Pointers III

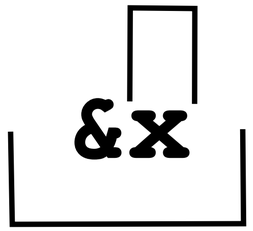
CS143: lecture 9

Konstantinos Ameranis, July 7

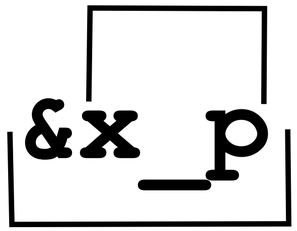
Pointers

Review

```
type : int
value: 25
```

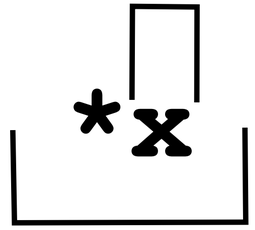



```
type : int *
value: 100
```

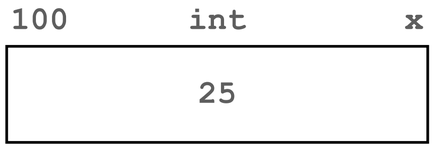


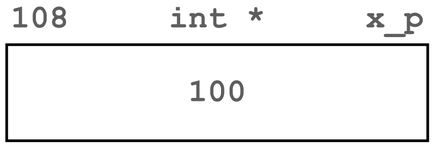

```
type : int **
value: 108
```

```
type : int
value: 25
```




```
error
```



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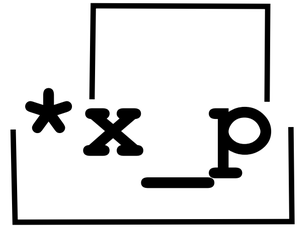


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Pointers

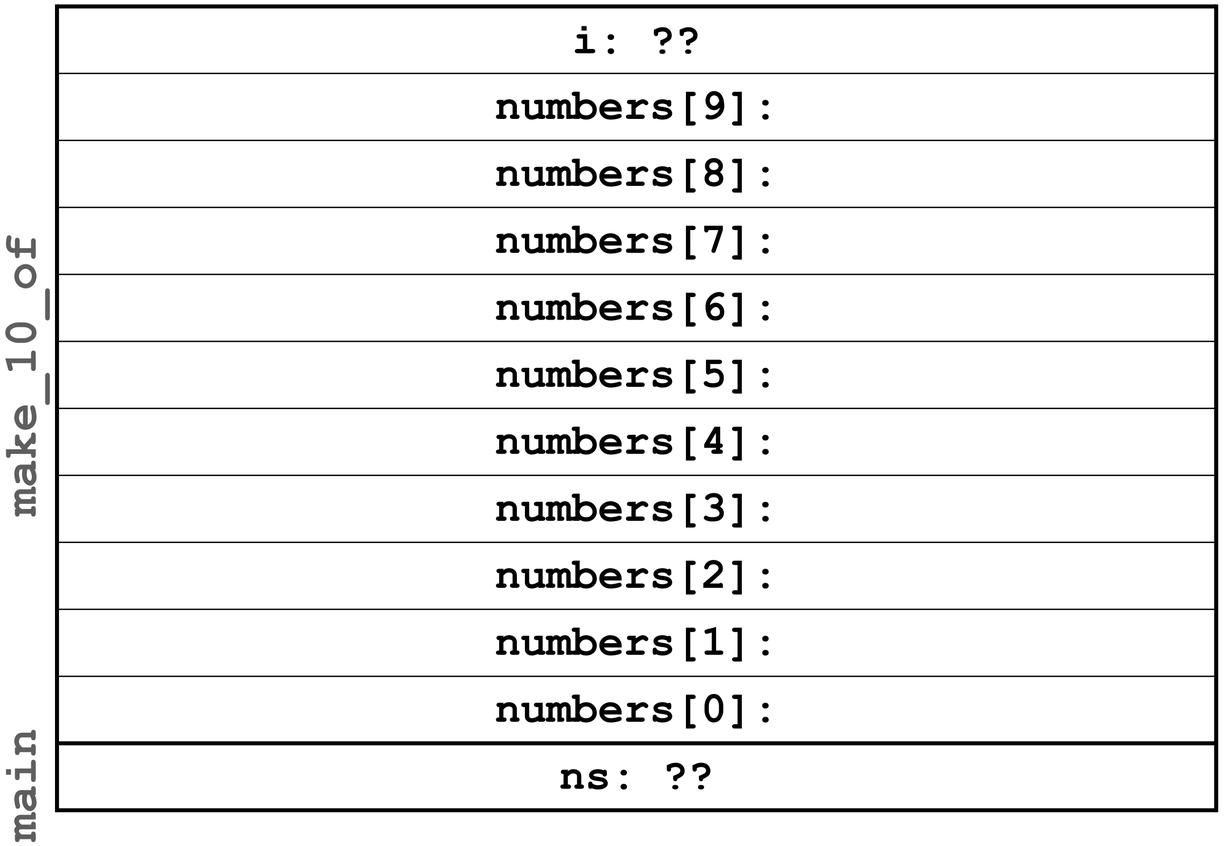
How about returning an array?

```
int *make_10_of(int n)
{
        int numbers[10];

        for (int i = 0; i < 10; i++) {
                numbers[i] = n;
        }

        return numbers;
}


int main()
{
        int *ns = make_10_of(42);
        ...
        return 0;
}
```



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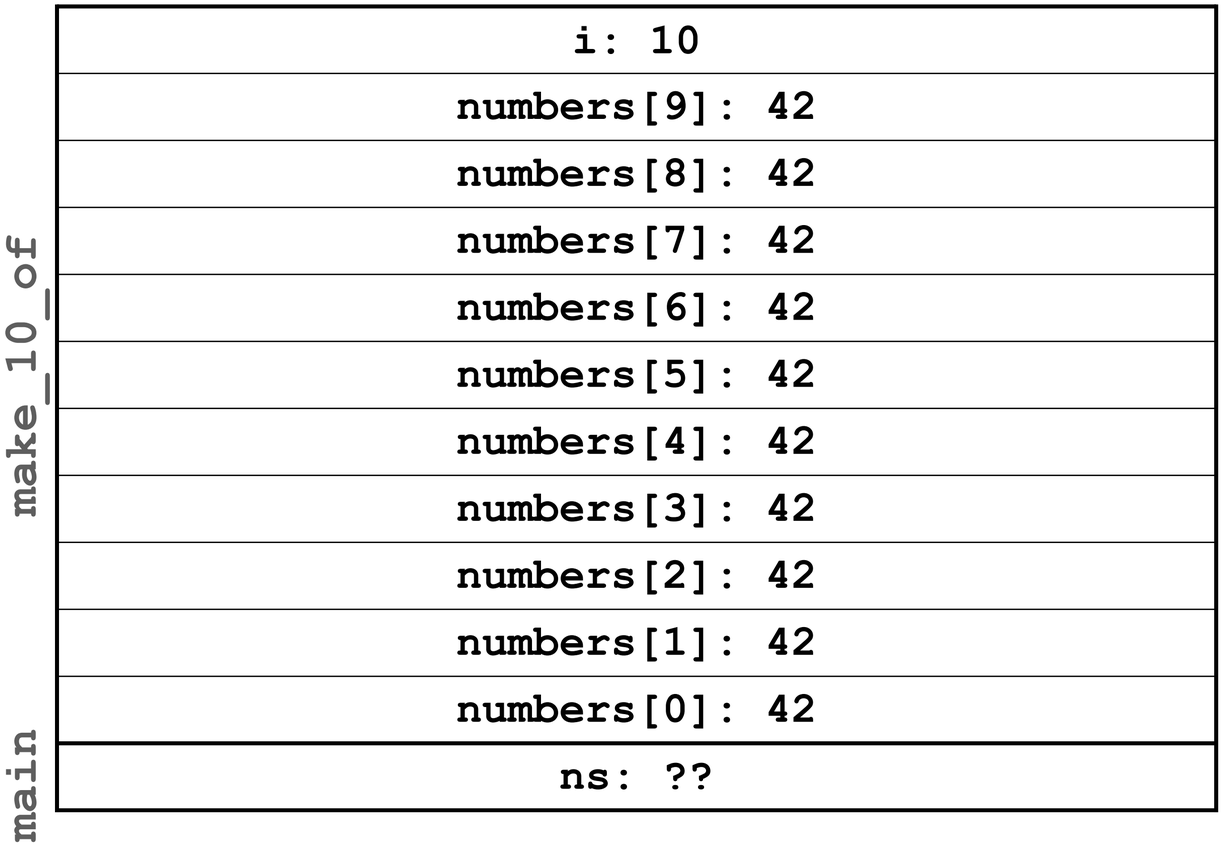

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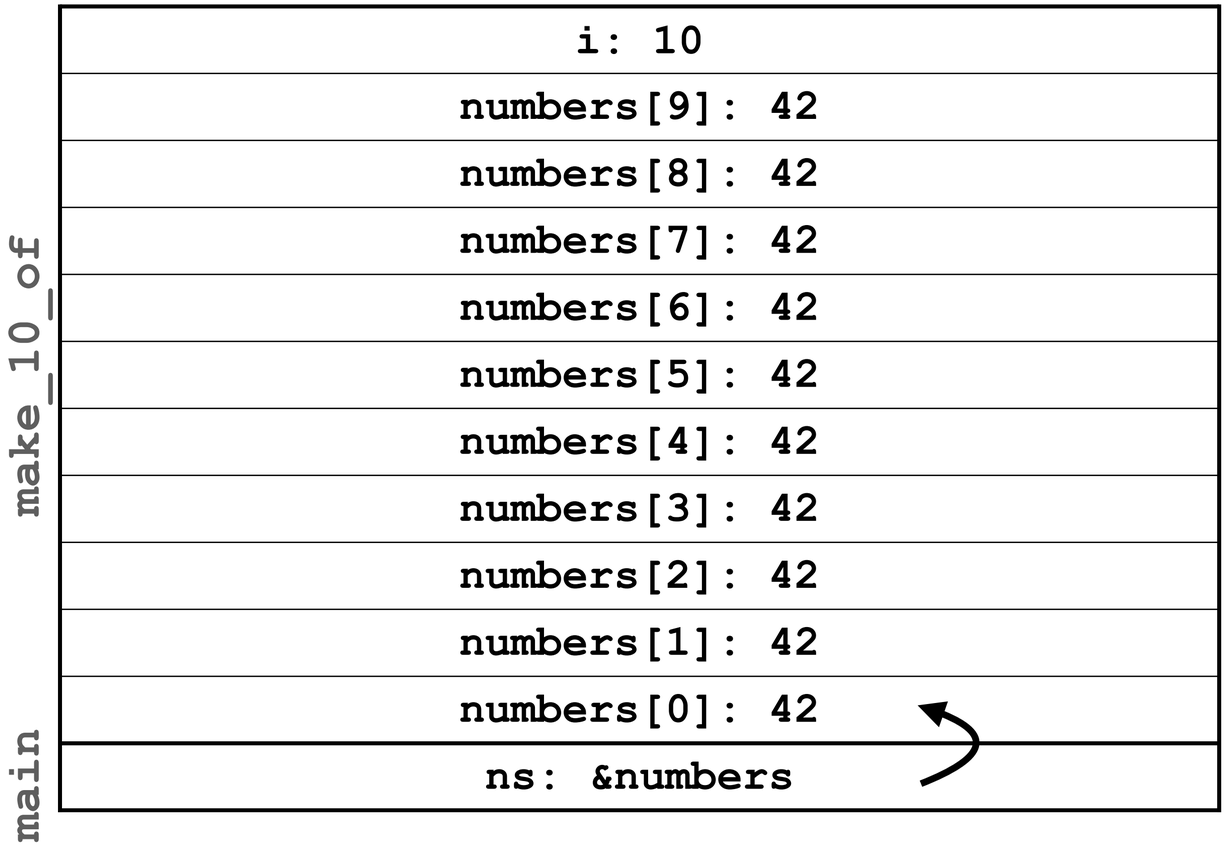

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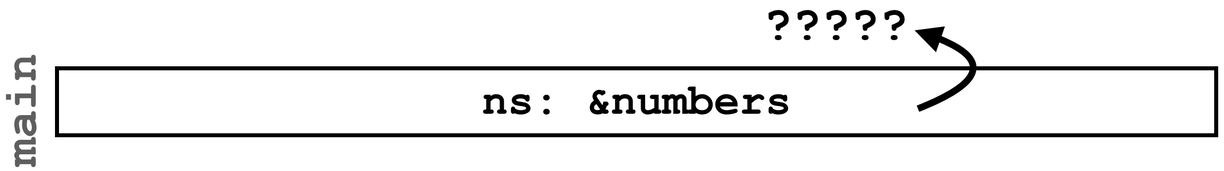

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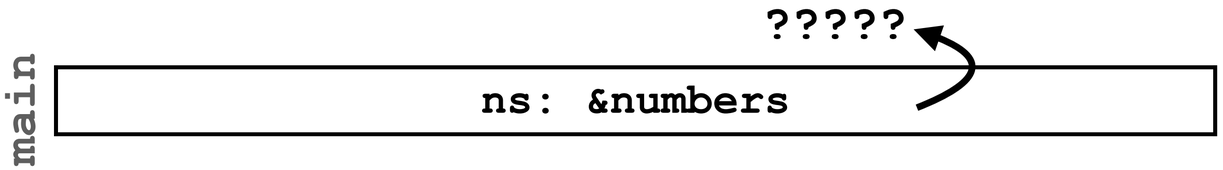

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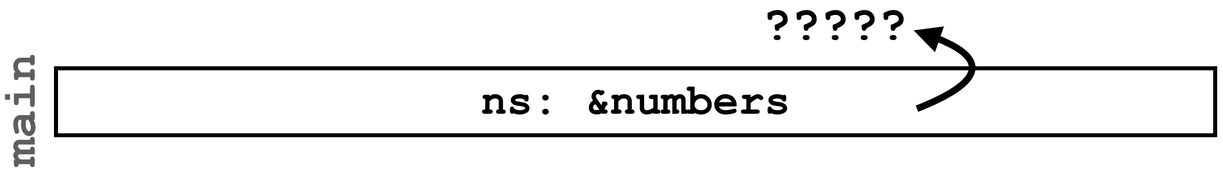
- `numbers` is recycled after returning
- `ns` becomes a pointer to invalid/ non-existent/dead data.



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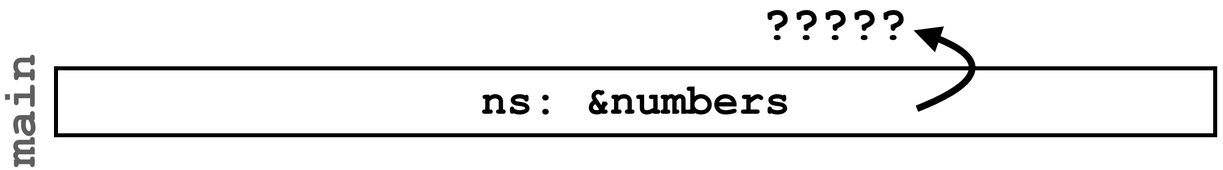
- We call `ns` a dangling pointer



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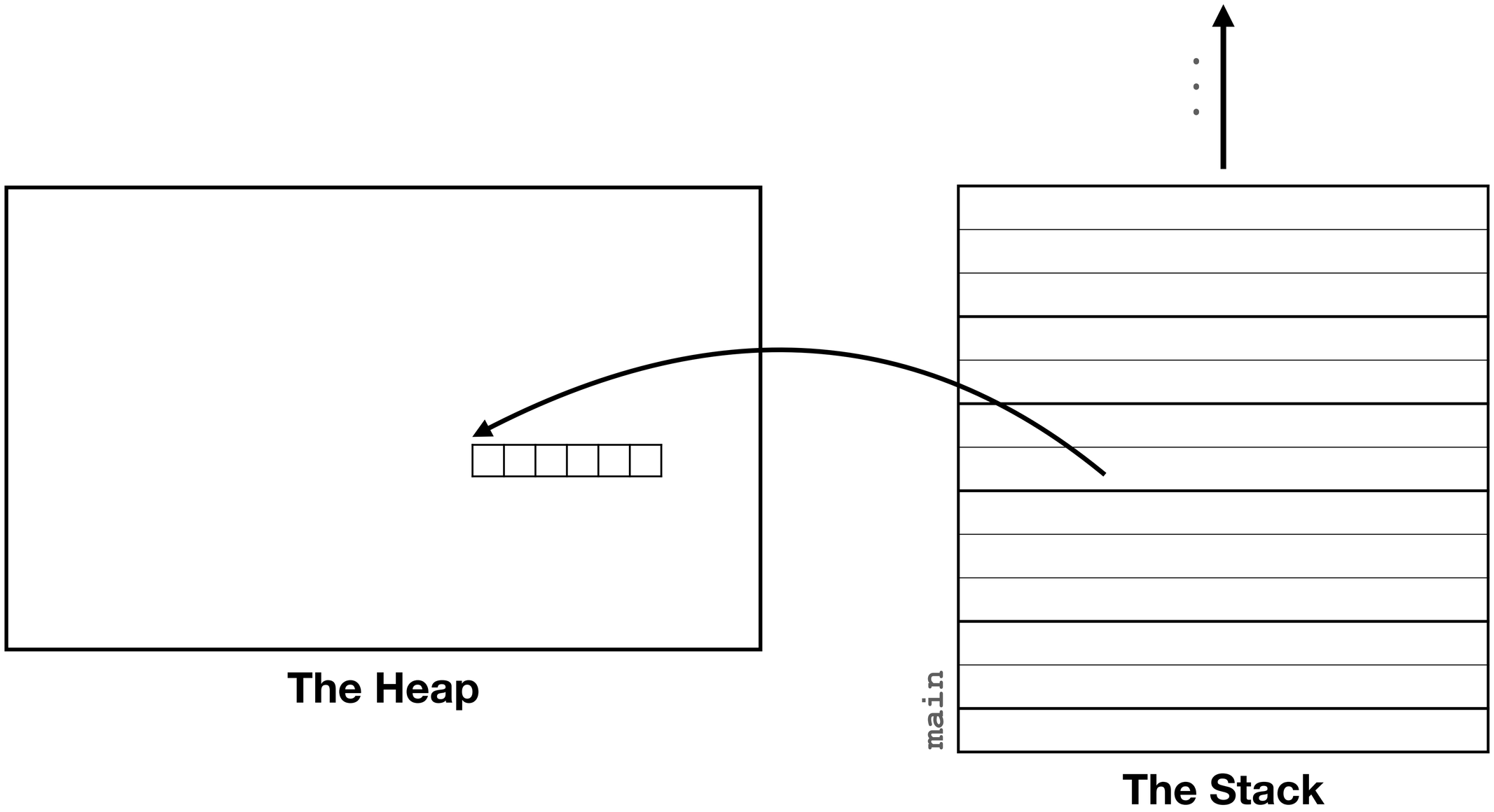
The Heap



