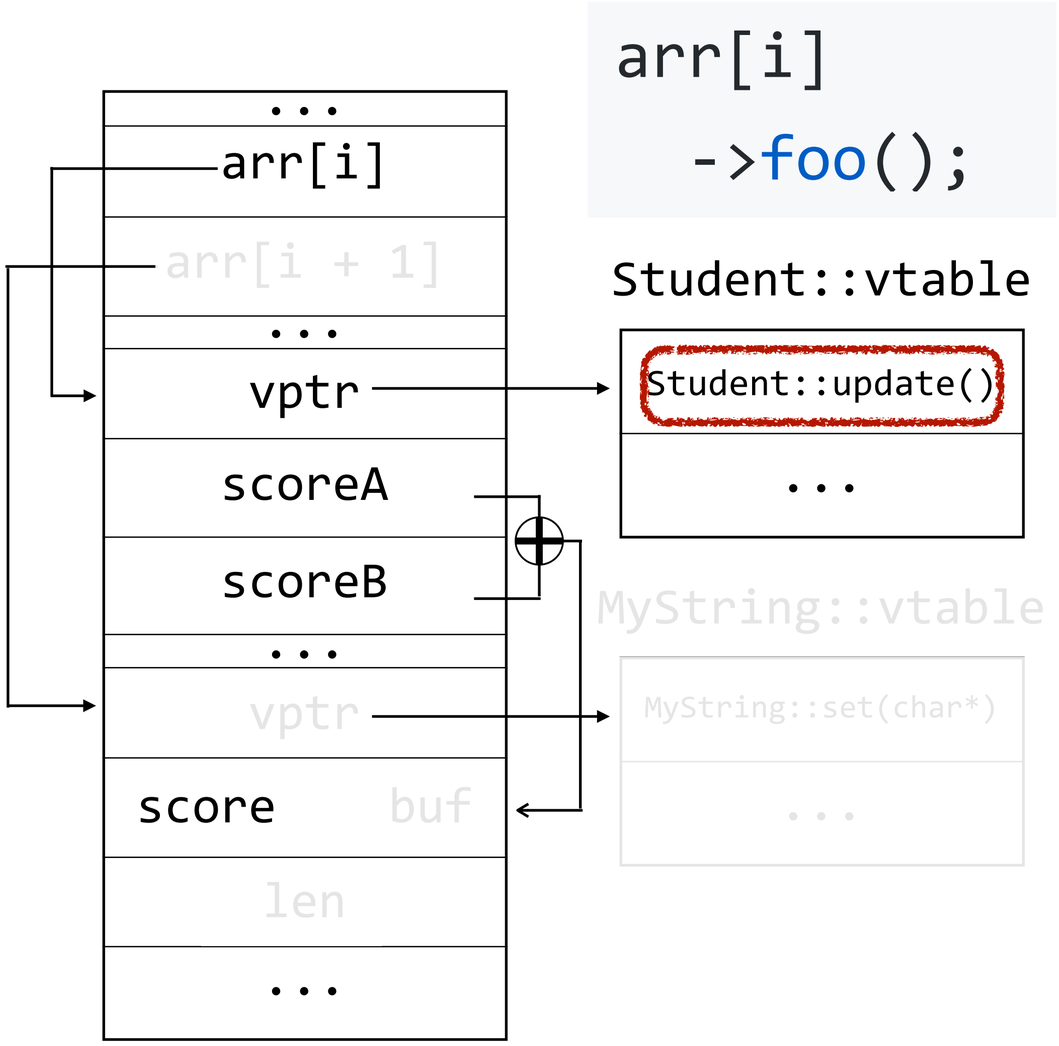

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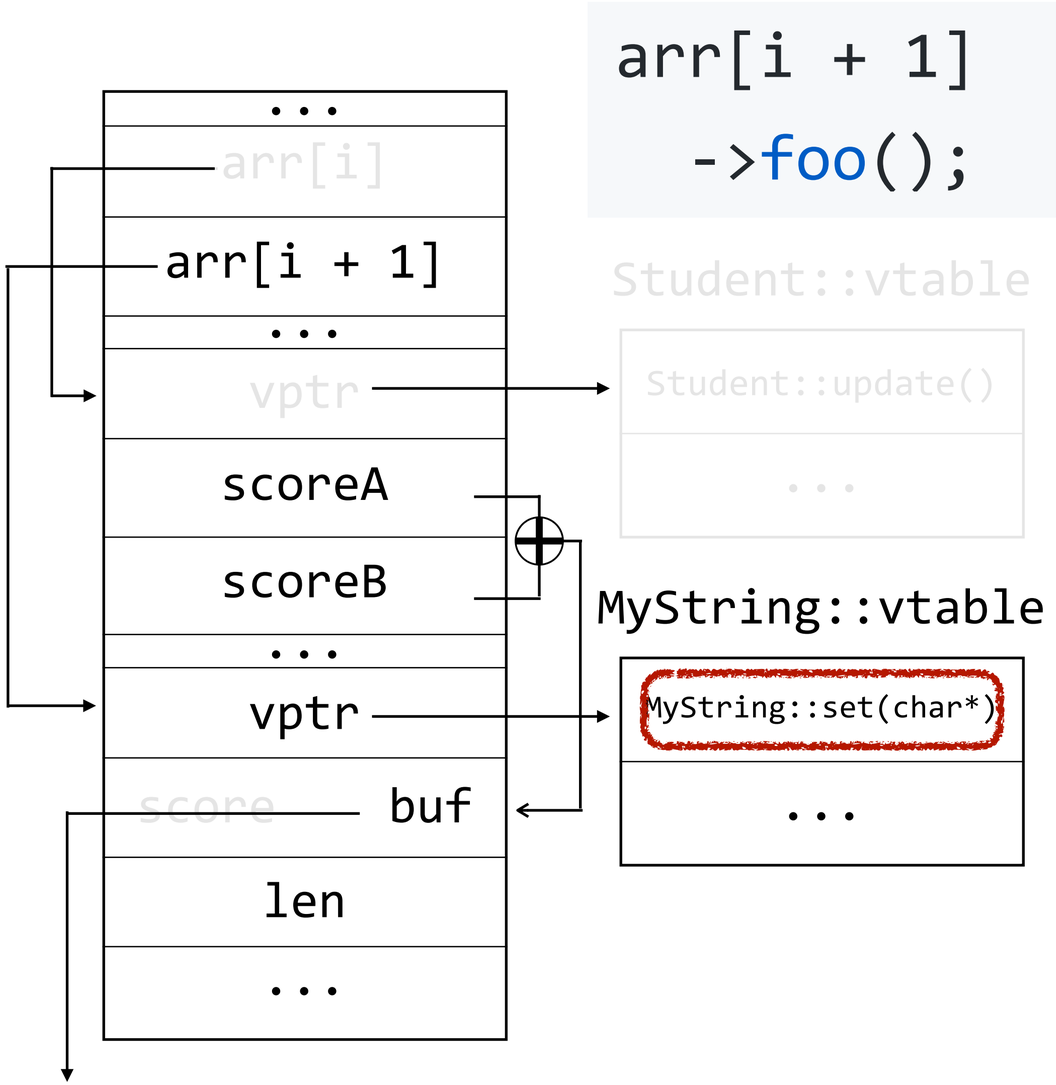
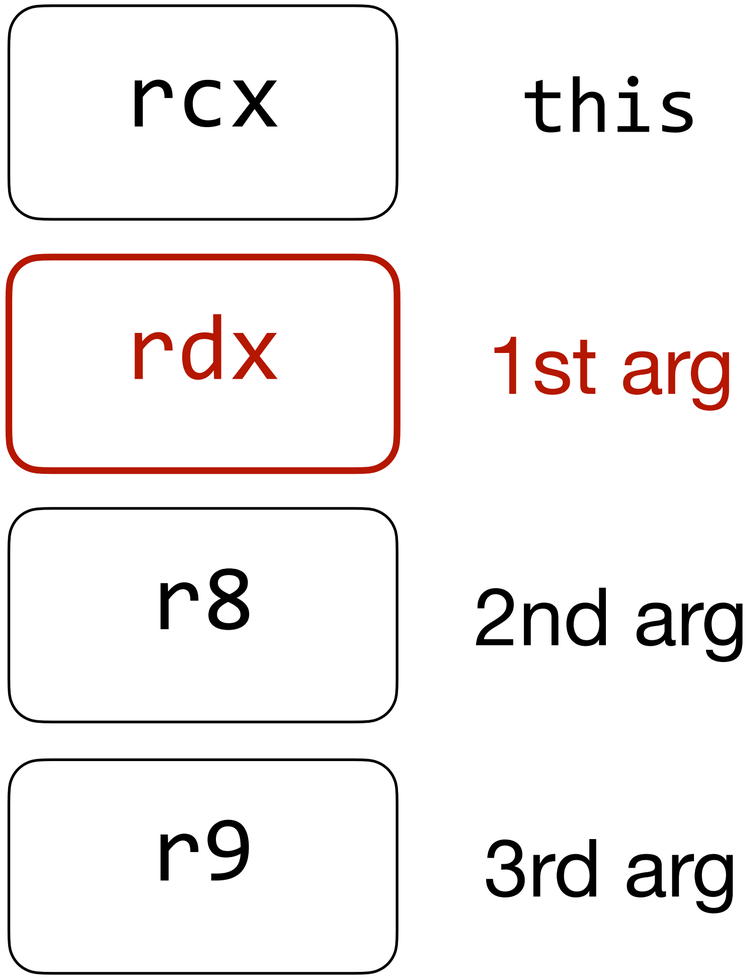


