# C++ for Java Programmers – II

WL101.1b

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Risky but rewarding.

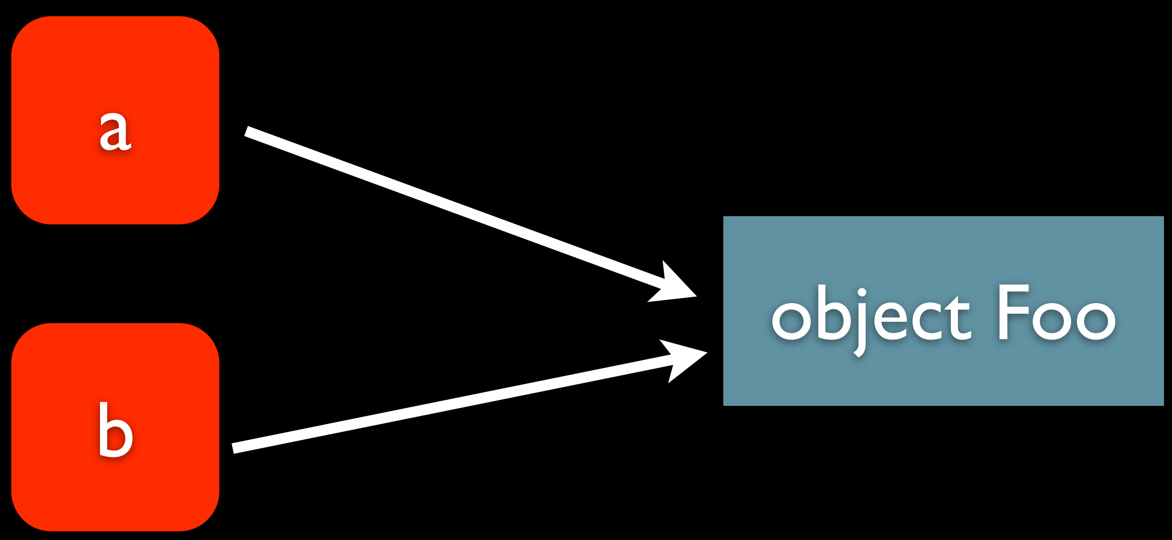
# Outline

- Pointers
- References
- Arrays
- Memory Model
  - ✦ Scoping and Lifetime
  - ✦ Casts
  - ✦ Memory layout
  - ✦ `sizeof`
  - ✦ Strings
  - ✦ Dynamic Allocation
  - ✦ L-values and R-values

# Pointers

- Recall: In Java, all object identifiers are pointers.

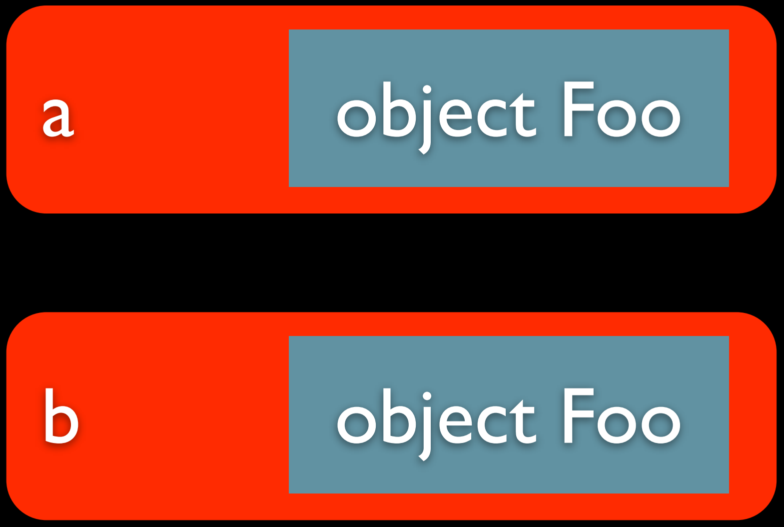
```java
public static void main(String [] args) {
   Foo a = new Foo();
   Foo b = a;
}
```



# Pointers

- In C++, this is not the case.
- Remember the principle: *Treat all objects as if they are primitives.*

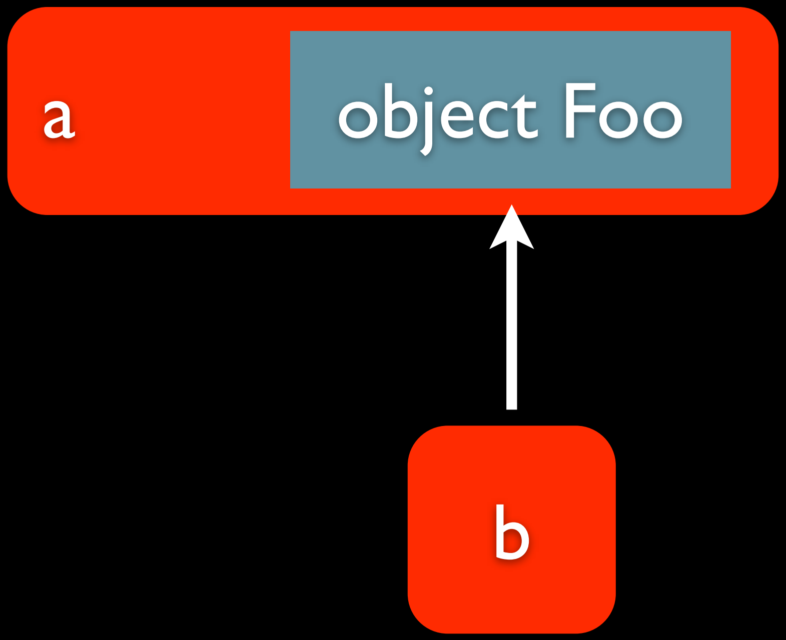
```
int main() {
  Foo a;
  Foo b = a;
  return 0;
}
```



# Pointers

- Such pointers have to be declared explicitly using * when declaring variables.
- The "address" of a variable can be retrieved by the address-of operator &.
- Everything else works like Java... *almost.*

```
Foo a;
Foo *b = &a;
```



# Pointers

- Adhering again to the C++ type principle, you can do the same for primitives.
- No `int` v.s. `Integer`, `float` v.s. `Float`, `char` v.s. `Character`, `boolean` v.s. `Boolean`, etc.

```
int main() {
  int a = 0;
  int *b = &a;
  return 0;
}
```

# Pointers

- The * modifier only affects the immediate identifier. Compound declarations beware!
- It doesn't matter where the space is placed.
- Typedef may help here.

```
int *a, b; //b is not a pointer!
typedef int* IntPtr;
IntPtr c, d; //c and d are both pointers.
```

# Pointers

- Temporary objects, known as **R-values**, have no addresses thus, they can't be pointed to.

```
int *a = &(1 + 2); //illegal!
```

Generally, if the value has no name, it has no address (more to this later).

# Pointers

- A “null pointer” in C++ is basically `0`.
- Some people (and compilers) predefine `NULL` and use it instead.
- C++0x defines `nullptr` to fill this gap.

```
int main() {
  Foo *a = 0;
  Foo *b = NULL; //works most of the time.
  return 0;
}
```

# Pointers

- Given a pointer, we access the actual object using the "dereference" * operator.
- It can be used both for assigning and reading.

```
int main() {
  int a = 0;
  int *b = &a;
  *b = 0xBEEF;
  return a; //what does this return?
}
```

# `const` Pointers

- Pointers can be `const` in 2 non-exclusive senses:
  - The location it's pointing to is `const` (`a`).
  - The value of the pointer itself is `const` (`b`).
- They can be both (`c`).

```
const int *a;
int * const b;
const int * const c;
```

Read from *right to left.*

# Const Pointers

- Note that dereferenced const pointers cannot be assigned even if the location they're pointing to is non-const.

```
int a = 5;
const int *ptr = &a;
*ptr = 10; //will not compile!
```

# Pointers

- For objects, operator `->` is a shorcut to `(*object).member`

`foo->bar` ⟷ `(*foo).bar;`

# Checkpoint 2.0

Assume class `Foo` has an `int` field named `bar`, what does `main` return?

What happens when `b->bar = 20;` is removed?

```
int main() {
  Foo a;
  Foo *b = &a;
  a.bar = 10;
  b->bar = 20;
  return (*b).bar;
}
```

# Checkpoint 2.1

What does `swap` do and what does `main` return?

```
void swap(int *a, int *b) {
  int temp = *a;
  *a = *b;
  *b = temp;
}

int main() {
  int a = 0, b = 1;
  swap(&a, &b);
  return a; //what does this return?
}
```

Bonus: What's the equivalent in Java?

# Checkpoint 2.2

What does each version do? Are they all correct?

```
void swap(int *a, int *b) {
  int temp = *a;
  *a = *b;
  *b = temp;
}
```

```
void swap(int a, int b) {
  int temp = a;
  a = b;
  b = temp;
}
```

```
void swap(int *a, int *b) {
  int *temp = a;
  a = b;
  b = temp;
}
```

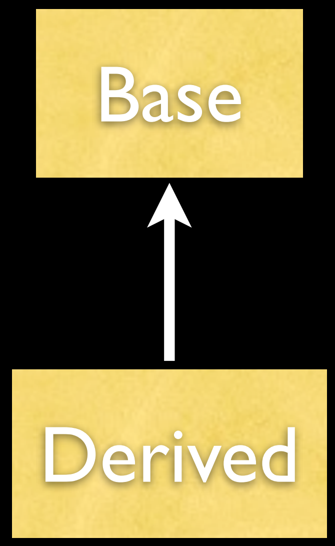
# Checkpoint 2.3

What's the improvement of this over the earlier version?

```
void swap(int *a, int *b) {
  if ( !a || !b ) return;
  int temp = *a;
  *a = *b;
  *b = temp;
}
```

# Pointer Polymorphism

- Pointers and references (later) are the only ways to do polymorphism.
- Like Java, no explicit cast is needed when upcasting.




```
Derived d;
Base *b = &d;
```

# Checkpoint 2.4

What's possibly wrong with the following?

```
void foo(Base b) {
//do something to b
}

int main() {
  Derived d;
  foo(d);
  return 0;
}
```

# Checkpoint 2.4 “solution”

Correct version:

```
void foo(Base *b) {
//do something to b
}

int main() {
  Derived d;
  foo(&d);
  return 0;
}
```

# Void Pointer

- The void pointer (`void *`) is the "mother of all pointers"; any pointer can be upcasted to a void pointer.
- Downcasts are necessary when dereferencing.
- Similar to `Object` in Java.

```
int main() {
   int a = 0;
   Foo b;
   void *c;
   c = &b;
   c = &a;
   return *((int*)c);
}
```

# Function Pointers

- Pointers can also refer to functions.
- Declaration is in the form:

```
return_type (*PointerName)(parameters);
```

1. Never omit the first set of parenthesis.
2. Typedef will greatly help.
3. Parameter names can be omitted.
4. They are invoked as if they are normal functions.

# Function Pointer Example

```
int* a();
int (*b)();
int* (*c)();
void (*d)(int);
void (*e)(void (*)());
```

```
typedef int (*IntFP)();

IntFP f;
IntFP (*g)(IntFP);
```

# Function Pointer Example

```
#include<iostream>
using namespace std;

int add(int a, int b) { return a + b; }
int multiply(int a, int b) { return a * b; }

typedef int (*binary_op)(int, int);

int main() {
  binary_op operation = 0;
  int x, y;
  char op;
  cin >> x >> op >> y;
  if ( op == '+' ) {
    operation = add;
  } else {
    operation = multiply;
  }
  cout << operation(x, y) << '\n';
  return 0;
}
```

# Checkpoint 2.5

Declare a function pointer that...

- returns a void pointer.
- accepts a pointer to an int.

```
void* (*FunPtr)(int *);
```

Describe the following:

```
void (*ptr)( void (*)(int) );
```

# Pointer to Pointers

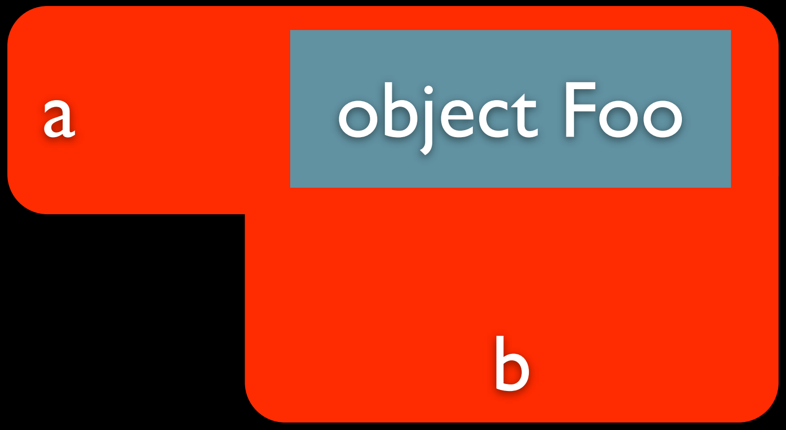
- It’s also possible to declare a pointer of pointers.
- Used in some C programs but not so much in C++.

```
int **ptrptr;
```

# References

- References are similar to pointers that they are aliases.
- However, unlike pointers, they're "permanent" – they can't be reassigned to point to another object.
- Declare them by using the & modifier.
- They have to be bound upon declaration.

```
int main() {
  Foo a;
  Foo &b = a;
  return 0;
}
```



# References

- Unlike pointers, they are transparent – they can be used like normal variables.

```
int main() {
  int a = 0;
  int &b = a;
  b = 0xBEEF;
  return a; //what does this return?
}
```

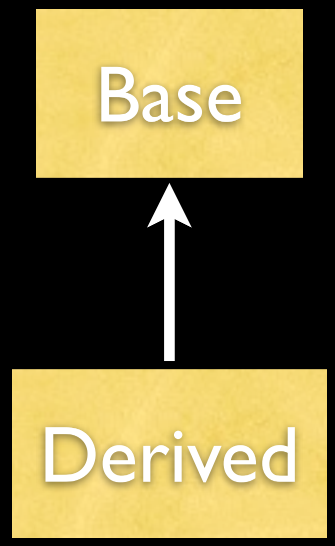
# Returning References

- Functions can return references by appending & to their return type.
- Make sure the object is still alive when returning its reference.

```
int a = 1;
int& getFoo() {
 return a;
}
int main() {
 getFoo() = 0;
 return a;
}
```

# Reference Polymorphism

- References (aside from pointers) can also be used to do polymorphism.
- No copying is involved.




```
Derived d;
Base &b = d;
```

# Reference Example

```
void swap(int &a, int &b) {
  int temp = a;
  a = b;
  b = temp;
}

int main() {
  int a = 0, b = 1;
  swap(a, b);
  return a; //what does this return?
}
```

# Reference Example Comparison

```
void swap(int &a, int &b) {
   int temp = a;
   a = b;
   b = temp;
}

int main() {
   int a = 0, b = 1;
   swap(a, b);
   return a;
}
```

Reference Version

```
void swap(int *a, int *b) {
   int temp = *a;
   *a = *b;
   *b = temp;
}

int main() {
   int a = 0, b = 1;
   swap(&a, &b);
   return a;
}
```

Pointer Version

# References v.s. Pointers

- Pointers are NULL-able, references aren't.

```
int *a = NULL;
int &b = NULL; //no!
```

- Pointers are reassignable, references aren't (they are bound upon initialization).

```
int c;
a = &c;
&b = c; //no!
```

# References v.s. Pointers

- As a general guideline, use references when you can, pointers when needed.
- References are usually used in short-term execution (function parameters).
- Pointers are used for long-term usage like in data structures (trees, linked-list, etc.)
- Case in point: the `swap` function.

# References + Const

- Sometimes, you just want to pass “heavy” objects (like vectors) and not modify it.
- Though consts help, they still copy objects.
- Const + References = const references!

```
void printArray(const string str) {
    for ( size_t i = 0; i < str.size(); ++i )
        cout << str[i] << ' ';
}
```

```
void printArr(const string &str) {
    for ( size_t i = 0; i < str.size(); ++i )
        cout << str[i] << ' ';
}
```

# References + Const

- Also, const references are more “compatible”

```
const string TEMP_DIR = "C:\Temp";

void foo(string &path);
void bar(const string &path);

foo(TEMP_DIR);
bar(TEMP_DIR);
```

Which will fail to compile?