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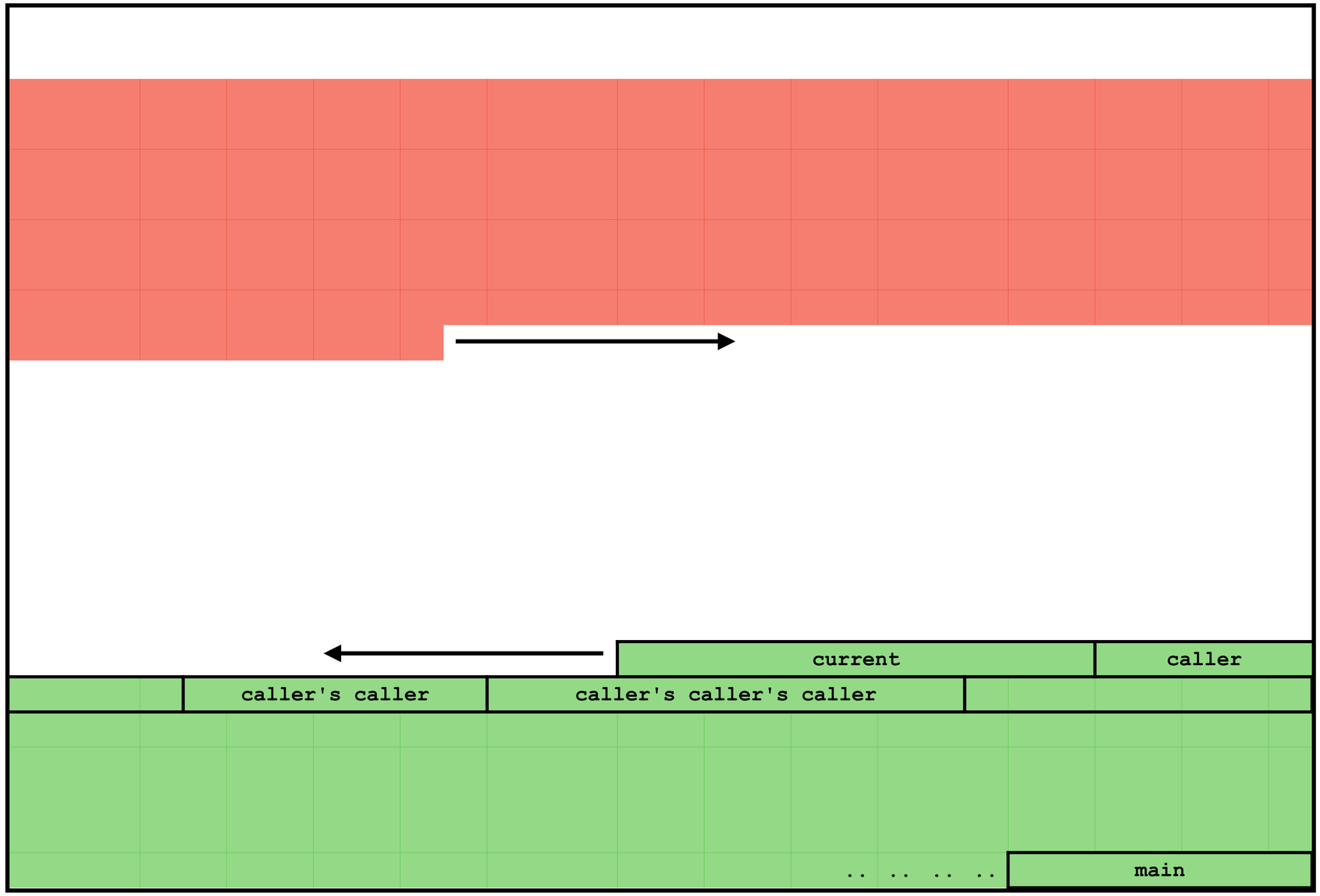
current
caller
caller's caller
caller's caller's caller
.. ..
main

The Heap

The Stack

- To request space on the stack, we *declare* a variable.
  - Compiler figures out the size according to the type.
- To release space on the stack, we do *nothing*.
  - Compiler recycles the space when we reach the end of the enclosing function.
- How about the heap?

The Heap

`malloc` and `free`

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int *numbers = malloc(104);

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Big no-no! Because this address is probably used by something else, this *corrupts* the memory -- memory error.

The Heap

Stack vs Heap

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- Acquire memory:

Heap

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The Heap

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  - You can forget to release; *memory leak*

- Accessing released memory is bad; *memory error*

Pointers

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```

Forgetting to free here causes memory leak.

Pointer Hazards

Be aware of shallow copy

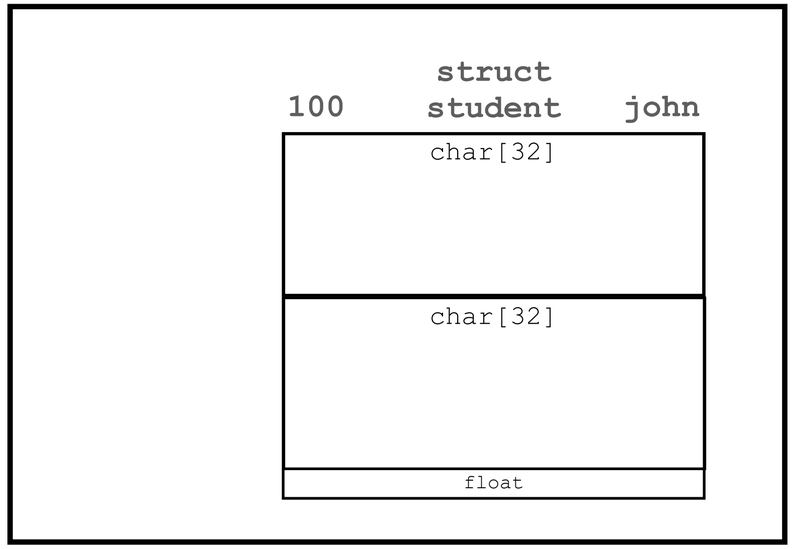
```c
struct student {
        char first_name[32];
        char last_name[32];
        float gpa;
};

void print_student(struct student *s_p)
{
        printf("%s %s: %.2f\n", s_p->first_name,
                                s_p->last_name,
                                s_p->gpa);
}

int main(void)
{
        struct student john;
        ...
        print_student(&john);

        return 0;
}
```

Say, you want to remove the character limit on names



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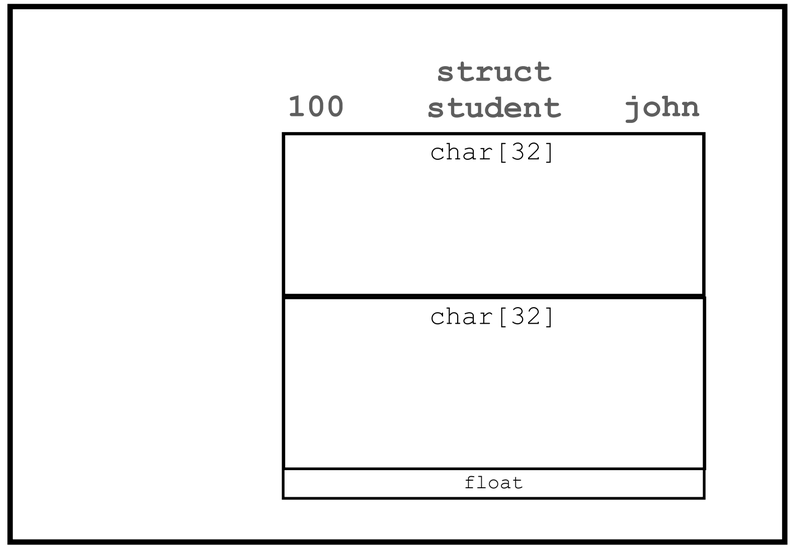

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int main(void)
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        char first_name[] = "John";
        char last_name[] = "Doe";

        struct student john;
        john.first_name = first_name;
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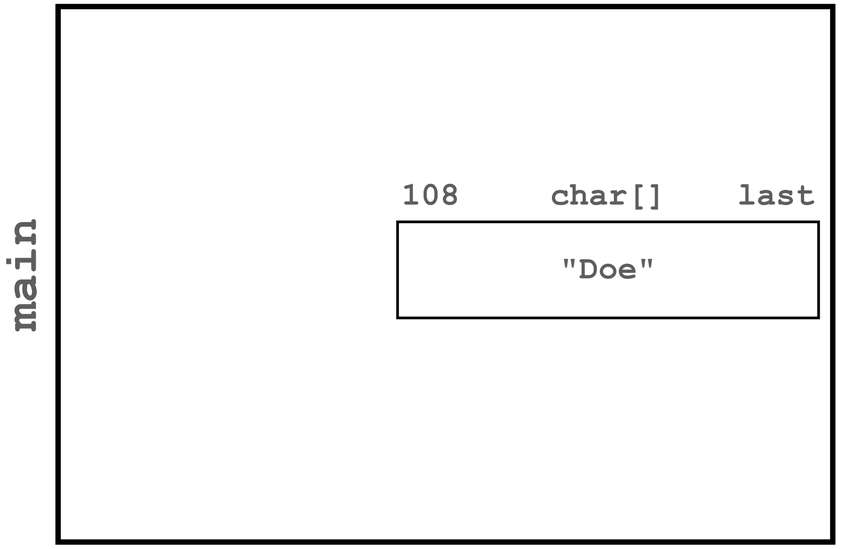

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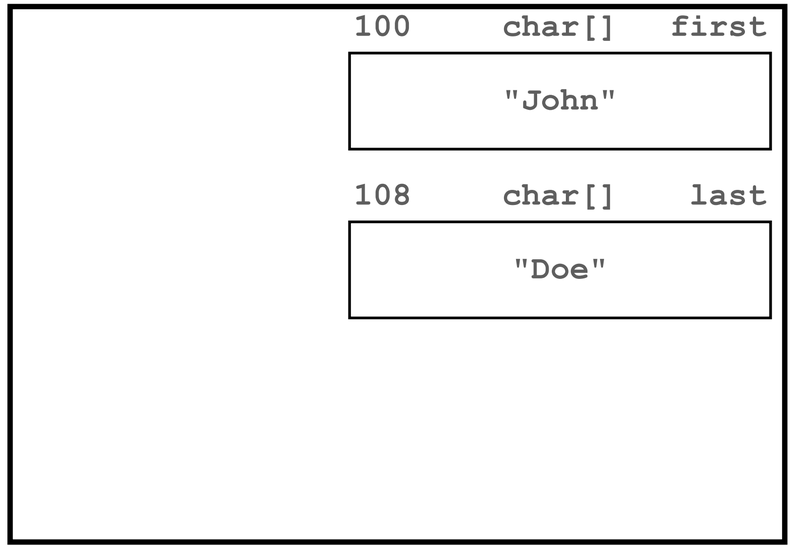


Pointer Hazards

Be aware of shallow copy

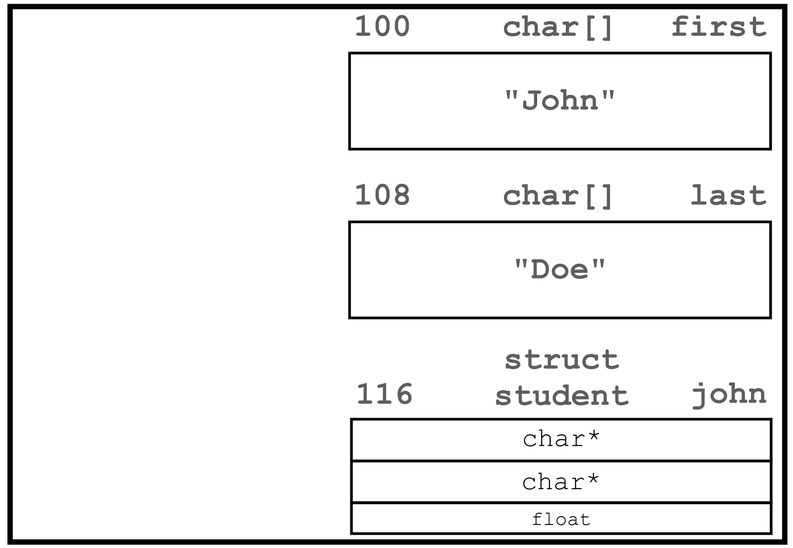
```
struct student {
        char *first_name;
        char *last_name;
        float gpa;
};

void print_student(struct student *s_p)
{
        ...
}

int main(void)
{
        char first_name[] = "John";
        char last_name[] = "Doe";

        struct student john;
        john.first_name = first_name;
        john.last_name = last_name;
        john.gpa = 3.0;

        return 0;
}
```



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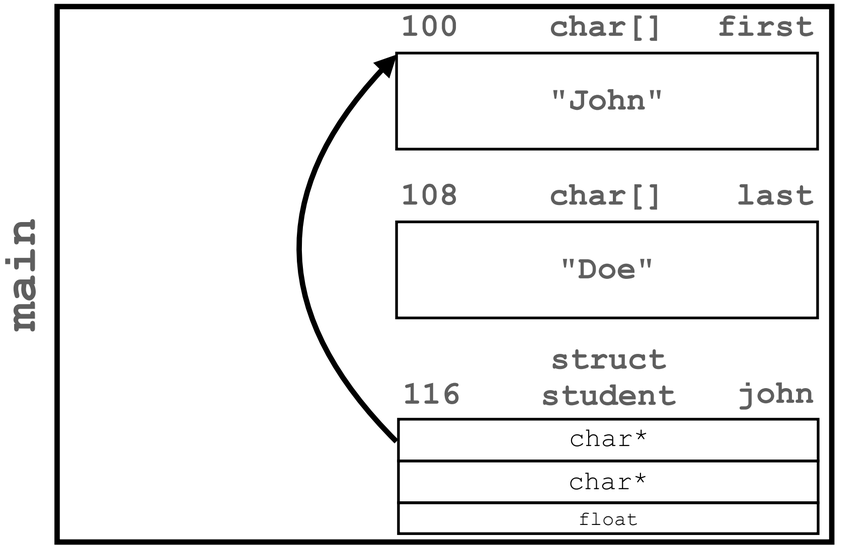

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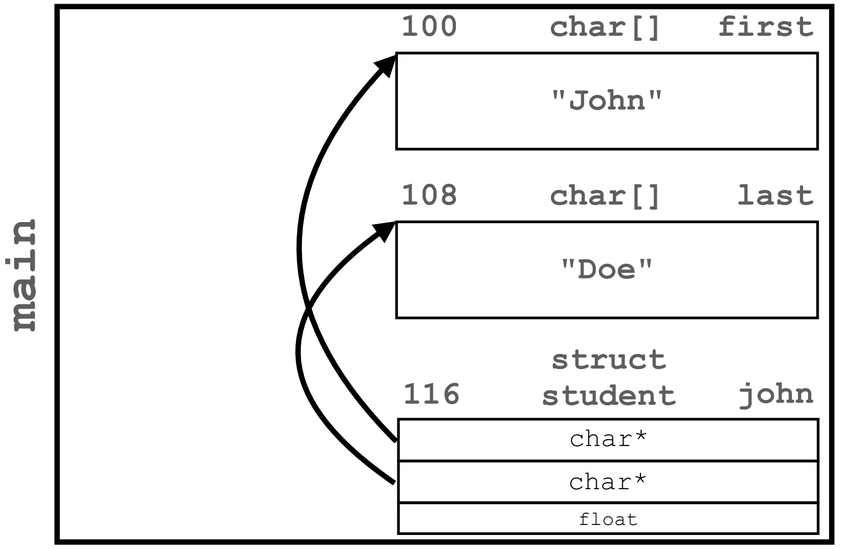

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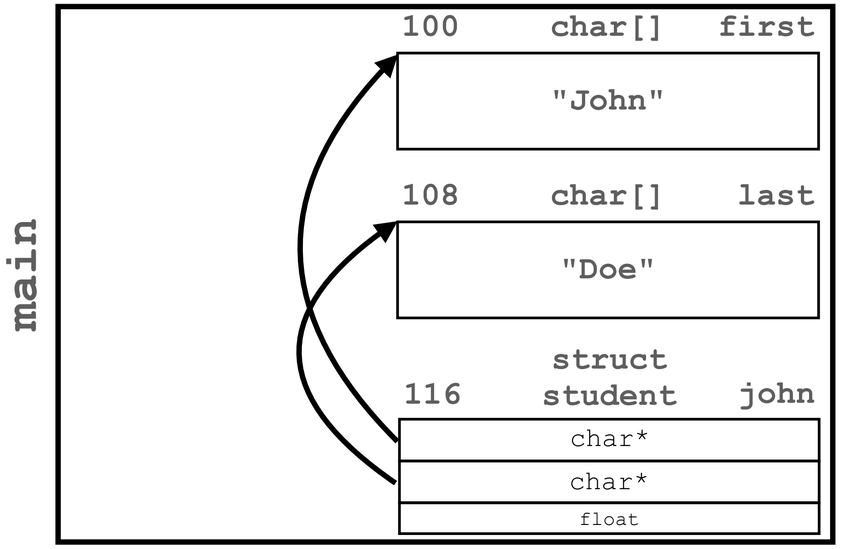

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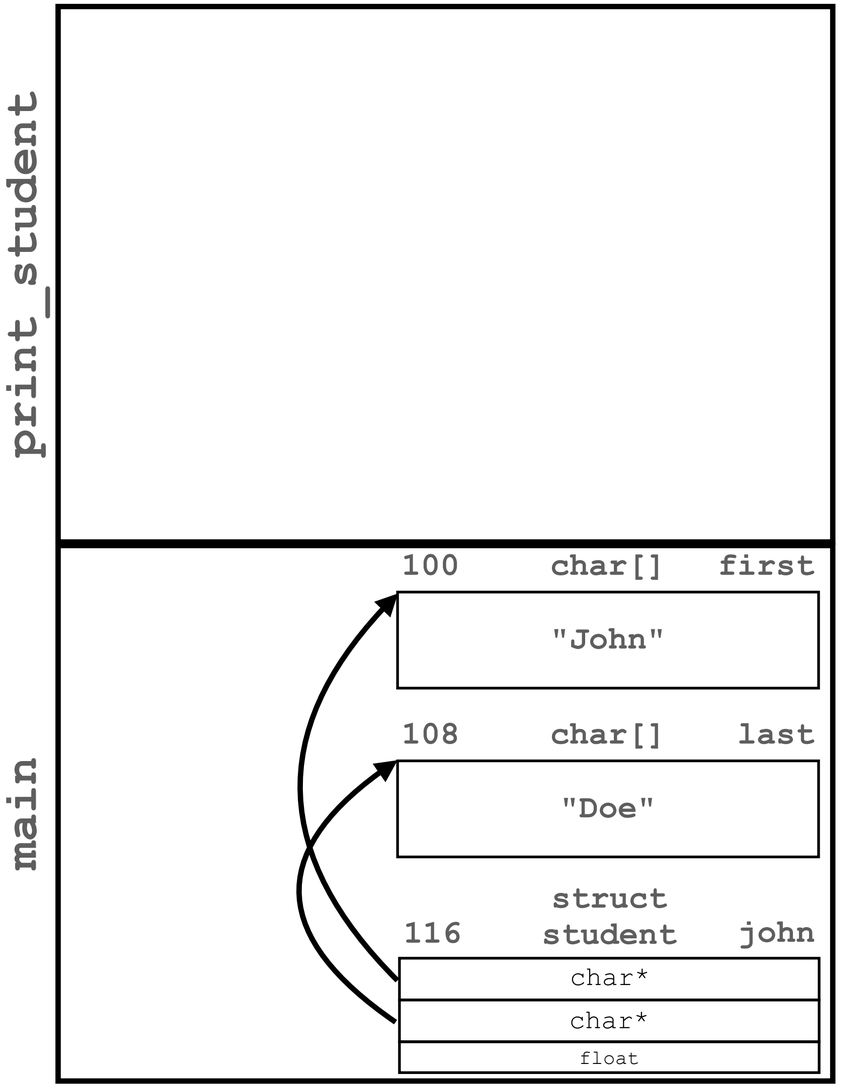

