Introduction to Programming (C/C++)

03: C Memory

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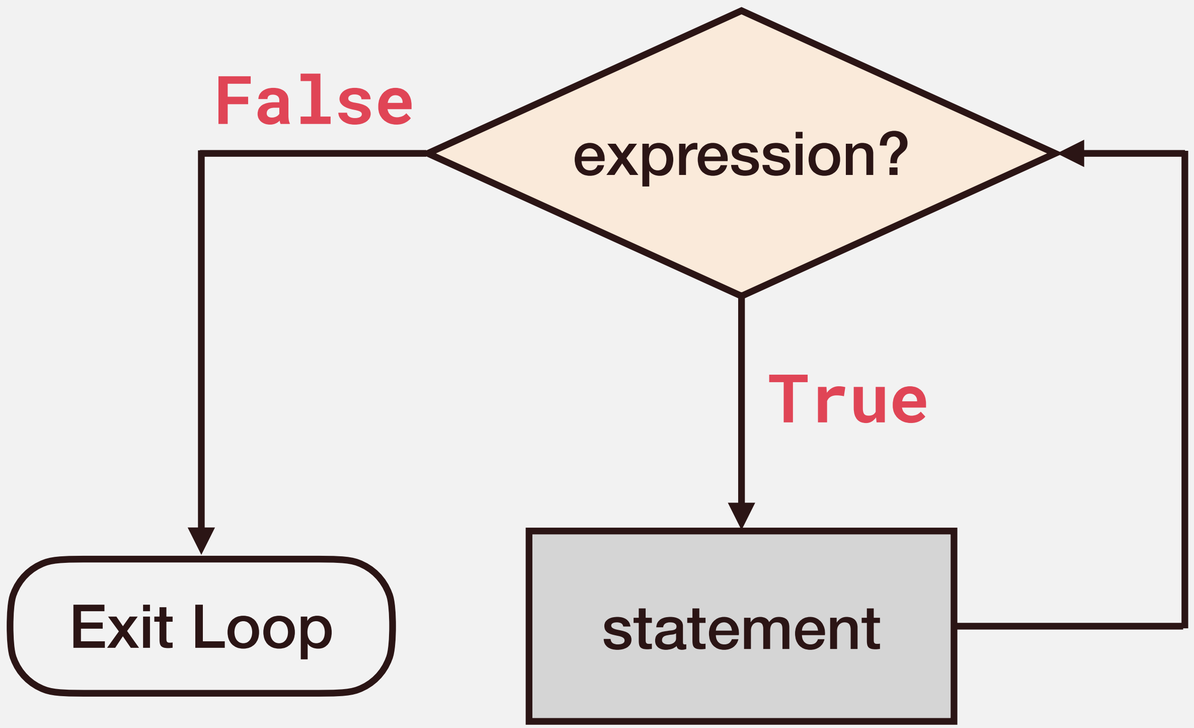
Loops

```
while (expression)
   statement
```



Task: Given a positive integer n user, print out “#” n times

```
int i = 0;
```

Task: Given a positive integer n user, print out “#” n times

```
int i = 0;
while () {
  printf(“#”);
}
```

Task: Given a positive integer n user, print out “#” n times

```
int i = 0;
while (1) {
  printf(“#”);
}
```

Task: Given a positive integer n user, print out “#” n times

```
int i = 0;
while (i <= n) {
  printf(“#”);
}
```

Task: Given a positive integer n user, print out “#” n times

```
int i = 0;
while (i <= n) {
  printf(“#”);
  i++;
}
```

Task: Given a positive integer n user, print out “#” n times

```
int i = 0;
while (i < n) {
  printf(“#”);
  i++;
}
```

Task: Given a positive integer n user, print out “#” n times

```
int i = 0;
while (i < n) { // easy to have off-by-one error here
  printf(“#”);
  i++;
}
```

Task: Given a positive integer n user, print out “#” n times

```
int i = 0;
while (i < n) { // easy to have off-by-one error here
  printf(“#”);
  i++; // infinite loop if this is forgotten
}
```

Be careful about infinite-loops and off-by-one errors

For Loops

```
for (i = 0; i < n; i++)
  statement
```

For Loops

```
for (i = 0; i < n; i++)
  statement
```

← Execute this statement **n** times

For Loops

```
for (e_init; e_test; e_modify)
  statement
```

For Loops

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for (e_init; e_test; e_modify)
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...
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For Loops

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for (e_init; e_test; e_modify)
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...

e_init;
```

For Loops

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for (e_init; e_test; e_modify)
  statement

...

e_init;
while (e_test) {
```

For Loops

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for (e_init; e_test; e_modify)
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...

e_init;
while (e_test) {
  statement
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e_init;
while (e_test) {
  statement
  e_modify
}
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Task: Given a positive integer n user, print out “#” n times

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while (i < n) {
  printf(“#”);
  i++;
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int i = 0;
while (i < n) {
  printf(“#”);
  i++;
}

for (i = 0; i < n; i++) {
  printf(“#”);
}
```

Exercise: print out a pyramid

n rows

```
   #
  # #
 # # #
# # # #
# # # # #
```

space

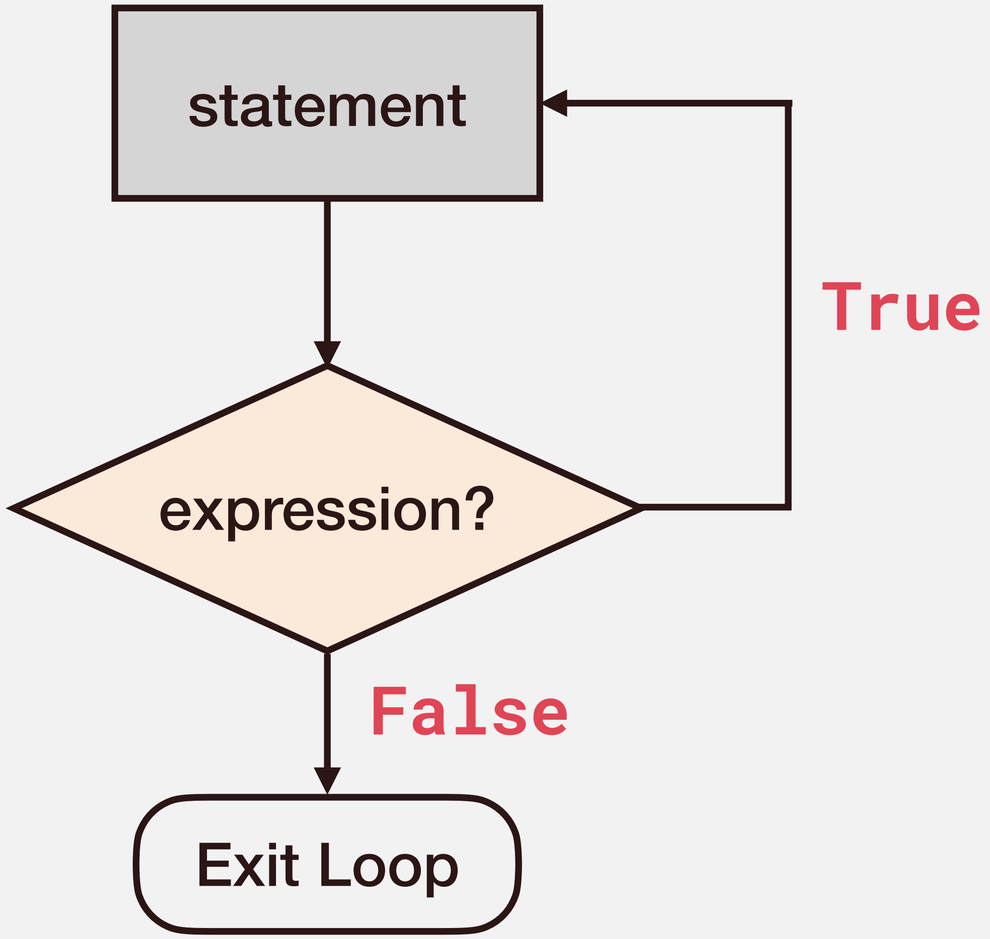
Exercise: print out a pyramid

n rows

```
,,,,#
,,,#,#
,,#,#,#
,#,#,#,#
#,#,#,#,#
```

Loops

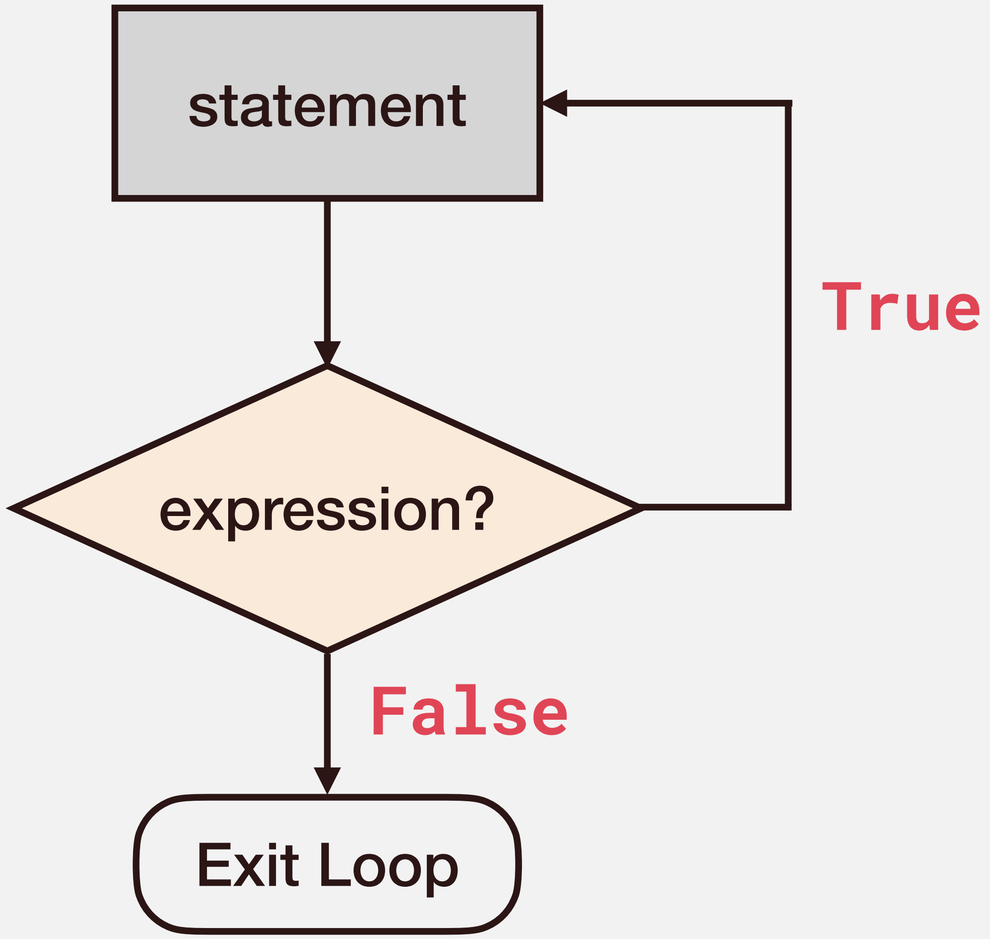
```
do
   statement
while (expression)
```



Loops