# Reference + Const

Important: Const references can also accept R-values.

```
int main() {
 int &a = 1 + 1; //cannot
 const int &b = 1 + 1; //can
 return 0;
}
```

# Alias Usage Summary

- References and pointers are usually used with functions on two occasions:
   1. Huge objects are being passed (they incur copying overhead)
   2. Return values are complex (like the `swap` function)
   3. Parameters need to be modified.
- As a rule-of-the-thumb, always pass objects *by (const) reference* for efficiency.

# BREAKTI3M

# Arrays

- C++ has two kinds of built-in arrays: static and dynamic.
- Array sizes have to be manually tracked.
- No "ArrayIndexOutOfBounds" exception is thrown when you go out of bounds.
- Important: Arrays are always contiguous.

| | | | | | |
|---|---|---|---|---|---|
| 0 | 1 | 2 | 3 | 4 | 5 |

# Static Arrays

- Sizes are fixed at compile time.
- Like normal variables, initial content is dirty.
- Only literals or `const` can be used.
- Array size must be tracked manually (i.e. no `Array.length` property).

```
int arr[10];
const int ARRAY_SIZE = 20;
int arr2[ARRAY_SIZE];
for ( int i = 0; i < ARRAY_SIZE; ++i )
 arr2[i] = i;
```

# Static Arrays

- Notice the difference in the [ ] placement.

```
//Java
int [] arr = new int[10];

//C++
int arr[10];
```

# Static Arrays

- Contents can be specified upon declaration.
- When doing so, the size may be omitted.
- If declaration content is less than the array size, the rest of the entires are zeroed out.

```
int a[2] = {0, 1};
int b[] = {0, 1, 2, 3};
int c[10] = {0};
```

# Dynamic Arrays

- Pointers must be used.
- Create with `new`, release with `delete []`
- Since C++ has no GC, anything dynamically allocated must be explicitly released.
- As with static arrays, sizes are manually tracked.

```
int *a = new int[10];
delete [] a;
```

# Dynamic Array

- Unlike in Java, allocated dynamic arrays are already initialized.
- If the Java behavior is preferred, use a pointer to a pointer. (later)

Java

```
Foo [] a = new Foo[2];
a[0] = new Foo();
a[1] = new Foo();
```

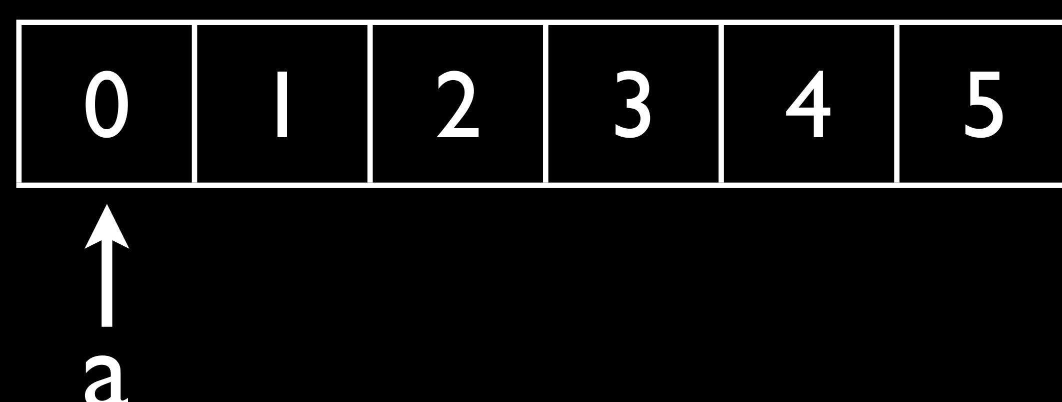
C++

```
Foo *a = new Foo[2];
//a[0] and a[1] already constructed
```

# Pointer-Array Dualism

- Recall the array layout.
- Dynamic arrays can be viewed as...

```
int *a = new int[6];
```

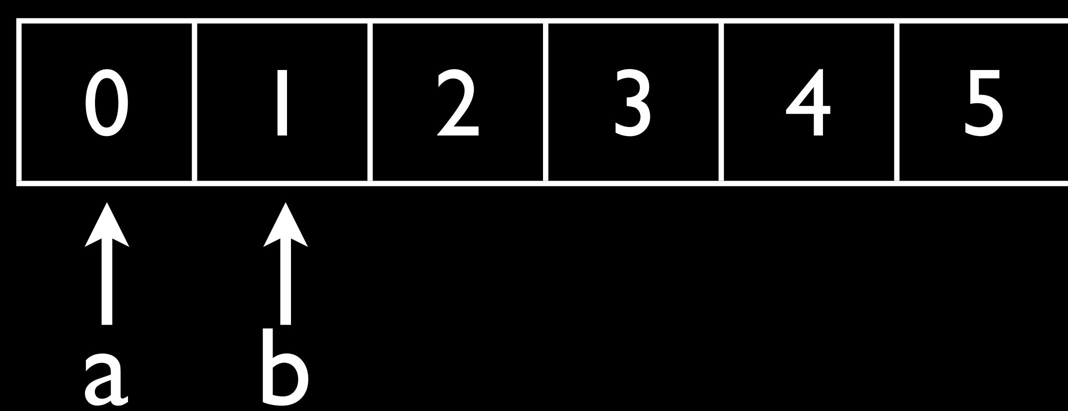



This means `a[0] == *a`

# Pointer-Array Dualism

- What if I did this:

```c
int *b = &(a[1]);
```




```c
b[0] == a[1]
```

# Pointer-Array Dualism

- What about static arrays?
- a is basically a pointer to the first element.
- The same concepts can be used.


```
int a[6];
int *b = a;
int *c = &(a[1]);
```

# Passing Arrays as Arguments

- When passing arrays to functions, two pieces of information are needed:
    - Pointer to the array
    - Array size

```
int sum(const int *elements, const int n) {
  int s = 0;
  for ( int i = 0; i < n; ++i )
     s += elements[i];
  return s;
}
```

# Checkpoint 2.5.1

Given the `sum` function in the previous slide and the array

```
int a[] = {1, 2, 3, 4, 5, 6, 7};
```

what is the output of

`sum(a + 2, 3)` ?

# `std::vector<>`

- An easier and safer way to do dynamic arrays.
- Analogous to `java.util.ArrayList`
- Access elements using `[ ]`.
- Automatically deallocates upon scope exit.

```
{
  std::vector<int> arr;
  arr.push_back(1);
}
//arr automatically gets released
```

# std::vector<>

- Guaranteed to be contiguous.
- Can act like a normal dynamic array.

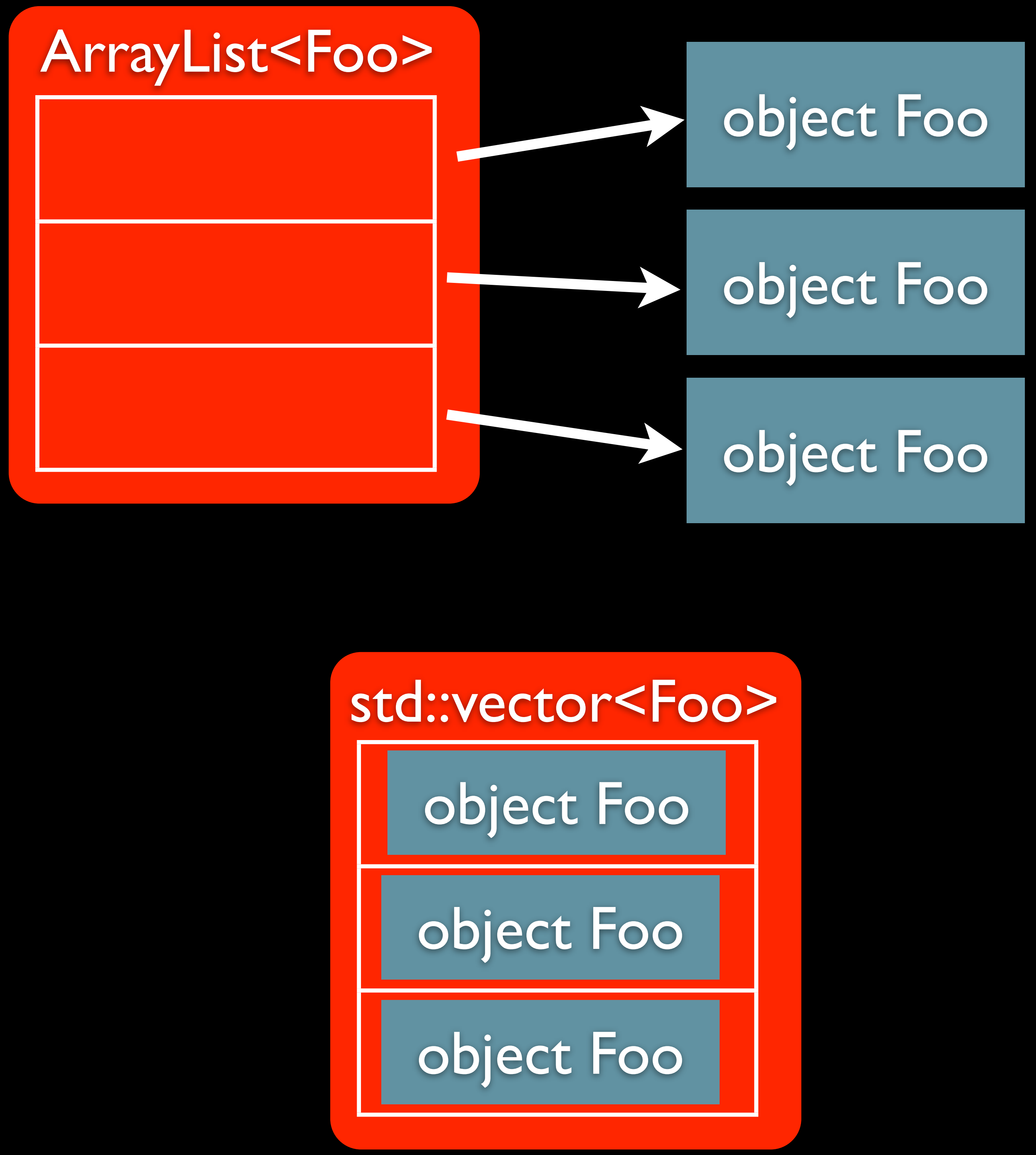
```
int sum(const int *elements, const int n) {
  int s = 0;
  for ( int i = 0; i < n; ++i )
     s += elements[i];
  return s;
}

vector<int> a;
//insert elements to a.
int total = sum(&(a[0]), a.size());
```

# `std::vector<>`

- Append elements using `vector<>.push_back(item)`
- Get the size using `vector<>.size()`
- Check if it's empty by calling `vector<>.empty()` (or just check if `vector<>.size() == 0`)
- `vector<>.front()` and `vector<>.back()` to access the first and last element (will crash if the vector is empty).
- Resize using `vector<>.resize(newsize, fill)`
- Clear the vector by calling `vector<>.clear()`

# std::vector<>

- Stores exactly what's in its type (not a pointer, unlike Java).
- If objects are large, it may be more efficient to store pointers of them instead; like the Java way. (later)



# std::vector<> examples

```
using namespace std;
vector<int> a;
vector<float> b;
for ( int i = 0; i < 10; ++i )
 a.push_back(i);
for ( int i = 0; i < a.size(); ++i )
 b.push_back(a[i] * 1.5f);

a.clear();
```

# Checkpoint 2.6

Rewrite the following to use `std::vector<>` directly.

```
int sum(const int *elements, const int n) {
 int s = 0;
 for ( int i = 0; i < n; ++i )
    s += elements[i];
 return s;
}
```

```
int sum(const std::vector<int> &elements) {
 int s = 0;
 for ( int i = 0; i < elements.size(); ++i )
    s += elements[i];
 return s;
}
```

# Checkpoint 2.7

## Is the following safe?

```
int sum(const int *elements, const int n) {
  int s = 0;
  for ( int i = 0; i < n; ++i )
      s += elements[i];
  return s;
}
```

```
vector<int> a;
a.push_back(0);
a.push_back(1);

int *p = &(a[0]);
int n = a.size();
a.clear();

int total = sum(p, n);
```

# Arrays

- I skipped the part on how to arrays having 2 dimensions and above.

# BREAKTI3M

# Memory Model

- Scoping and Lifetime
- Casts
- Memory layout
- `sizeof`
- Strings
- Dynamic Allocation
- L-values and R-values

# Scoping and Lifetime

- Every object has a lifetime subject to their scope.
  - Begins upon declaration.
  - Ends upon scope exit.
- Global and static variables die upon program exit.

```
void foo(int *a) {
 int b;
}
int c;
foo(&c);
```

# Scoping and Lifetime Exercise

Copy the following code to the top of the source.

```
class Foo {
  int i;
public:
  Foo(int i) : i(i) {
      std::cout << "Foo " << i << " created\n";
  }
  Foo(const Foo &f) {
      std::cout << "Foo " << f.i << " being copied\n";
      i = f.i;
  }
  ~Foo() {
      std::cout << "Foo " << i << " releasing\n";
  }
};
```

# Scoping and Lifetime Exercise

Try to following codes and see what's the output.

a
```cpp
Foo a(0);

int main() {
  Foo b(1);
  return 0;
}
```

b
```cpp
int main() {
  Foo a(0), b(1);
  return 0;
}
```

c
```cpp
int main() {
  {
      Foo a(0);
  }
  Foo b(1);
  return 0;
}
```

d
```cpp
int main() {
  Foo a(0);
  Foo b(a);
  return 0;
}
```

f
```cpp
void bar() {
  Foo b(1);
}

int main() {
  bar();
  Foo a(0);
  bar();
  return 0;
}
```

g
```cpp
void bar(const Foo &p) {
  Foo b(1);
}

int main() {
  Foo a(0);
  bar(a);
  return 0;
}
```

h
```cpp
void bar(Foo p) {
  Foo b(1);
}

int main() {
  Foo a(0);
  bar(a);
  return 0;
}
```

# Scoping and Lifetime Exercise

## More things to try.

i

```
Foo bar() {
  return Foo(1);
}

int main() {
  Foo a = bar();
  return 0;
}
```

j

```
Foo bar(const Foo &p) {
  return p;
}

int main() {
  Foo a(0);
  Foo b = bar(a);
  return 0;
}
```

k

```
Foo bar() {
  return Foo(0);
}

int main() {
  const Foo &a = bar();
  Foo b(1);
  return 0;
}
```

# Checkpoint 2.8

What's wrong with this code?

```
Foo* getFoo() {
 Foo a;
 return &a;
}
```

# Checkpoint 2.9

Is this ok?

```
Foo* getFoo() {
 static Foo a;
 return &a;
}
```

# Casts

- C++ is a weakly-typed language.
- Usually, anything can be cast to anything.
- There are 2 types of casts. They both achieve the same thing.
  - C-style: Simpler but less verbose.
  - C++-style: More complex but "safer".

# C++ Casts

- C++ casts are more discriminate as to what kind of cast is used.
- 4 types:
  - `static_cast`
  - `reinterpret_cast`
  - `const_cast`
  - `dynamic_cast`

# static_cast

- The most "normal" cast.
- What you'll want/need most of the time.

```
int i = static_cast<int>(2.3/1.4);
```

- It's "static" because it's evaluated compile-time.

# static_cast

- Cannot be used for casting across "weirder" type boundaries (casting a pointer to an integer). A compiler error will happen.
- ***Do not use*** for downcasting unless you're 100% sure that the object type is correct or else an undefined behavior will happen.

```
Base *base = Factory::createRandomInstance();
Derived *d = static_cast<Derived*>(base); //dangerous!
```

# reinterpret_cast

- Used for "weirder" casts that require reinterpretations.
- Examples
  - `int*` to `char*`
  - `int*` to `int`
  - `float*` to `char*`

```
char *stuff = "Hello";
int *p = reinterpret_cast<int*> (stuff);
```

# `const_cast`

- Used to cast-away const.
- Not used often.