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        return 0;
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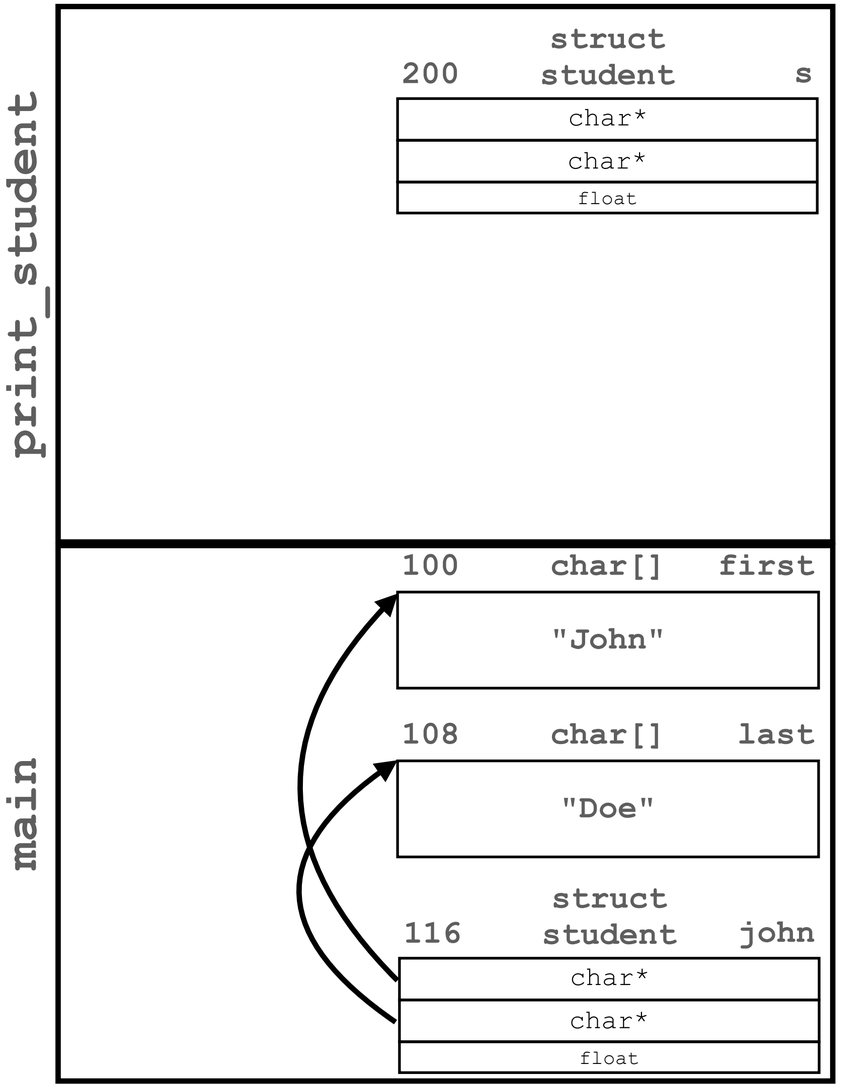

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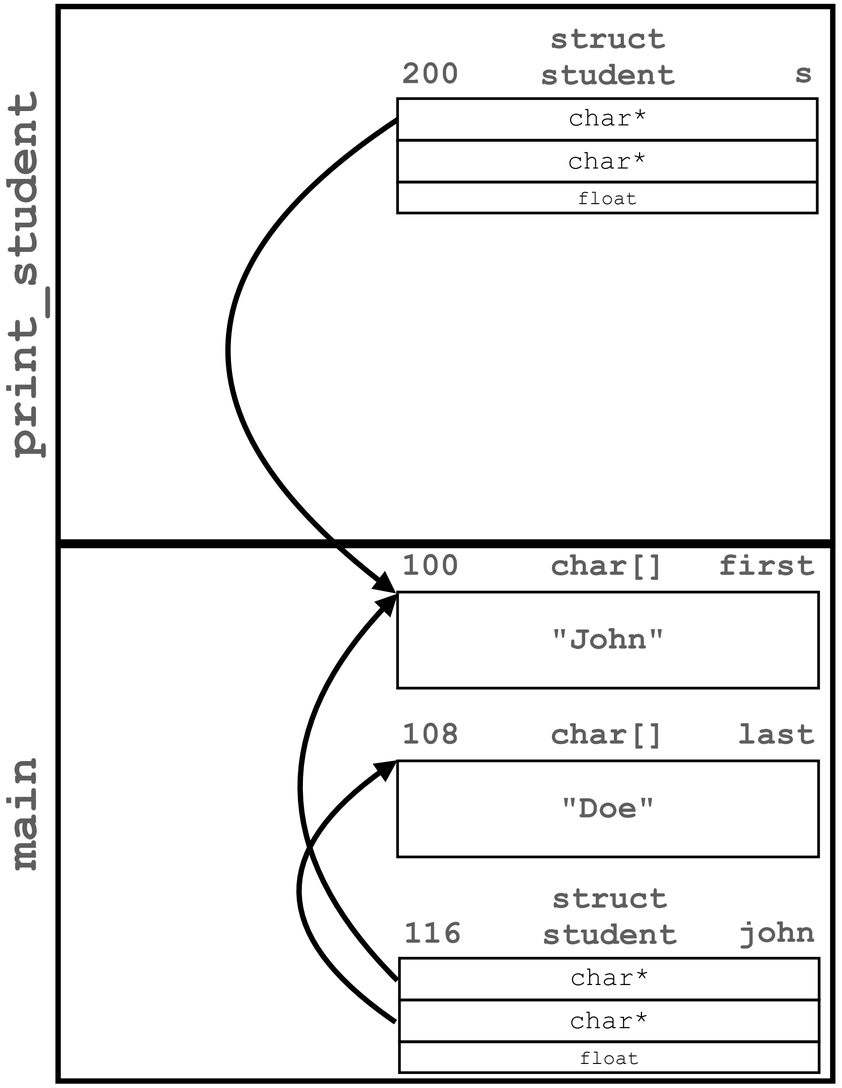

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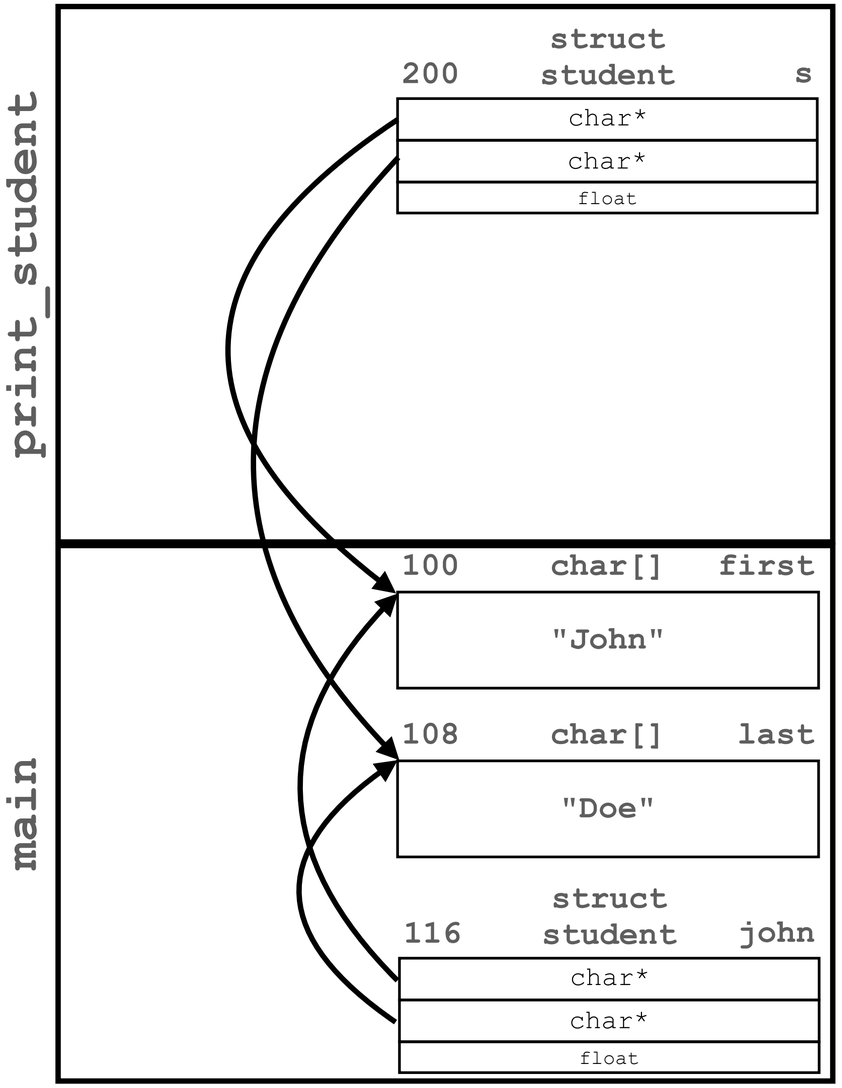

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        ...
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int main(void)
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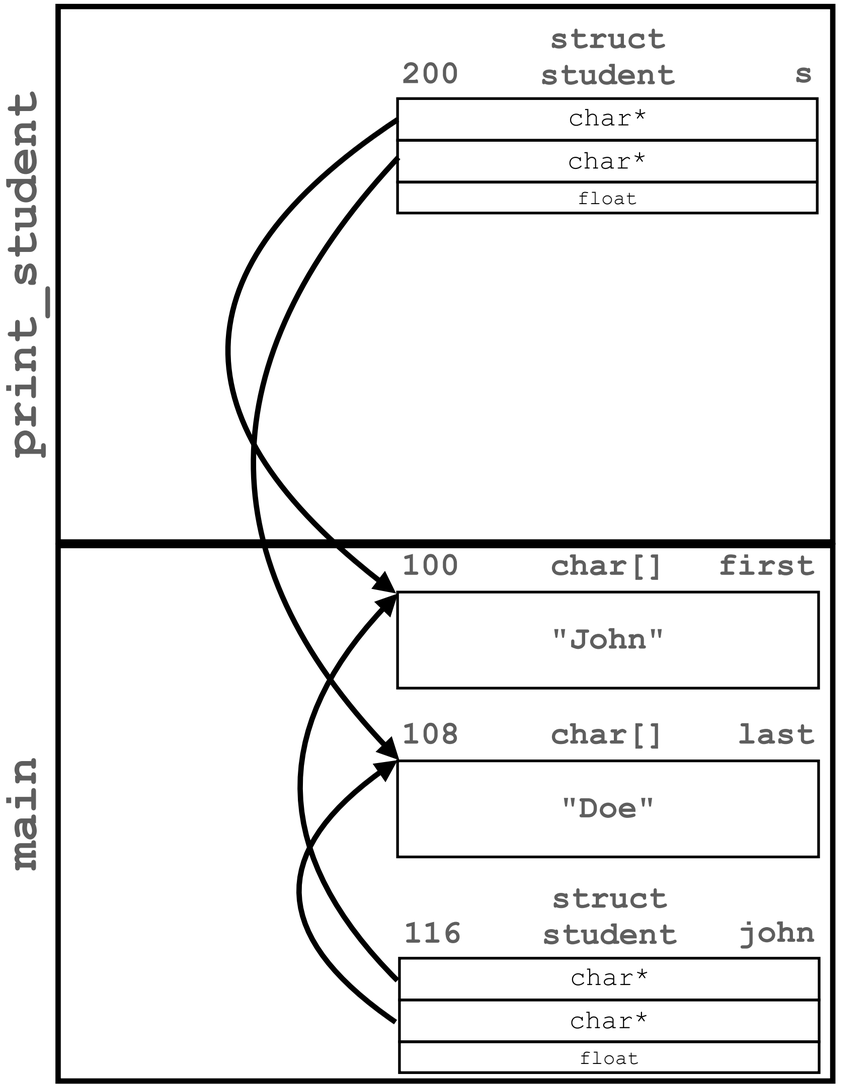
        struct student john;
        john.first_name = first_name;
        john.last_name = last_name;
        john.gpa = 3.0;

        return 0;
}
```

If you change s.first_name here, first_name and john.first_name are also changed in main.



Pointer Hazards

Be aware of dangling pointer (again)

```
struct student {
        char *first_name;
        char *last_name;
        float gpa;
};

struct student create_student(void)
{
        char first_name[] = "John";
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        struct student john;
        john.first_name = first_name;
        john.last_name = last_name;
        john.gpa = 3.0;
        return john;
}

int main(void)
{
        struct student john = create_student();