```
do
   statement
while (expression)
```

Less Used



Early-Exit

```
while (expression) {
   ...
   break;
   ...
}
...
```

Early-Exit

```
while (expression) {
   ...
   break;
   ...
}
...
```

Early-Exit

```
while (expression) {
  ...
  if (condition)
    break;
  ...
}
...
```

Early-Exit

```
for (e_init; e_test; e_modify) {
  ...
  if (condition)
    break;
  ...
}
...
```

Early-Exit

```
for (e_init; e_test; e_modify) {
  ...
  if (condition)
    break;
  ...
}
...
```

Used in **loop** and **switch** **only**

Early-Exit

```
int n = 0;
int sum = 0;
for (i = 0; i < 10; i++) {
  scanf("%d", &n);
  if (n < 0)
    break;
  sum += n;
}
```

Early-Exit

```
int n = 0;
int sum = 0;
for (i = 0; i < 10; i++) {
  scanf("%d", &n);
  if (n < 0)
    break;
  sum += n;
}
```

← **Exit** loop upon negative input

Next Iteration

```
while (expression) {
   ...
   continue;
   ...
}
```

Next Iteration

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   ...
   continue;
   ...
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```

Next Iteration

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  ...
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Next Iteration

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while (expression) {
  ...
  if (condition)
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}
```

Used in **loop only**

Next Iteration

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int n = 0;
int sum = 0;
for (i = 0; i < 10; i++) {
  scanf("%d", &n);
  if (n < 0)
    continue;
  sum += n;
}
```

Next Iteration

```
int n = 0;
int sum = 0;
for (i = 0; i < 10; i++) {
  scanf("%d", &n);
  if (n < 0)
    continue;
  sum += n;
}
```

Skip negative inputs

Control Flow Summary

- Execute with **conditions**
  - `if, else if, else`
  - `switch`
- **Loops**
  - `while, do-while, for`
- Interrupt loops
  - `break, continue`

Control Flow Summary

- Execute with **conditions**
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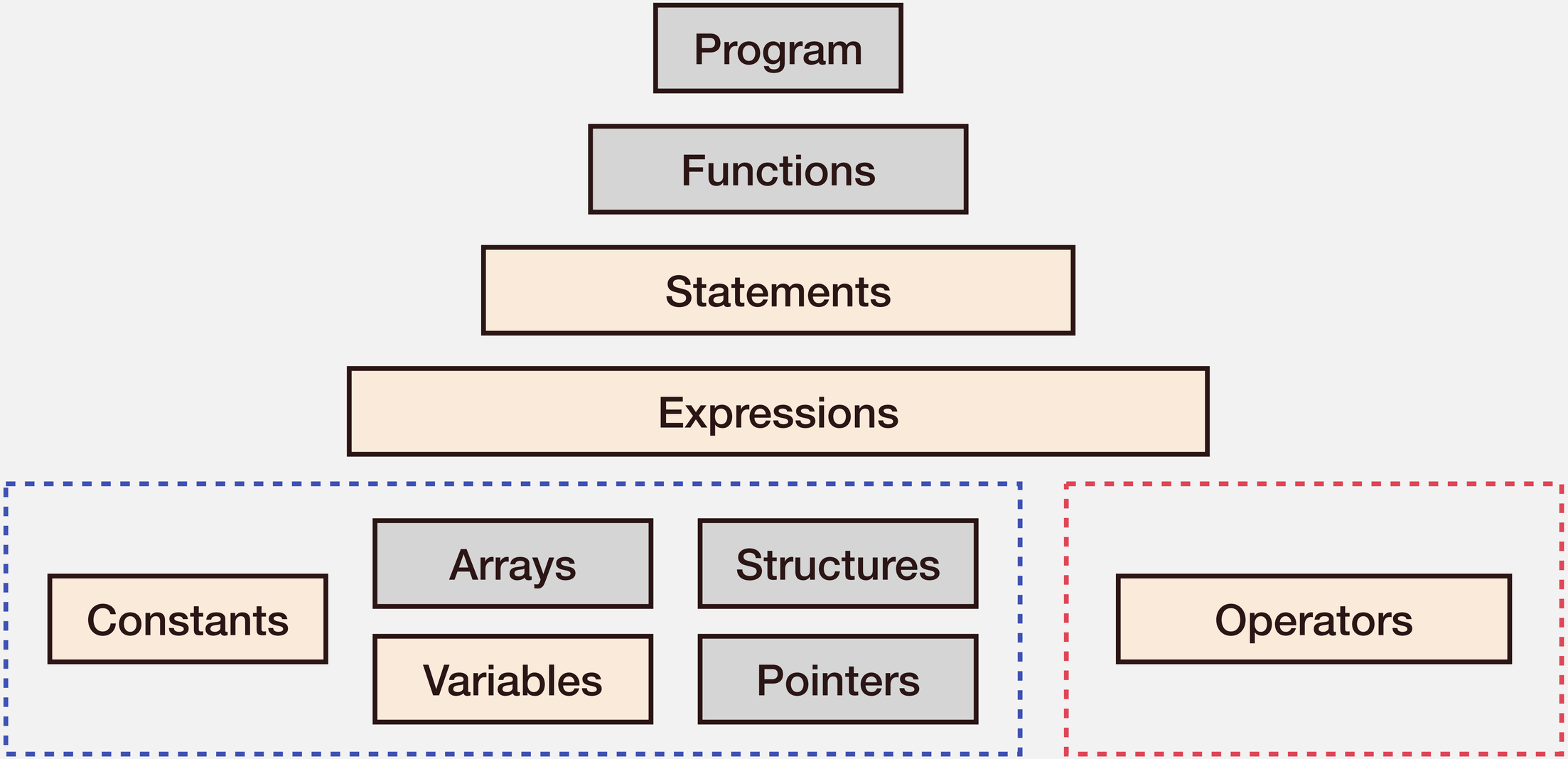
- Jump to arbitrary location
  - `goto`

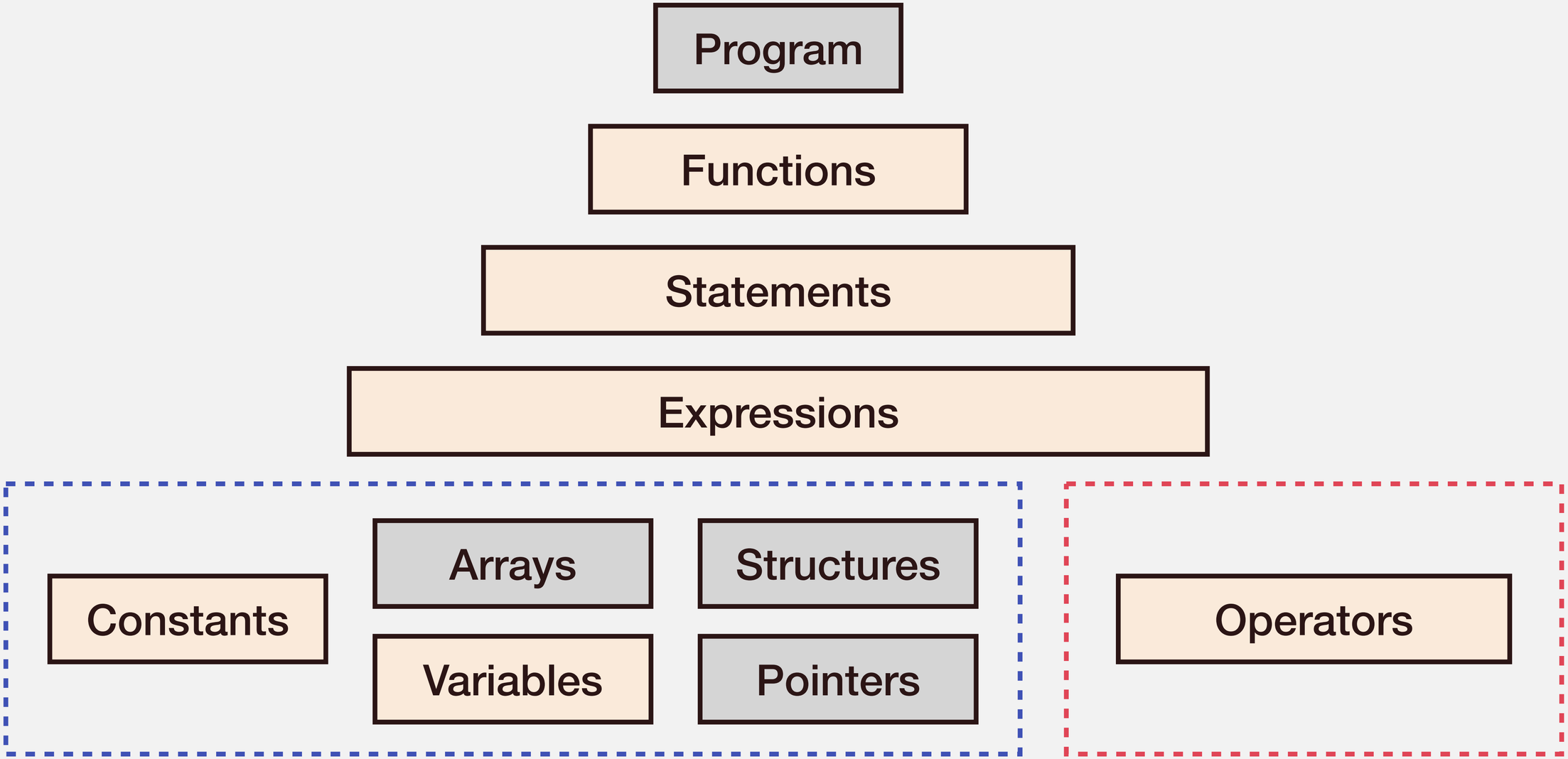
Control Flow Summary

- Execute with **conditions**
  - `if, else if, else`
  - `switch`
- **Loops**
  - `while, do-while, for`
- Interrupt loops
  - `break, continue`
- Jump to arbitrary location **Usually bad**
  - `goto`

Road Map


Program
Functions
Statements
Expressions
Constants
Arrays
Variables
Structures
Pointers
Operators

Road Map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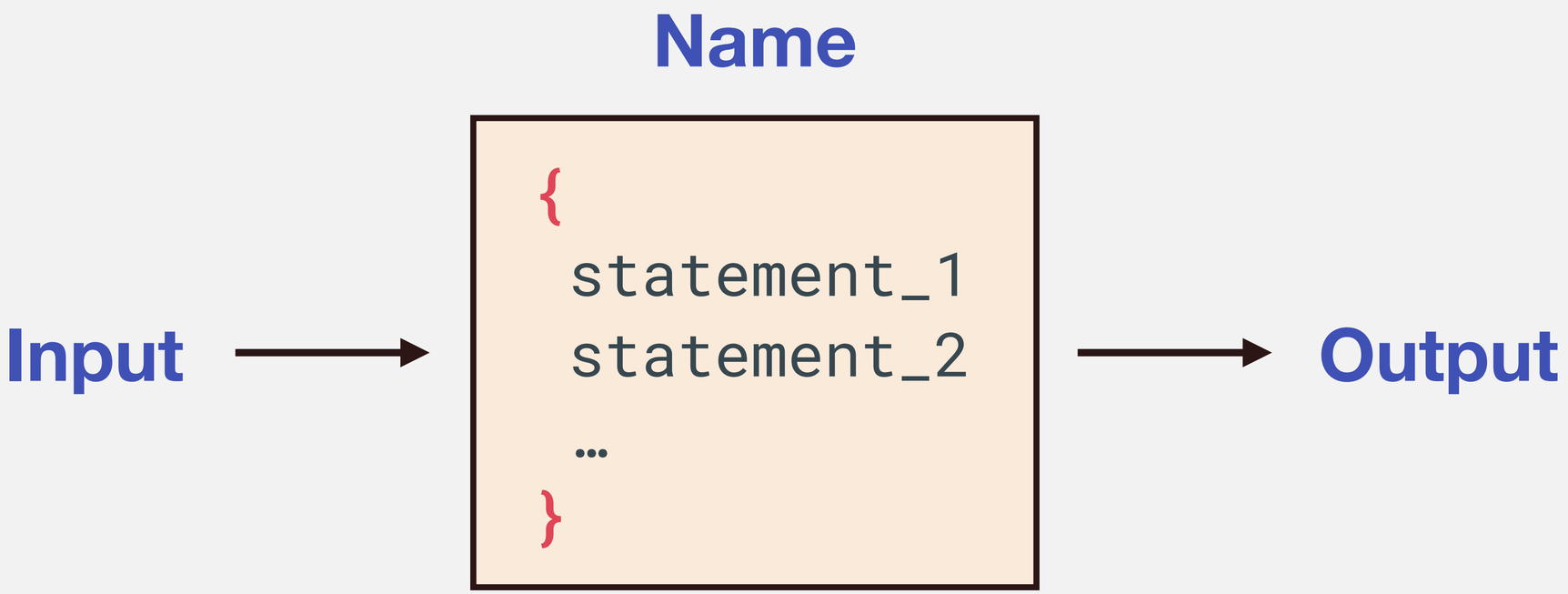
Functions

➜ A group of statements that together forms a **task**



Why Functions?

- Break large tasks into **smaller** and more **manageable** pieces

Why Functions?

- ➔ Break large tasks into **smaller** and more **manageable** pieces
- ➔ Facilitate **Reusing** code
  - Built on what others have done

Copy-paste code usually indicates bad design

Why Functions?

- ➔ Break large tasks into **smaller** and more **manageable** pieces
- ➔ Facilitate **Reusing** code
  - Built on what others have done
- ➔ Hide unnecessary details
  - More readable code
  - Easier to make changes

Function Definition