x64 uses registers to pass arguments.

```
class MyString {
    char *buf;
    int len;

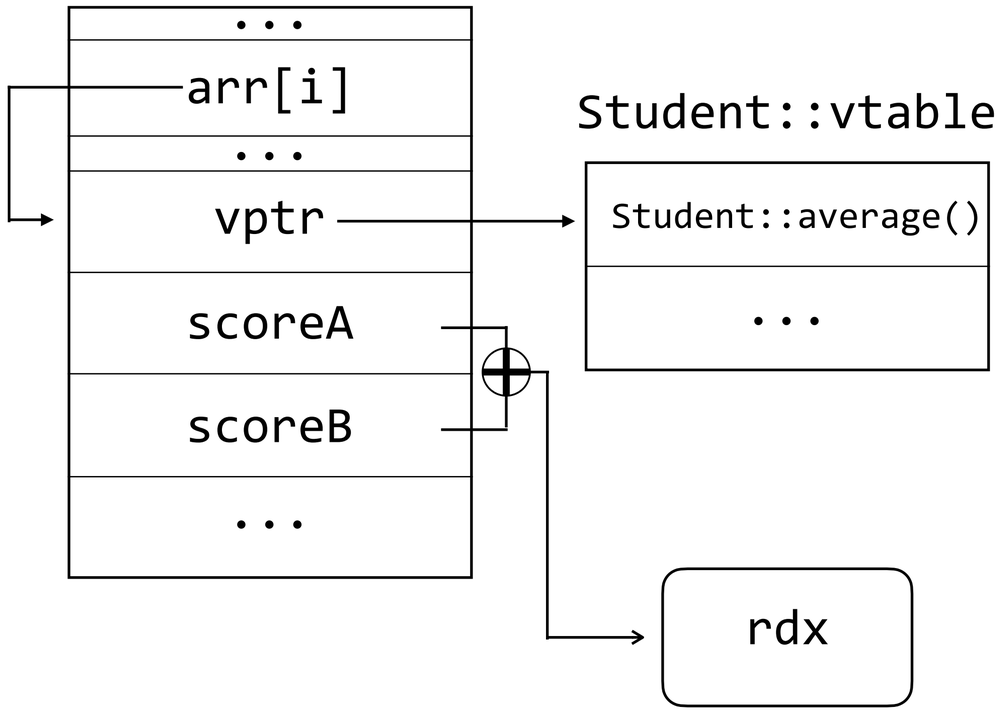
    virtual void set(char *src) {
        strncpy(buf, src, len);
    }
};
```



Caller-saved registers store intermediate results.

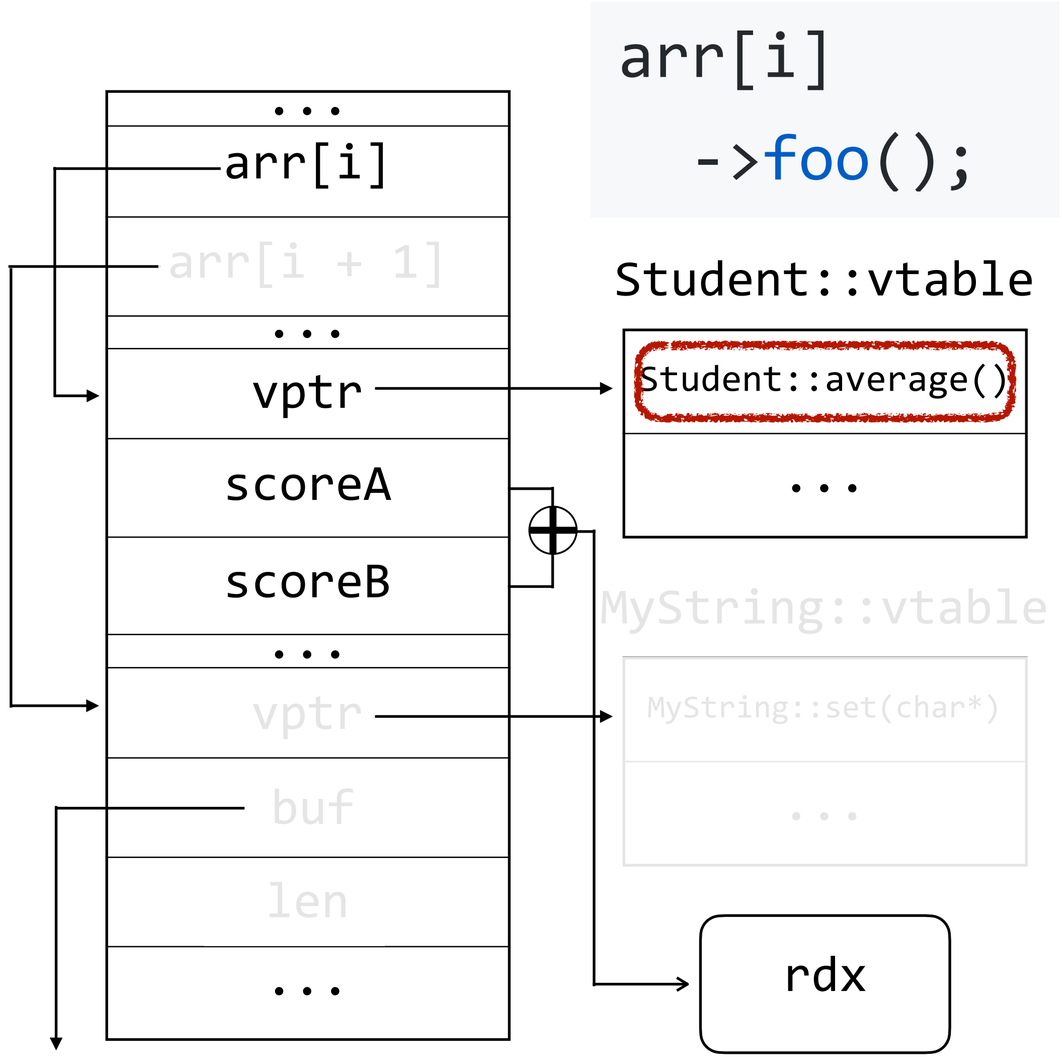
```
class Student {
    int scoreA, scoreB;

    virtual int average() {
        return (scoreA+scoreB)/2;
    }
};
```



Intermediate results are arguments for the next call.

```
class Student {
    int scoreA, scoreB;
    virtual void average() { .. }
};
class MyString {
    char *buf; int len;
    virtual void set(char *src)
    { .. }
};
```



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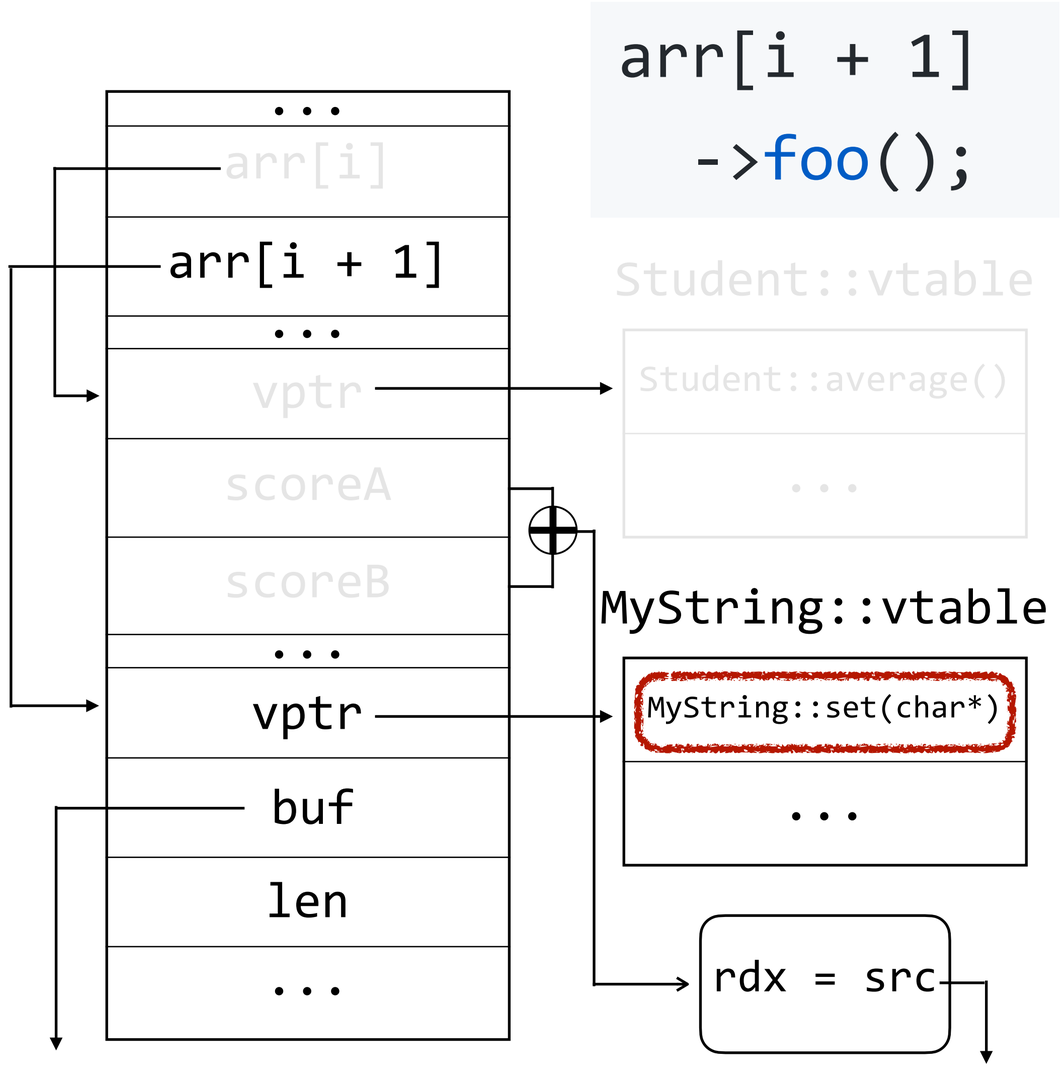
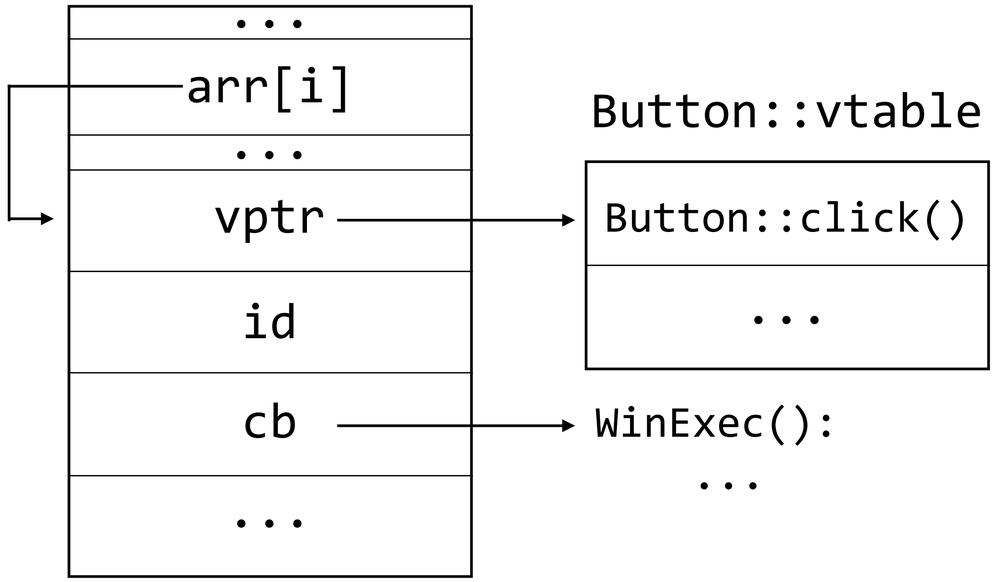