        return 0;
}
```

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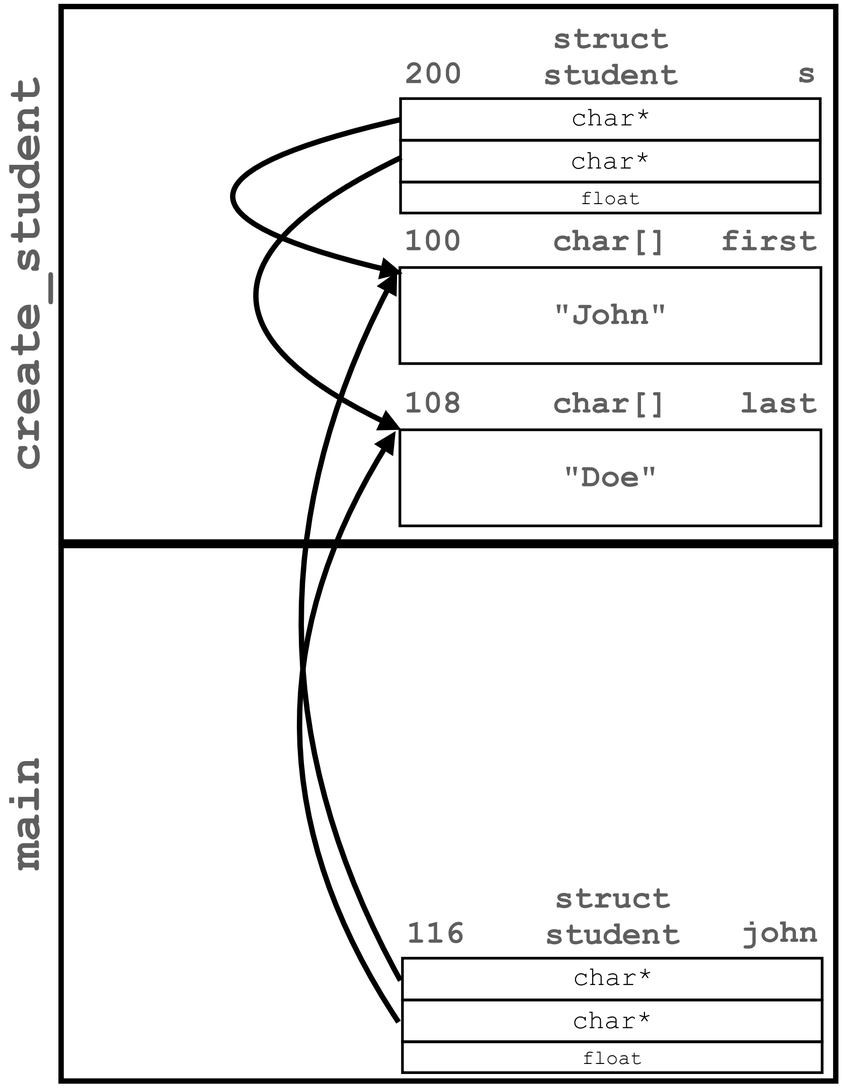

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```c
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};

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        john.gpa = 3.0;
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}

int main(void)
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        return 0;
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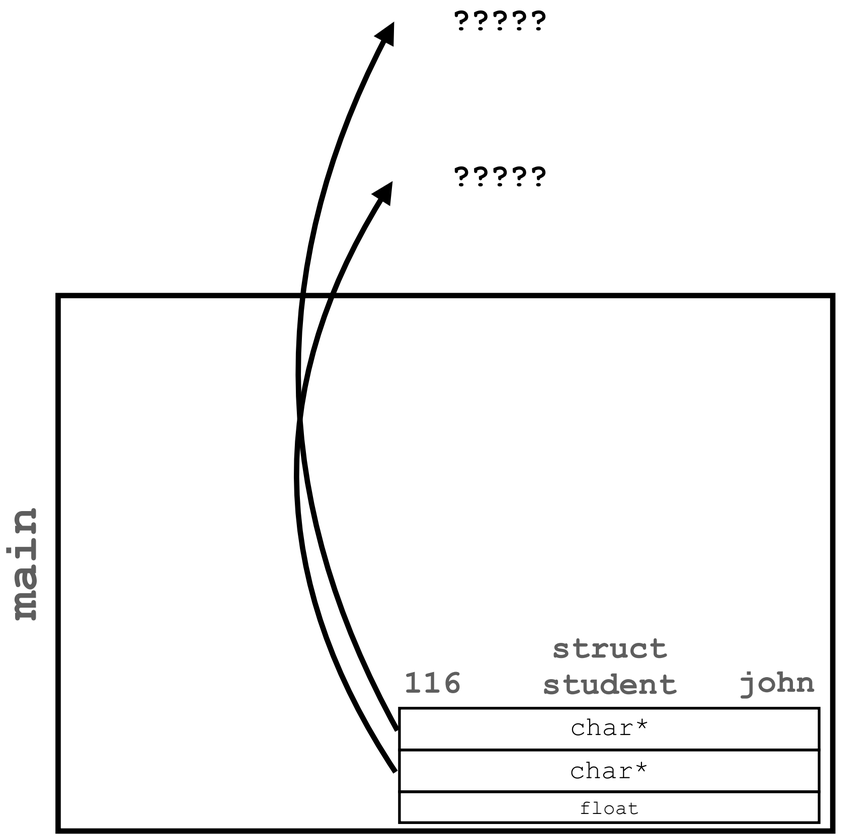

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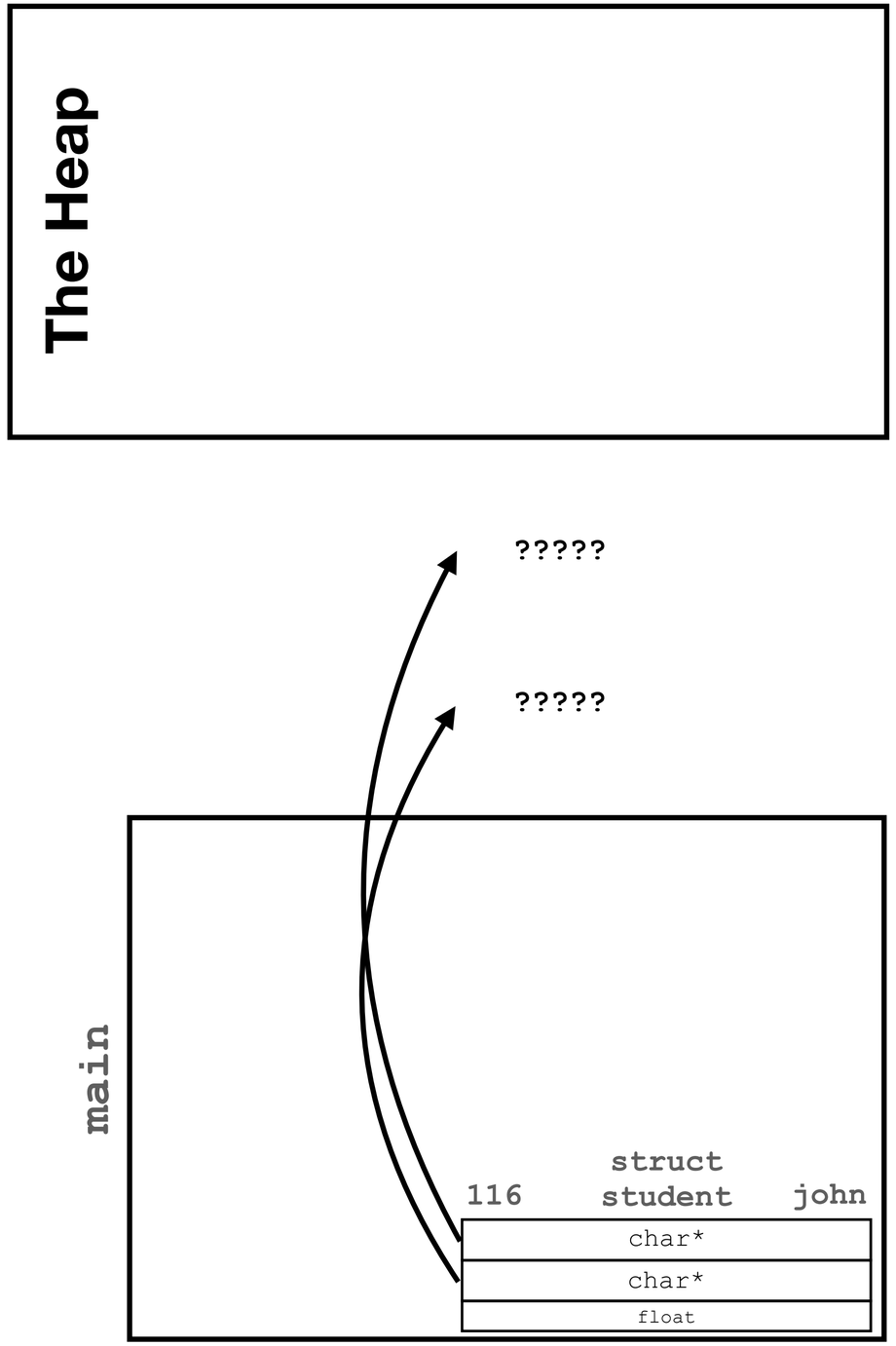

Pointer Hazards

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struct student {
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        struct student john;
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strdup in <string.h> duplicates the string on the heap. i.e. strdup calls malloc, and then copy the string to the malloc'ed space.
It's a very handy function.

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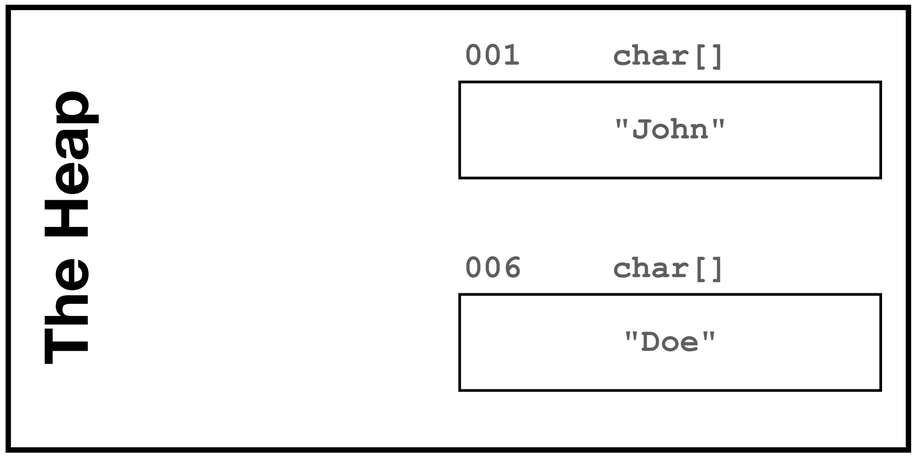

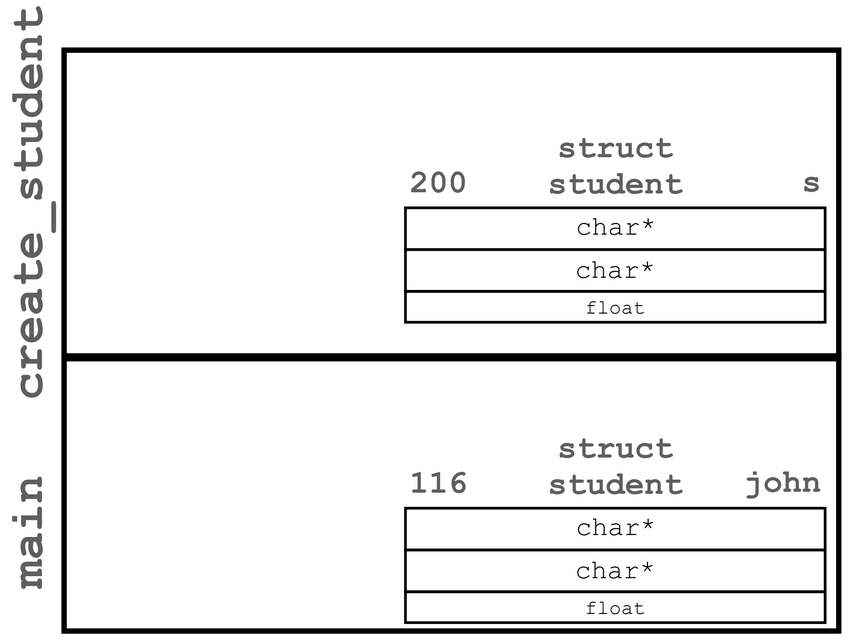

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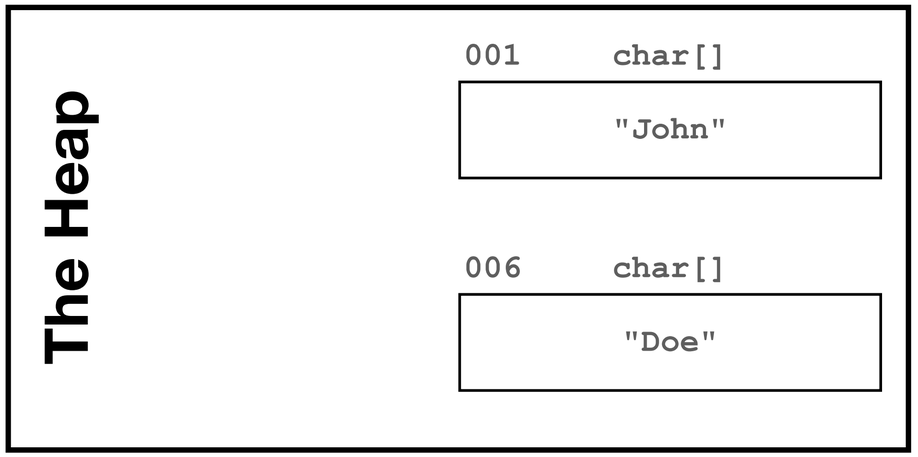

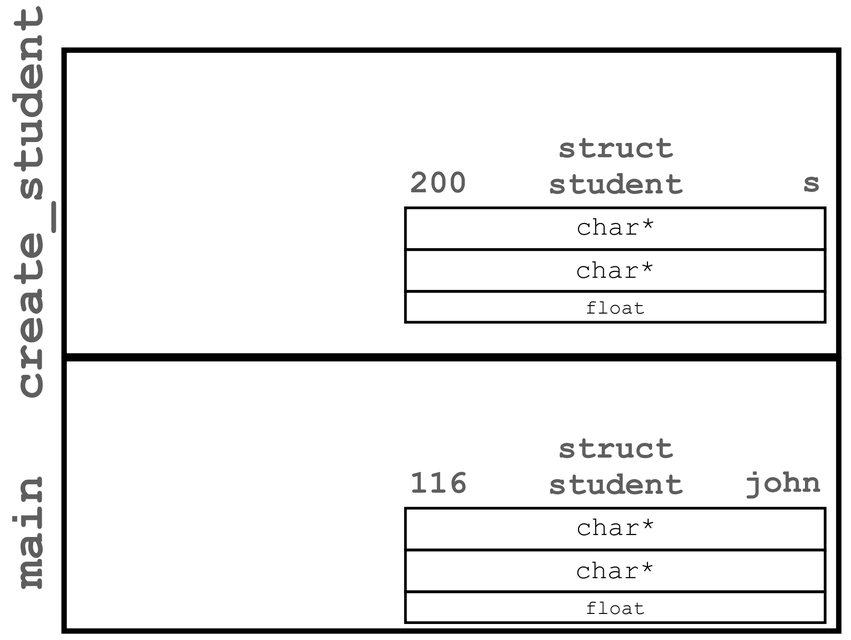

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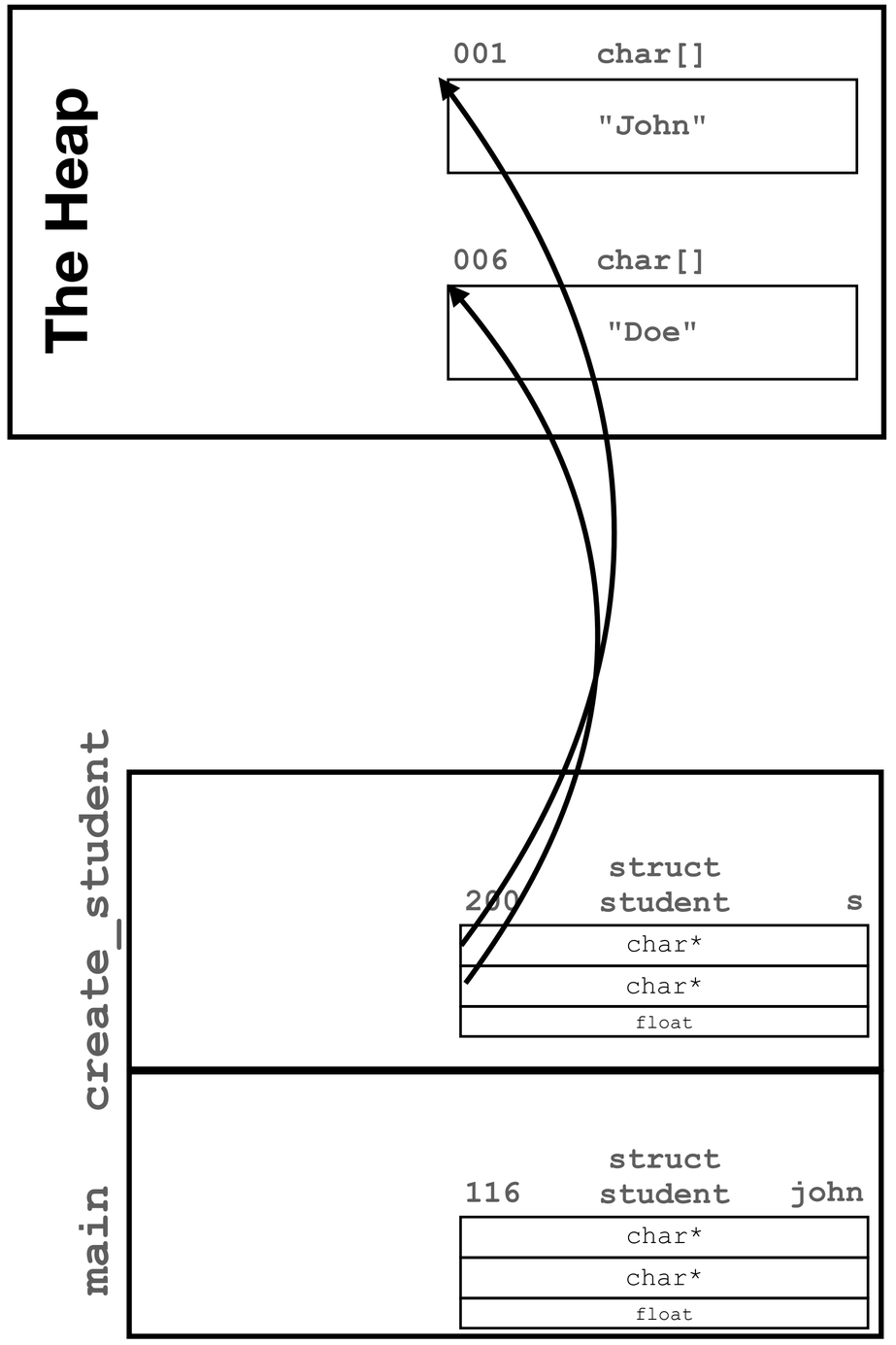

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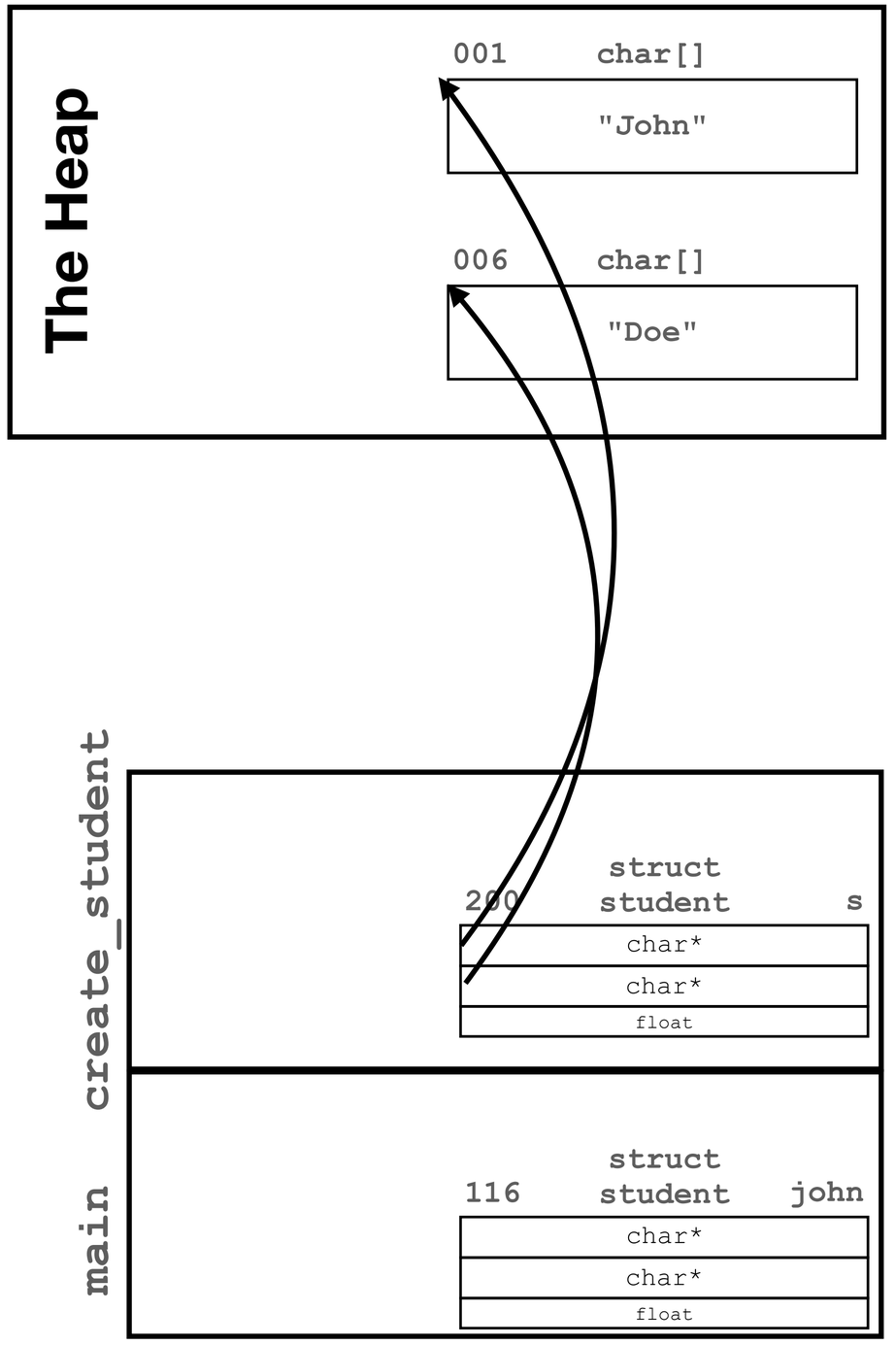

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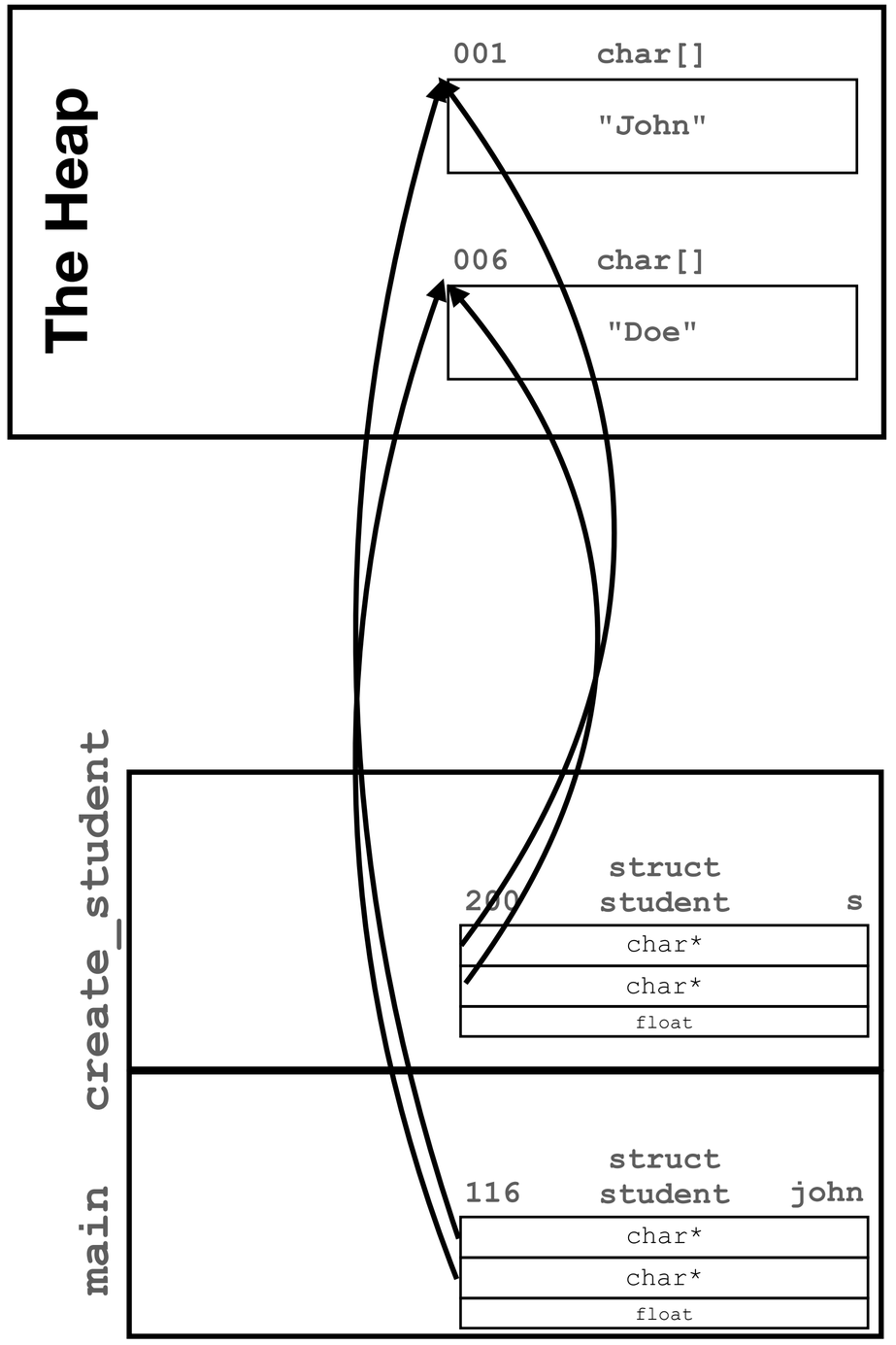

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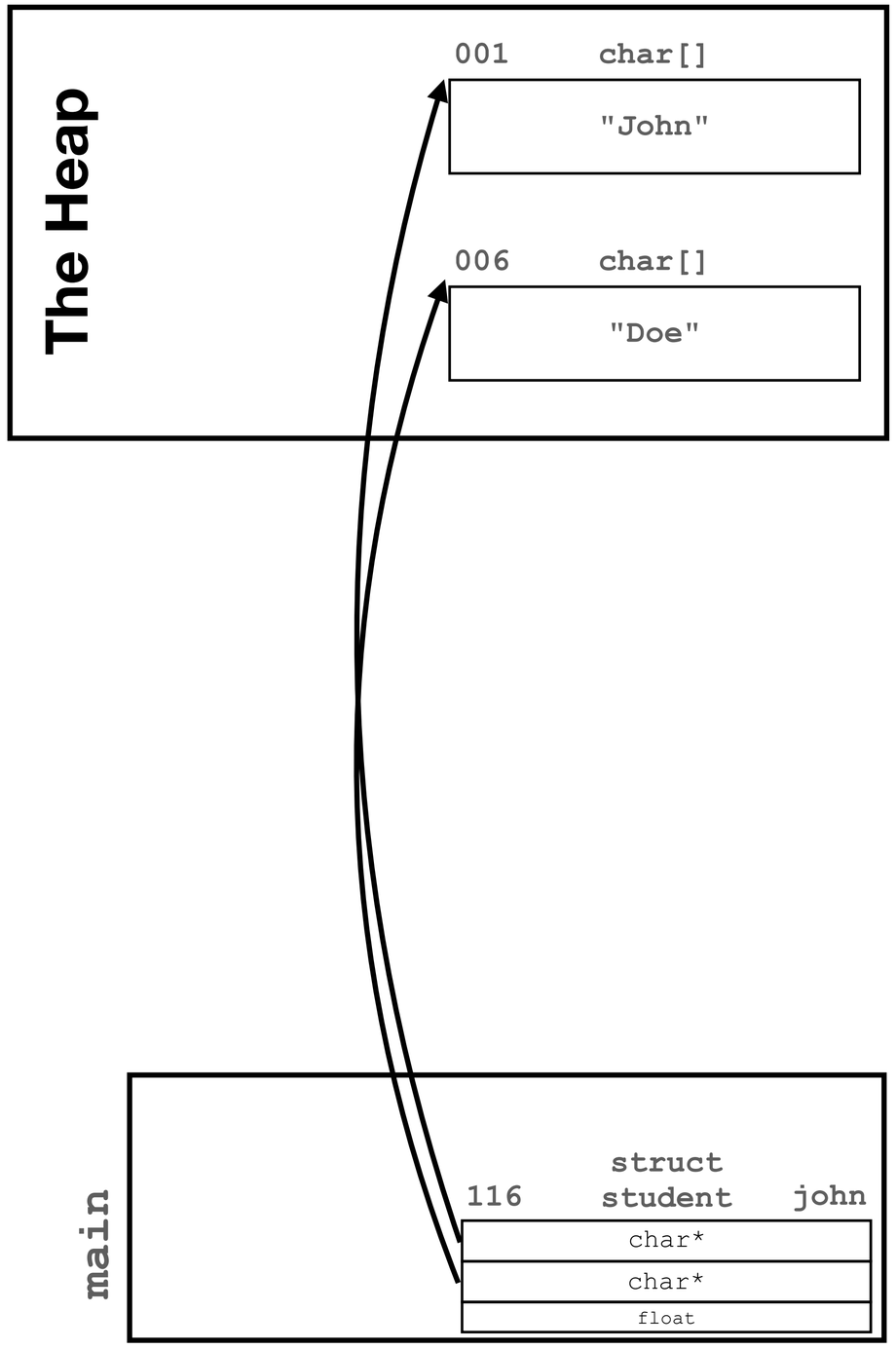

Pointer Hazards

Be aware of memory leak