# dynamic_cast

- Used for downcasting.
- When the downcast cannot be performed, 0 (null pointer) is returned.
- A bit slower than static_cast due to type checking at runtime ("dynamic").

```
Base *base = Factory::createRandomInstance();
Derived *d = dynamic_cast<Derived*>(base); //null when cannot
```

# C casts

- Syntax exactly like Java's.
- `static_cast`, `reinterpret_cast` and `const_cast` combined (but no `dynamic_cast`!)
- Normal form

```
float f = (float)3/5;
```

- Function form

```
float f = float(3)/5;
```

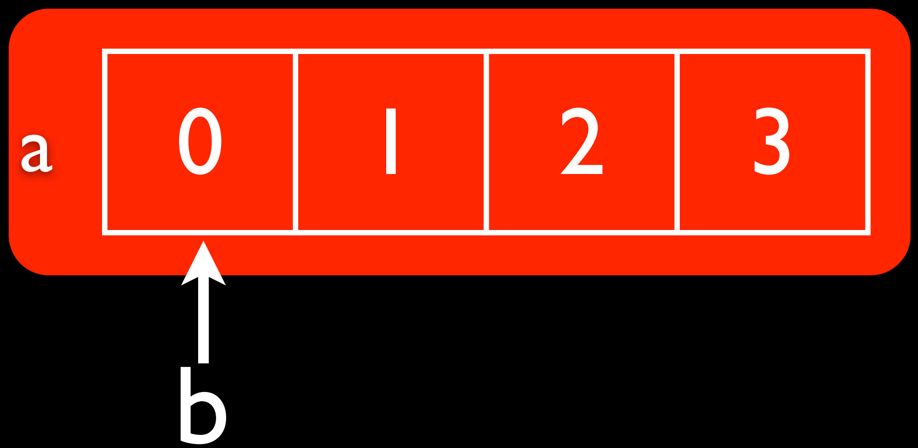
# Memory Layout

- C++, being a mid-level language, exposes some aspects of the hardware.
- Disclaimer: The following examples are for *illustrative purposes only*.
  - ***Do not*** do them unless you know and are **really** sure what you're doing.
  - They are to give an insight on how computers handle programs.

# Memory Layout

- An `int` has 4 bytes.
- Each byte can be accessed by turning it into an array of bytes (`char`).

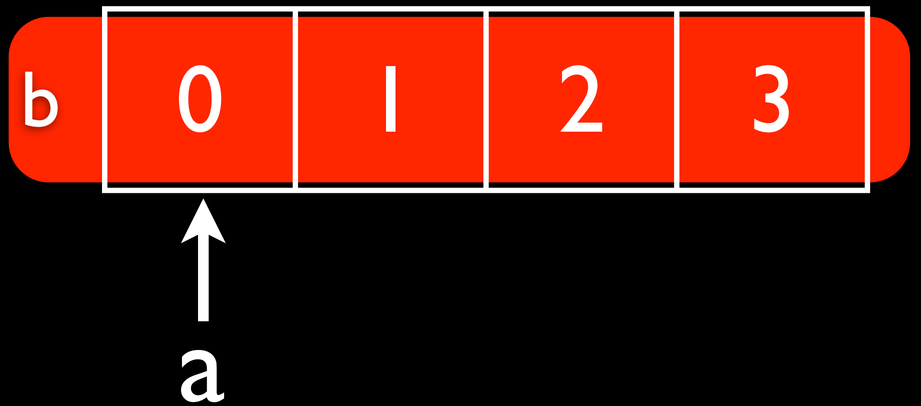
```
int a;
char *b = (char*)&a;
```



# Memory Layout

- Interpreting an array of bytes as an `int` can also be done.

```
char b[] = {0, 1, 2, 3};
int *a = (int*)b;
```



# Memory Layout

- A pointer is essentially a number representing where in the memory is the value.
- A pointer in a 32-bit OS is 32-bits (`int`) while a pointer in a 64-bit OS is 64-bits (`long long`).
- You can `#include <cstdint>` and use the typedef `uintptr_t`.
- The address can be printed by `reinterpret_cast`ing to the appropriate type.

# Example: Print the value of a pointer.

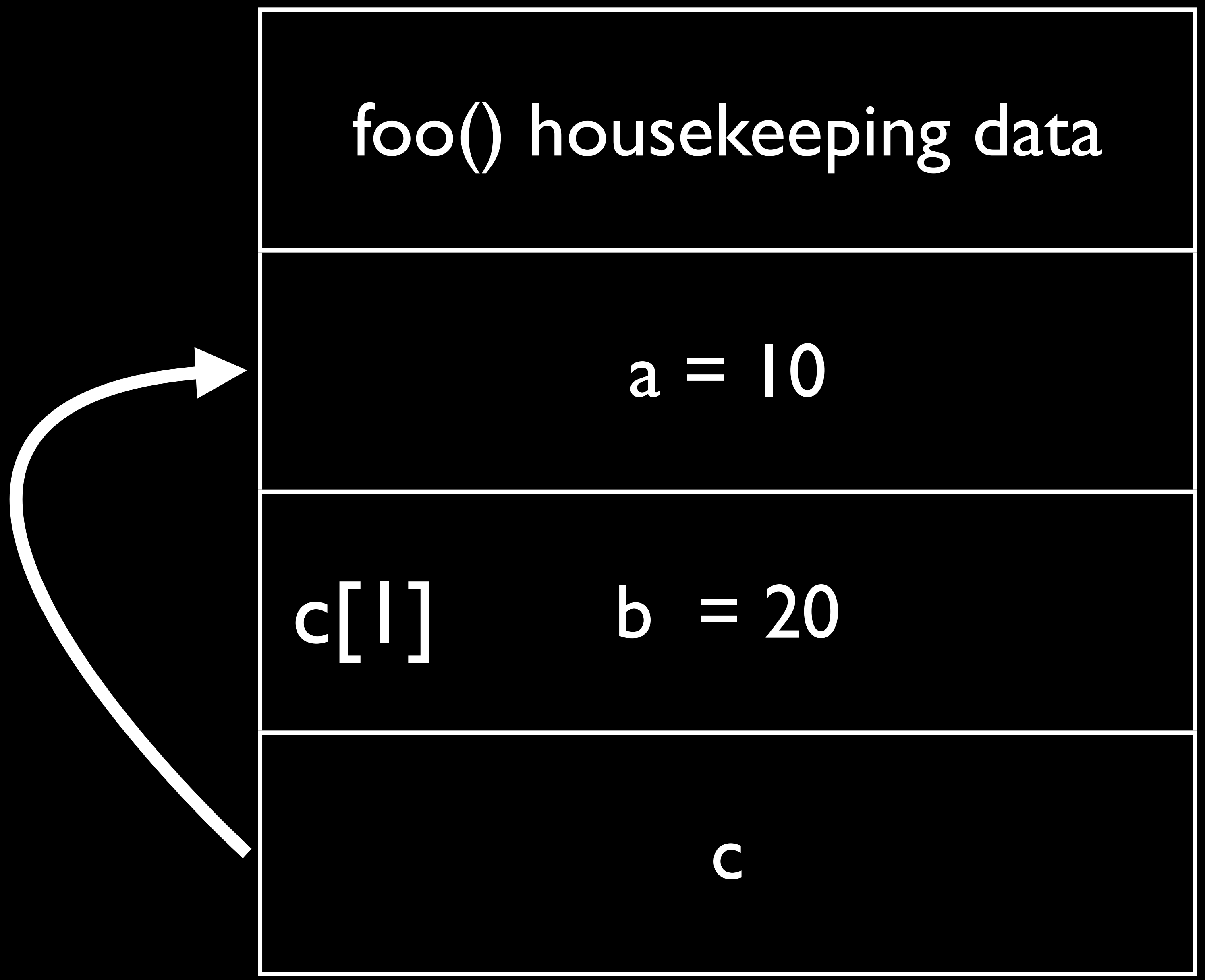
```
#include <cstdint>
#include <iostream>
using namespace std;

int main() {
  uintptr_t mainPtr = reinterpret_cast<uintptr_t>(main);
  cout << "Address of main: " << mainPtr << endl;
  return 0;
}
```

# Memory Layout

- Weird things can happen if your array runs out of bounds.
- Generally they're undefined but some cases can be isolated.
- Disclaimer: Never ***ever*** rely on these behaviors. They may help in debugging but don't intentionally cause them.

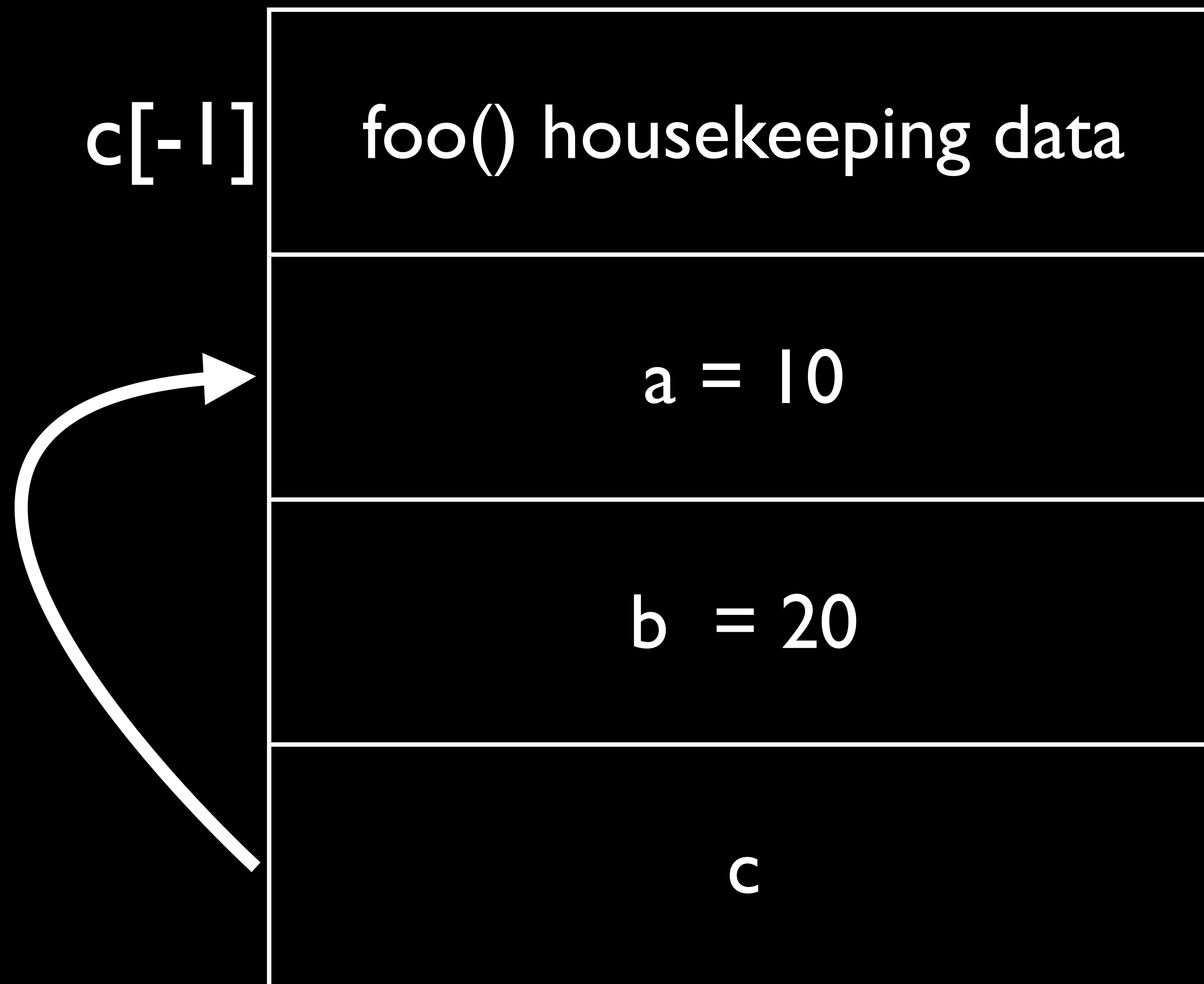
# Case 0:

```
int foo() {
 int a = 10;
 int b = 20;
 int *c = &a;
 return c[1];
}
```



# Case 1:

```c
int foo() {
 int a = 10;
 int b = 20;
 int *c = &a;
 return c[-1];
}
```




Will return the internal data of the function.
Modifying this will result in a crash.

# Case 2:

```
int bar() {
 int b_a;
}

int foo() {
 int f_a;
 bar();
 {
    int f_b;
 }
 int f_c;
}
```

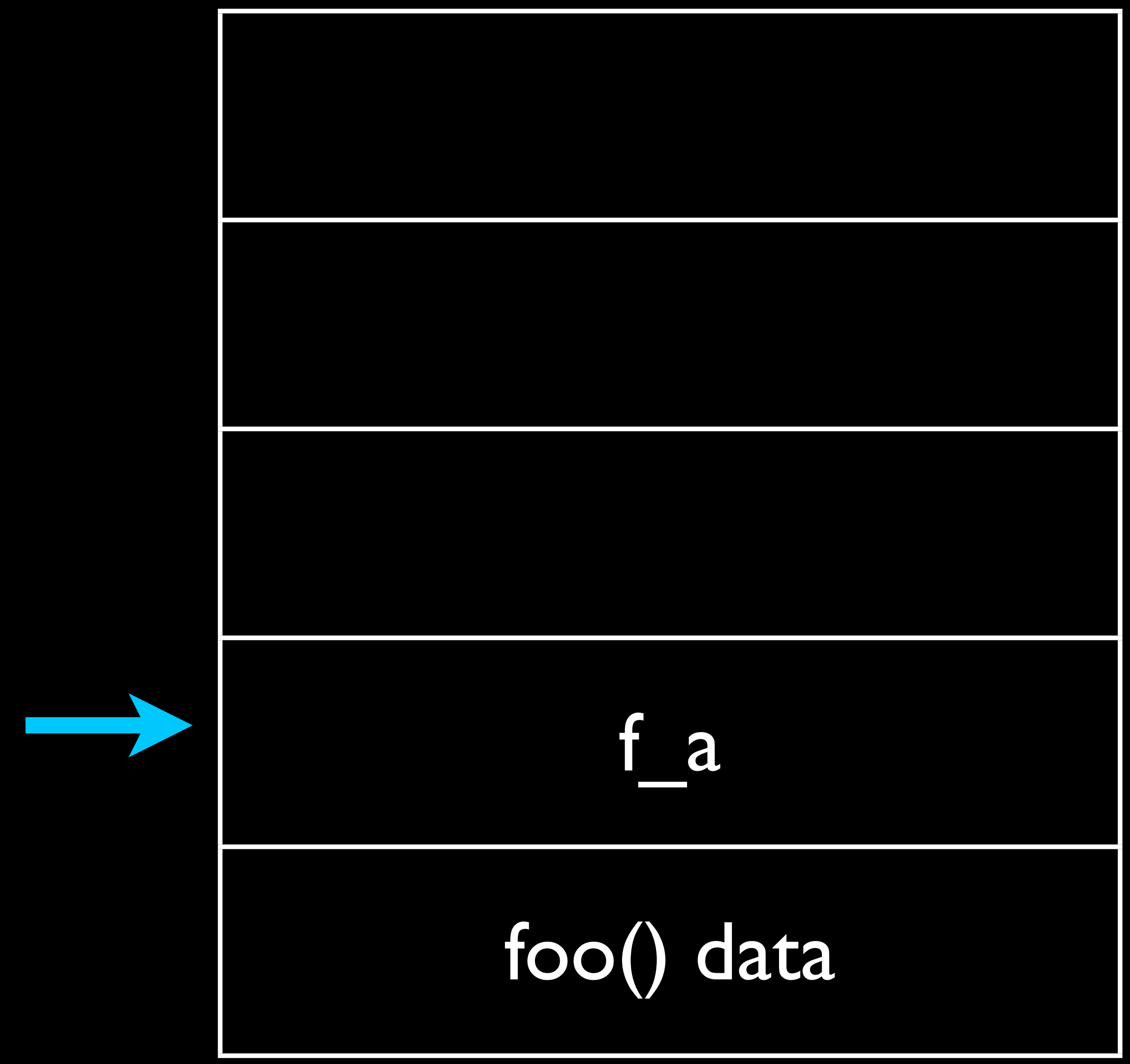
Suppose `foo()` is called.