Gadgets calling function pointers can be used for system calls.

```
class Button {
    int id;
    void (* cb)(int);

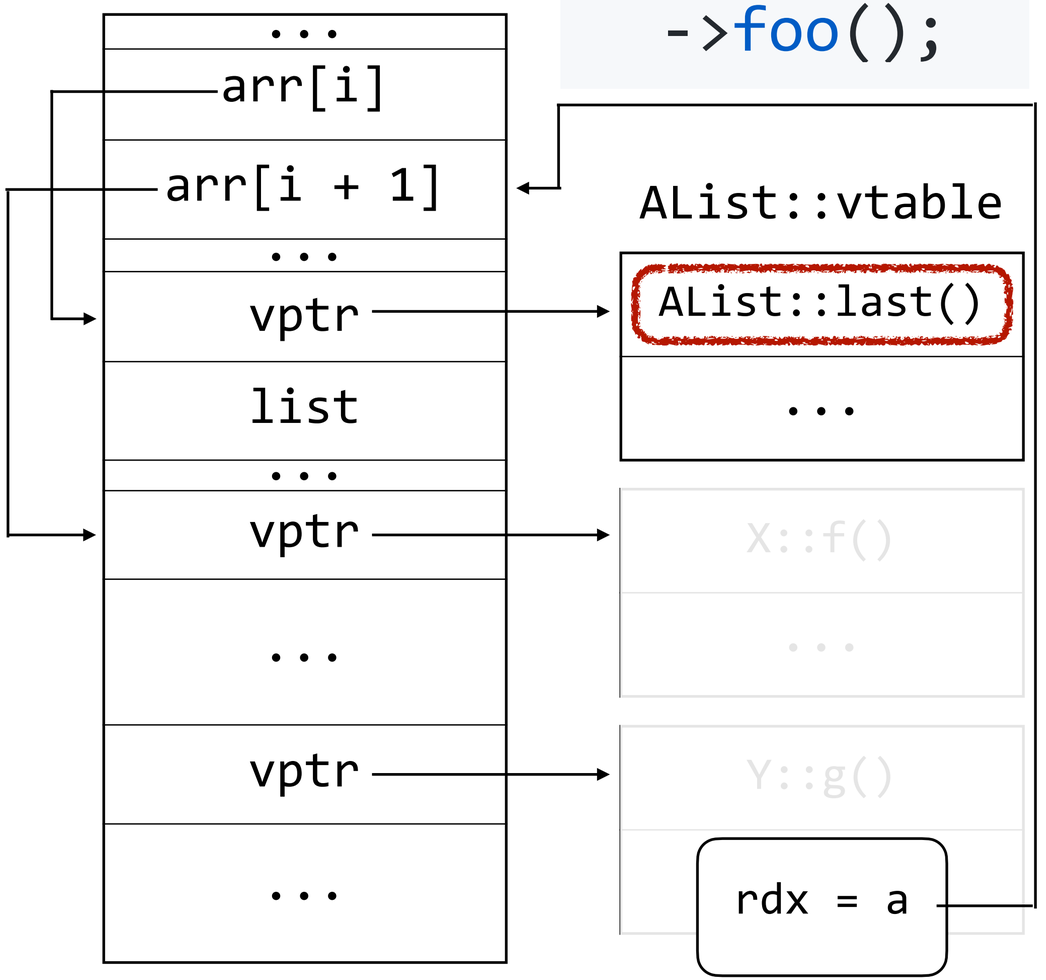
    virtual void click() {
        cb(id);
    }
};
```



A conditional write is a conditional branch.

```
class AList {
    std::list<A> list;
    virtual bool last(A *a) {
        if (list->empty())
            return false;
        *a = list->back();
        return true;
    }
};
```

```
arr[i]
  ->foo();
```



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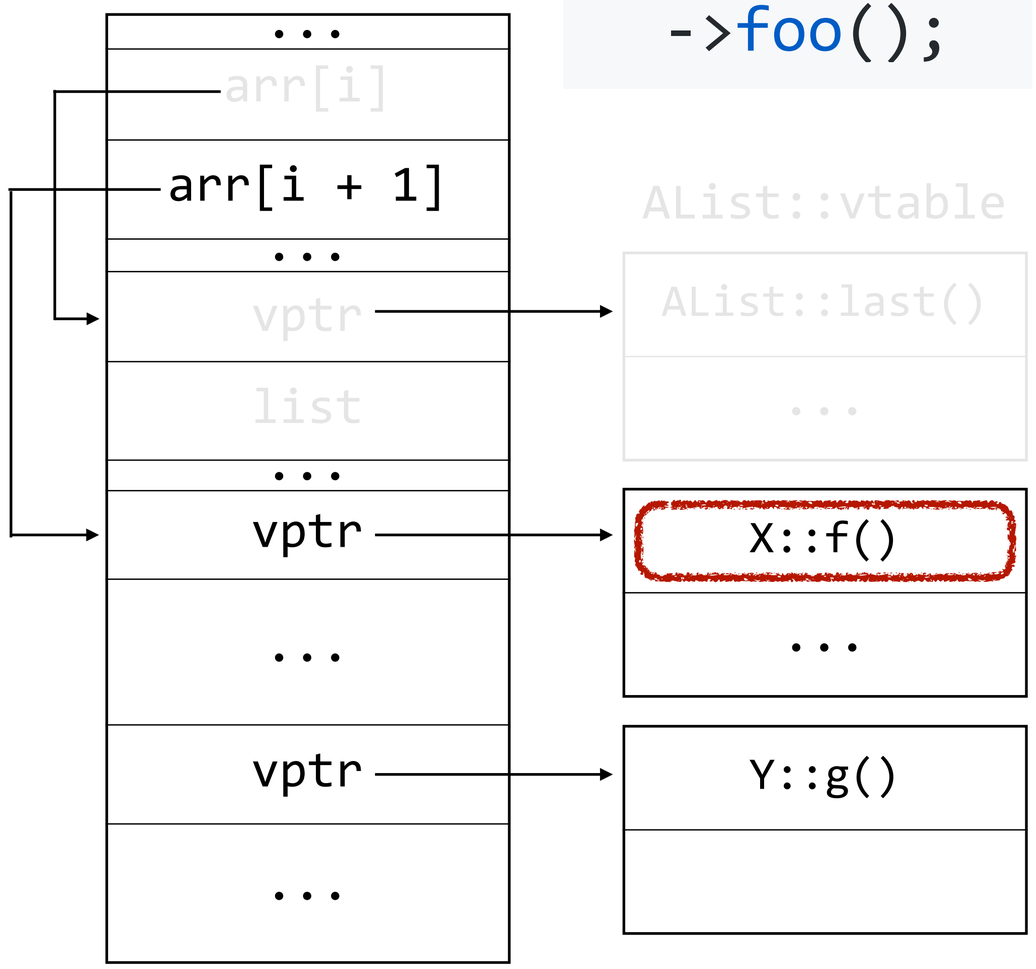
        if (list->empty())
            return false;
        *a = list->back();
        return true;
    }
};
```

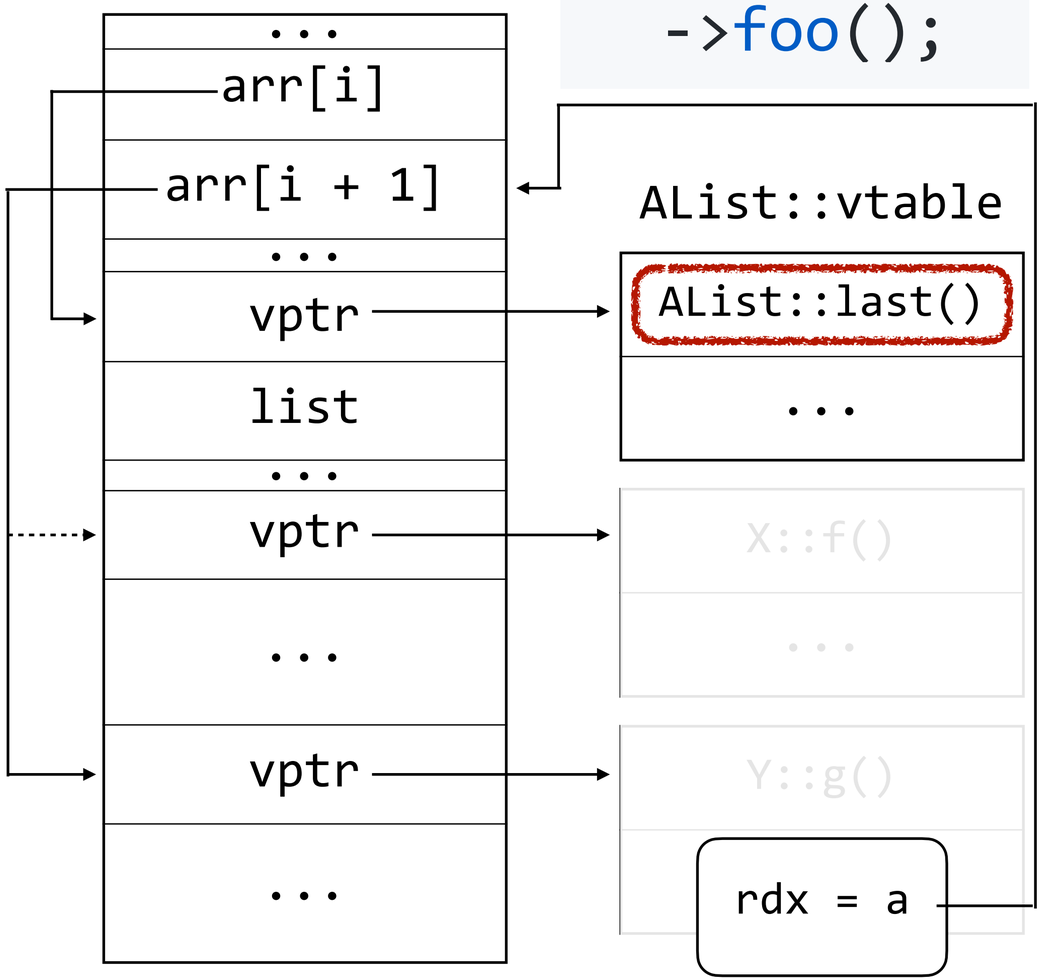
```
arr[i + 1]
  ->foo();
```



A conditional write is a conditional branch.