```
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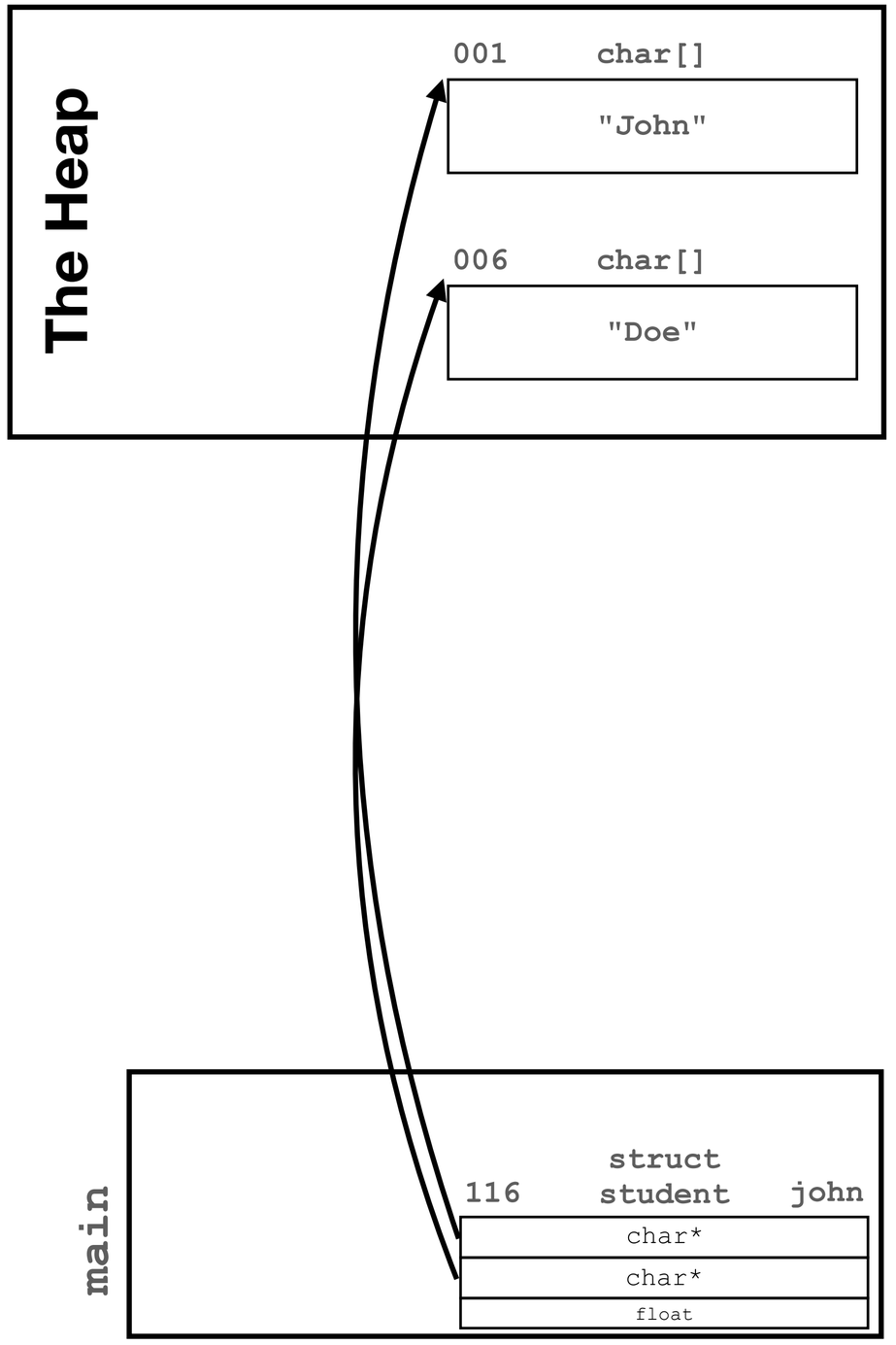

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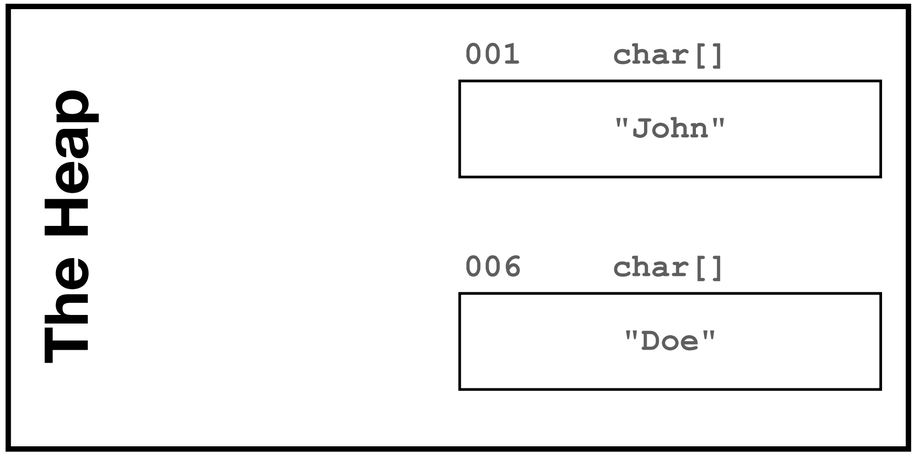

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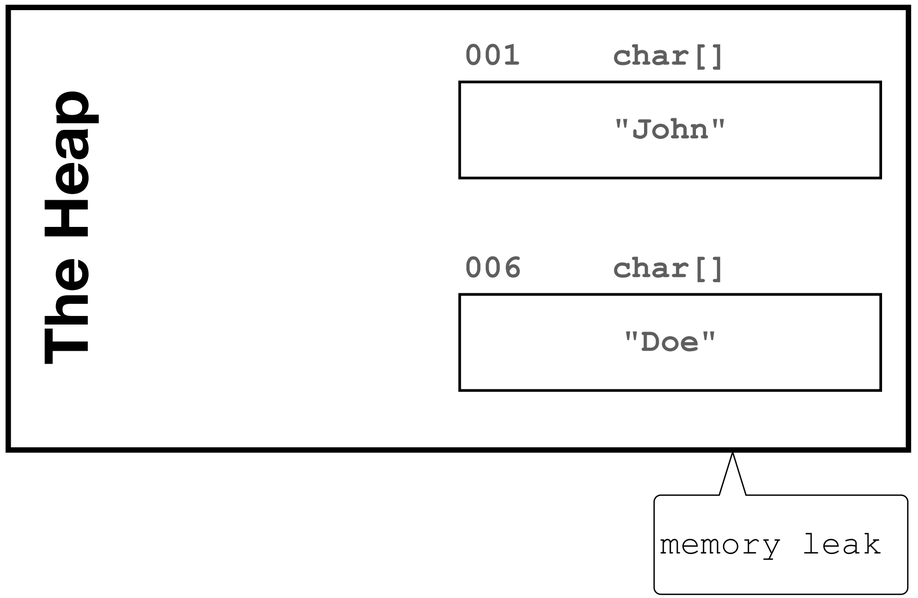

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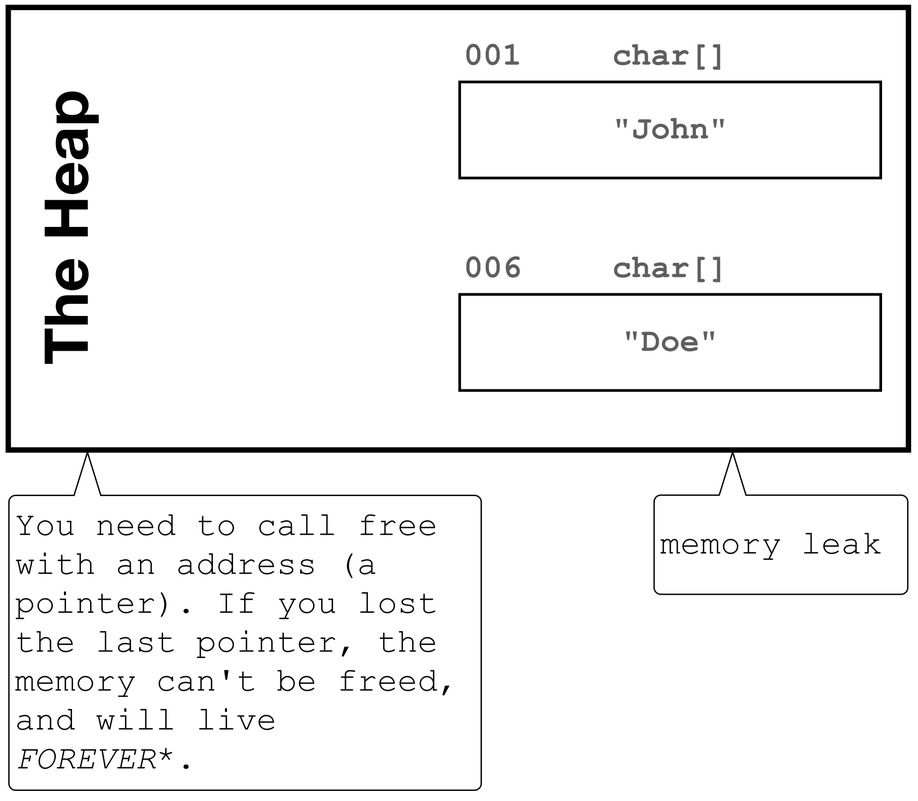

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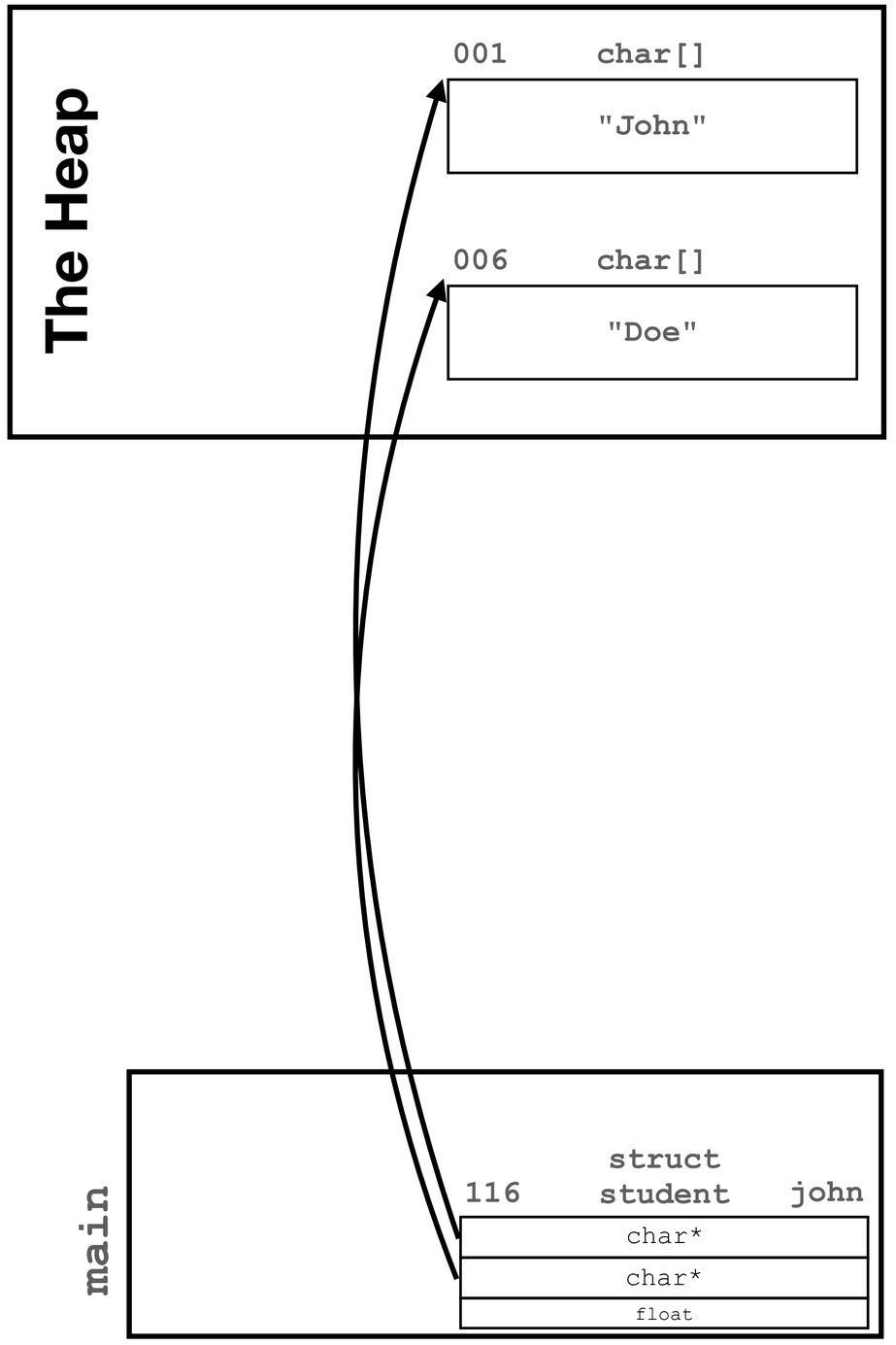
        return john;
}