# Case 2:

```c
int bar() {
 int b_a;
}

int foo() {
 int f_a;
 bar();
 {
    int f_b;
 }
 int f_c;
}
```

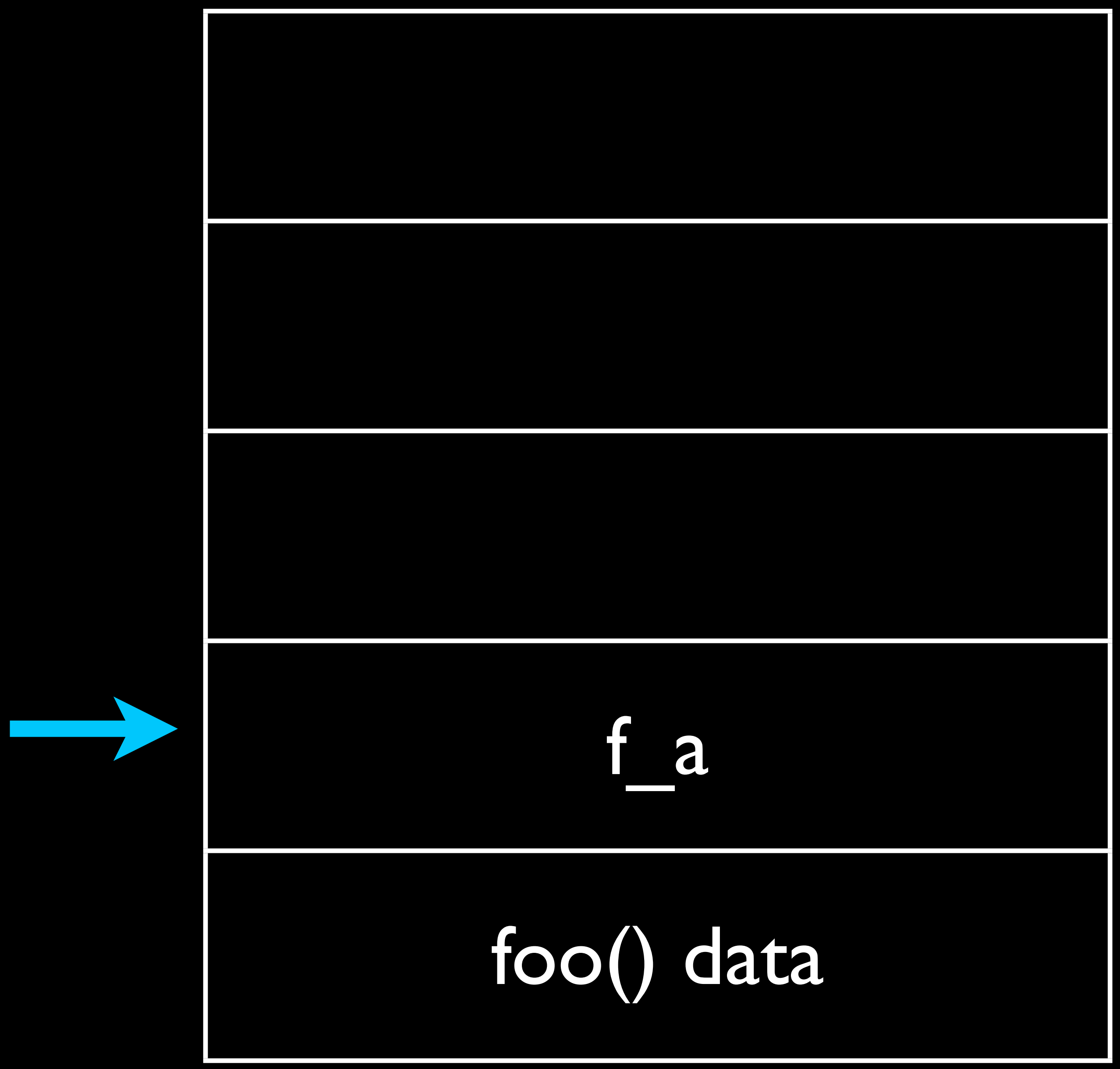
# Case 2:

```
int bar() {
 int b_a;
}

int foo() {
 int f_a;
 bar();
 {
    int f_b;
 }
 int f_c;
}
```



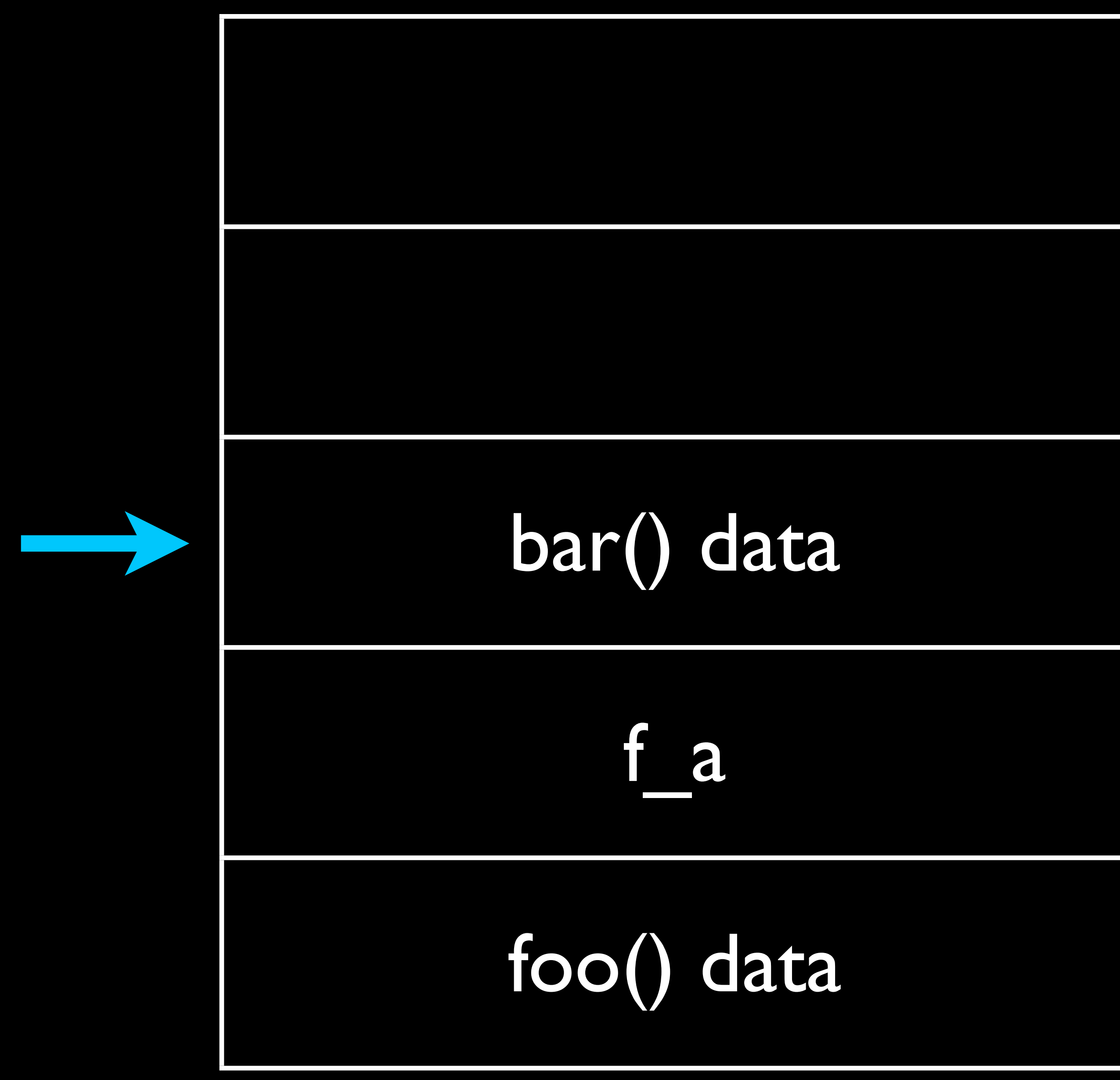
# Case 2:

```
int bar() {
 int b_a;
}

int foo() {
 int f_a;
 bar();
 {
    int f_b;
 }
 int f_c;
}
```



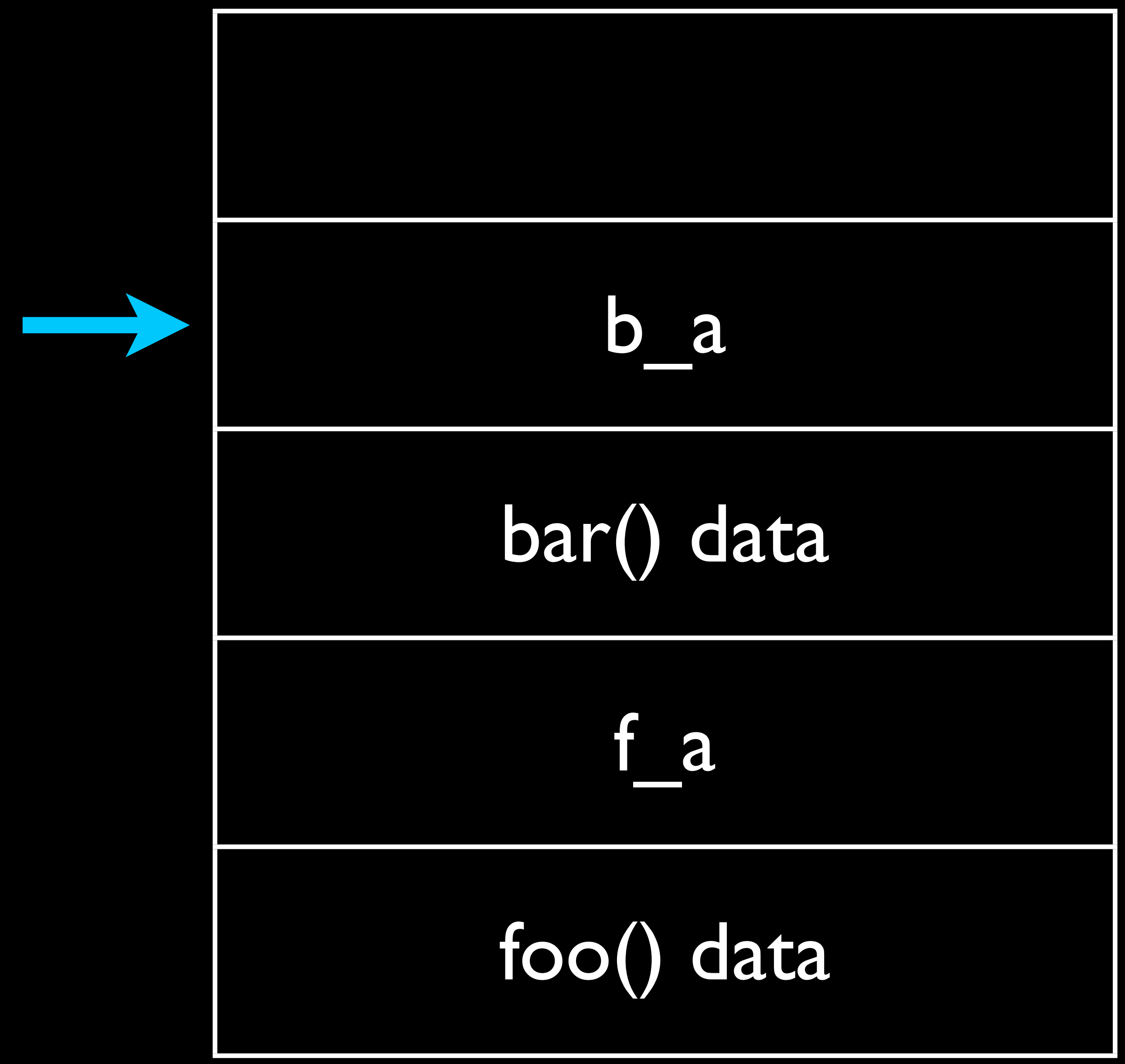
# Case 2:

```
int bar() {
 int b_a;
}

int foo() {
 int f_a;
 bar();
 {
    int f_b;
 }
 int f_c;
}
```



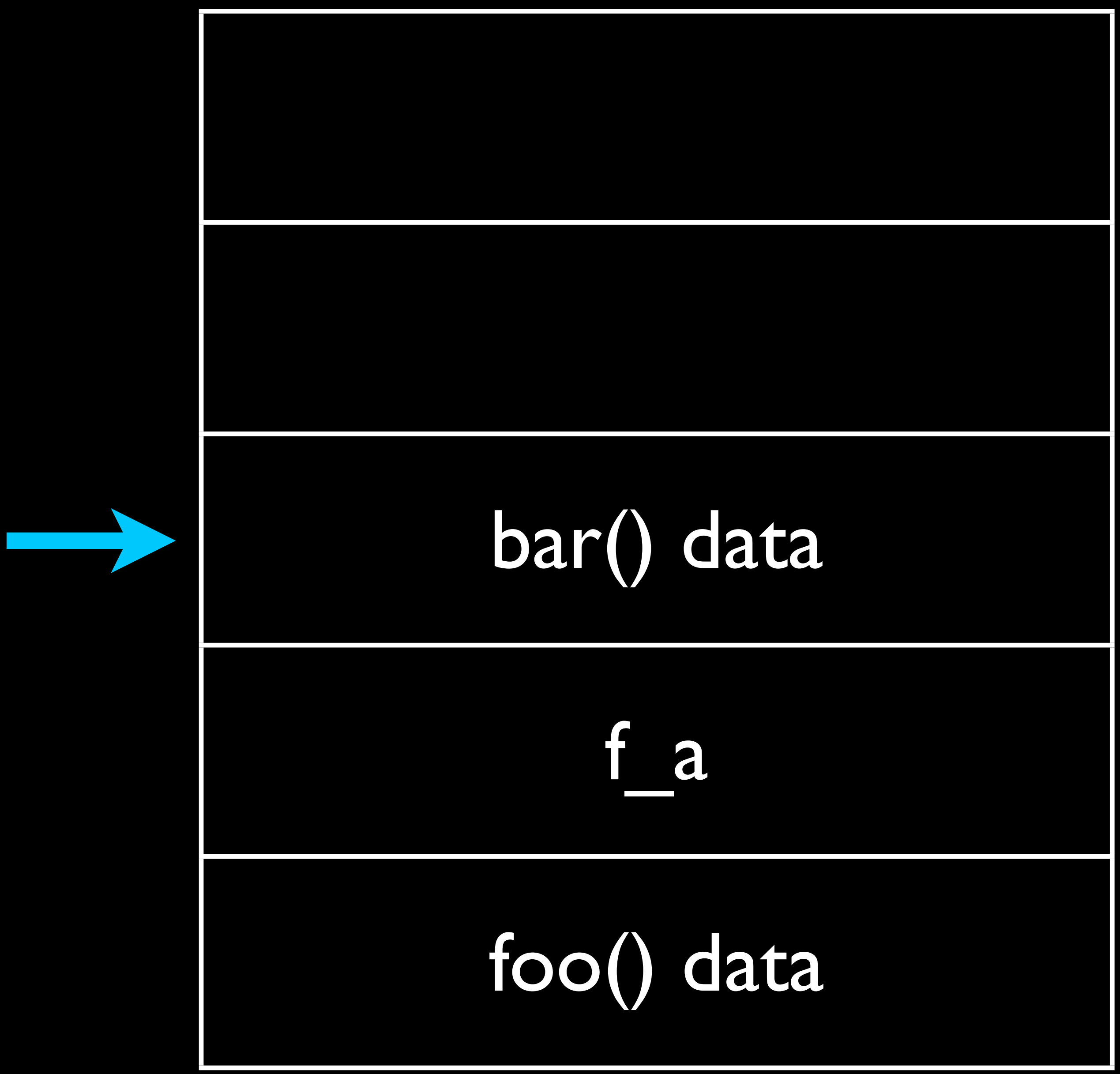
# Case 2:

```
int bar() {
 int b_a;
}

int foo() {
 int f_a;
 bar();
 {
    int f_b;
 }
 int f_c;
}
```