```
return_type func_name(arg declarations) {
  statements
}
```

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}

int max2(int x, int y) {
  return ((x > y) ? x : y);
}
```

Function Call

```
int max2(int x, int y) {
  return ((x > y) ? x : y);
}

int main() {
  int a, b;
  scanf("%d%d", &a, &b);
  int c = max2(a, b);
  ...
}
```

Function Call

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int max2(int x, int y) {
  return ((x > y) ? x : y);
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int main() {
  int a, b;
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$$f(x, y) = \ldots$$

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  ...
}
```

$$f(x, y) = \ldots$$

$$c = f(a, b)$$

Function Call

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}
```

$$f(x, y) = \ldots$$

$$x = a$$
$$y = b$$

$$c = f(a, b)$$

Function Call

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int max2(int x, int y) {
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  ...
}
```

$$f(x, y) = \ldots$$

$$\boxed{\begin{aligned} x &= a \\ y &= b \end{aligned}}$$

Pass-by-Value
(make a copy)

$$c = f(a, b)$$

Swap.c

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

int main() {
  int a = 1;
  int b = 2;
  swap(a, b);
}
```

Call Stack / Stack Memory

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

int main() {
  int a = 1;
  int b = 2;
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}
```
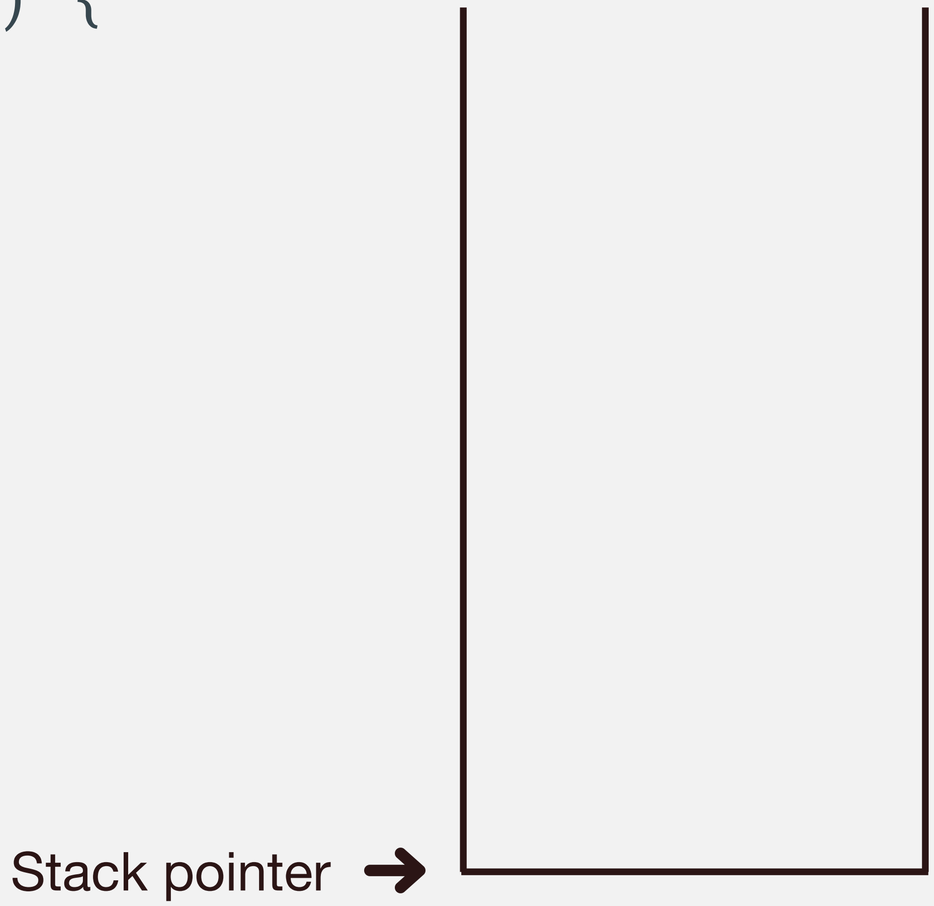
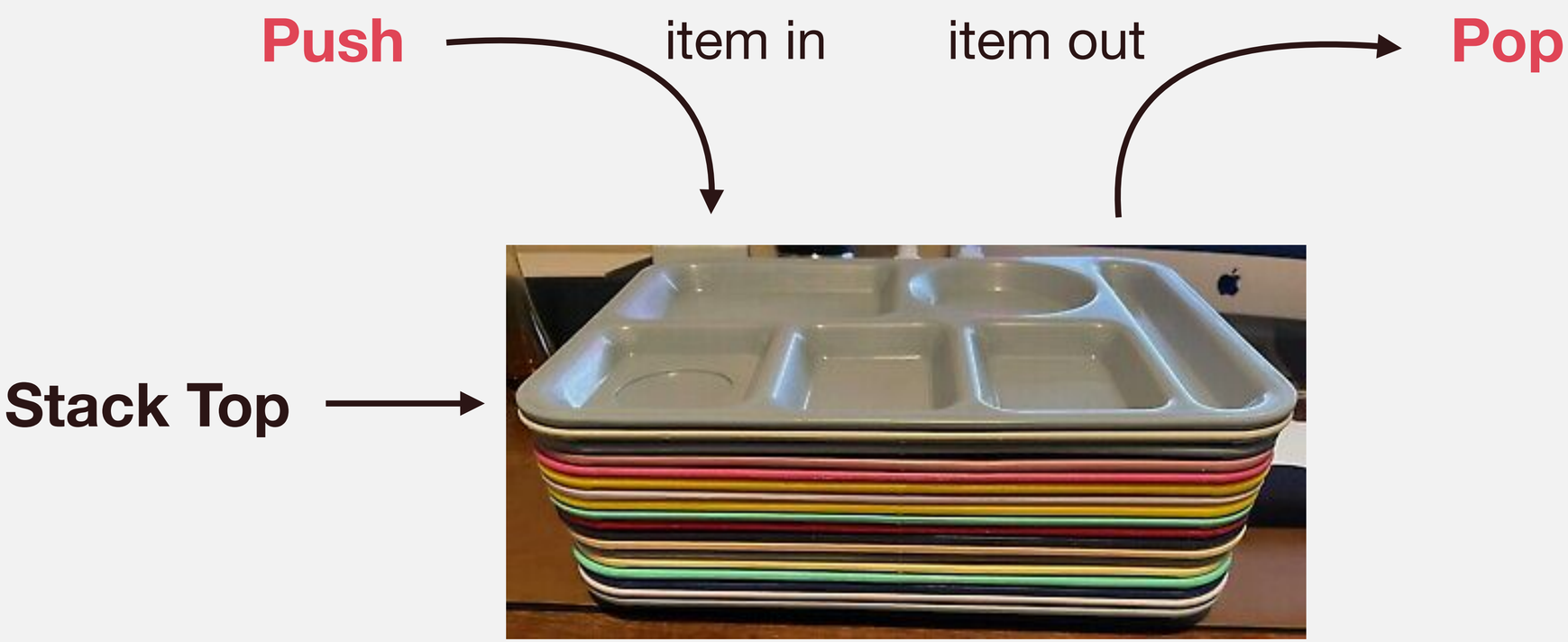



Stack

Stack

Stack Top

Stack



Stack

Push item in item out Pop

Stack Top

Last-In-First-Out (LIFO)

Call Stack

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

int main() {
➔ int a = 1;
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}
```