```
class AList {
    std::list<A> list;
    virtual bool last(A *a) {
        if (list->empty())
            return false;
        *a = list->back();
        return true;
    }
};
```

```
arr[i]
  ->foo();
```



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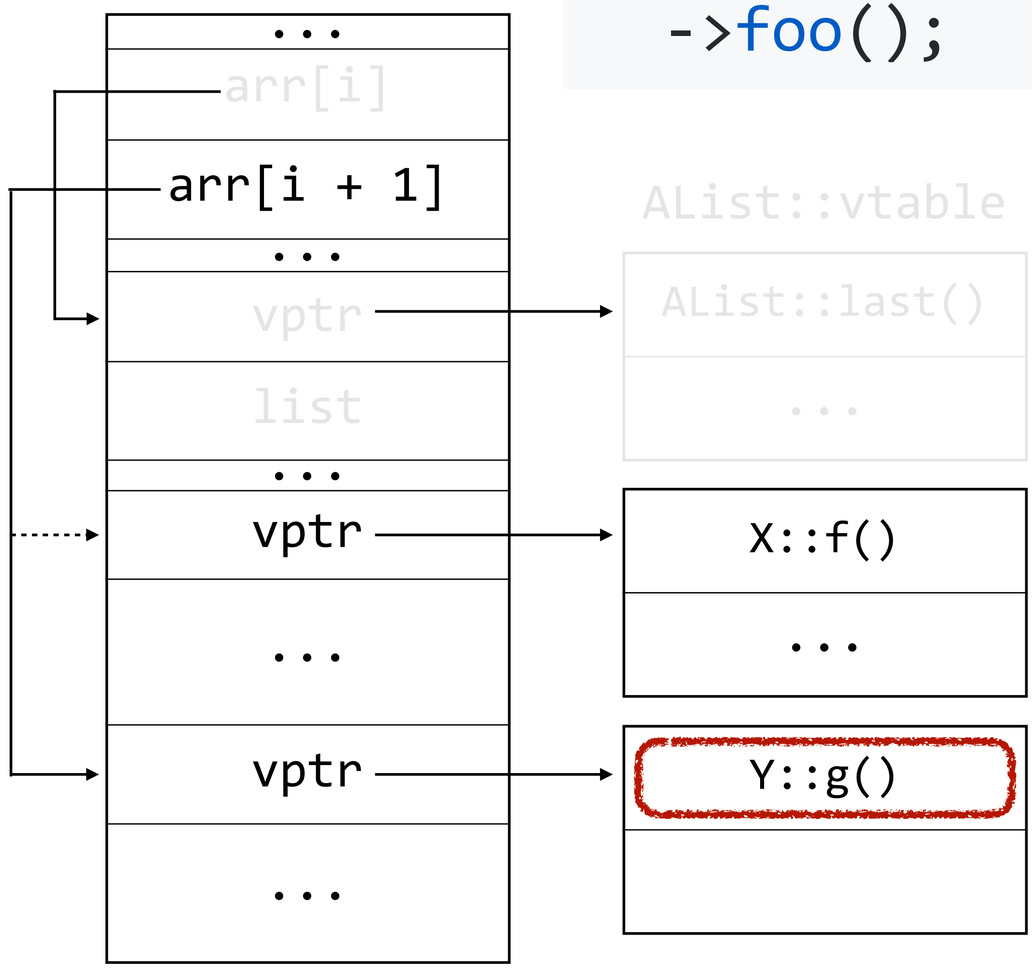
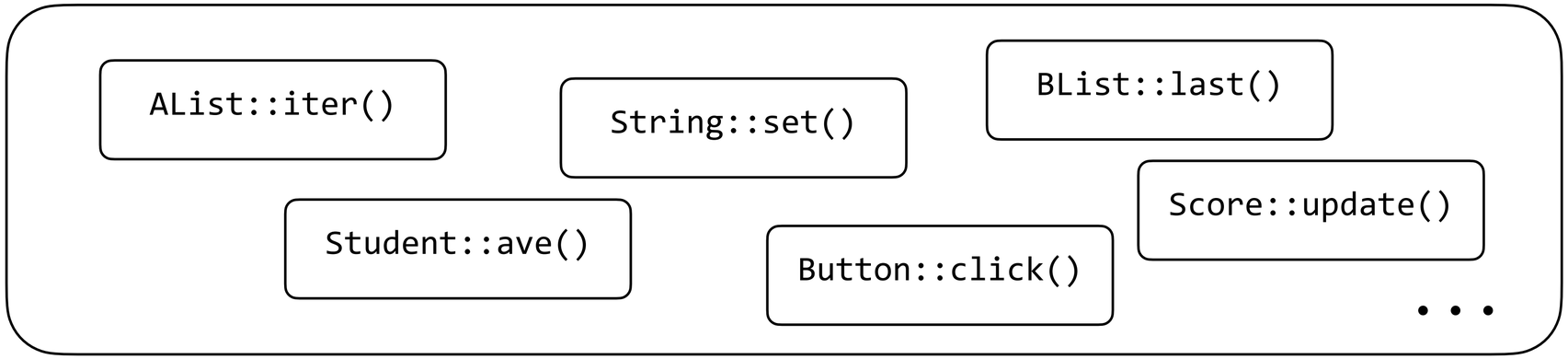


COOP achieves Turing completeness.

`AList::iter()`	Main loop
`Score::update()`	Arithmetic/logical
`String::set()`	Read/write
`Student::ave()`	Load argument
`Button::click()`	Function call
`BList::last()`	Conditional branch

The COOP framework consists of 3 steps.

1. Find gadgets



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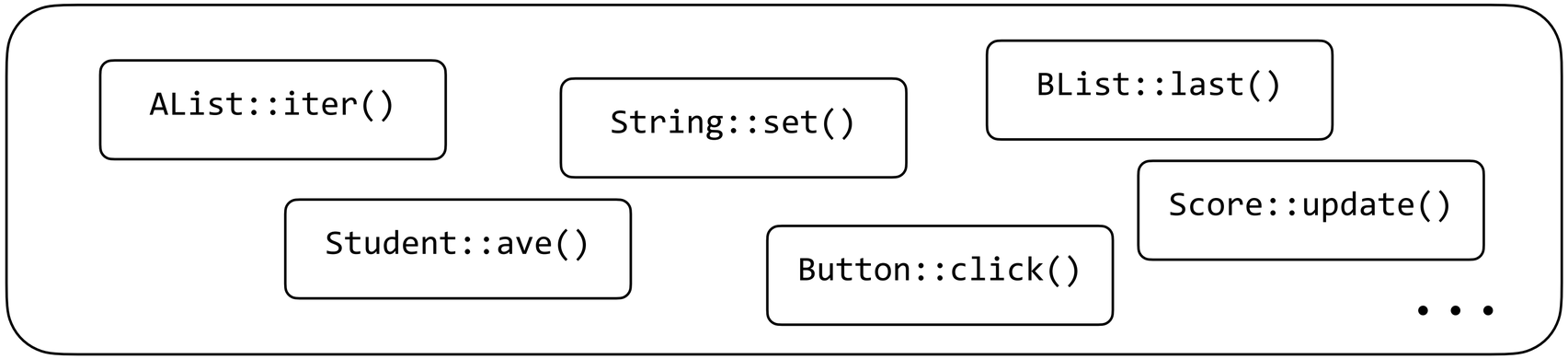