int main(void)
{
        struct student john = create_student();
        free(john.first_name);
        free(john.last_name);
        return 0;
}
```



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}

int main(void)
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        struct student john = create_student();
        free(john.first_name);
        free(john.last_name);
        return 0;
}
```
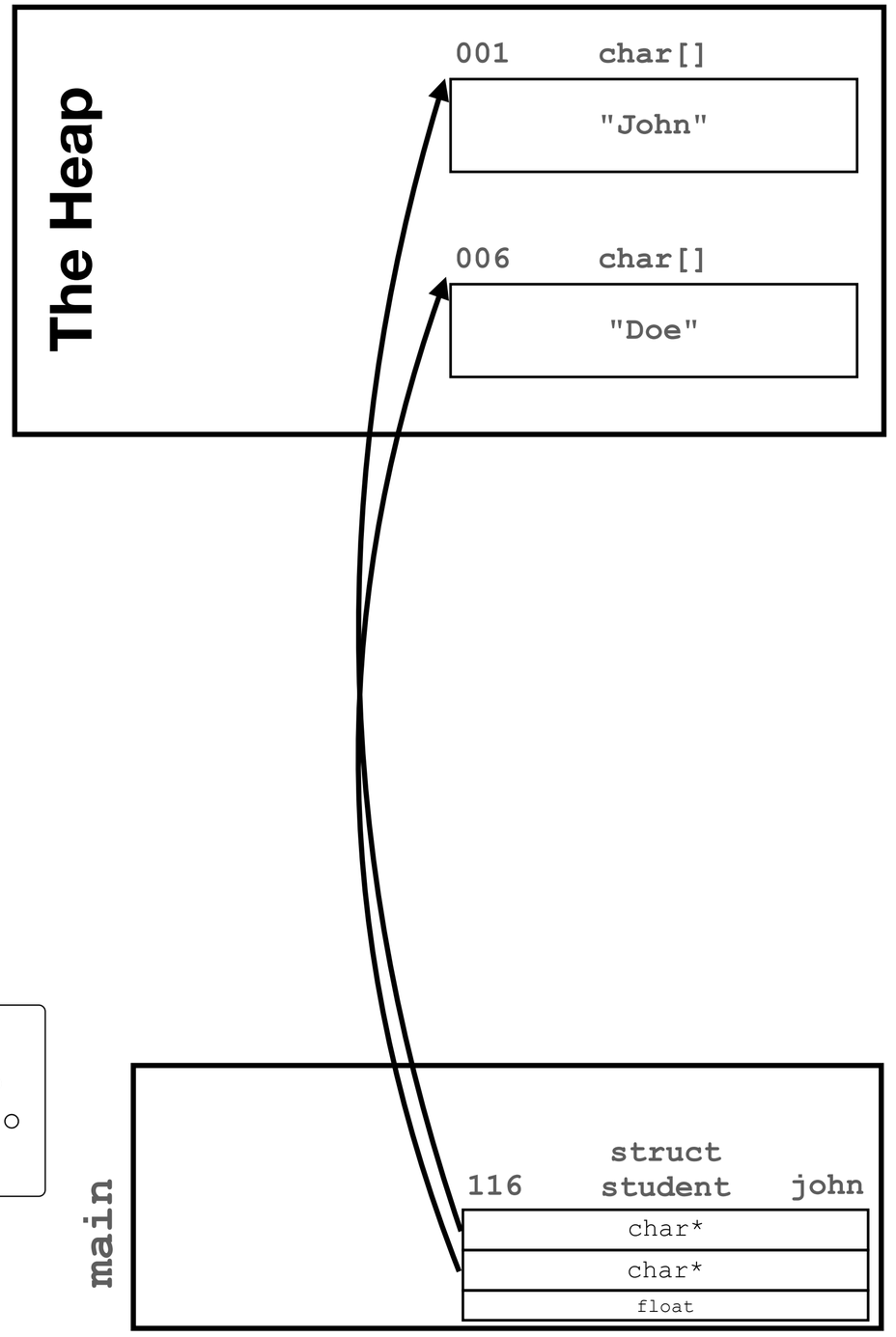
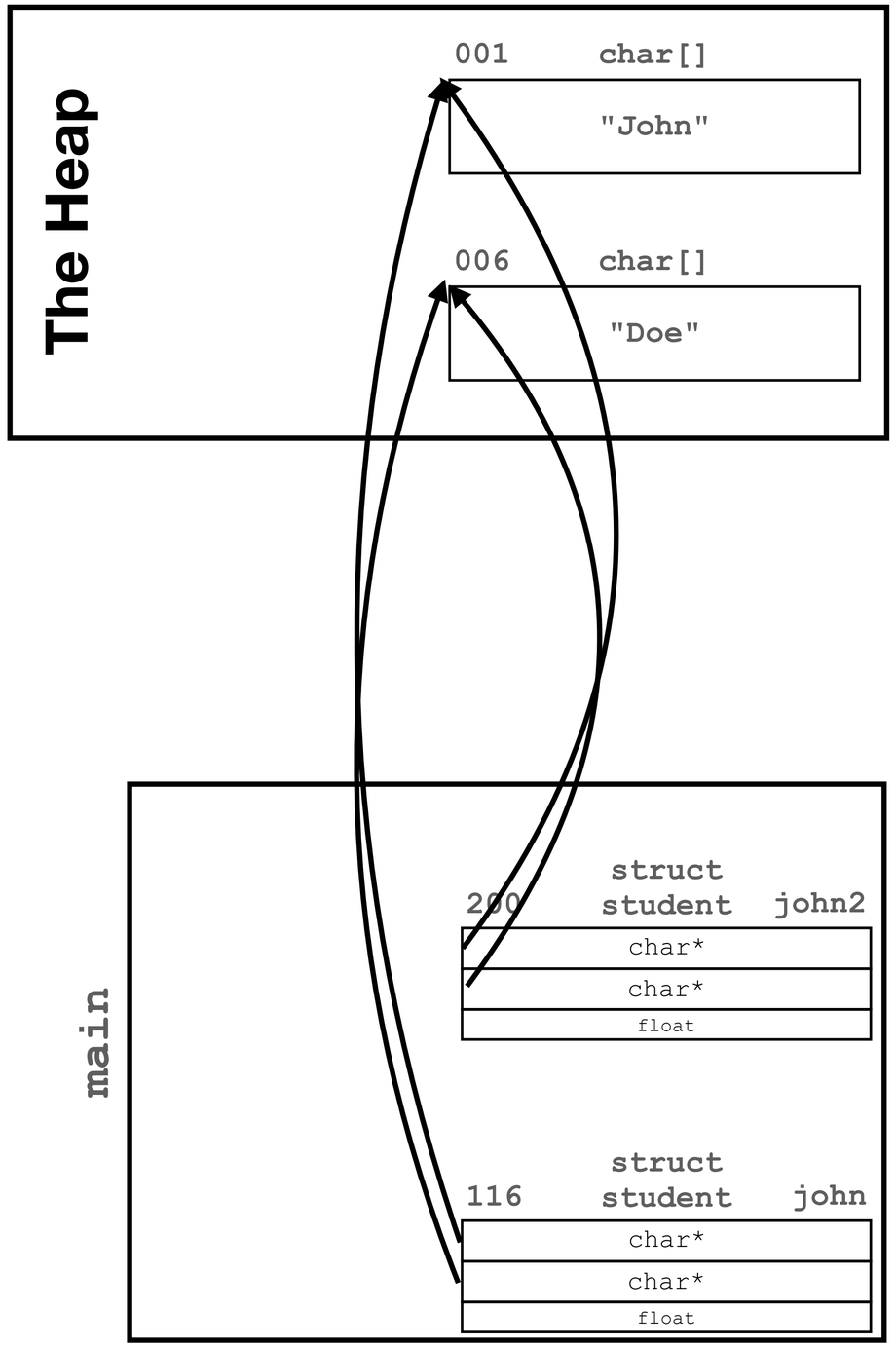

remember to call free when the last pointer to the heap data is about to go out of scope



Pointer Hazards

Be aware of double-free corruption

```
struct student {
        char *first_name;
        char *last_name;
        float gpa;
};

struct student create_student(void)
{
        ...
}

int main(void)
{
        struct student john = create_student();
        struct student john2 = john;
        return 0;
}
```



Pointer Hazards

Be aware of double-free corruption

```
struct student {
        char *first_name;
        char *last_name;
        float gpa;
};

struct student create_student(void)
{
        ...
}

int main(void)
{
        struct student john = create_student();
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        free(john.first_name);
        free(john.last_name);

        return 0;
}
```

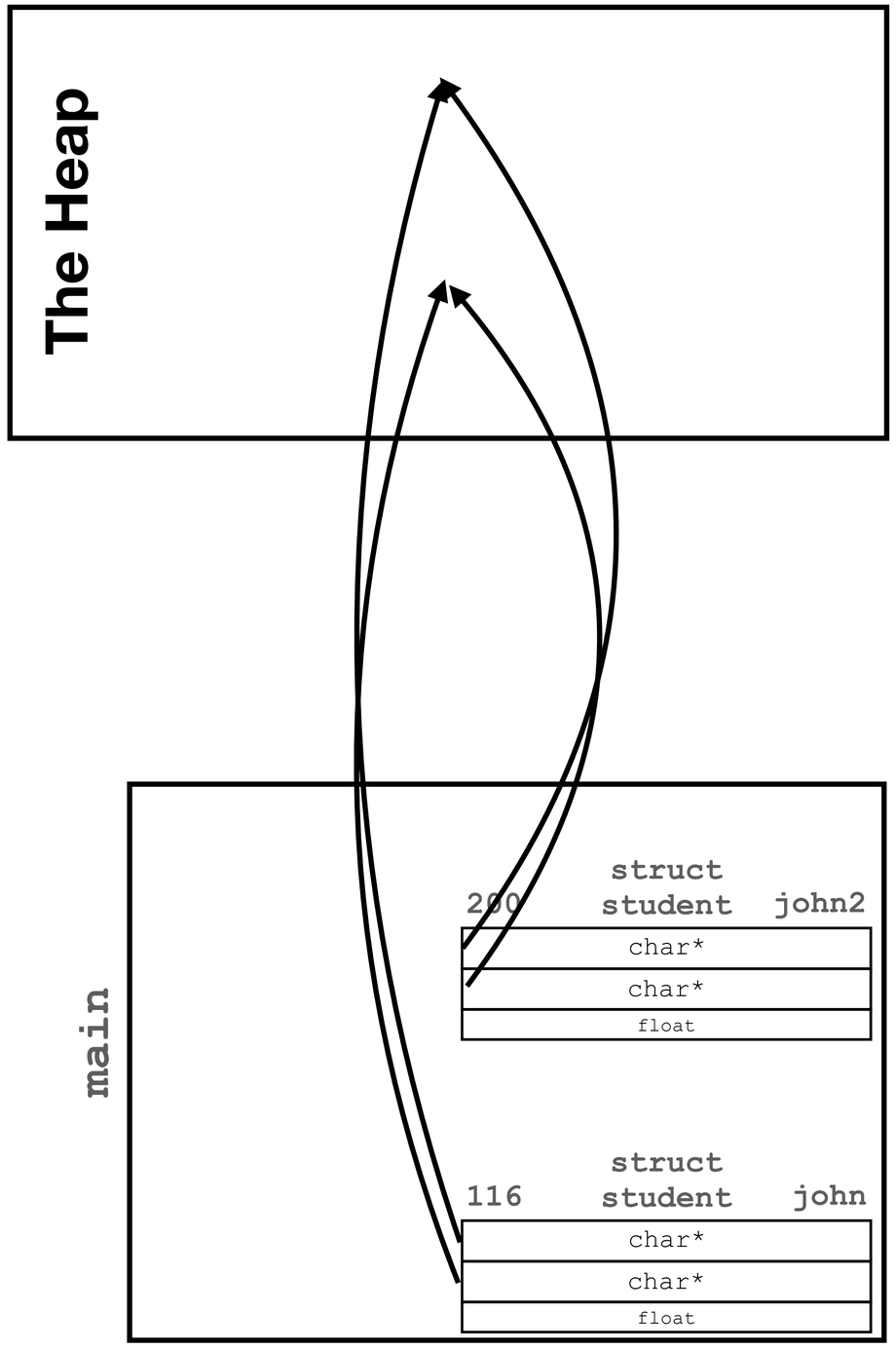

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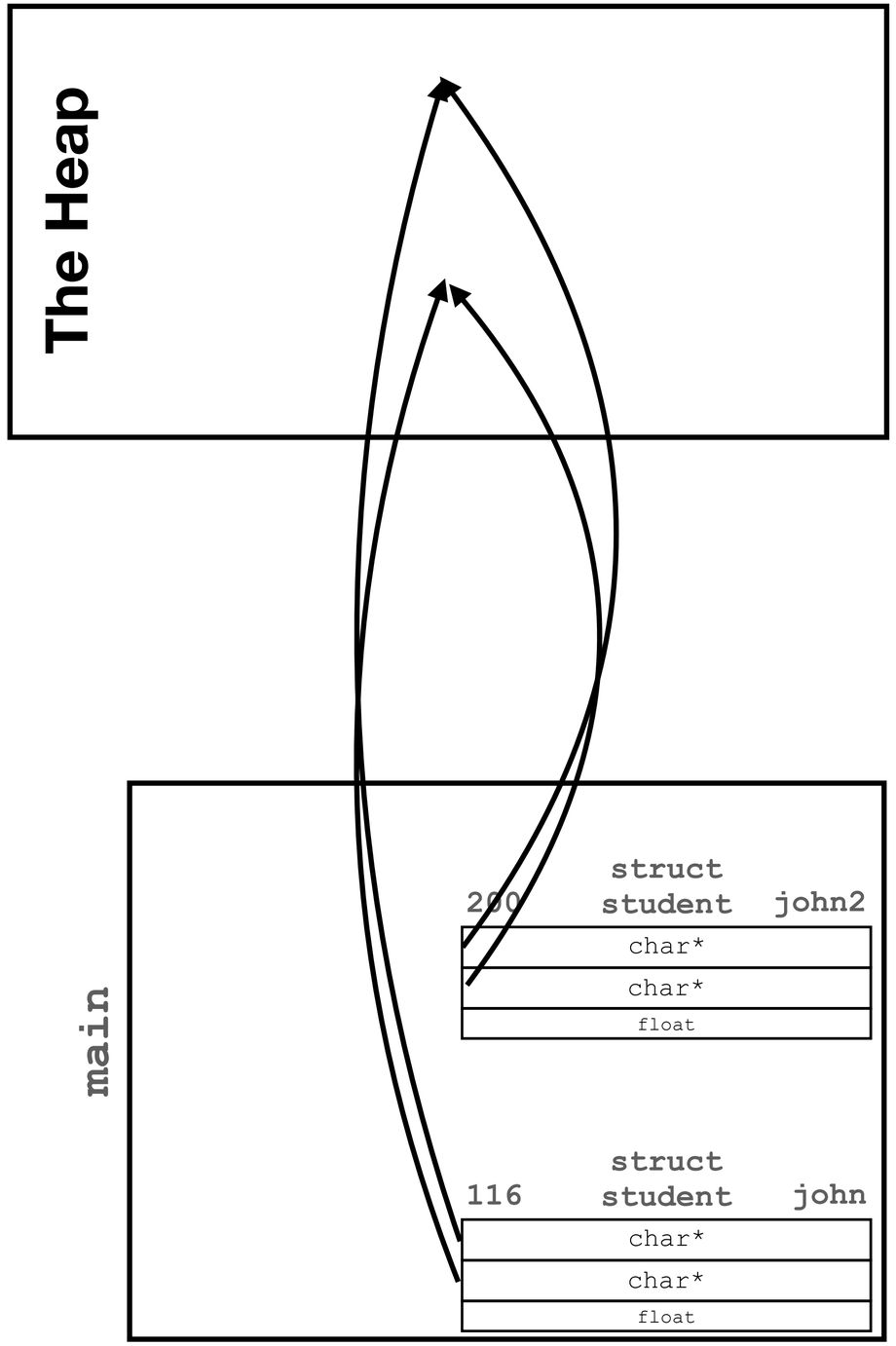
```



Pointer Hazards

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        free(john2.first_name);
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}
```
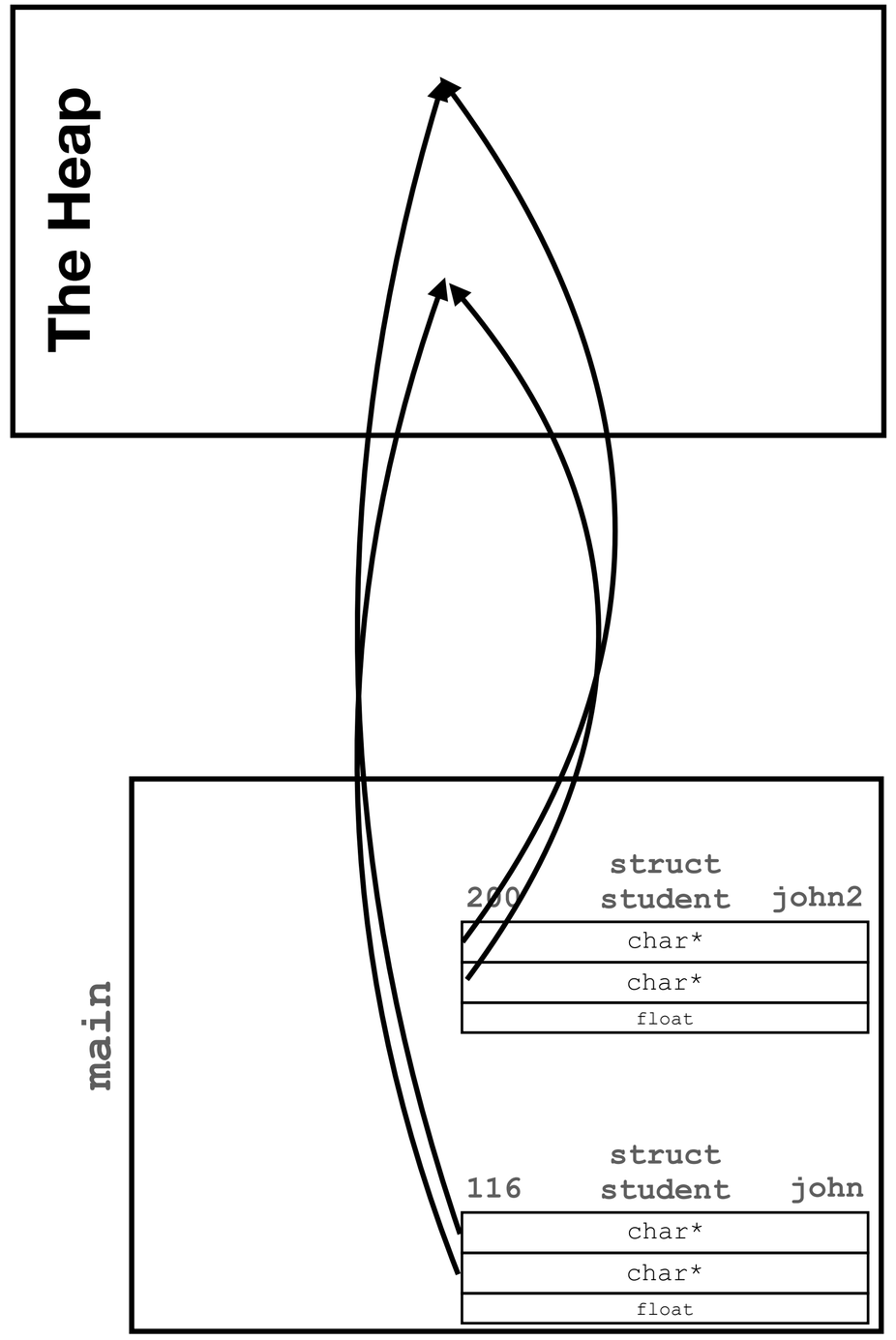

Oh, no



Pointer Hazards

Defense

- One `malloc`, one `free` (per pointer *values*), and do not use the pointer after `free`
- When you see a pointer, ask:
  - Where does it point to?
  - If on the stack, what is the function that will destroy it?
  - If on the heap, who is in charge of freeing it?
    - When is the last time this data is needed?
    - Who else might have this pointer?
- When in doubt, `valgrind`

Review

Review

- Pointers: Syntax and meanings

Review

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- Stack: Frames, pass-by-value, pass-by-reference

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The Stack

The Heap

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- Pointers: Syntax and meanings
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- Building structures in the heap via pointers

The Stack

The Heap

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- Stack: Frames, pass-by-value, pass-by-reference
- Heap: `malloc` and `free`
- Building structures in the heap via pointers
  - Data structures!