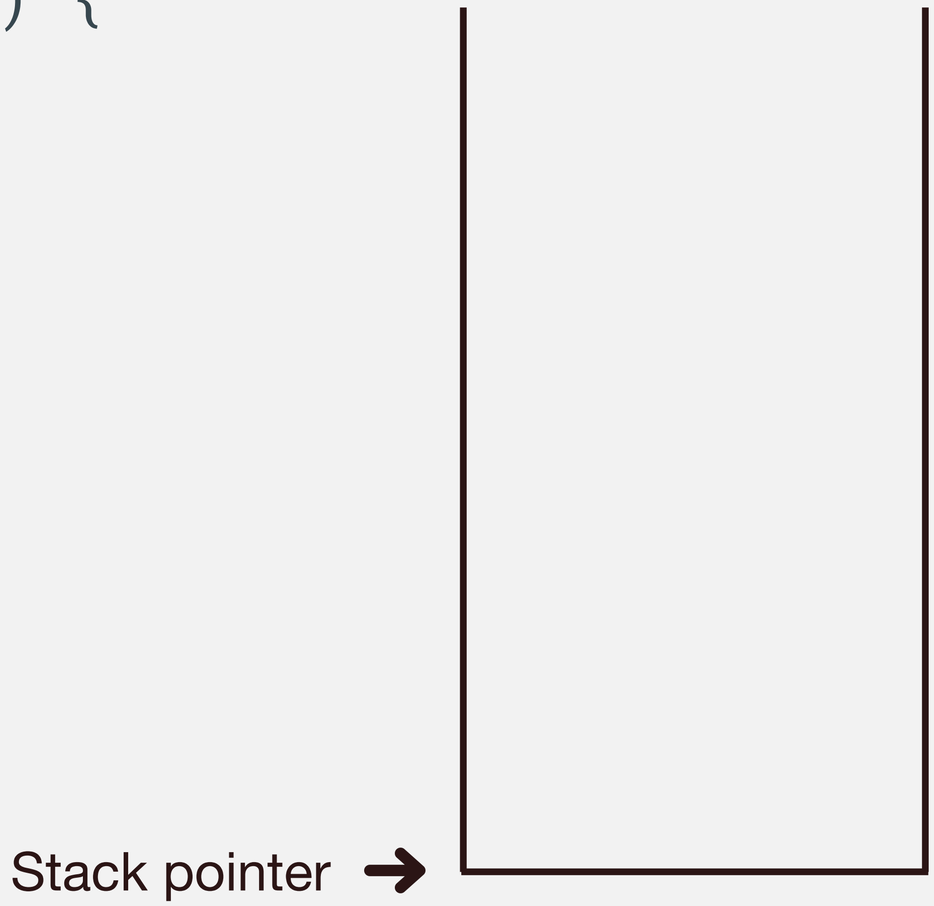

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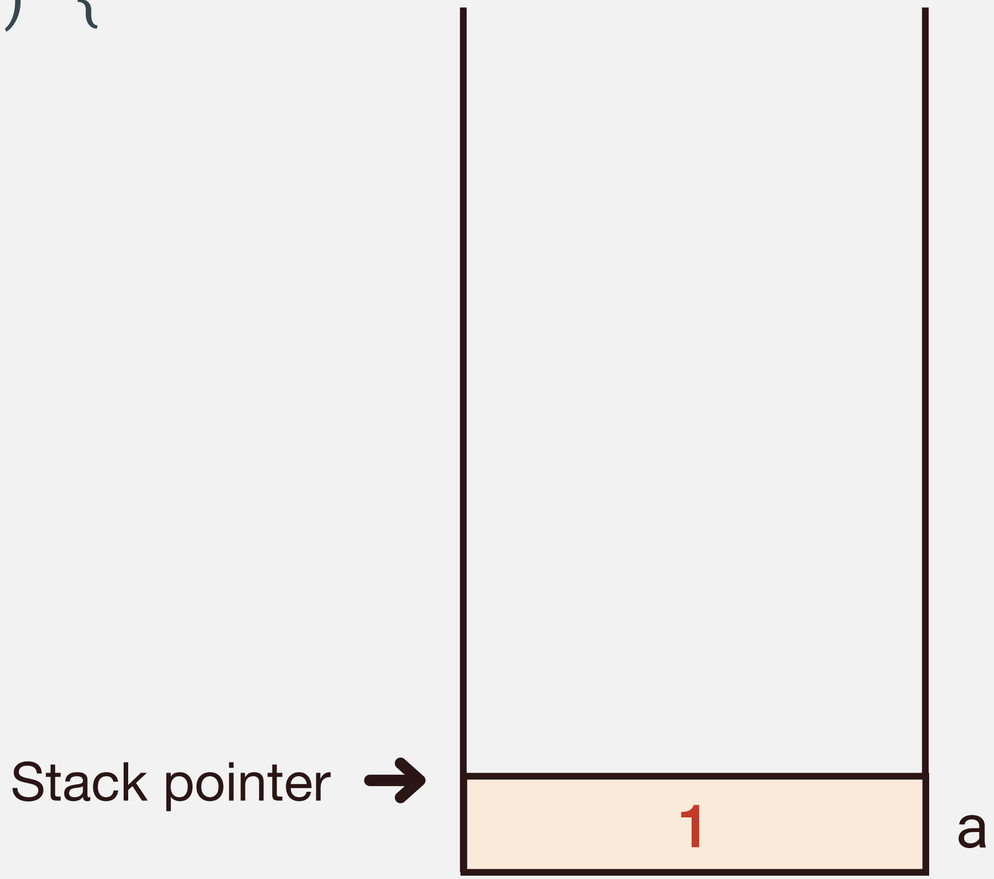

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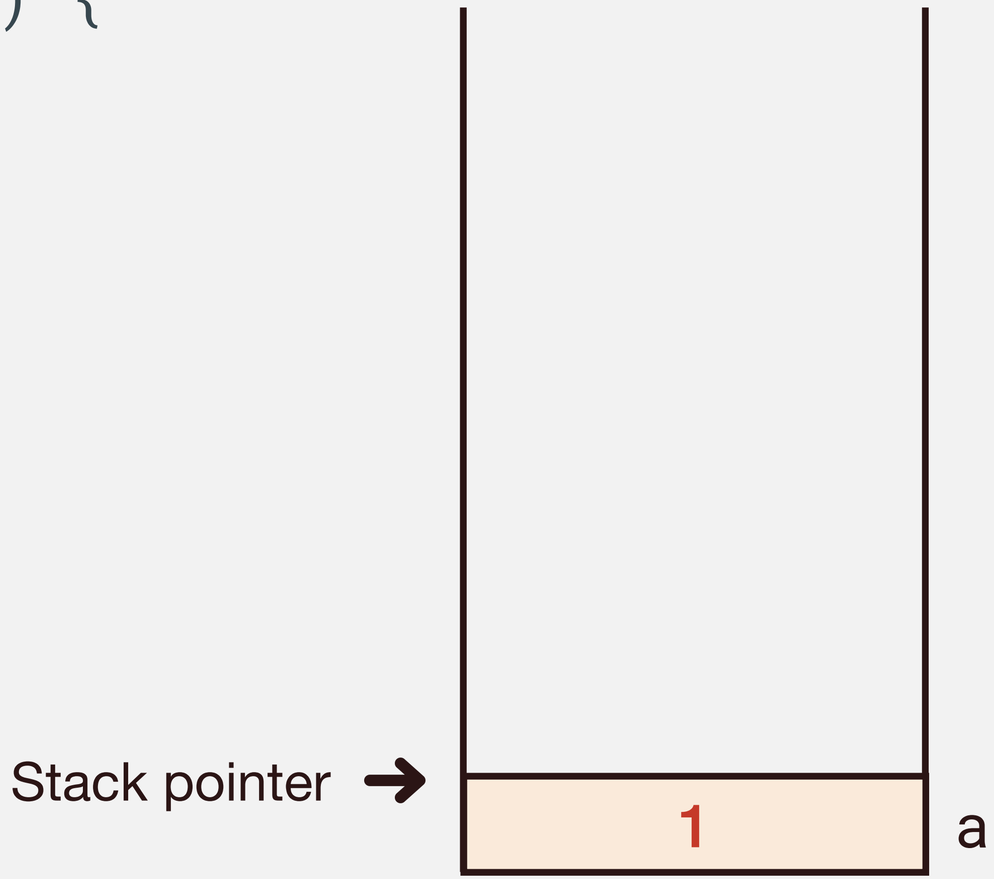