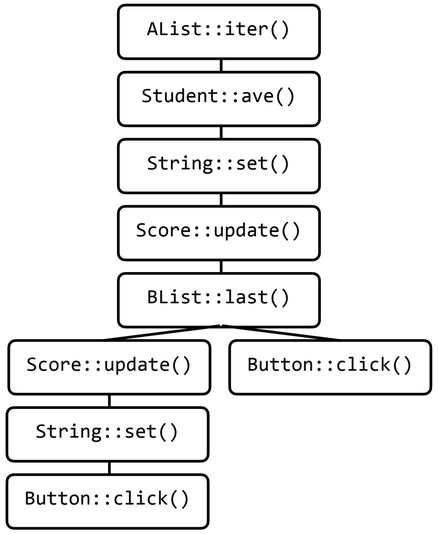


2. Design an attack



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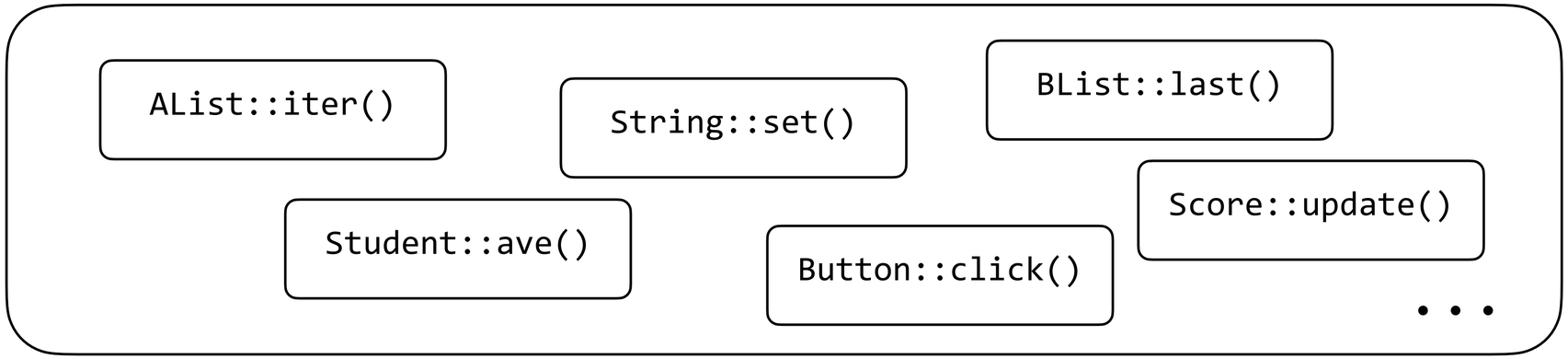

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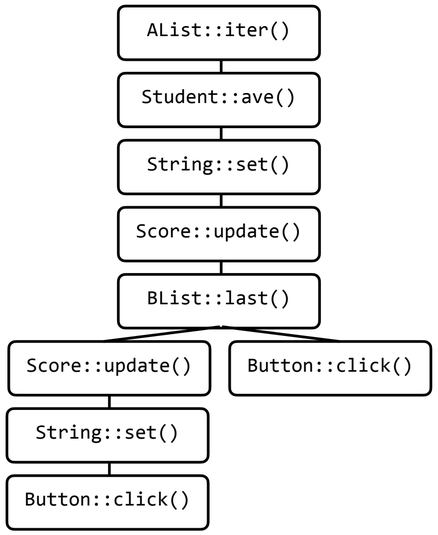
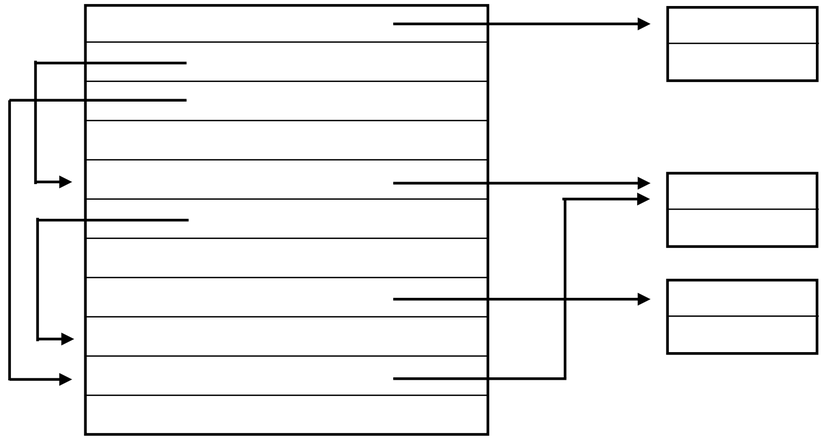


3. Arrange objects in memory



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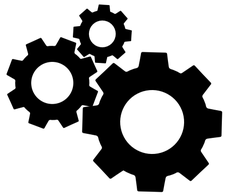
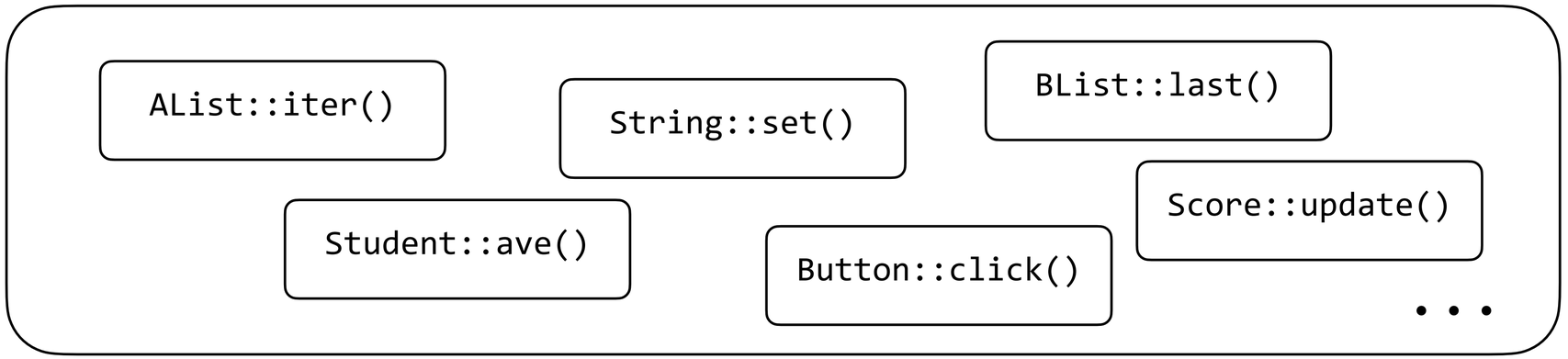
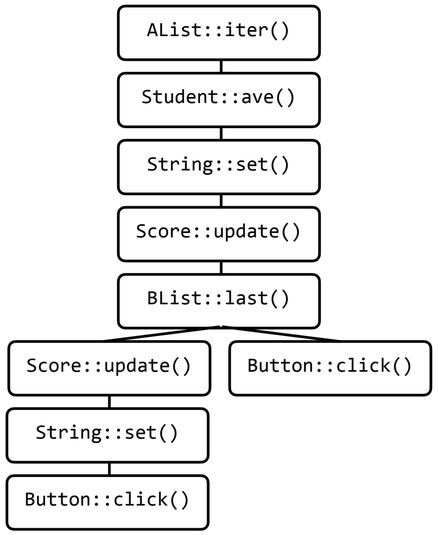
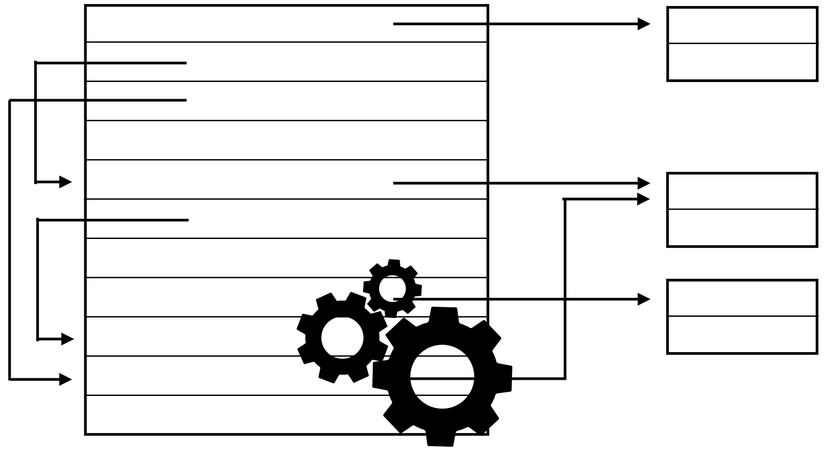




2. Design an attack

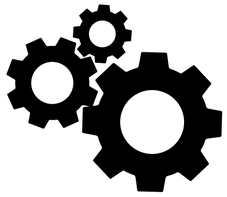


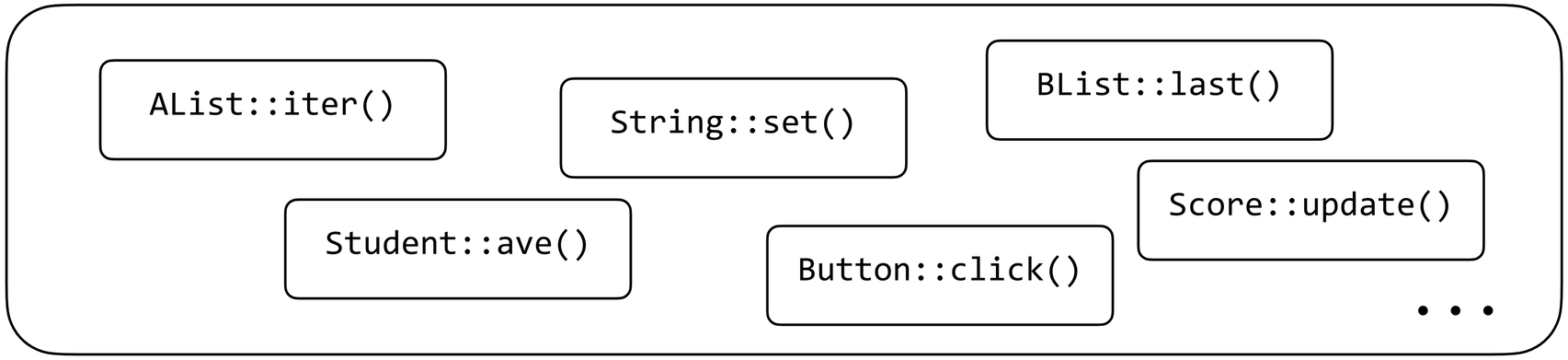


3. Arrange objects in memory

Gadgets are automatically extracted from the binary.

1. Find gadgets