The Stack

The Heap

Review

- Pointers: Syntax and meanings
- Stack: Frames, pass-by-value, pass-by-reference
- Heap: `malloc` and `free`
- Building structures in the heap via pointers
  - Data structures!
  - This week and next week

The Stack

The Heap

List

What is a list?

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- An ordered collection of elements is a list: [🍏, 🍎, 🍐, 🍊, 🍋]

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  - Ordered: 0th, 1st, 2nd, 3rd, ... (does not mean sorted)
- Dynamic size: can grow/shrink as needed
- What operations does a list support?

List Operations

List Operations

- `append`

List Operations

- `append`
- `prepend`

List Operations

- `append`
- `prepend`
- `len`

List Operations

- `append`
- `prepend`
- `len`
- `insert_at`

List Operations

- `append`
- `prepend`
- `len`
- `insert_at`
- `remove_at`

List Operations

- `append`
- `prepend`
- `len`
- `insert_at`
- `remove_at`
- `is_empty?`

List Operations

- `append`
- `prepend`
- `len`
- `insert_at`
- `remove_at`
- `is_empty?`
- `at(i)`

Array as a List

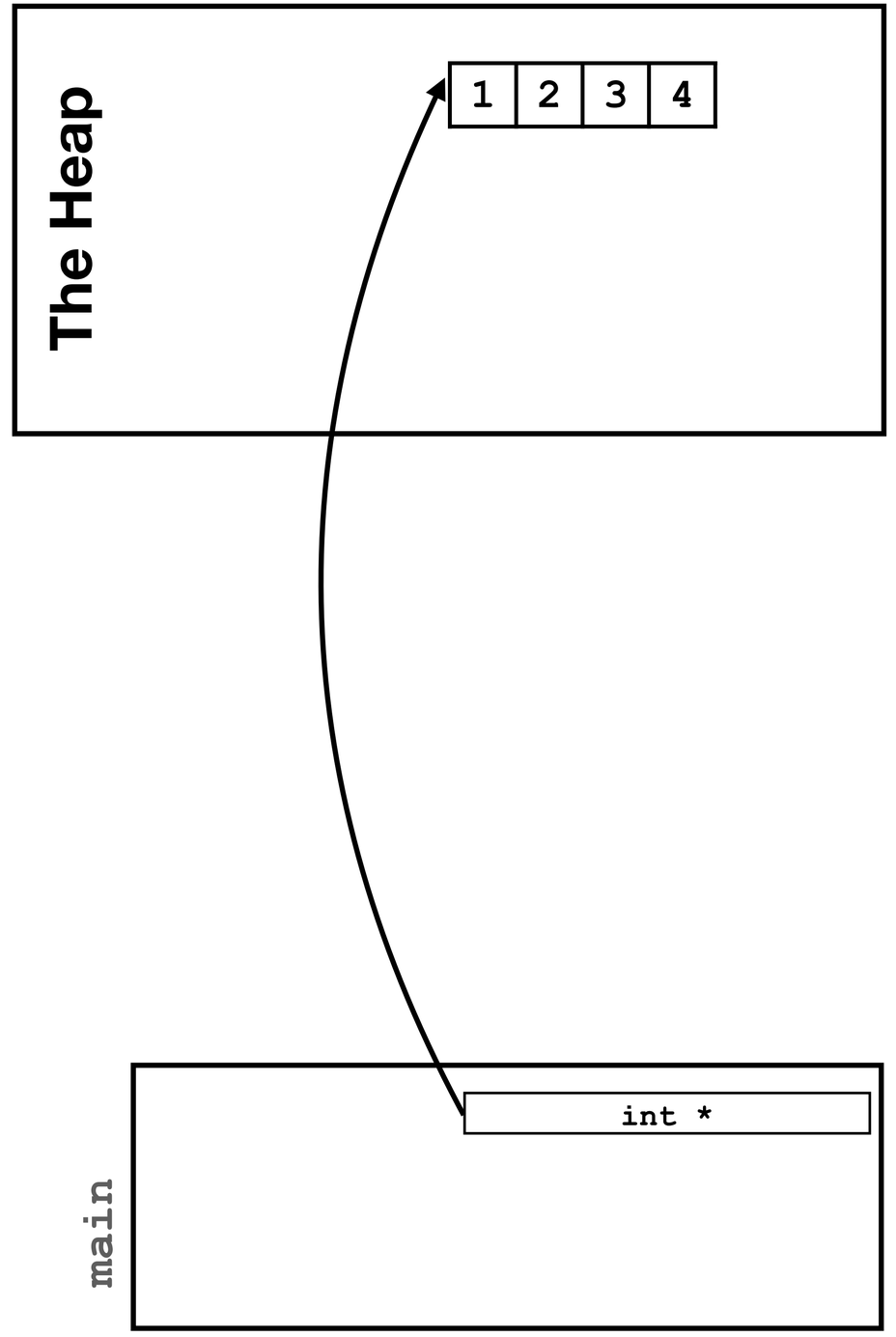
Array

- Can we just use an array to implement a list?
- Almost! Arrays have a fixed size, but ...
  - If it's on the stack, no luck here
  - If it's on the heap, we may have some ways around this

Array

Growing an array

- Create a bigger array.



Array

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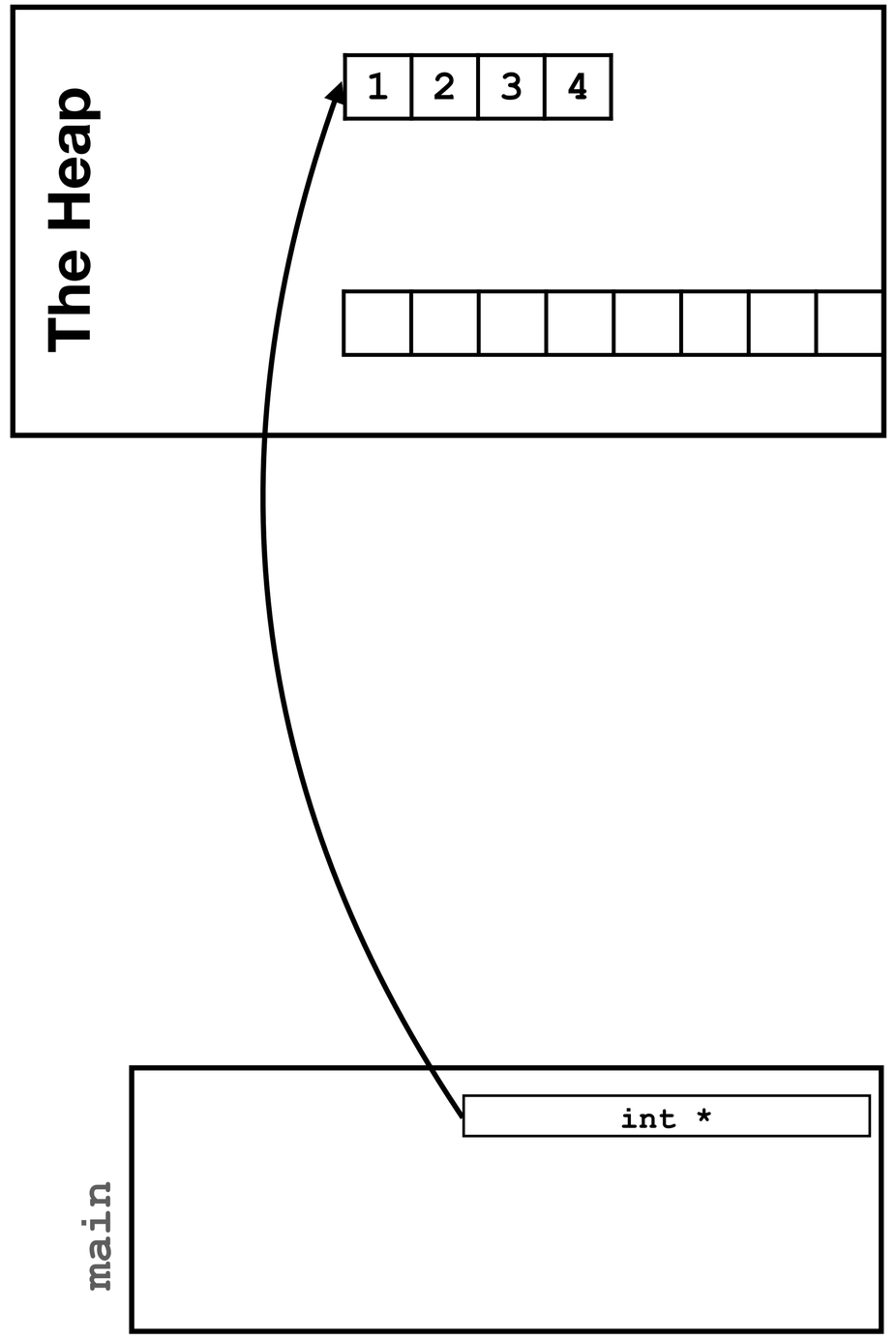

Array

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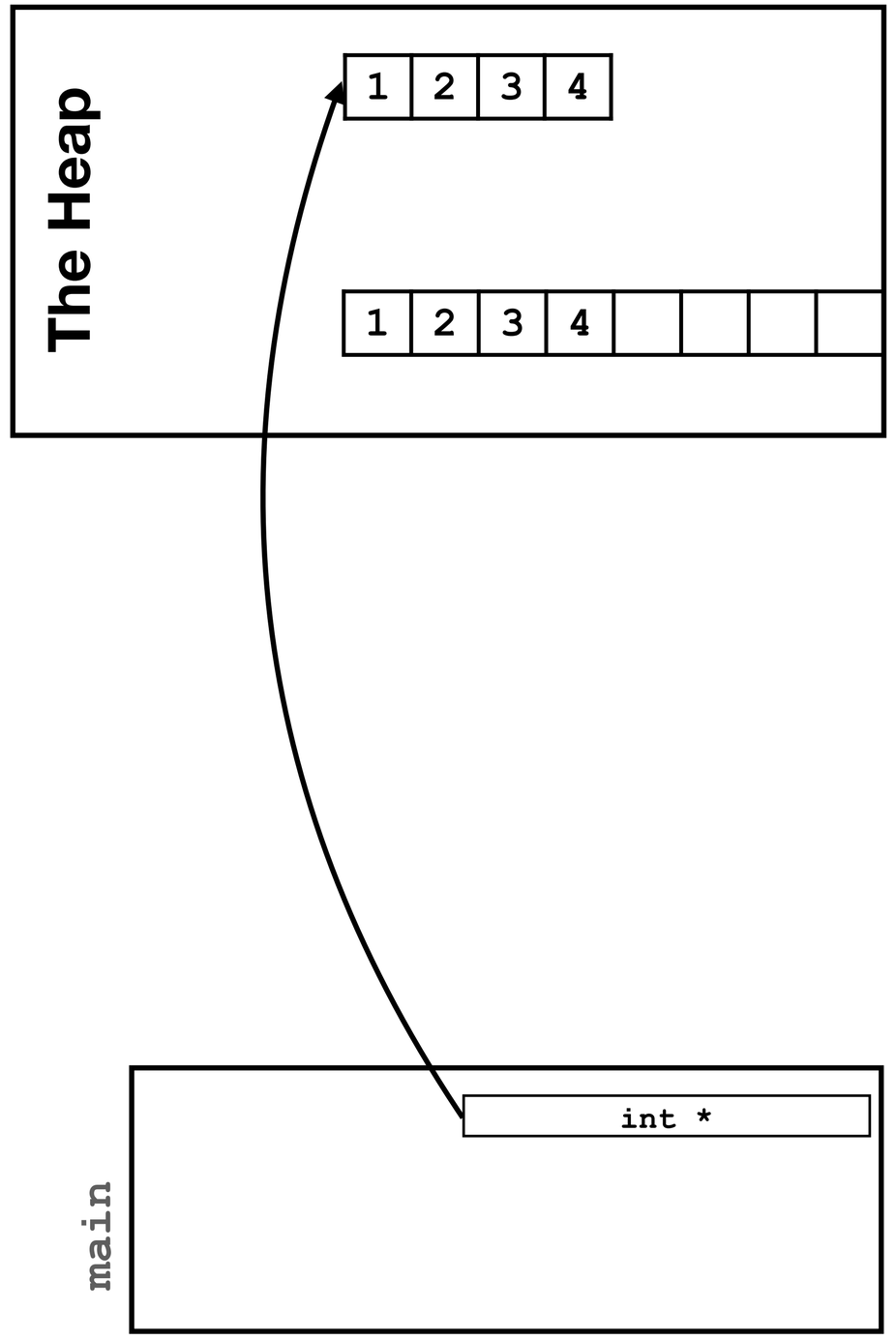
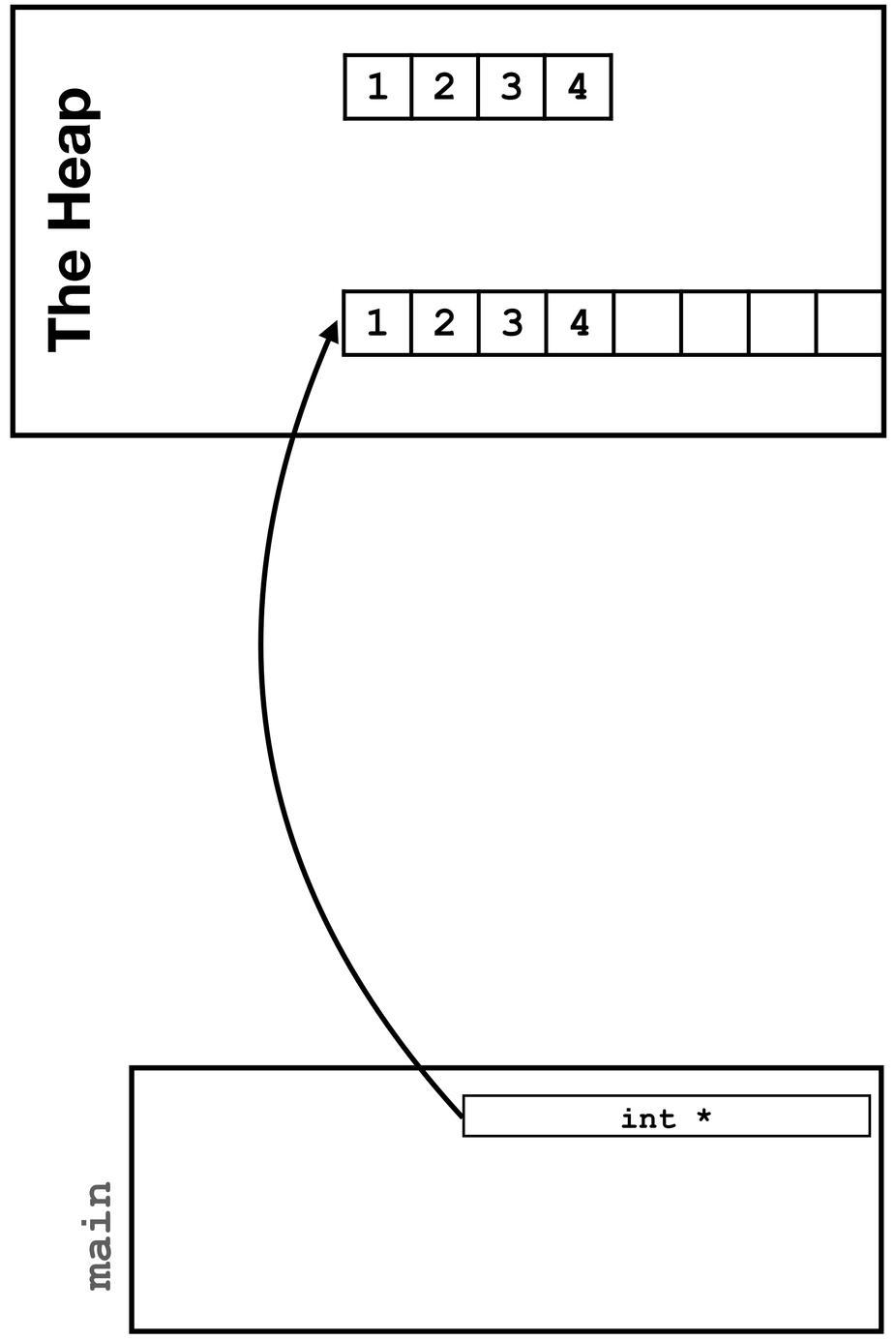
- Create a bigger array.
- Copy the elements into the new array



Array

Growing an array

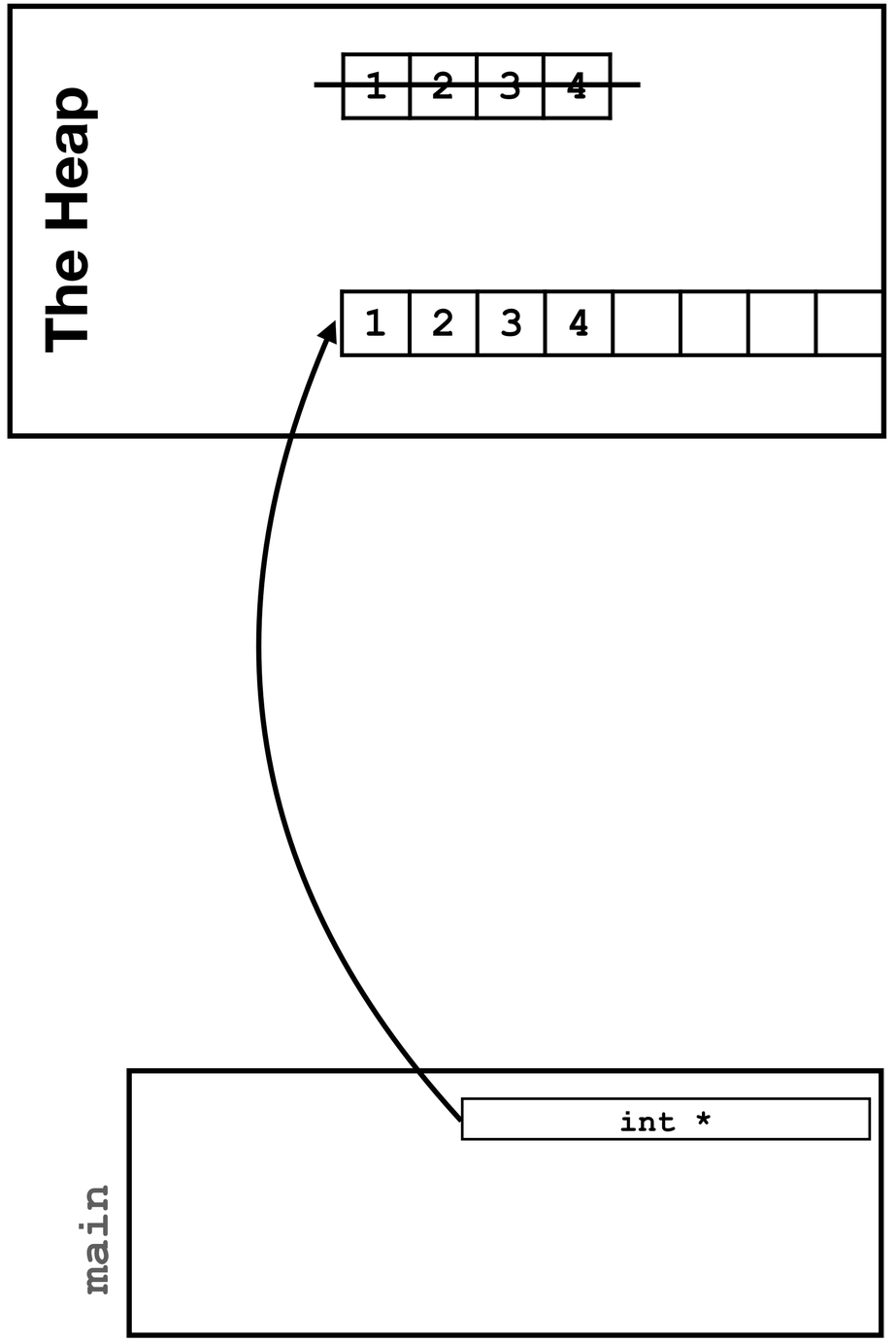
- Create a bigger array.
- Copy the elements into the new array
- Reassign the pointer to point to the new array