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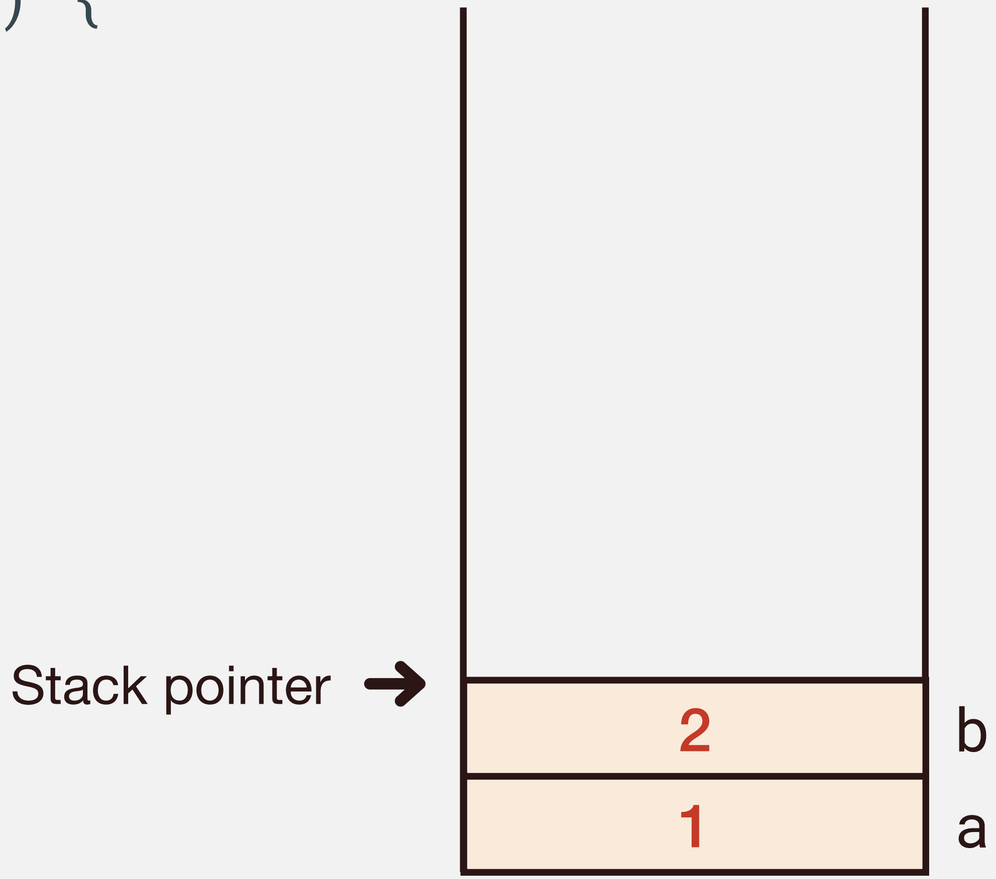

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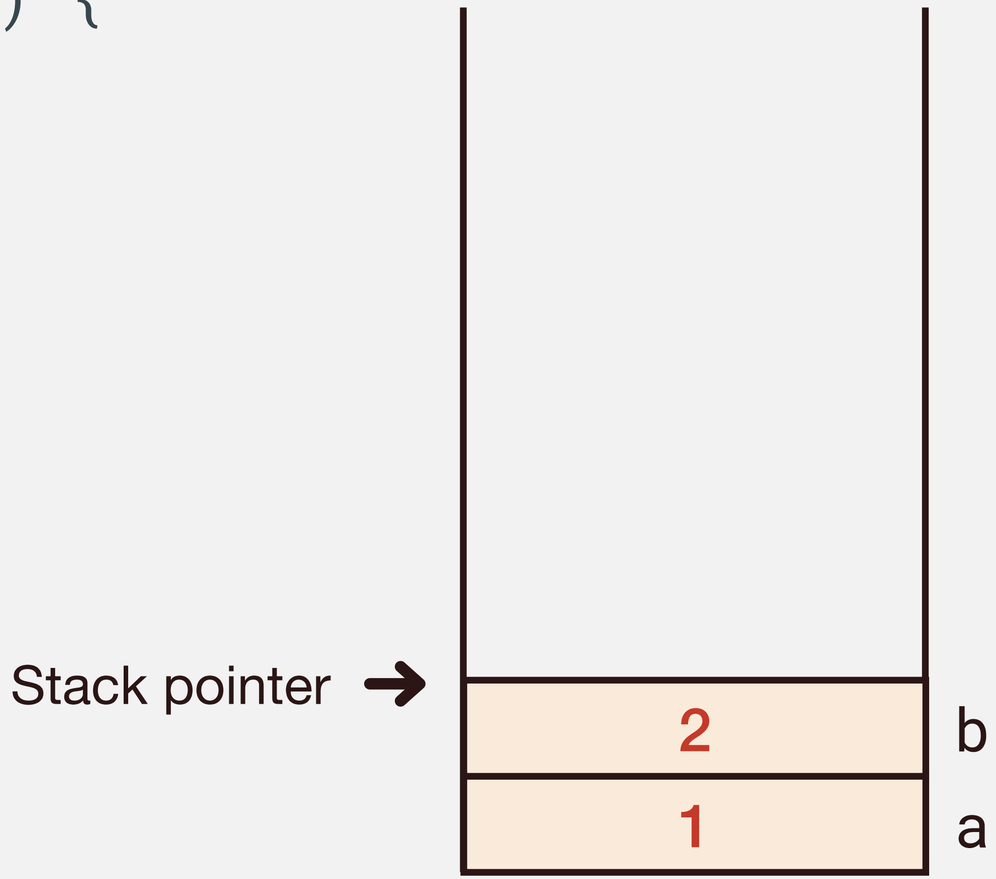

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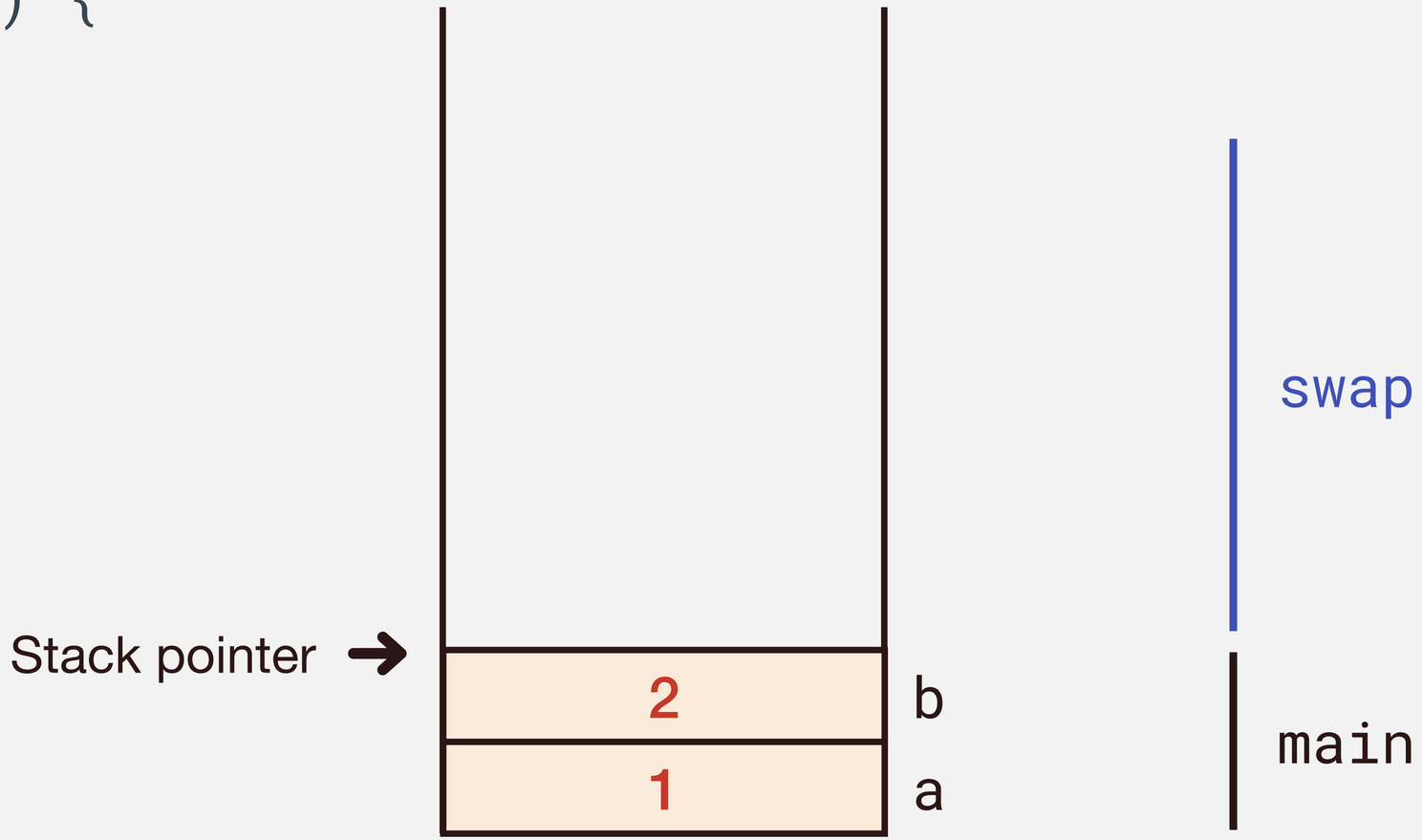