```
0101010111010101
0101010101010111
0100001010101100
0010101111100011
0101011010100101
0111100101010101
0010101010101010
1111101101010101
```

Gadgets are automatically extracted from the binary.

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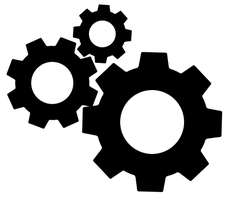

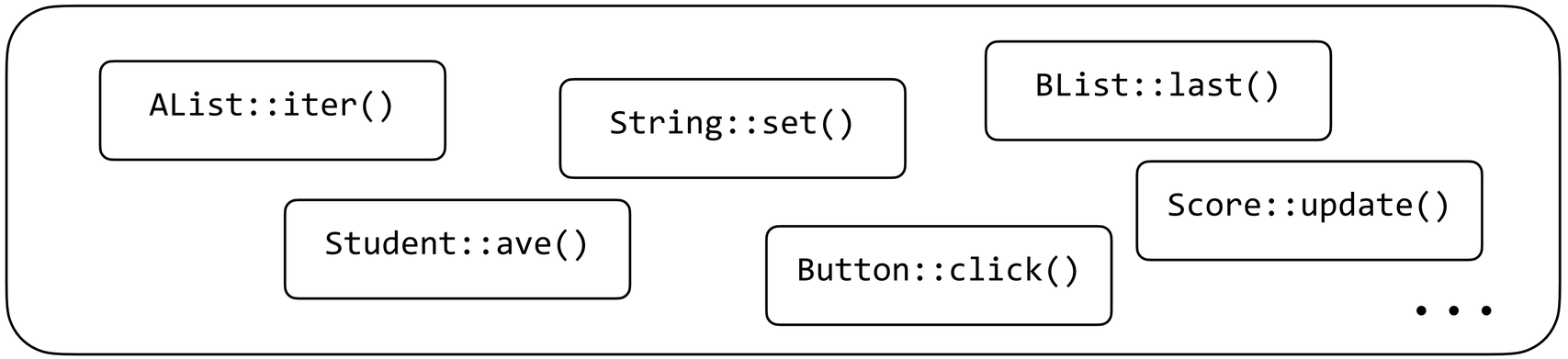

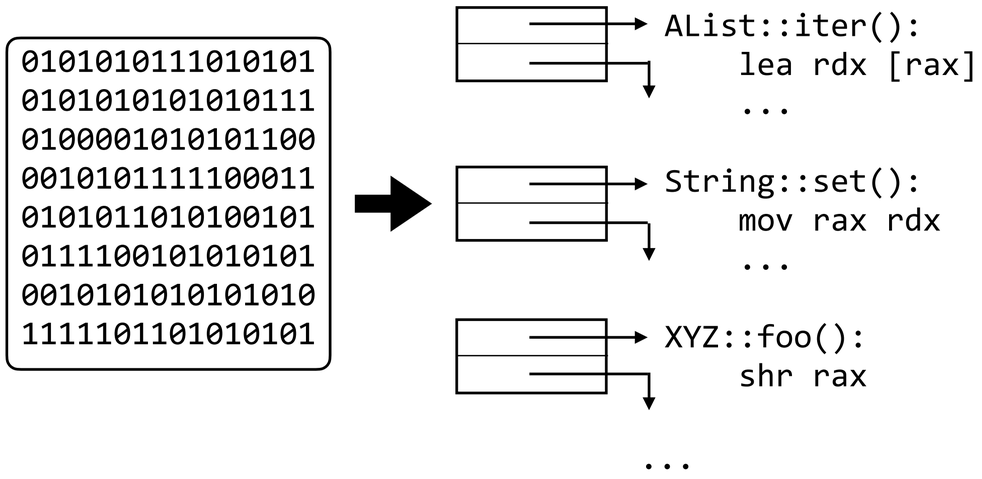

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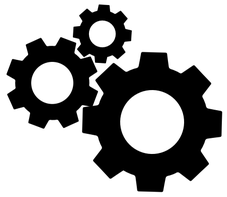

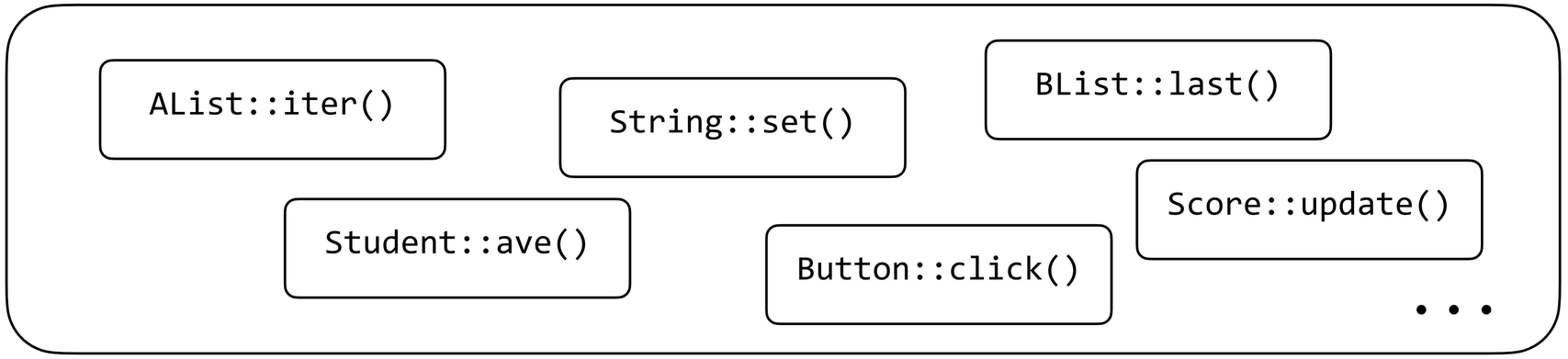

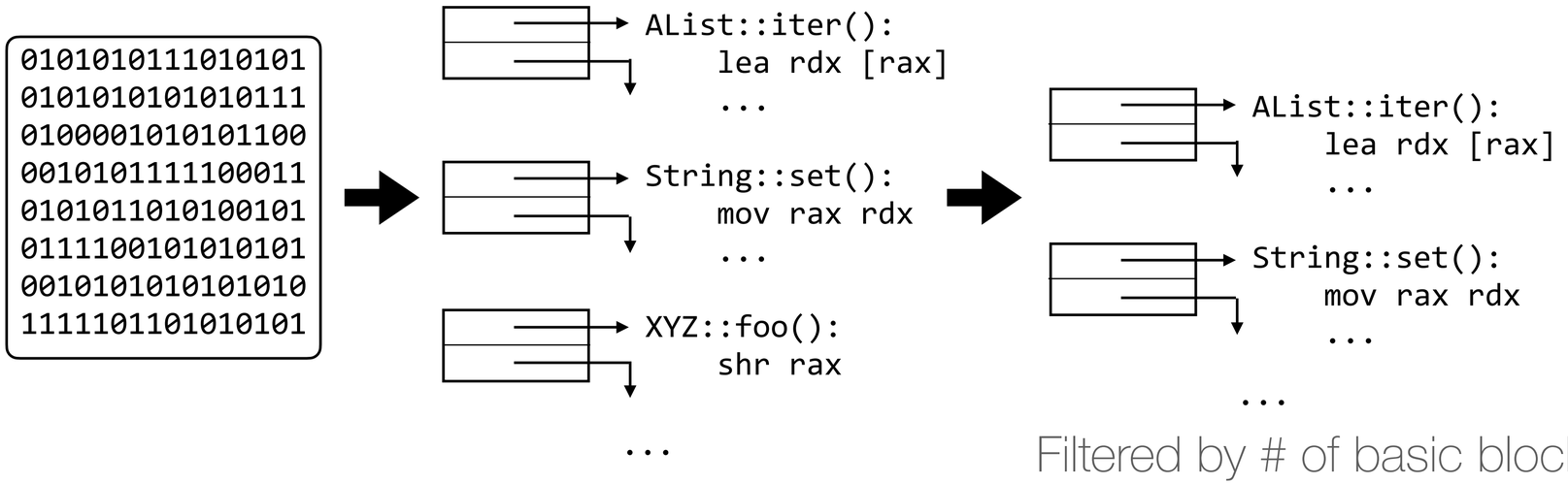

Filtered by # of basic blocks

Gadgets are automatically extracted from the binary.