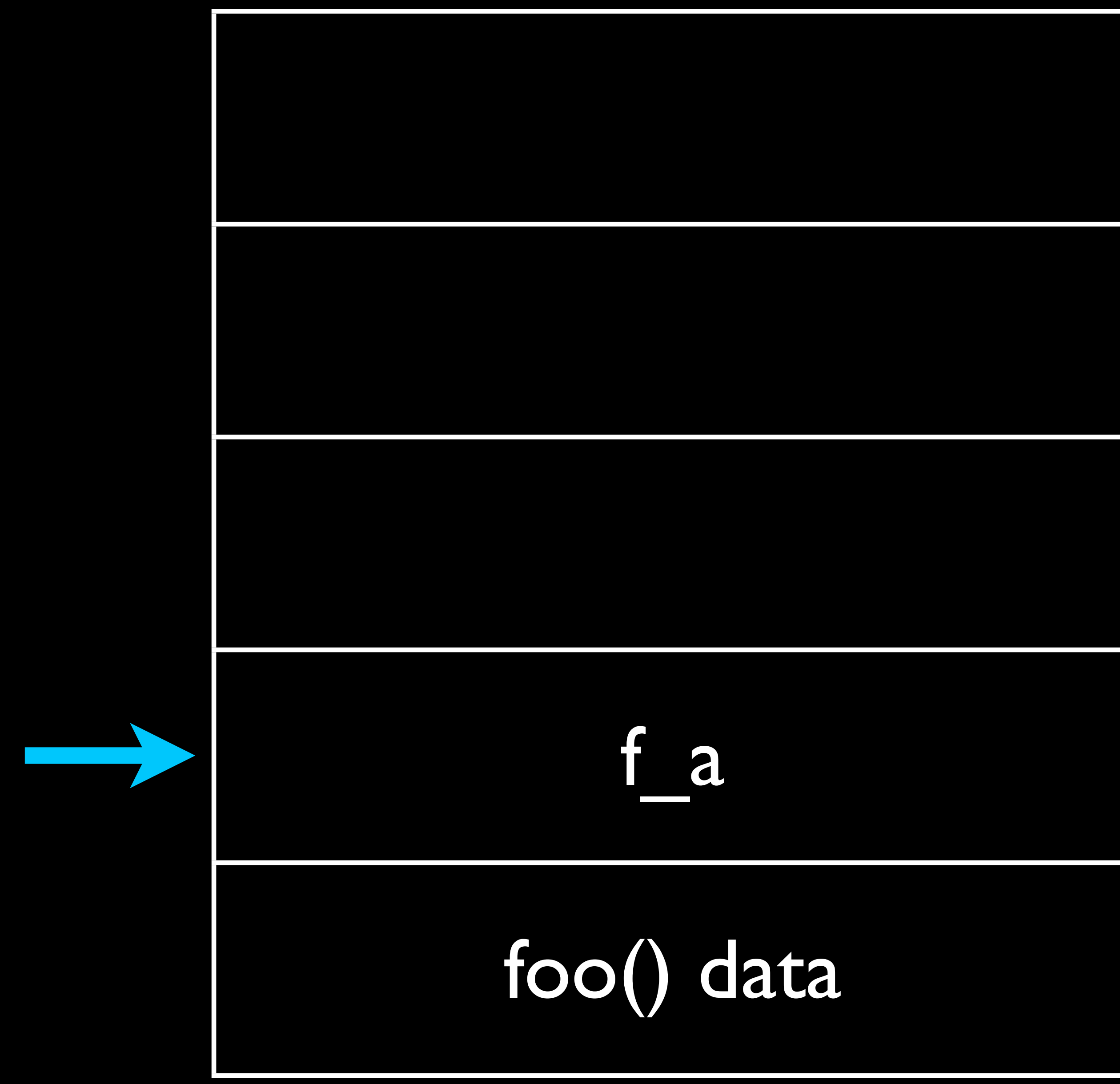
# Case 2:

```
int bar() {
 int b_a;
}

int foo() {
 int f_a;
 bar();
 {
    int f_b;
 }
 int f_c;
}
```



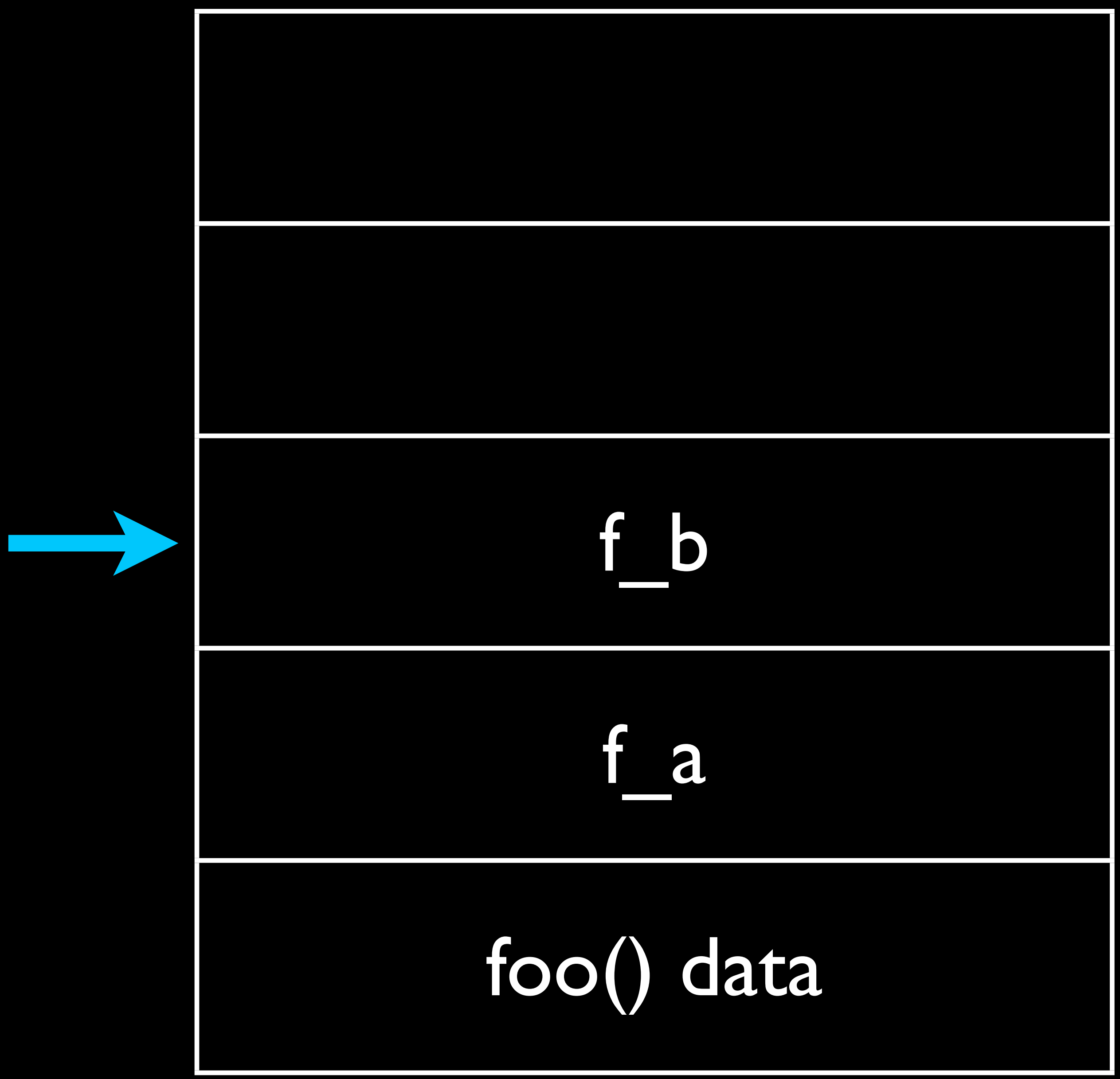
# Case 2:

```
int bar() {
 int b_a;
}

int foo() {
 int f_a;
 bar();
 {
    int f_b;
 }
 int f_c;
}
```



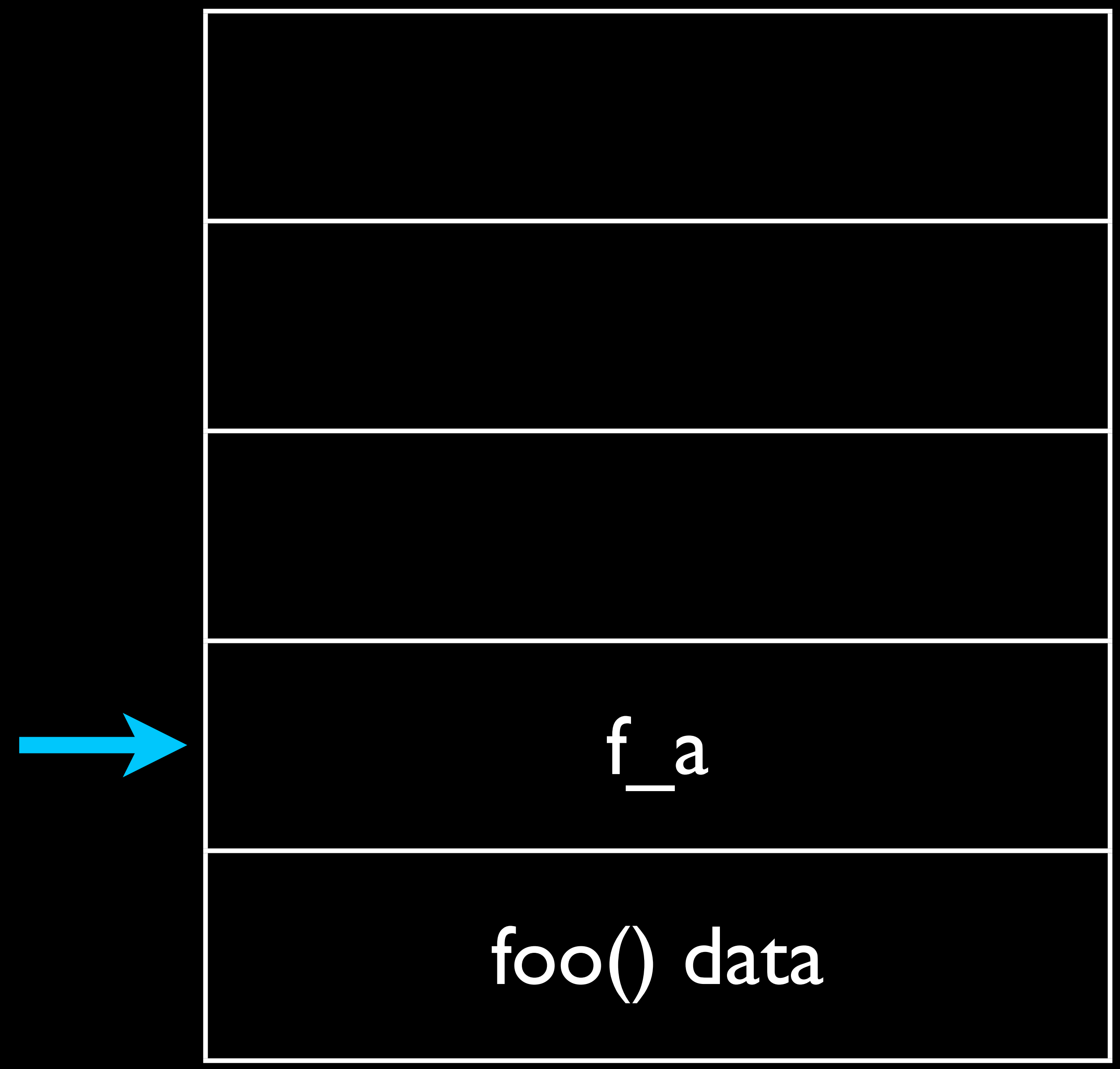
# Case 2:

```
int bar() {
 int b_a;
}

int foo() {
 int f_a;
 bar();
 {
    int f_b;
 }
 int f_c;
}
```



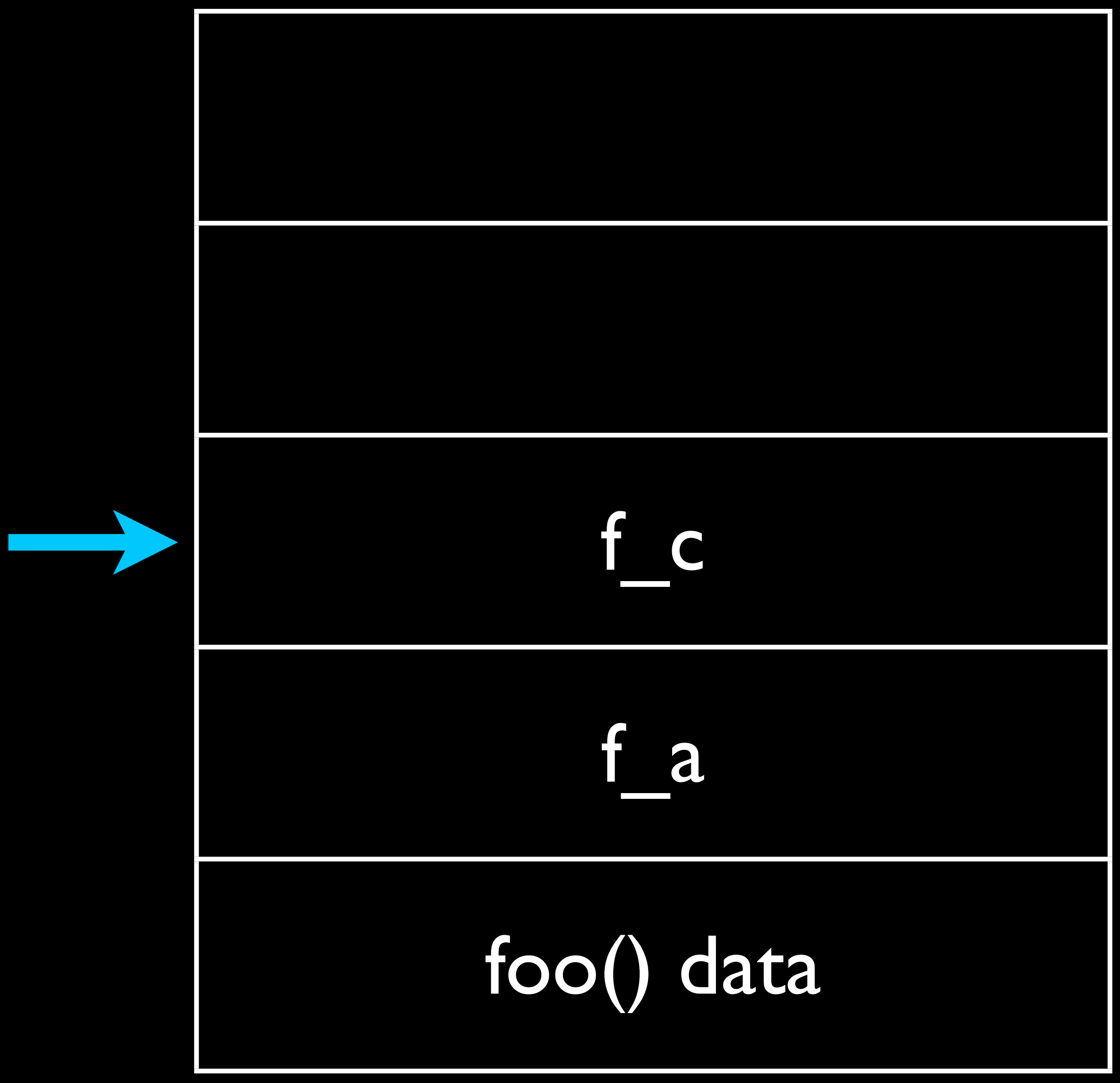
# Case 2:

```c
int bar() {
 int b_a;
}

int foo() {
 int f_a;
 bar();
 {
    int f_b;
 }
 int f_c;
}
```