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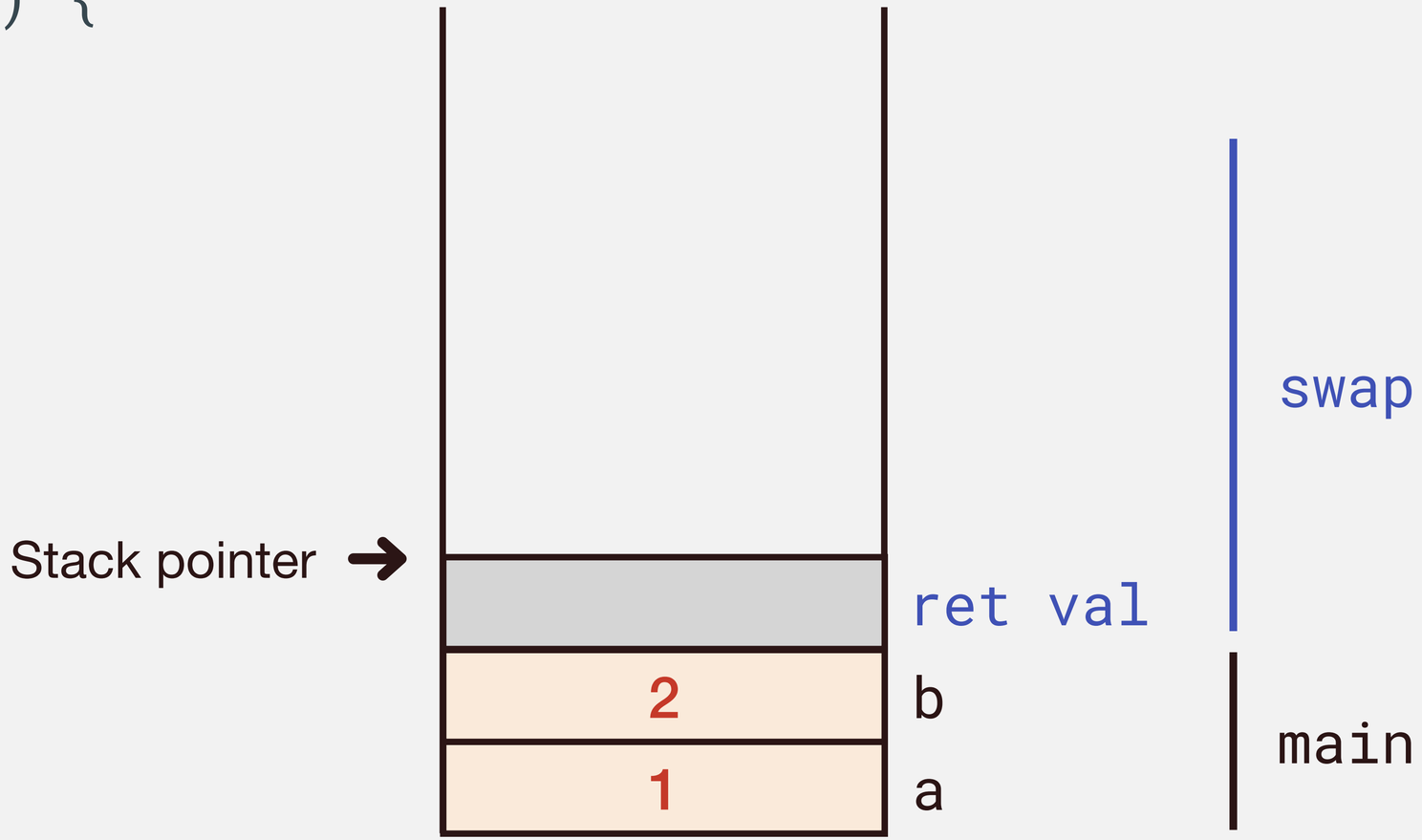

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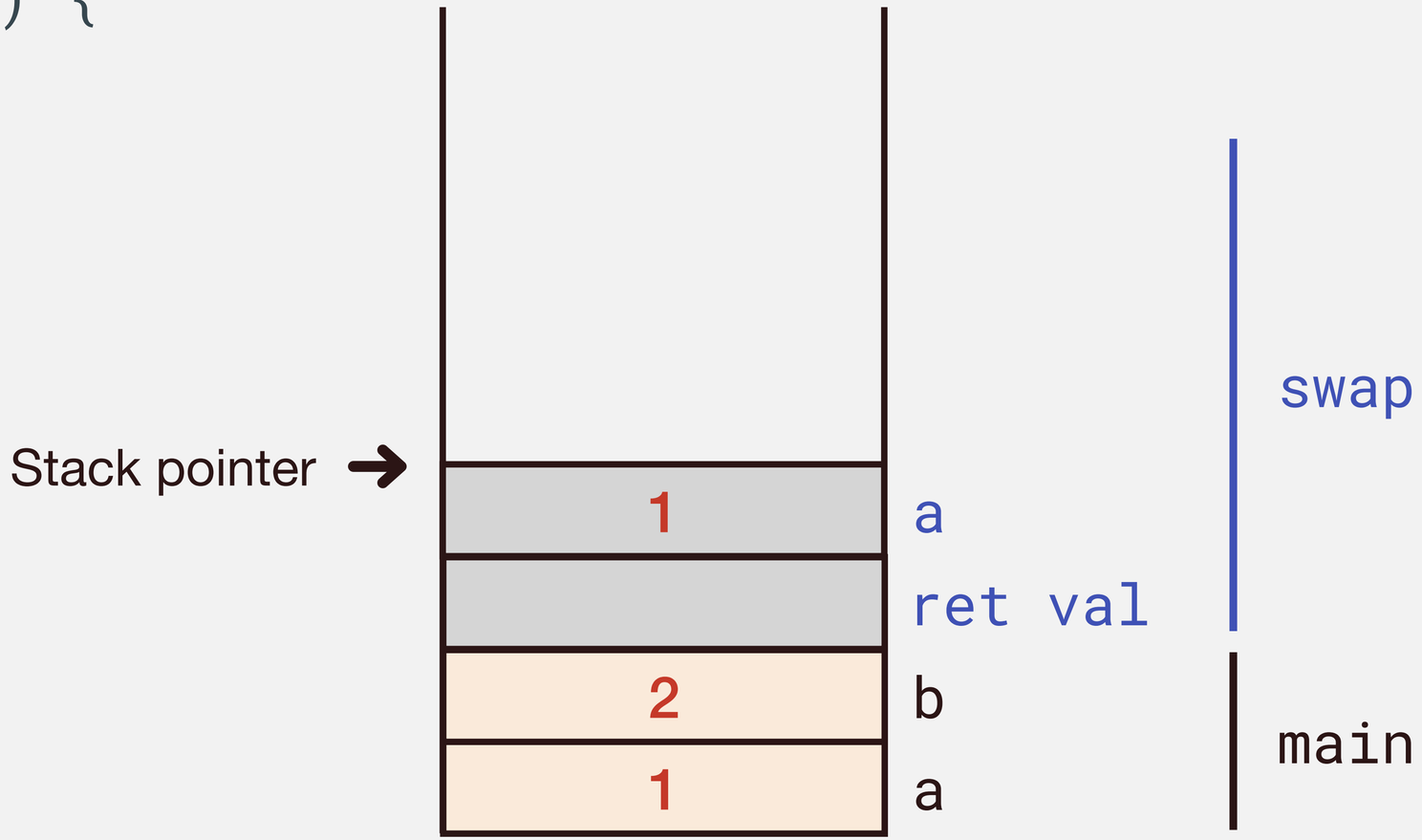

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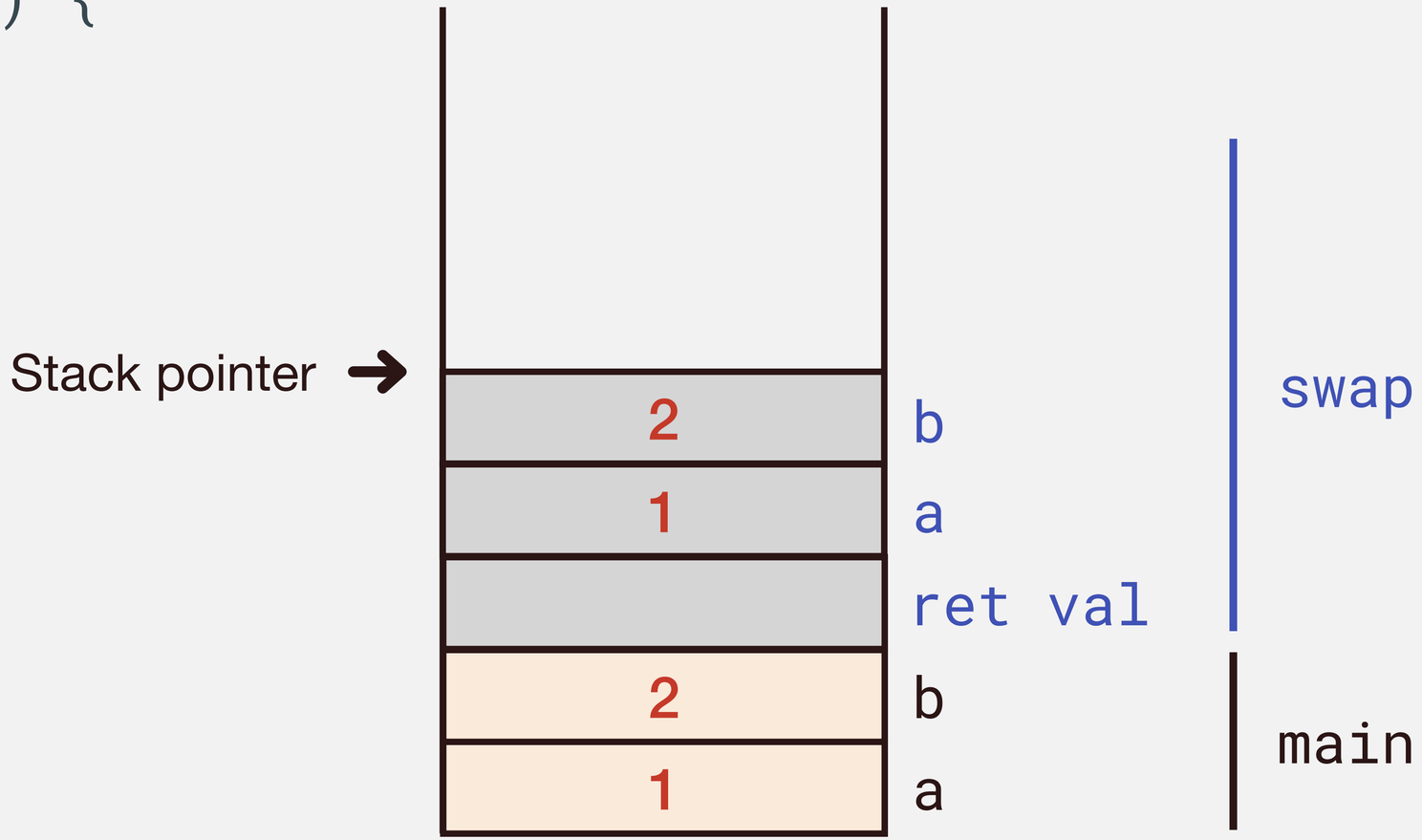