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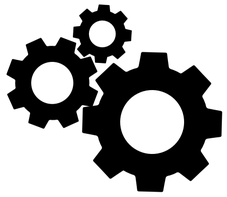

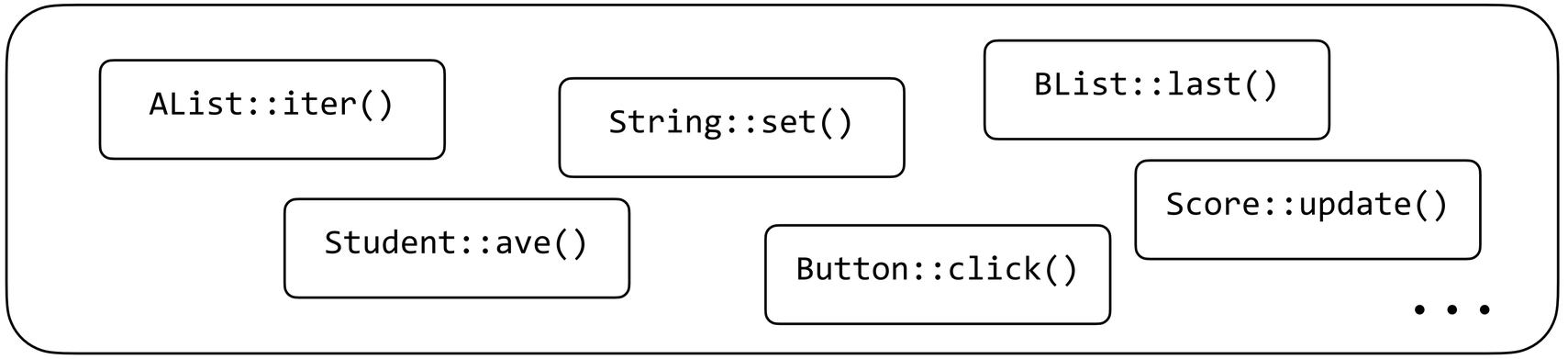

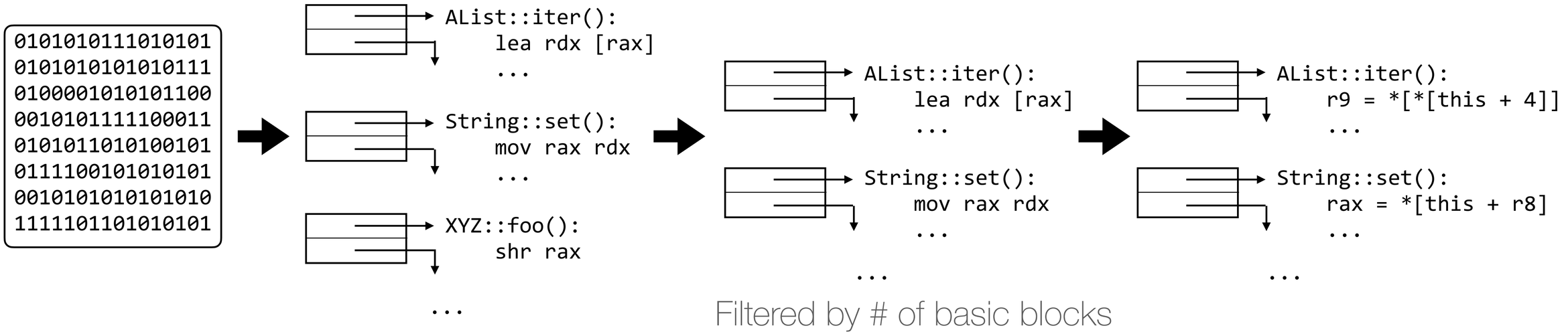

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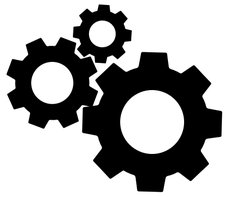
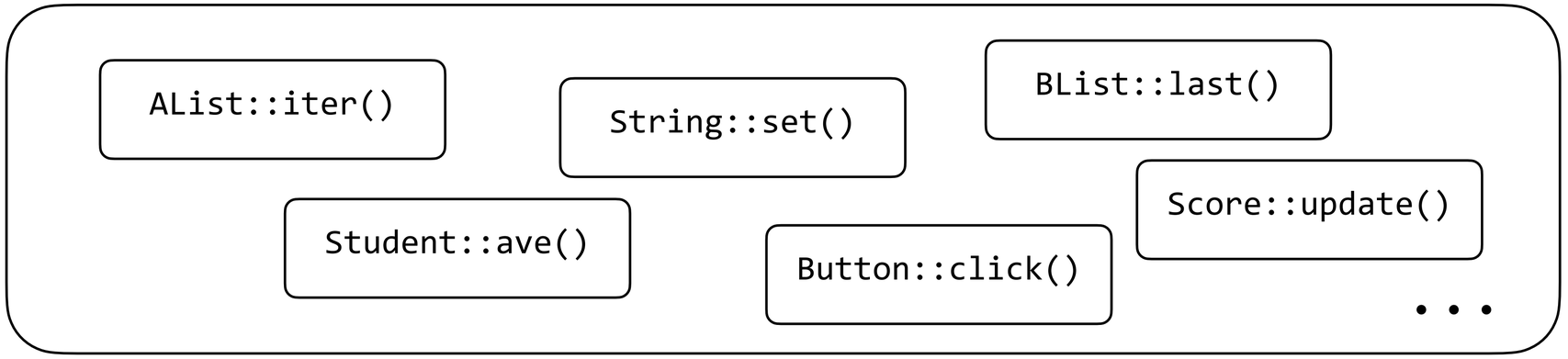
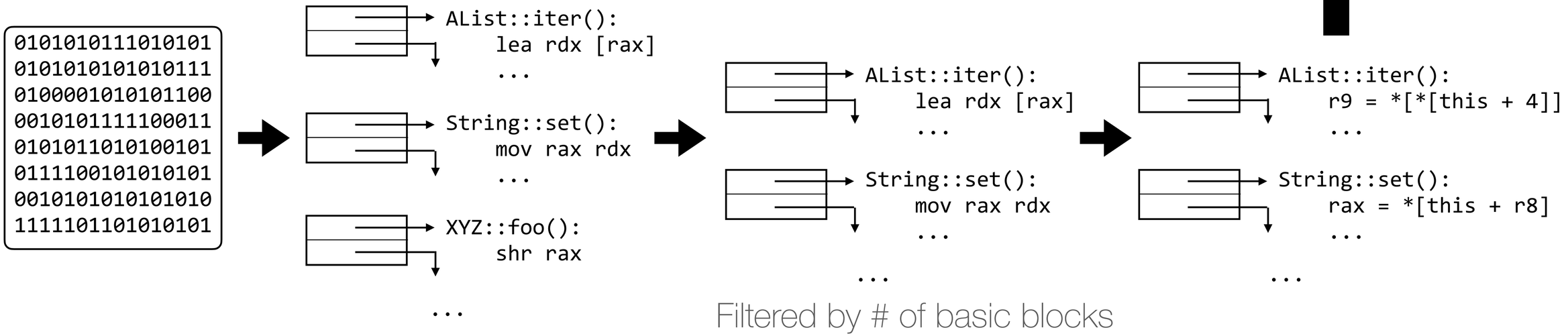


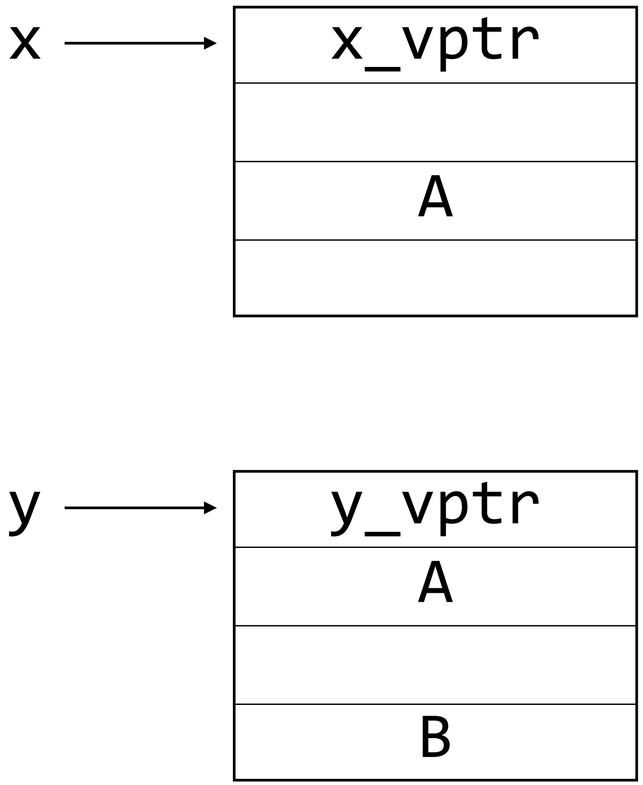


Filtered by semantics



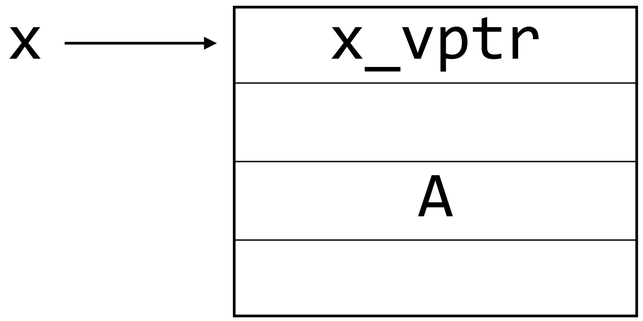
Filtered by # of basic blocks

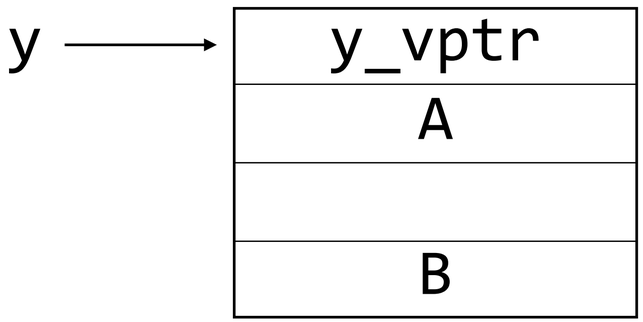
Z3 solves constraints to determine the layout.



3. Arrange objects in memory

Z3 solves constraints to determine the layout.