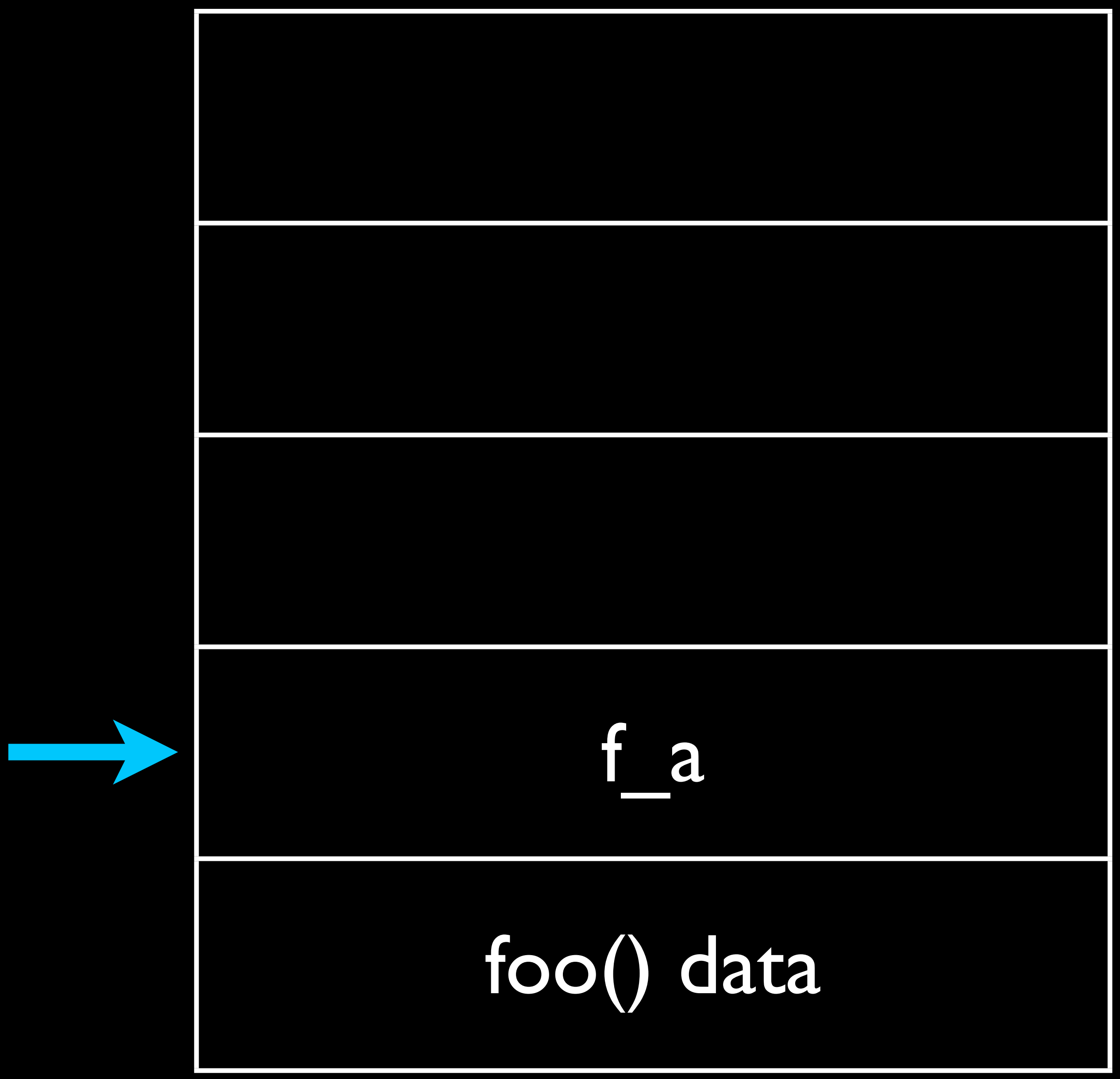
# Case 2:

```
int bar() {
 int b_a;
}

int foo() {
 int f_a;
 bar();
 {
   int f_b;
 }
 int f_c;
}
```



# Case 2:

```
int bar() {
 int b_a;
}

int foo() {
 int f_a;
 bar();
 {
   int f_b;
 }
 int f_c;
}
```



# Case 2:

```c
int bar() {
 int b_a;
}

int foo() {
 int f_a;
 bar();
 {
    int f_b;
 }
 int f_c;
}
```

# Case 2:

```c
int bar() {
 int b_a;
}

int foo() {
 int f_a;
 bar();
 {
   int f_b;
 }
 int f_c;
}
```

And this is why it's called *stack* memory.

# sizeof

- Returns the size in bytes of the data type.
- Useful when dealing with low-level stuff.

```
cout << "sizeof(int)" << sizeof(int)
   << "\nsizeof(char)" << sizeof(char)
   << "\nsizeof(int*)" << sizeof(int*)
   << "\nsizeof(double)" << sizeof(double)
   << "\nsizeof(float)" << sizeof(float);
```

# Checkpoint 2.10

Compare the output of the `sizeof` in the 3 kinds of array and explain the difference (note: `sizeof(int) == 4`).

```
int a[5];
int *b = new int[5];
vector<int> c;
for ( int i = 0; i < 5; ++i )
  c.push_back(i);

cout << "a: " << sizeof(a)
   << "\nb: " << sizeof(b)
   << "\nc: " << sizeof(c);
```

# Checkpoint 2.11

What does the second line evaluate to?

```
int a[10];
sizeof(a)/sizeof(a[0]);
```

Will it also work for built-in dynamic arrays?

# Strings

- A string is essentially *an array of characters* terminated by a "null character" (a zero).
- This kind of representation is often called a "C-string".
- The total size of the storage is 1 more than the length of the string.

```
char str[] = "Hello";
```

| | | | | | | |
|---|---|---|---|---|---|---|
| str | 'H' | 'e' | 'l' | 'l' | 'o' | 0 |

String length is 5 but actual array size is 6.

# Strings

- Since all C-strings are terminated by a null character, the length of the string can be derived from the data itself.

```
int stringLength(char *p) {
 int len = 0;
 while ( p[len] != 0 )
   ++len;
 return len;
}
```

# Null Character

- Also called "end-of-string sentinel" or "null terminator"
- The integer value is 0
- The escape character is '\0'
- They can be used interchangeably.
- The string literal automatically appends the null terminator.

```
int stringLength(char *p) {
  int len = 0;
  while ( p[len] != '\0' )
      ++len;
  return len;
}
```

# String Concatenation

```
char* stringJoin(char *a, char *b) {
  int lenA = stringLength(a), lenB = stringLength(b);
  char *ret = new char[lenA + lenB + 1];

  for( int i = 0; a[i] != 0; ++i)
      ret[i] = a[i];
  for ( int i = 0; b[i] != 0; ++i )
      ret[i + lenA] = b[i];

  ret[lenA + lenB] = 0;
  return ret;
}
```

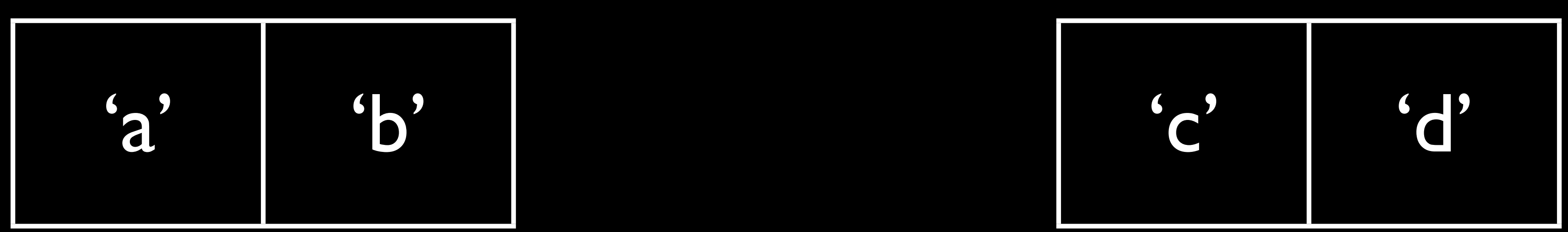
# String Concatenation

```
char* stringJoin(char *a, char *b) {
  int lenA = stringLength(a), lenB = stringLength(b);
  char *ret = new char[lenA + lenB + 1];

  for( int i = 0; a[i] != 0; ++i)
     ret[i] = a[i];
  for ( int i = 0; b[i] != 0; ++i )
     ret[i + lenA] = b[i];

  ret[lenA + lenB] = 0;
  return ret;
}
```

```
char *c = stringJoin("ab", "cd");
```

# String Concatenation

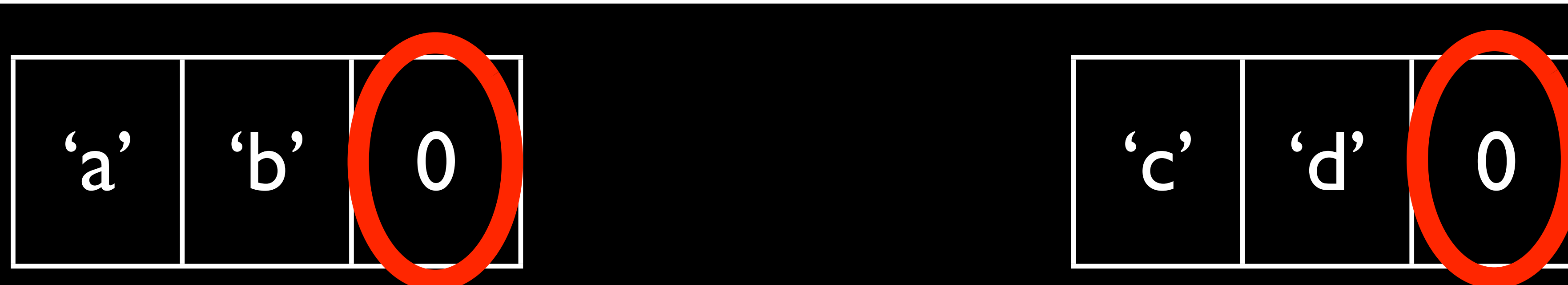
```
char* stringJoin(char *a, char *b) {
  int lenA = stringLength(a), lenB = stringLength(b);
  char *ret = new char[lenA + lenB + 1];

  for( int i = 0; a[i] != 0; ++i)
     ret[i] = a[i];
  for ( int i = 0; b[i] != 0; ++i )
     ret[i + lenA] = b[i];

  ret[lenA + lenB] = 0;
  return ret;
}
```




Something seems missing...

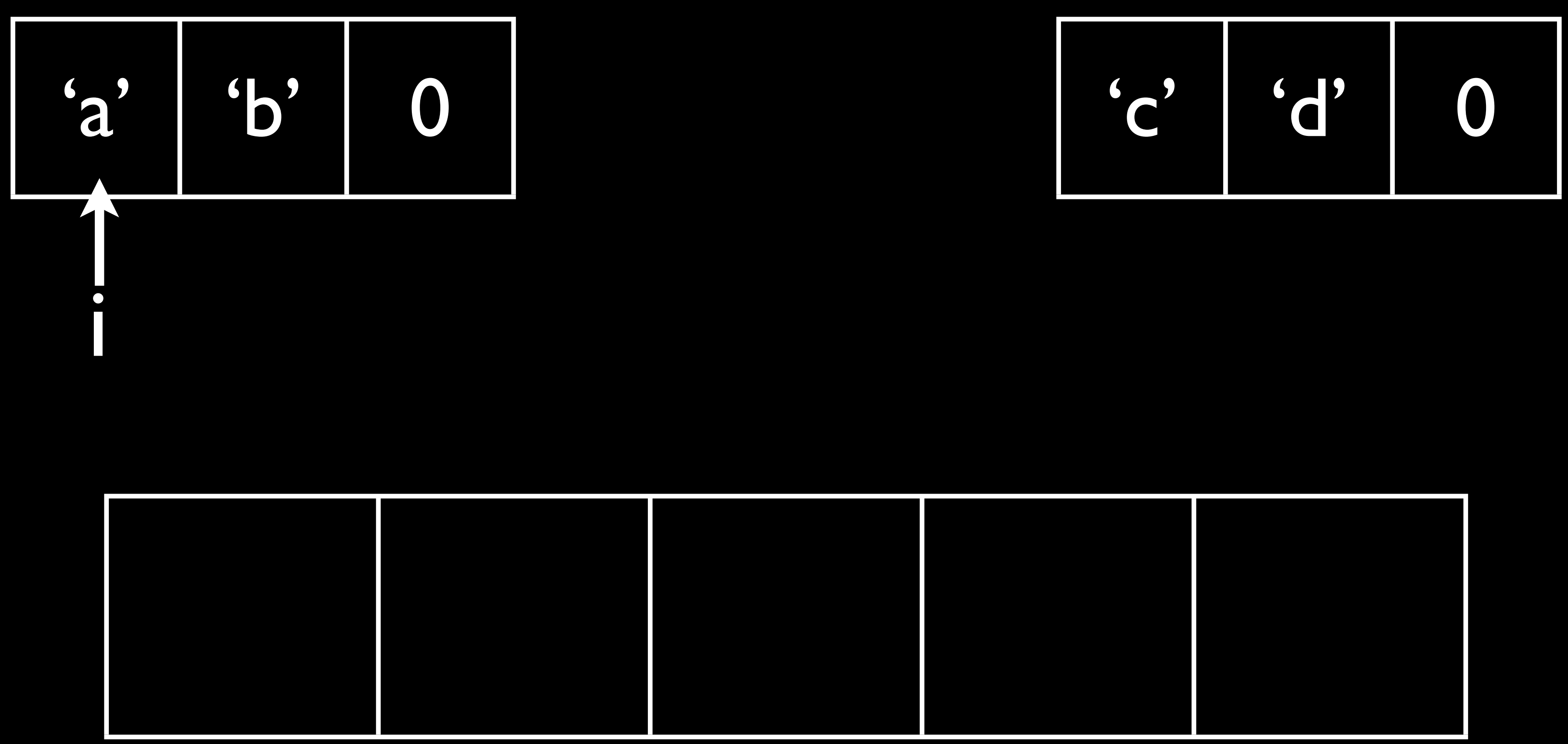
# String Concatenation

```
char* stringJoin(char *a, char *b) {
  int lenA = stringLength(a), lenB = stringLength(b);
  char *ret = new char[lenA + lenB + 1];

  for( int i = 0; a[i] != 0; ++i)
     ret[i] = a[i];
  for ( int i = 0; b[i] != 0; ++i )
     ret[i + lenA] = b[i];

  ret[lenA + lenB] = 0;
  return ret;
}
```



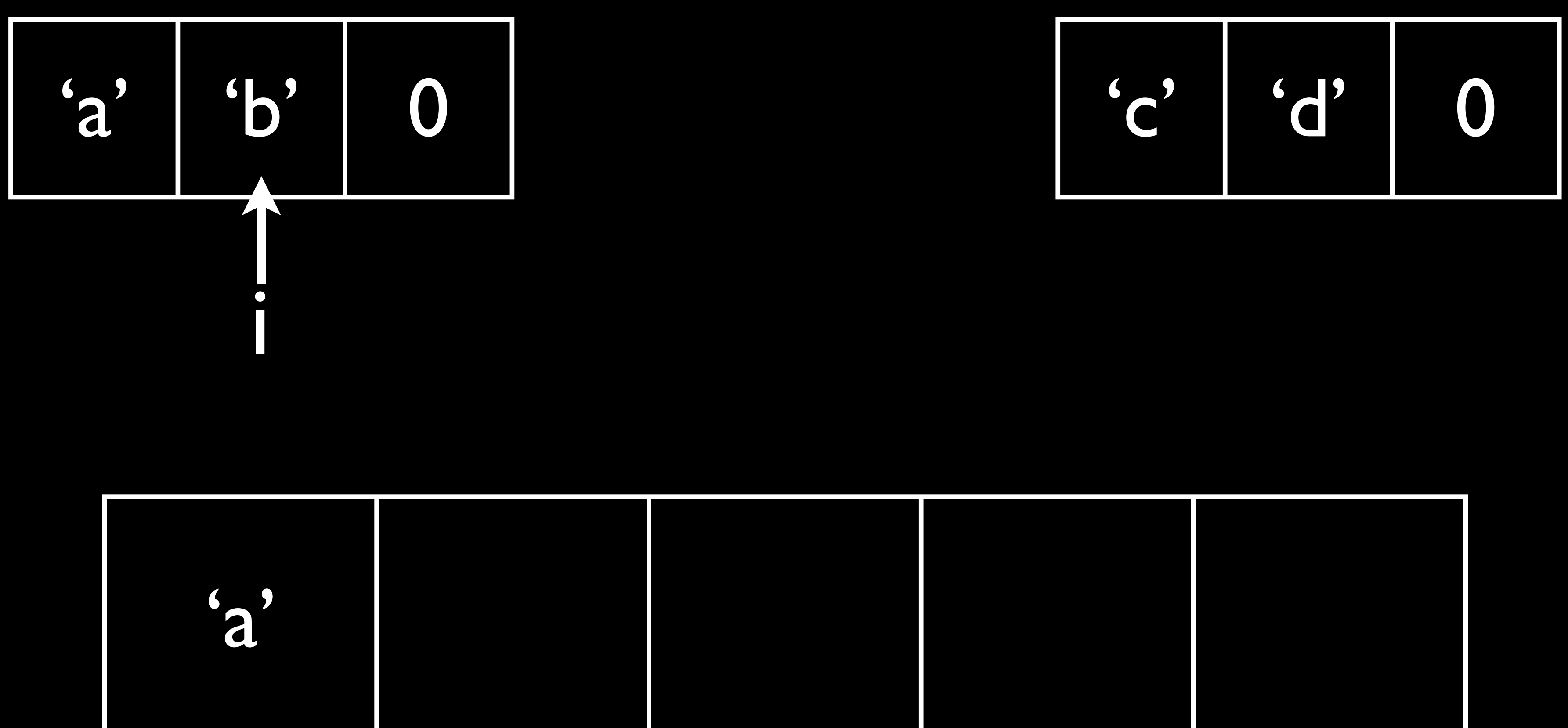
# String Concatenation

```
char* stringJoin(char *a, char *b) {
  int lenA = stringLength(a), lenB = stringLength(b);
  char *ret = new char[lenA + lenB + 1];

  for( int i = 0; a[i] != 0; ++i)
      ret[i] = a[i];
  for ( int i = 0; b[i] != 0; ++i )
      ret[i + lenA] = b[i];

  ret[lenA + lenB] = 0;
  return ret;
}
```