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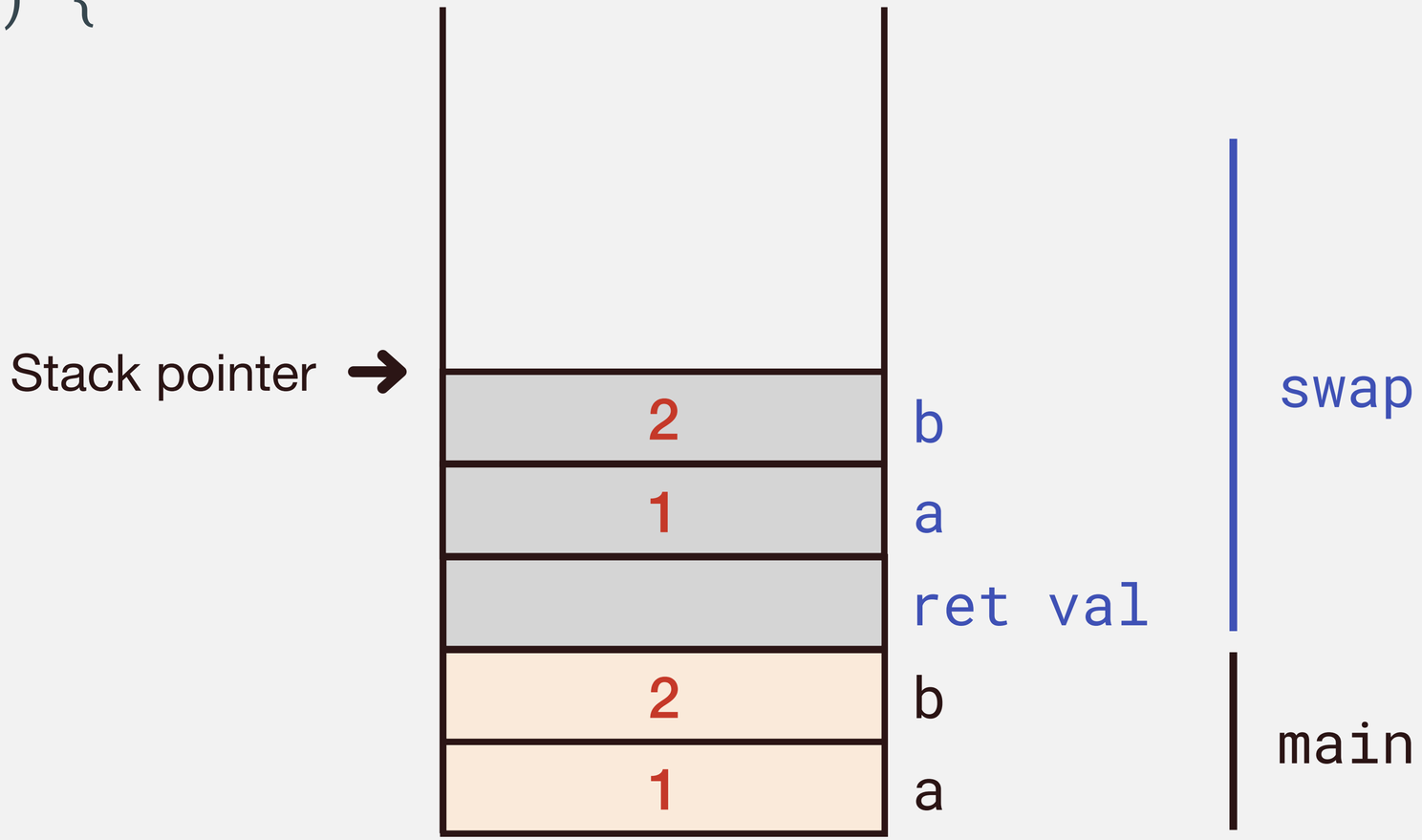

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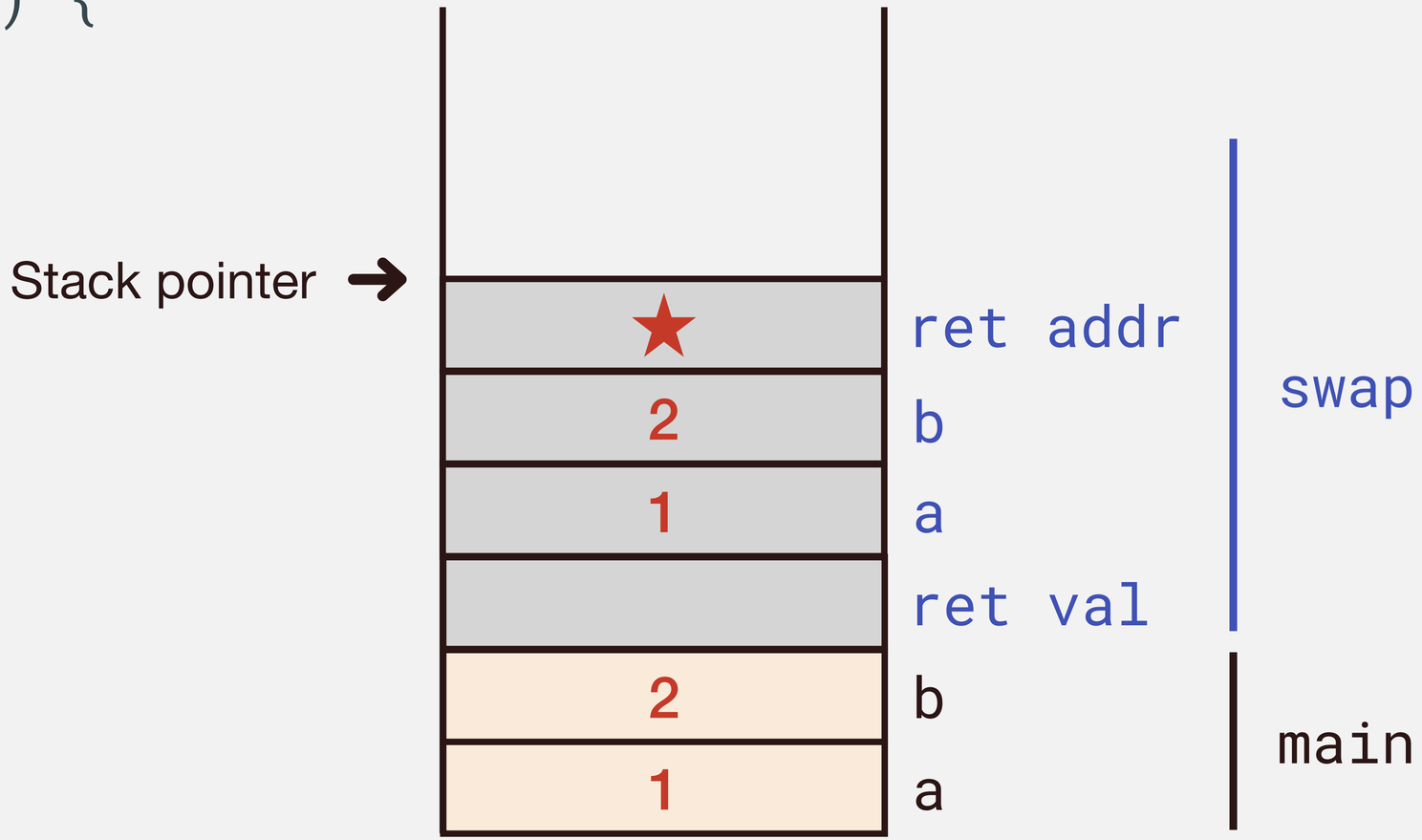