```
*x = x_vptr
*(x + 8) = A
*y = y_vptr
*(y + 4) = A
*(y + 12) = B

x + 8 = y + 4
```

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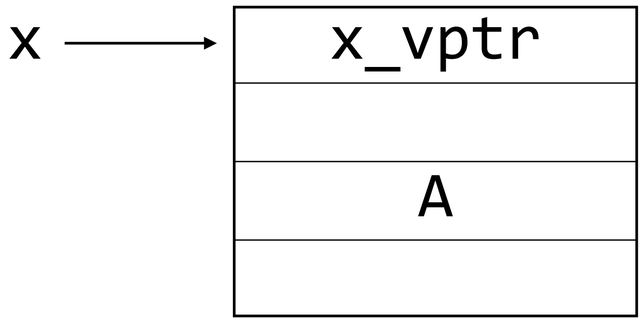
Z3 solves constraints to determine the layout.

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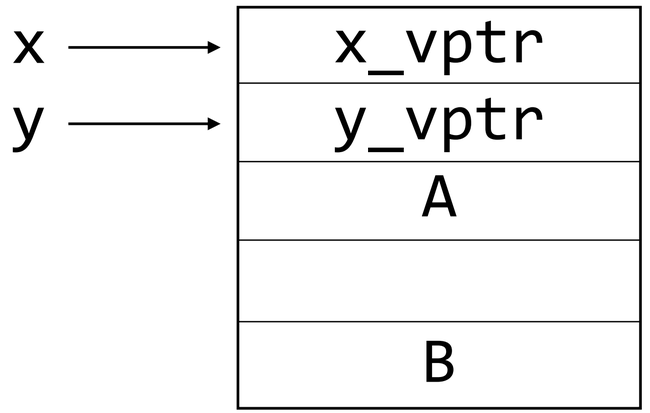
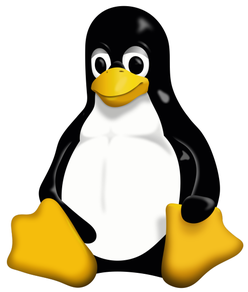



```
x = 0, y = 4
```

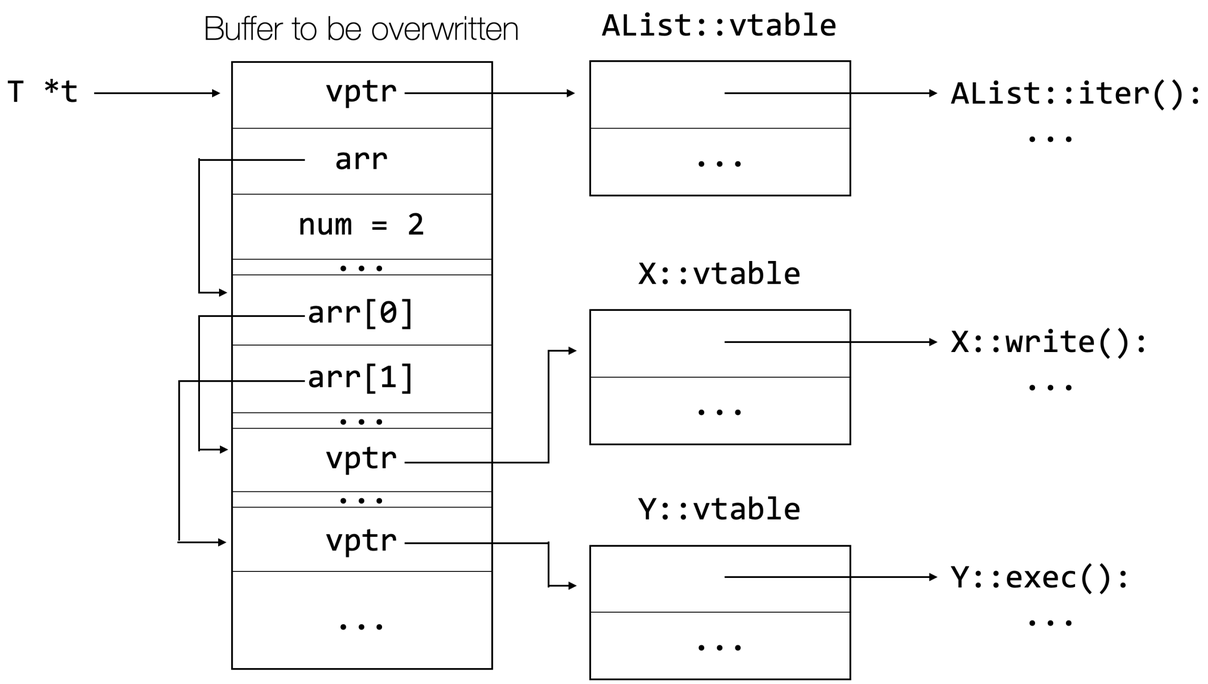
3. Arrange objects in memory

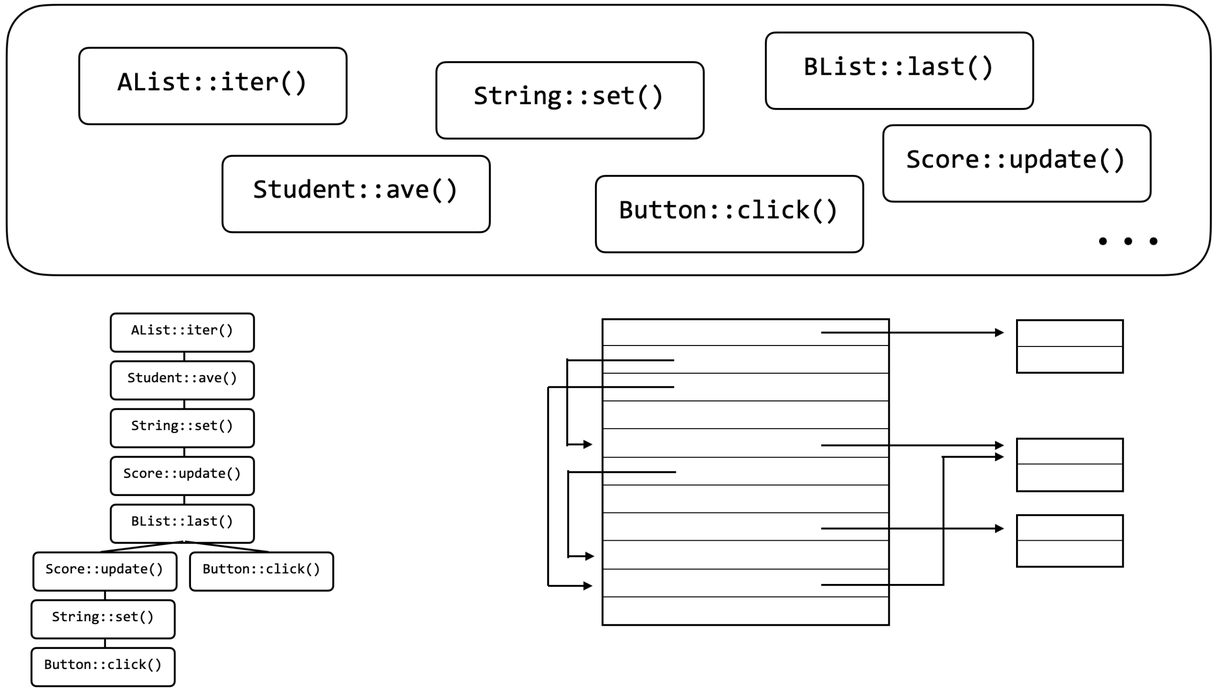
COOP is widely applicable.

x64	calc.exe / mspaint.exe
x86	calc.exe + ⊥



x64	/bin/sh





Counterfeit Object-oriented Programming