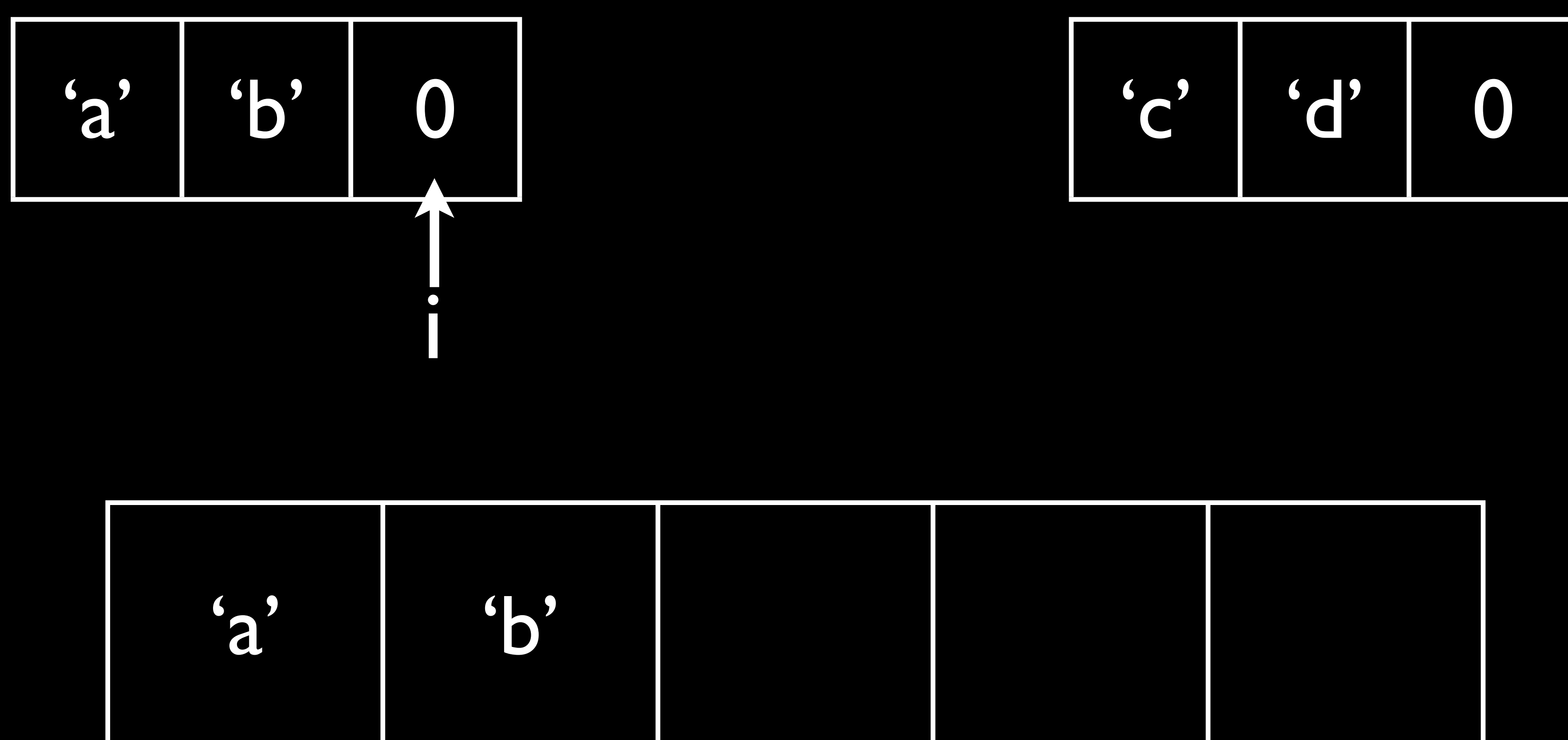
# String Concatenation

```
char* stringJoin(char *a, char *b) {
  int lenA = stringLength(a), lenB = stringLength(b);
  char *ret = new char[lenA + lenB + 1];

  for( int i = 0; a[i] != 0; ++i)
      ret[i] = a[i];
  for ( int i = 0; b[i] != 0; ++i )
      ret[i + lenA] = b[i];

  ret[lenA + lenB] = 0;
  return ret;
}
```



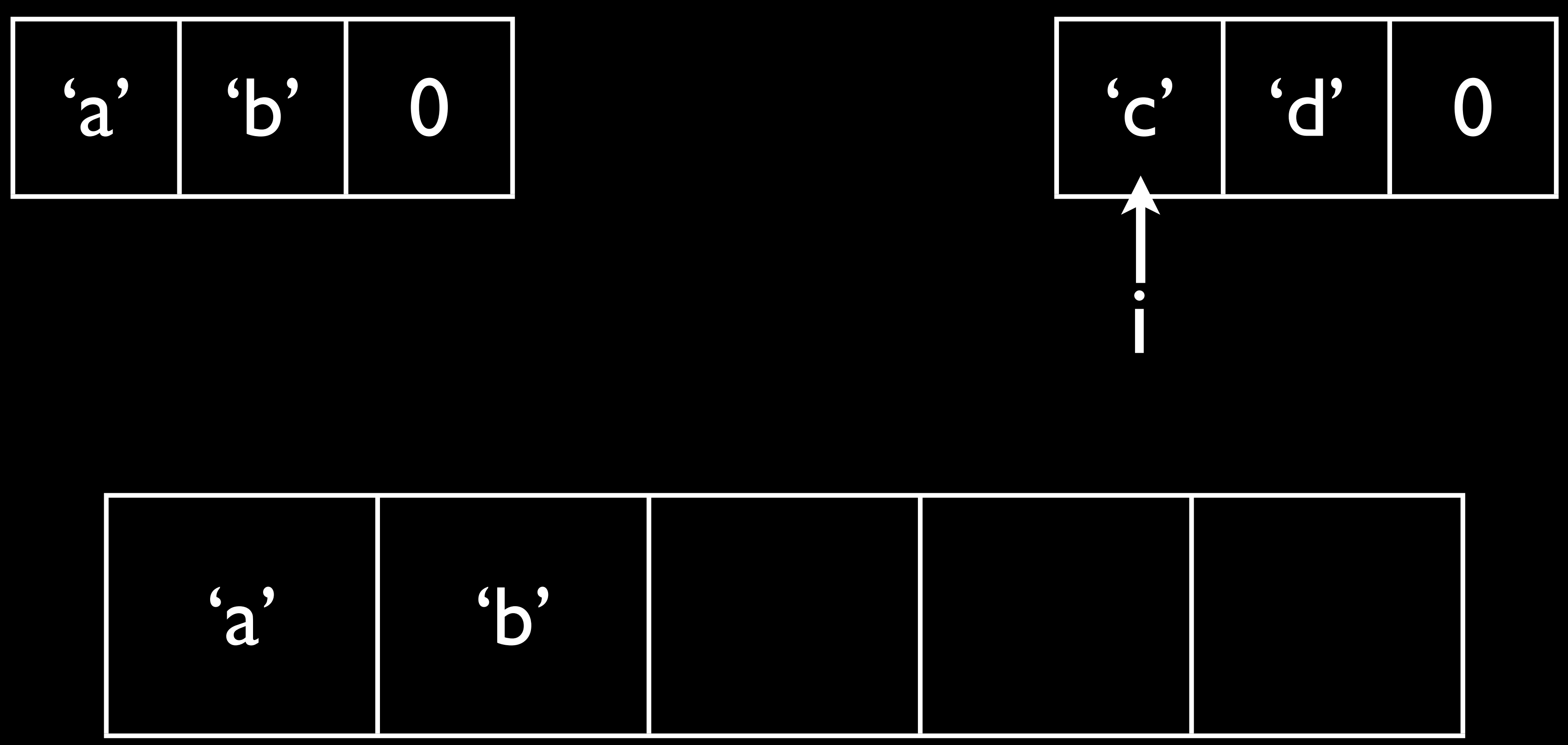
# String Concatenation

```
char* stringJoin(char *a, char *b) {
  int lenA = stringLength(a), lenB = stringLength(b);
  char *ret = new char[lenA + lenB + 1];

  for( int i = 0; a[i] != 0; ++i)
      ret[i] = a[i];
  for ( int i = 0; b[i] != 0; ++i )
      ret[i + lenA] = b[i];

  ret[lenA + lenB] = 0;
  return ret;
}
```



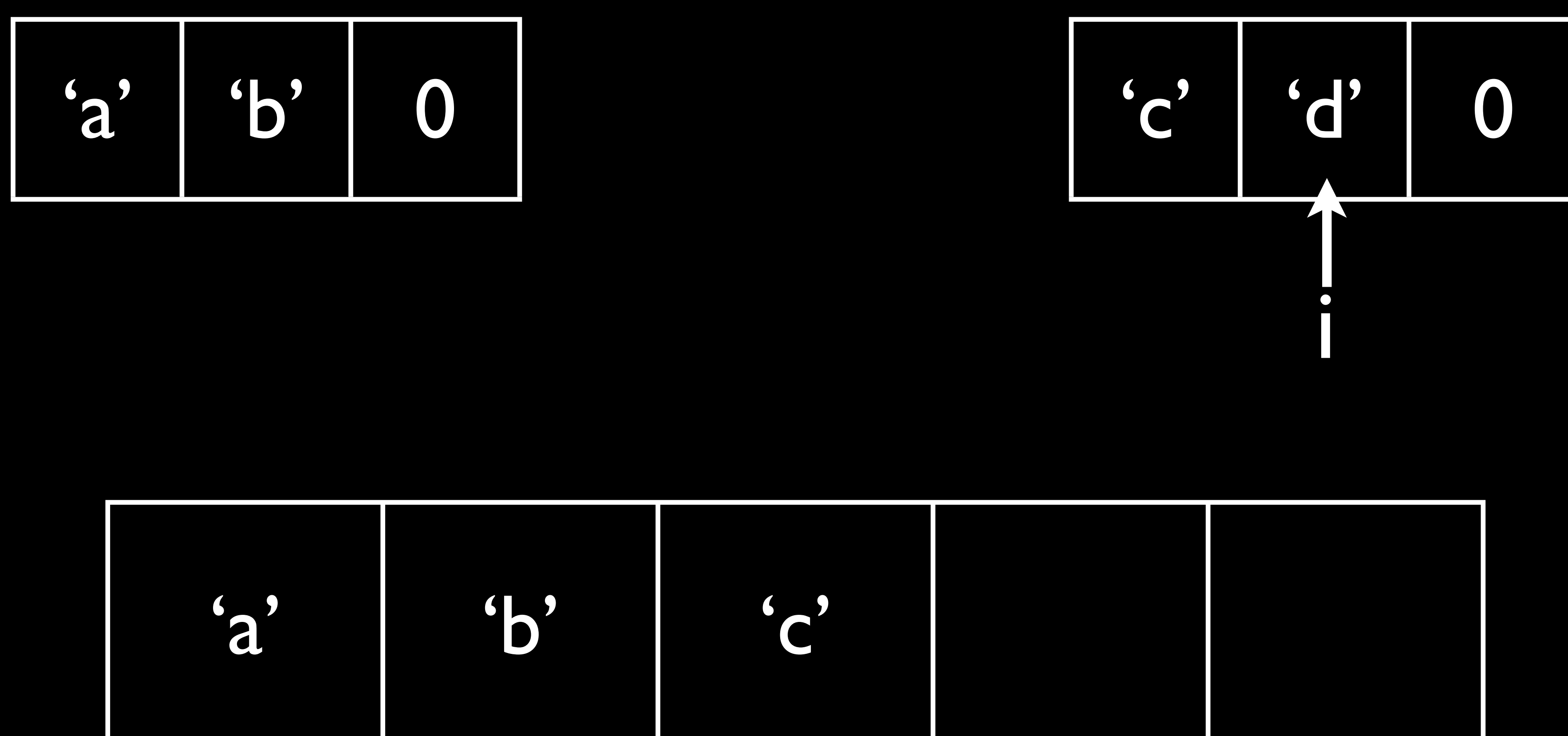
# String Concatenation

```
char* stringJoin(char *a, char *b) {
  int lenA = stringLength(a), lenB = stringLength(b);
  char *ret = new char[lenA + lenB + 1];

  for( int i = 0; a[i] != 0; ++i)
      ret[i] = a[i];
  for ( int i = 0; b[i] != 0; ++i )
      ret[i + lenA] = b[i];

  ret[lenA + lenB] = 0;
  return ret;
}
```