Array

Growing an array

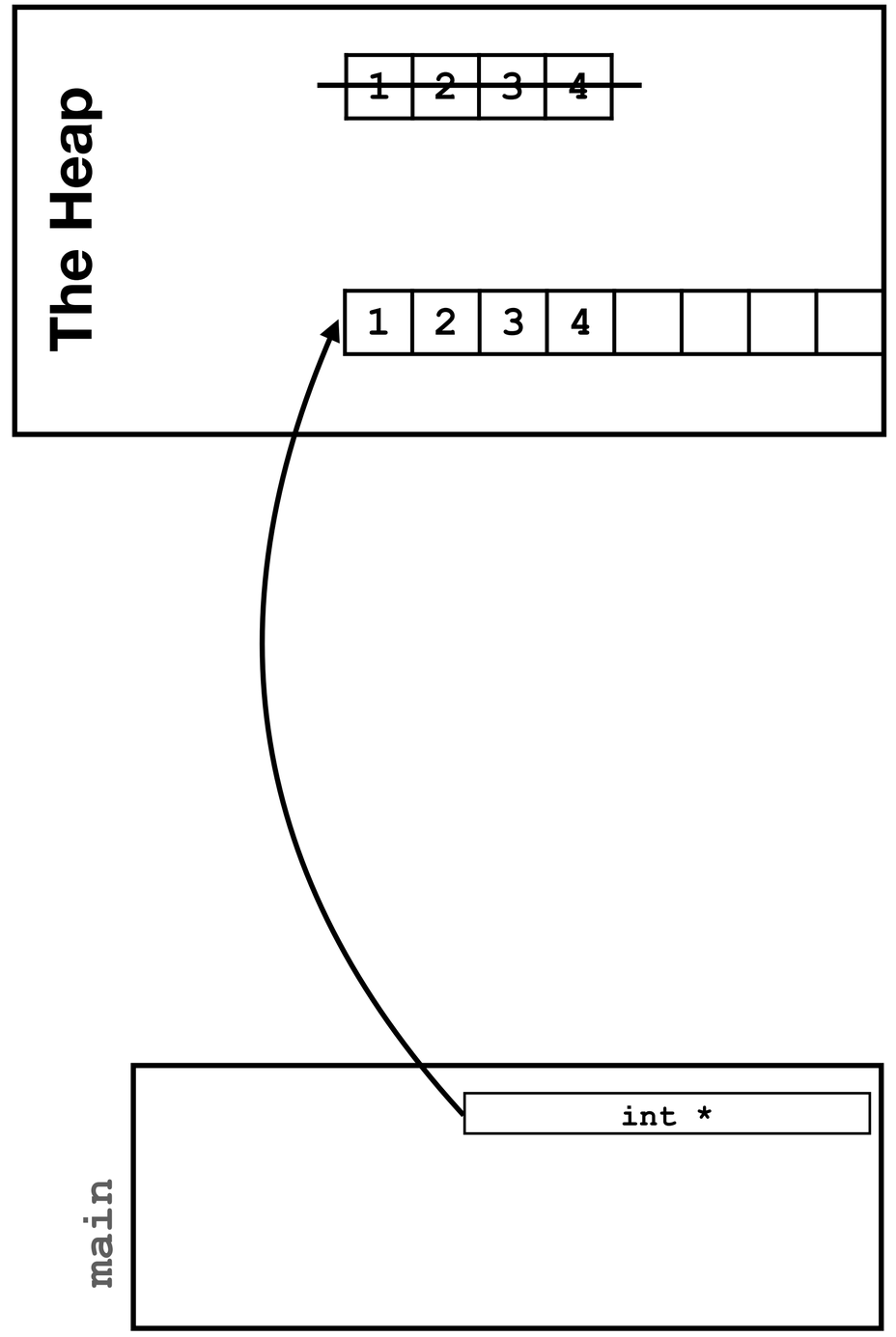
- Create a bigger array.
- Copy the elements into the new array
- Reassign the pointer to point to the new array
- Free the old array



Array

Growing an array

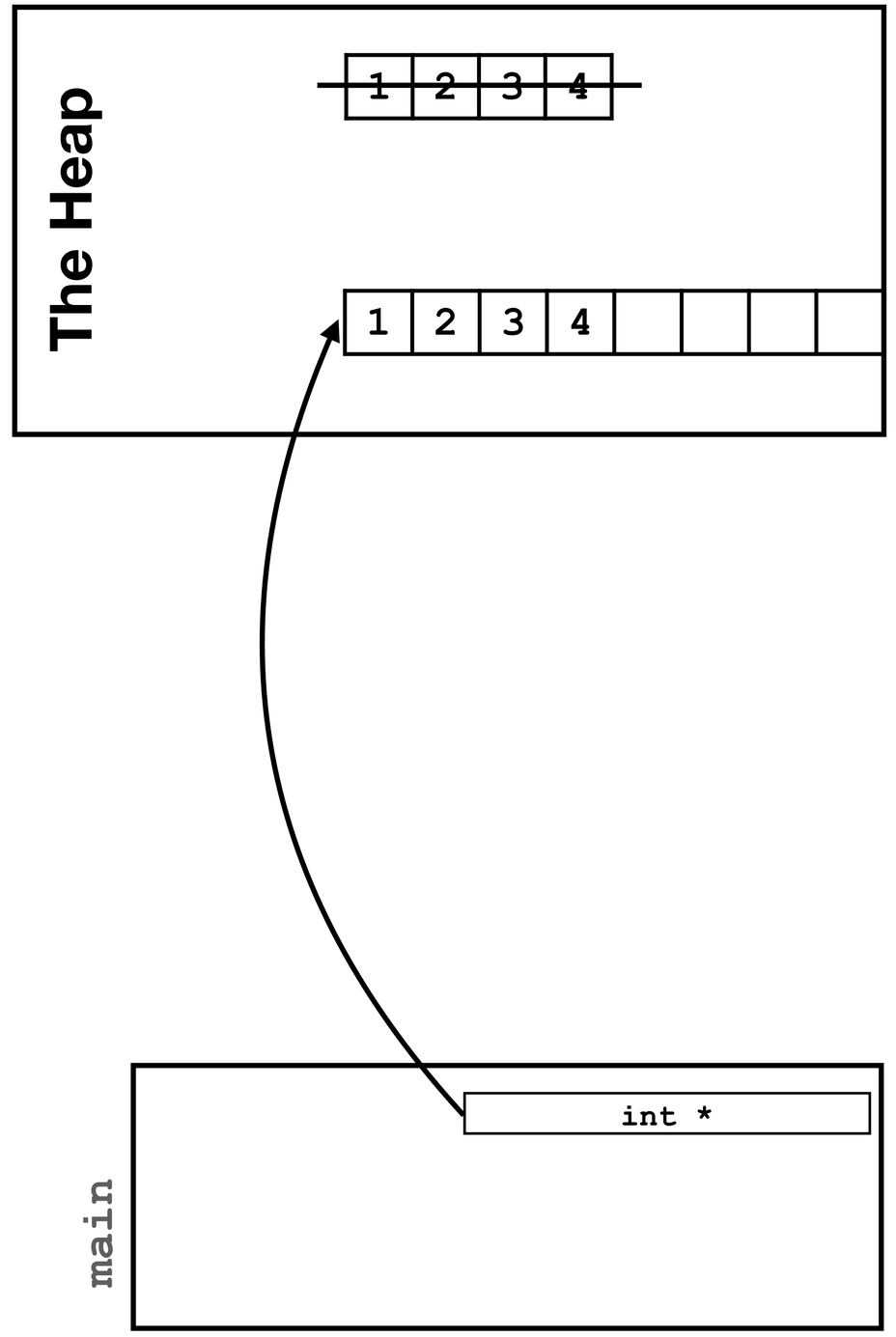
- Pointers serve as an indirection.
  - We aren't changing the size of the array; we are changing which array the pointers point to.
  - By changing the address of the pointer, it seems to the user that we have changed the size of the array.
- We create and delete memory however we want thanks to the heap.



Array

Abstractions

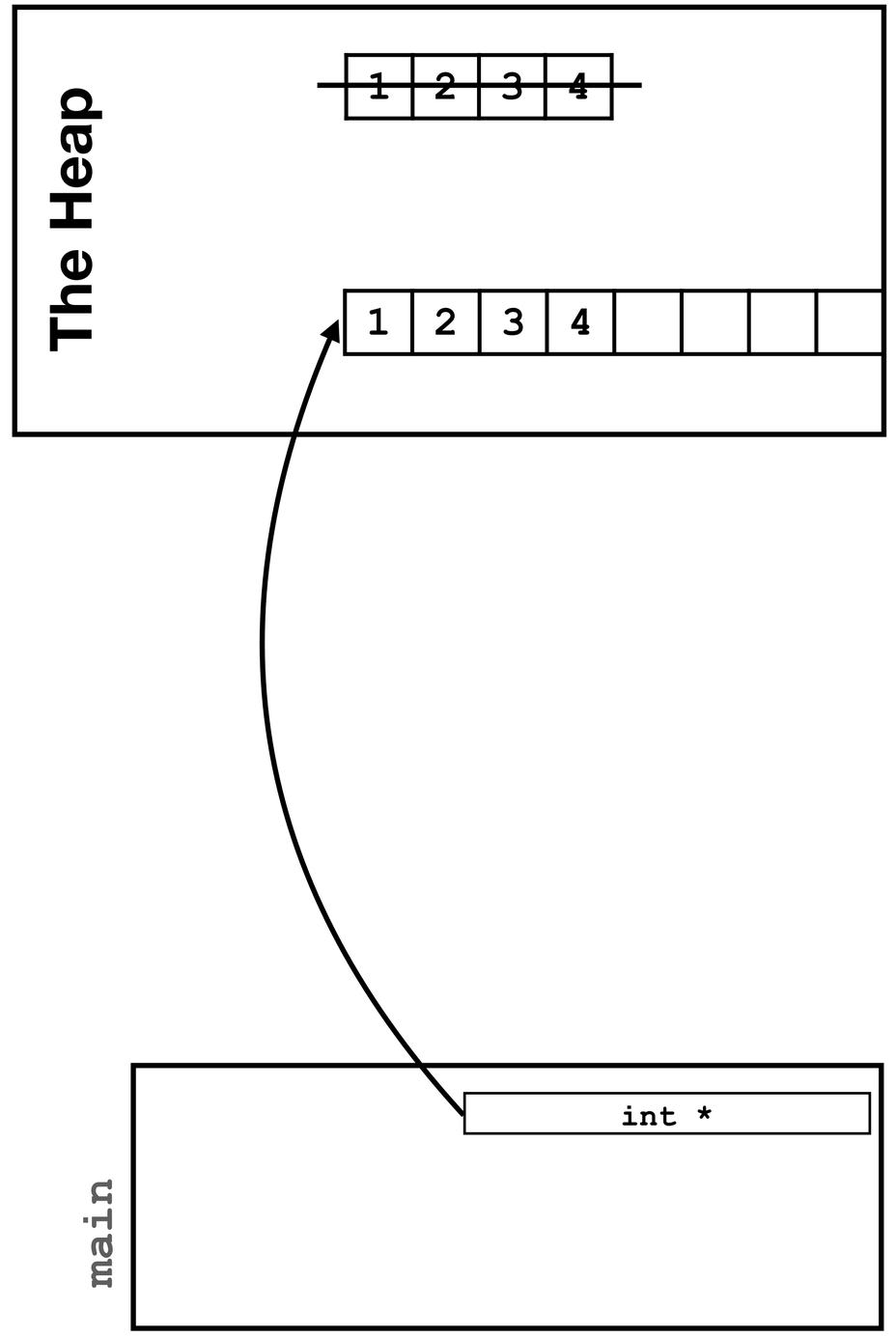
- Doing this repeatedly results in very messy code.
- Separation of concerns:
  - We wrap all of this up behind some interface
  - The user doesn't have to worry about any of that -- just adding and removing elements.



Array

Demo

- Let's write this together!



Array

Header File

Array

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- When writing a library or module you need to write a **header** file that contains the function signatures and typ definitions needed

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Array

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- `#include <stdio.h>` for standard library headers

Array

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- Python `import` = C `#include`
- `#include <stdio.h>` for standard library headers
- `#include` "my_library.h" for project specific header filed

Array

Header File

- When writing a library or module you need to write a **header** file that contains the function signatures and typ definitions needed
- Python `import` = C `#include`
- `#include <stdio.h>` for standard library headers
- `#include` "my_library.h" for project specific header filed
- If a header file is included multiple times then functions will have multiple signatures

Array

ArrayList.h

```
#include <stdlib.h>
#include <stdint.h>

typedef struct ArrayList_ {
    int *array;
    size_t length;
    size_t size;
} ArrayList;

ArrayList create(void);
void destroy(ArrayList array);
size_t length(const ArrayList array);
size_t size(const ArrayList array);
void append(ArrayList *array, const int elem);
void prepend(ArrayList *array, const int elem);
void insert_at(ArrayList *array, const int elem, const size_t i);
int remove_at(ArrayList *array, const size_t i);
int is_empty(const ArrayList array);
int at(const ArrayList array, const size_t i);
```

Array

ArrayList_example.c

```
#include <stdlib.h>

#include "ArrayList.h"
#include "ArrayList.h"

int main(void) {
    return EXIT_SUCCESS;
}
```

Array

ArrayList_example.c

```
clang -Wall -Wextra -pedantic -std=c11 -o ArrayList_example ArrayList.c ArrayList_example.c

In file included from ArrayList_example.c:4:
./ArrayList.h:23:16: error: redefinition of 'ArrayList_'
typedef struct ArrayList_ {
               ^
ArrayList_example.c:3:10: note: './ArrayList.h' included multiple times, additional include site here
#include "ArrayList.h"
         ^
ArrayList_example.c:4:10: note: './ArrayList.h' included multiple times, additional include site here
#include "ArrayList.h"
         ^
./ArrayList.h:23:16: note: unguarded header; consider using #ifdef guards or #pragma once
typedef struct ArrayList_ {
               ^
In file included from ArrayList_example.c:4:
./ArrayList.h:27:3: error: typedef redefinition with different types ('struct (unnamed struct at ./ArrayList.h:23:16)' vs 'struct
ArrayList_')
} ArrayList;
  ^
ArrayList_example.c:3:10: note: './ArrayList.h' included multiple times, additional include site here
#include "ArrayList.h"
         ^
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#include "ArrayList.h"
         ^
./ArrayList.h:27:3: note: unguarded header; consider using #ifdef guards or #pragma once
} ArrayList;
  ^
2 errors generated.
```

Array

ArrayList.h

`#pragma once` Preprocessor command "include this file only once"

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#include <stdlib.h>
#include <stdint.h>

typedef struct ArrayList_ {
    int *array;
    size_t length;
    size_t size;
} ArrayList;

ArrayList create(void);
void destroy(ArrayList array);
size_t length(const ArrayList array);
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void append(ArrayList *array, const int elem);
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Array

ArrayList.c - create

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- When declaring a new `ArrayList`, `array`, `length` and `size` will be allocated in the stack

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- But `*array` will not be any valid address → need to `malloc`

Array

ArrayList.c - create

- When declaring a new `ArrayList`, `array`, `length` and `size` will be allocated in the stack
- But `*array` will not be any valid address → need to `malloc`

```
// Create a new ArrayList
ArrayList create(void) {
    ArrayList array;
    array.array = malloc(4 * sizeof(*array.array));
    if (!array.array) {
        perror("Unable to allocate memory");
        abort();
    }
    array.length = 0;
    array.size = 4;

    return array;
}
```

Array

ArrayList.c - destroy

Array

ArrayList.c - destroy

- For every `malloc`, there needs to be a `free`

Array

ArrayList.c - destroy

- For every `malloc`, there needs to be a `free`

```
// Destroy an ArrayList
void destroy(ArrayList array) {
    free(array.array);
}
```

Array

ArrayList.c - length and size

Array

ArrayList.c - length and size

- Users should not be directly interacting with stuct members

Array

ArrayList.c - length and size

- Users should not be directly interacting with stuct members
- Instead we use **accessors**

Array

ArrayList.c - length and size

- Users should not be directly interacting with stuct members
- Instead we use **accessors**

```
// Takes in an ArrayList and returns the number of elements
size_t length(const ArrayList array) {
    return array.length;
}

// Takes in an ArrayList and returns its maximum size
size_t size(const ArrayList array) {
    return array.size;
}
```

Array

ArrayList.c - insert_at

Array

ArrayList.c - insert_at

```
// Inserts elem at array[i] = v
// insert_at(&array, v, i)
void insert_at(ArrayList *array, const int elem, const size_t i) {
    // If position is greater than length, show error
    if (i > array->length) {
        fprintf(stderr, "Attempting to insert at position %lu of an ArrayList of length %lu", i, array->length);
        abort();
    }

    // Do I need to reallocate
    if (array->length == array->size) {
        array->array = realloc(array->array, 2 * array->size * sizeof(*array->array));
        if (!array->array) {
            perror("Unable to allocate memory");
            abort();
        }
        array->size = 2 * array->size;
    }

    // Copy over all following elements
    for (size_t j = array->length; j > i; j--) {
        array->array[j] = array->array[j - 1];
    }

    // Assign element
    array->array[i] = elem;
    array->length++;
}
```

Array

ArrayList.c - append and prepend

Array

ArrayList.c - append and prepend

- We can use `insert_at` to implement `append` and `prepend`

Array

ArrayList.c - append and prepend

- We can use `insert_at` to implement `append` and `prepend`

```
void append(ArrayList *array, const int elem) {
    insert_at(array, elem, array->length);
}

void prepend(ArrayList *array, const int elem) {
    insert_at(array, elem, 0);
}
```