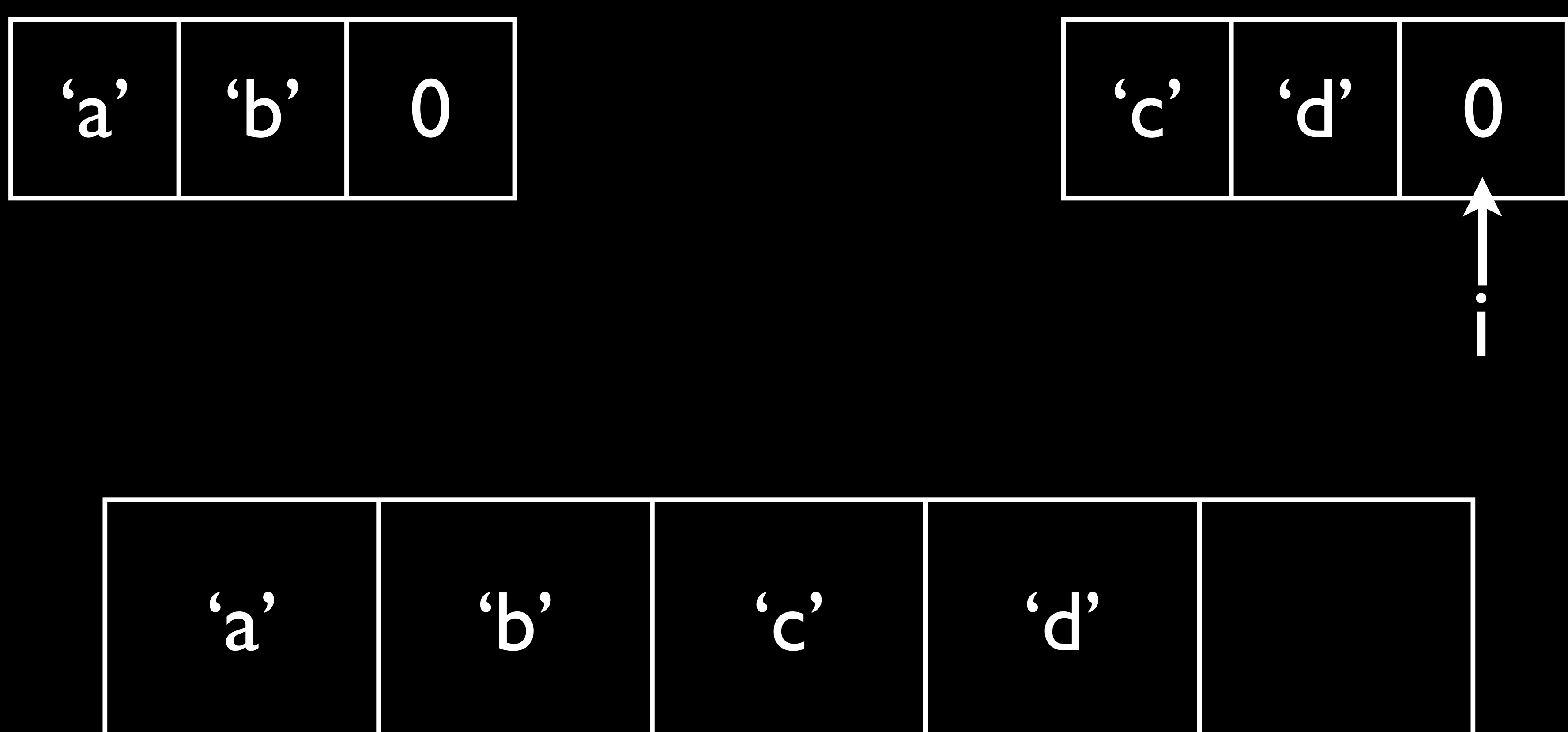
# String Concatenation

```
char* stringJoin(char *a, char *b) {
  int lenA = stringLength(a), lenB = stringLength(b);
  char *ret = new char[lenA + lenB + 1];

  for( int i = 0; a[i] != 0; ++i)
      ret[i] = a[i];
  for ( int i = 0; b[i] != 0; ++i )
      ret[i + lenA] = b[i];

  ret[lenA + lenB] = 0;
  return ret;
}
```



# String Concatenation

```
char* stringJoin(char *a, char *b) {
  int lenA = stringLength(a), lenB = stringLength(b);
  char *ret = new char[lenA + lenB + 1];

  for( int i = 0; a[i] != 0; ++i)
      ret[i] = a[i];
  for ( int i = 0; b[i] != 0; ++i )
      ret[i + lenA] = b[i];

  ret[lenA + lenB] = 0;
  return ret;
}
```



# String Concatenation

```
char* stringJoin(char *a, char *b) {
  int lenA = stringLength(a), lenB = stringLength(b);
  char *ret = new char[lenA + lenB + 1];

  for( int i = 0; a[i] != 0; ++i)
      ret[i] = a[i];
  for ( int i = 0; b[i] != 0; ++i )
      ret[i + lenA] = b[i];

  ret[lenA + lenB] = 0;
  return ret;
}
```

| | | |
|---|---|---|
| ‘a’ | ‘b’ | 0 |

| | | |
|---|---|---|
| ‘c’ | ‘d’ | 0 |

| | | | | |
|---|---|---|---|---|
| ‘a’ | ‘b’ | ‘c’ | ‘d’ | |

# String Concatenation

```
char* stringJoin(char *a, char *b) {
  int lenA = stringLength(a), lenB = stringLength(b);
  char *ret = new char[lenA + lenB + 1];

  for( int i = 0; a[i] != 0; ++i)
      ret[i] = a[i];
  for ( int i = 0; b[i] != 0; ++i )
      ret[i + lenA] = b[i];

  ret[lenA + lenB] = 0;
  return ret;
}
```

| | | |
|---|---|---|
| ‘a’ | ‘b’ | 0 |

| | | |
|---|---|---|
| ‘c’ | ‘d’ | 0 |

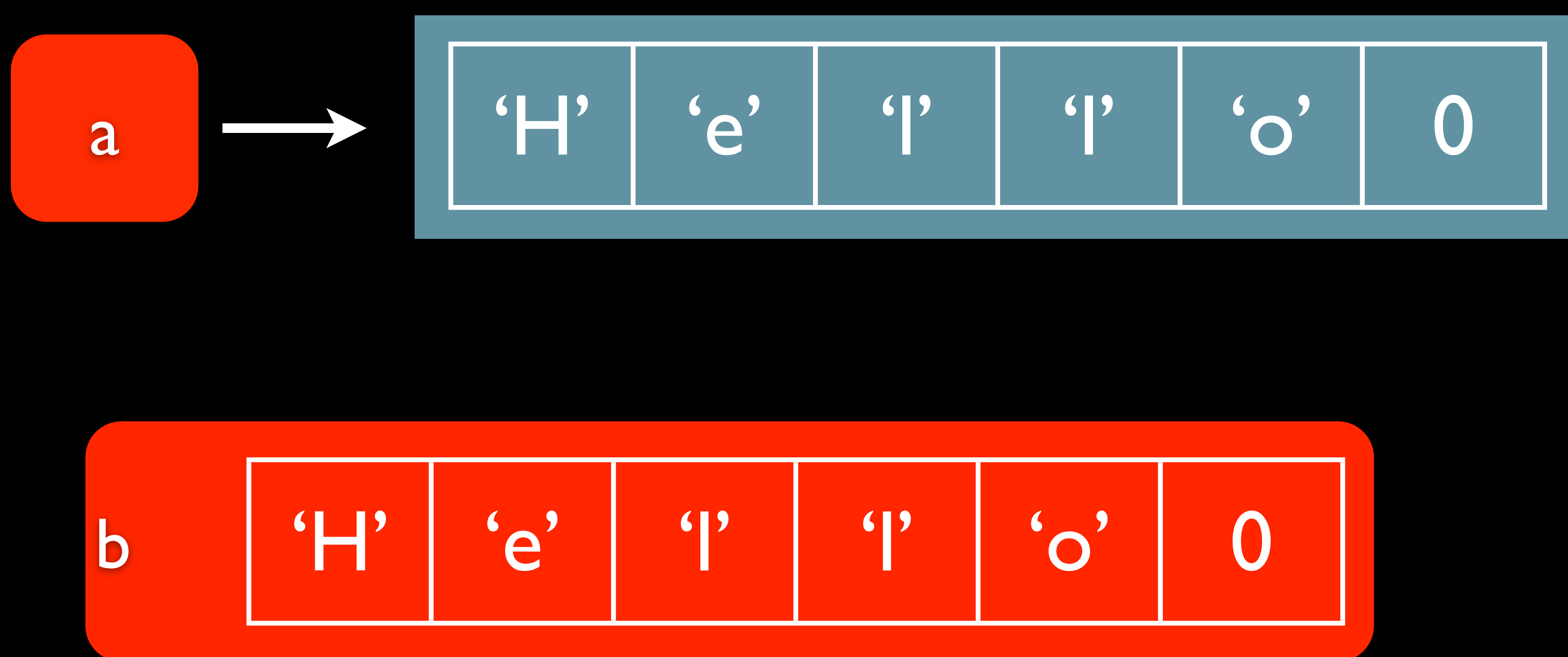
It is ***very*** important to terminate with a null!

| | | | | |
|---|---|---|---|---|
| ‘a’ | ‘b’ | ‘c’ | ‘d’ | 0 |

# Checkpoint 2.12

What’s the difference between the two?

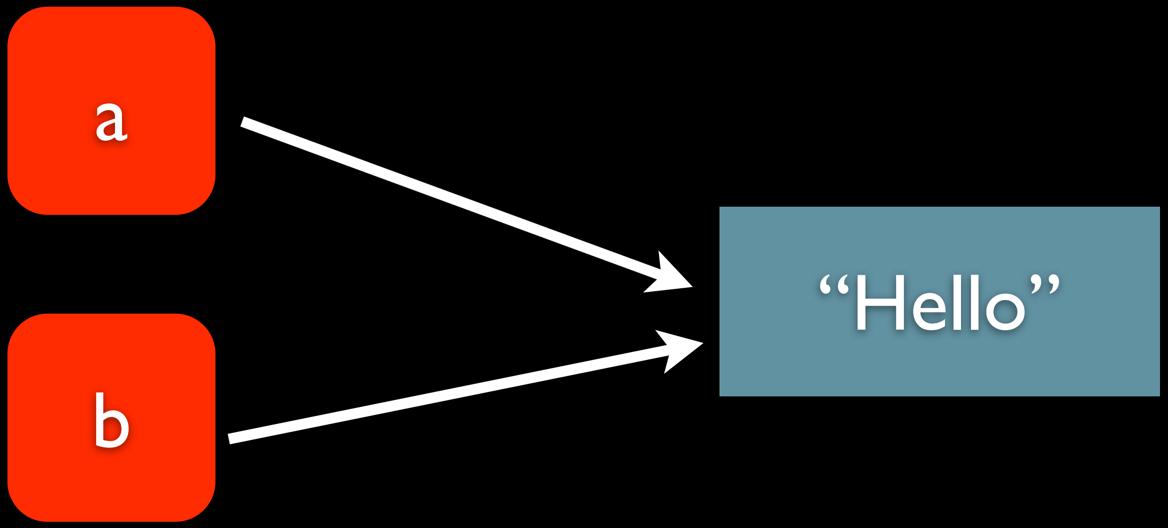
```c
char *a = "Hello";
char b[] = "Hello";
```



# Checkpoint 2.13

What happens in the end? Is this ok?

```
char *a = "Hello";
char *b = "Bye";
b = a;
```



# C-String helpers

- Checkout `<cstring>` for helper functions.
- Some notable functions: `strlen`, `strcat`, `strtok`, `sprintf`, `sscanf`

# C++ Strings

- More often than not, C++ classes wrap string functionality.
- `std::string` is the usual but some frameworks provide their own (e.g. `QString`, `WtString`, etc.)

```
using namespace std;
string a = "Hello";
string b = "World";
string c = a + b;
```

# C++ Strings

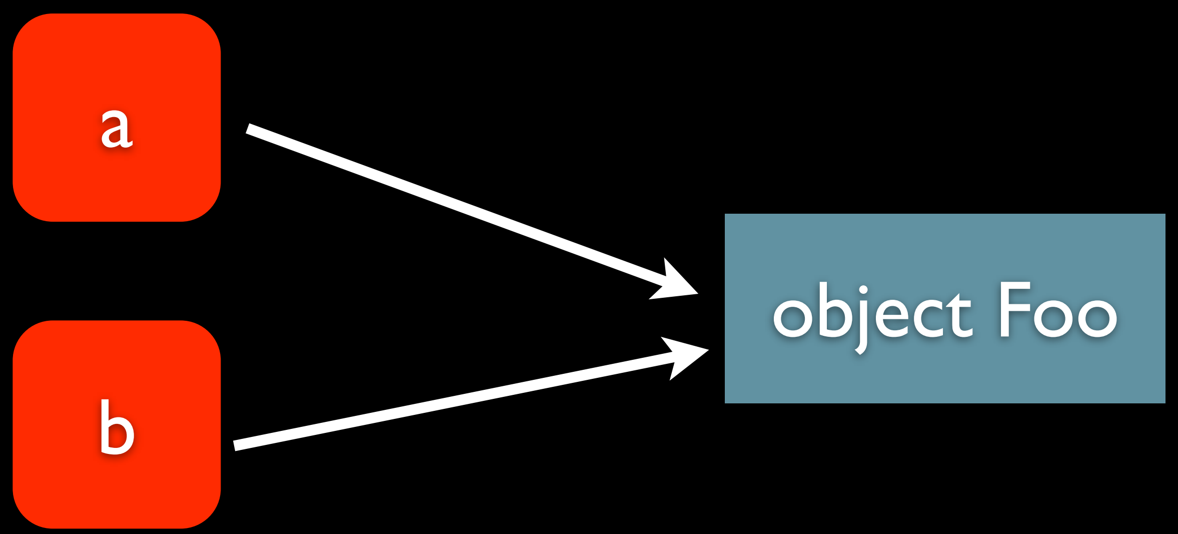
- Individual characters may also be accessed using the `[ ]` operator.
- Like `std::vector<>`, pass them as (const) references.
- Has the `.length()` and `.size()` property (they return the same value)
- `.c_str()` returns the `const char *` equivalent of the string (valid until the string changes).

BREAKTI3M

# Dynamic Allocation

Java

```java
Foo a = new Foo();
Foo b = a;
```




C++

```cpp
Foo a;
Foo *b = &a;
```

# Dynamic Allocation

```
Foo* fooFactory() {
 Foo *foo = //allocate new foo instance;
 return foo;
}
```

```
Foo* fooFactory() {
 Foo foo;
 return &foo;
}
```

Do not want.

```
Foo* fooFactory() {
 static Foo foo;
 return &foo;
}
```

?

Not sure if want.
(depends)

# Dynamic Allocation

```
Foo* fooFactory() {
 Foo *foo = new Foo();
 return &foo;
}
```

`new ClassName(parameters)` returns a *pointer* of type `ClassName`.

Allocates memory from the *heap* and not from the stack.

# Dynamic Allocation

- C++ is not a Garbage collected language.
- Dynamically allocated objects have to be manually `delete`-d;
- Failure to do so results in a *memory leak*.
- The OS usually cleans up all resources when a program exits.

```
Foo *foo = fooFactory();
//use foo...
delete foo;
```

# Dynamic Allocation

Note that there are two forms of delete.
Use the appropriate one.
Failure to do so will result in *undefined behavior.*

```
Foo *a = new Foo();  →  delete a;
```

```
Foo *b = new Foo[ARR_SIZE];  →  delete [] b;
```

No need to specify the size of the array for the array delete form.

# Dynamic Allocation.

- Do not delete the same address twice.
- Deleting a `NULL` pointer is safe.
- A pointer is usually set to `NULL` after deleting to prevent double-deletion.

```
Foo *a = new Foo();
delete a;
a = 0;
```

# Dynamic Allocation

- Java-style array allocation can be done.
- Allocate pointers instead of the actual object.
- Just don’t forget to delete them after.

```
std::vector<Foo*> a;
a.push_back(new Foo());

Foo* b[10];
b[0] = new Foo();
```

# Checkpoint 2.14

What's possibly wrong with the following code?

```
void initArray(vector<Foo*> &v, const int n) {
  for ( int i = 0; i < n; ++i )
     v.push_back(new Foo());
}

void doFoo() {
  vector<Foo*> v;
  initArray(v, 10);
  v.clear();
}
```

# L-values and R-values

- R-values: values that can only be placed on the right.
- L-values: values that can be placed on the left.
- Constants are considered L-values.

```
int i = 10;
```

L-value R-value

# Examples 0

Red: L-value

Blue: R-value

```
int i = 10;
int a = 20;
a = i;
i = 20;
20 = 10;
const int a = 20;
```

← Not allowed!

# Examples 1

Red: L-value

Blue: R-value

```
Foo a[10];
a[0] = 0;
Foo* b;
b = a;
void doBar() {}
void (*funPtr)();
funPtr = doBar;
```

# Examples 2

Red: L-value        Blue: R-value

```
int a = 1 + 2;
int b = 2 * 2;
int c = a + b;
int bar() { return 0; }
int foo() {
  int a = 10;
  return a;
}
a = bar() + foo();
```

# Examples 3

Red: L-value    Blue: R-value

```
int a = 0;
int b = 2;
int& getA() { return a; }
int getB() { return b; }
getA() = 1;
int c = getA() + getB();
```

# L-values and R-values

- Only L-values have addresses.
- Non-const references can only capture L-values.
- Const references can capture R-values.

```
int *a = &10; //cannot

void foo(int &) {}
foo(1); //cannot

void bar(const int &) {}
bar(1); //can
```

# L-values and R-values

- Functions returning references return L-values.
- Returned R-values can be captured by const references.

```
int& getA() { return a; }
getA() = 10;

Foo getFoo() { return Foo(); }
const &Foo = getFoo();
```

# Temporaries

- Temporary objects are R-values.
- Unintended creation of ***large temporary objects*** degrade performance.
- They can be ignored for primitives are small objects.

```
int bar() { return 0; }
int foo() { return 1; }
a = bar() + foo();
```