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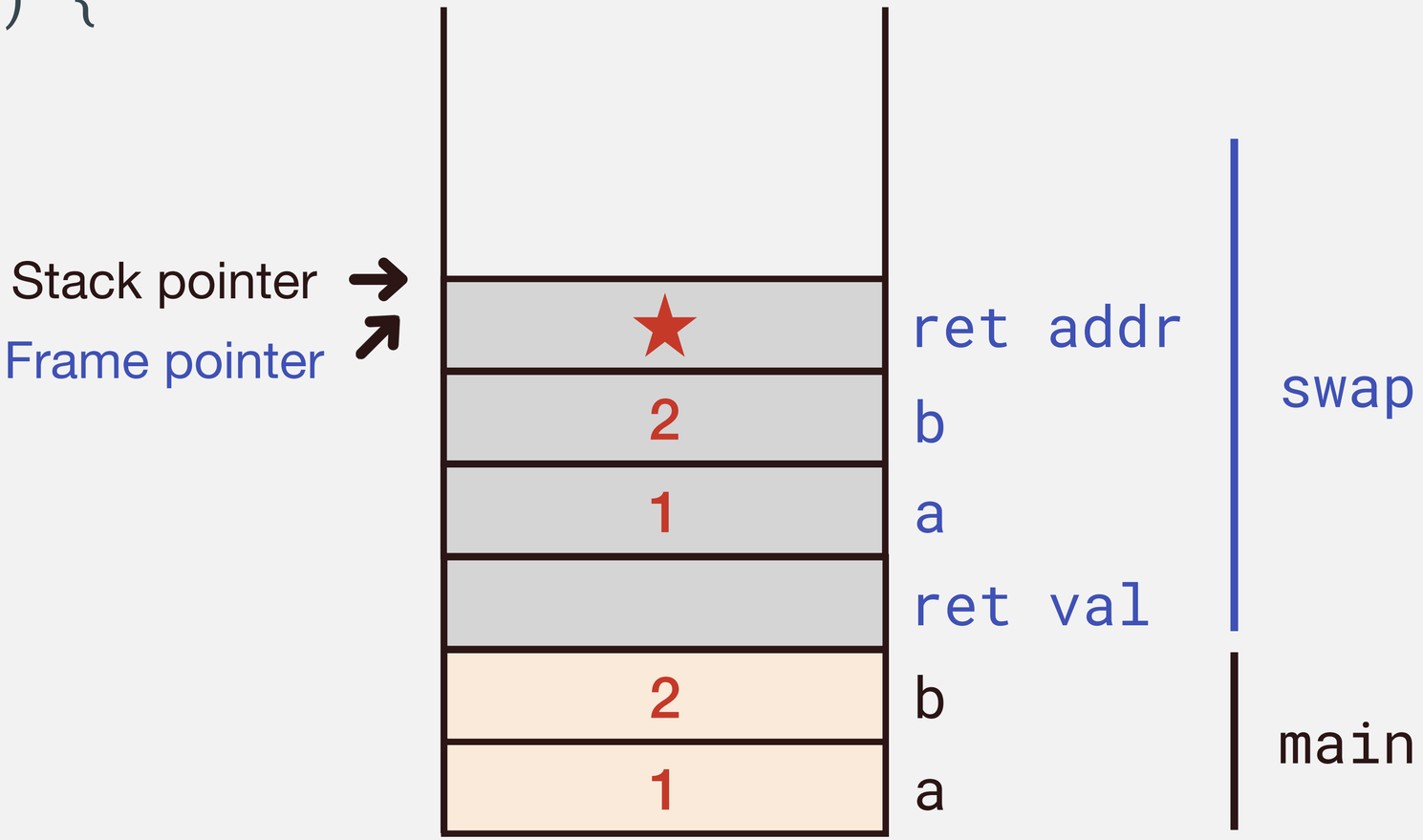

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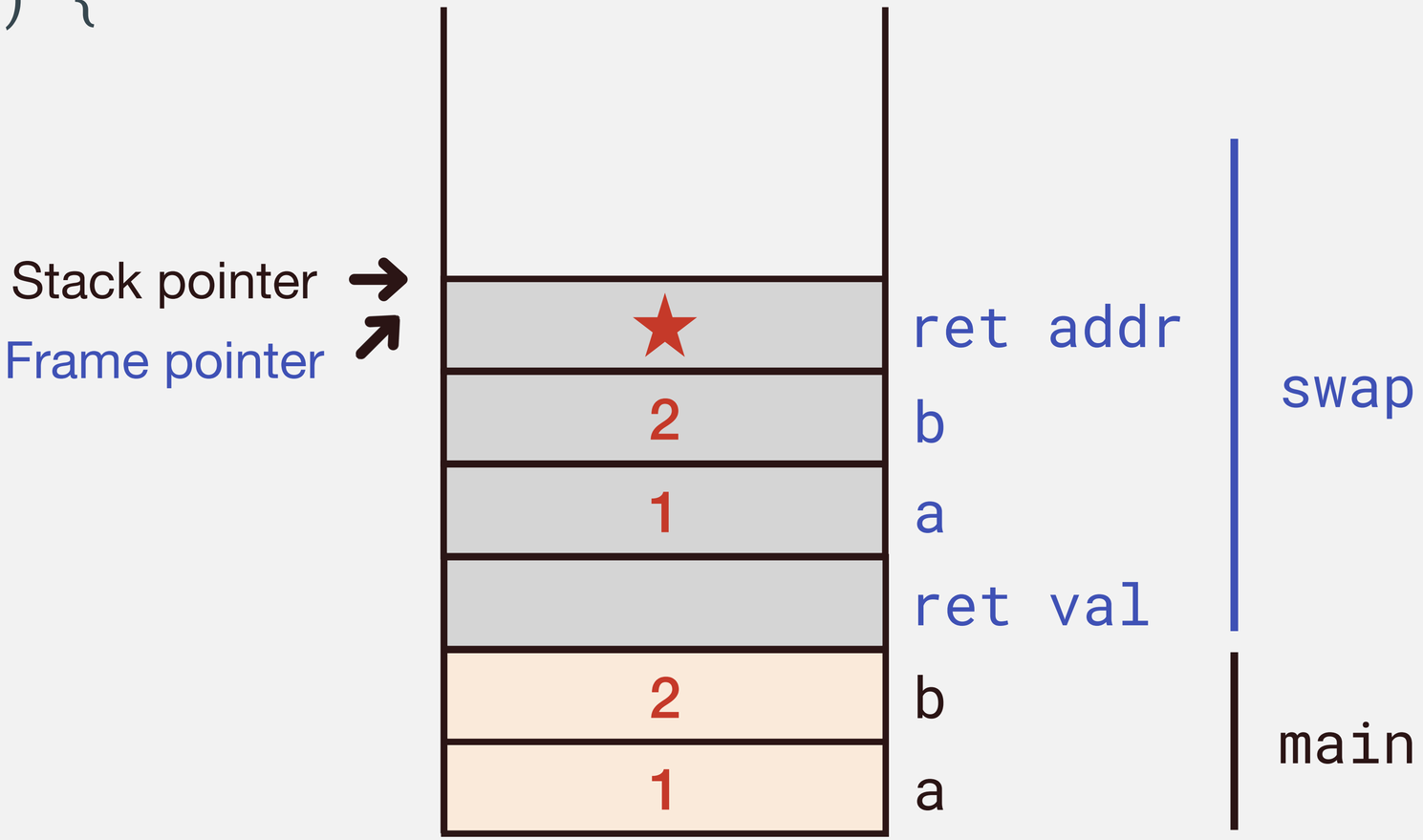

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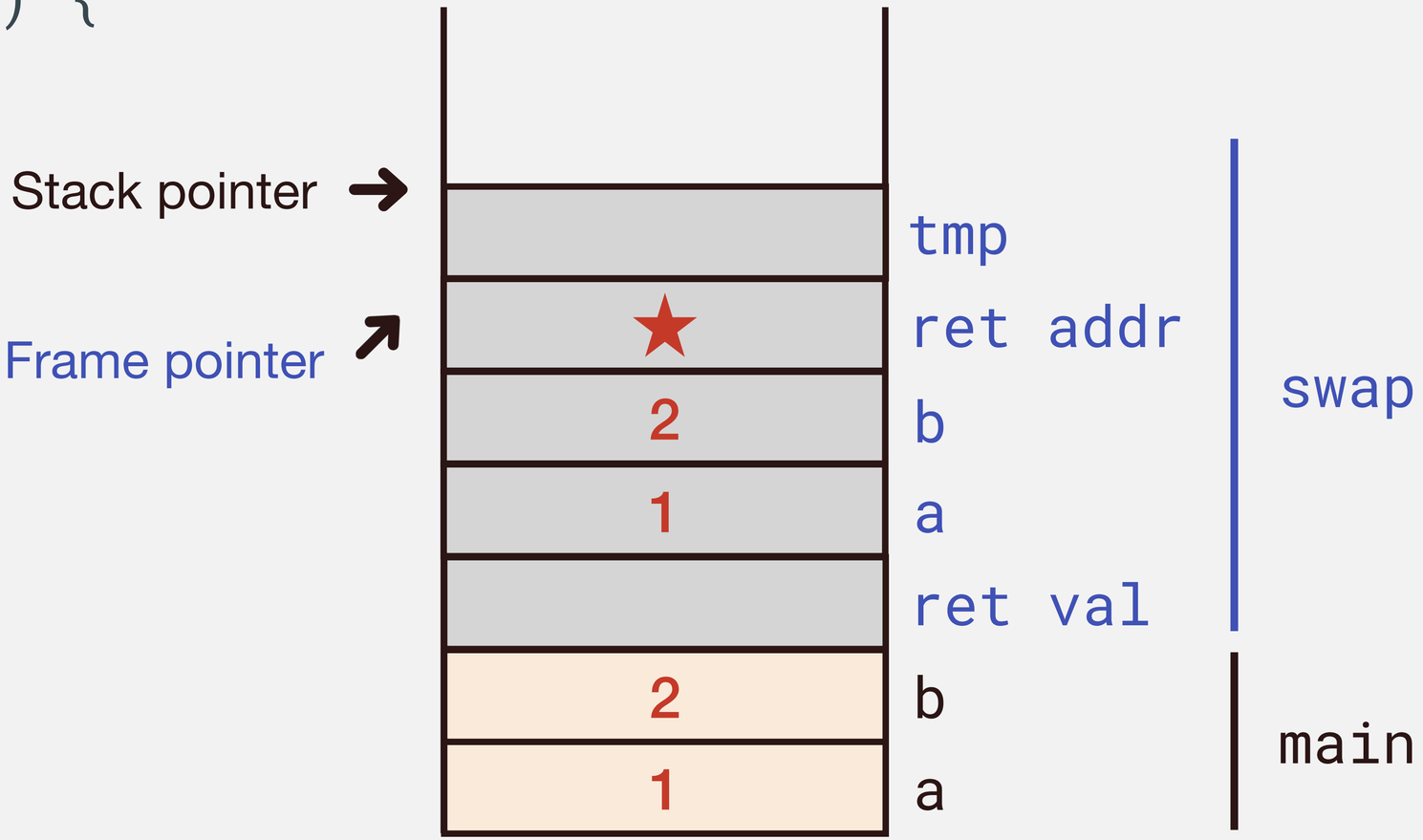

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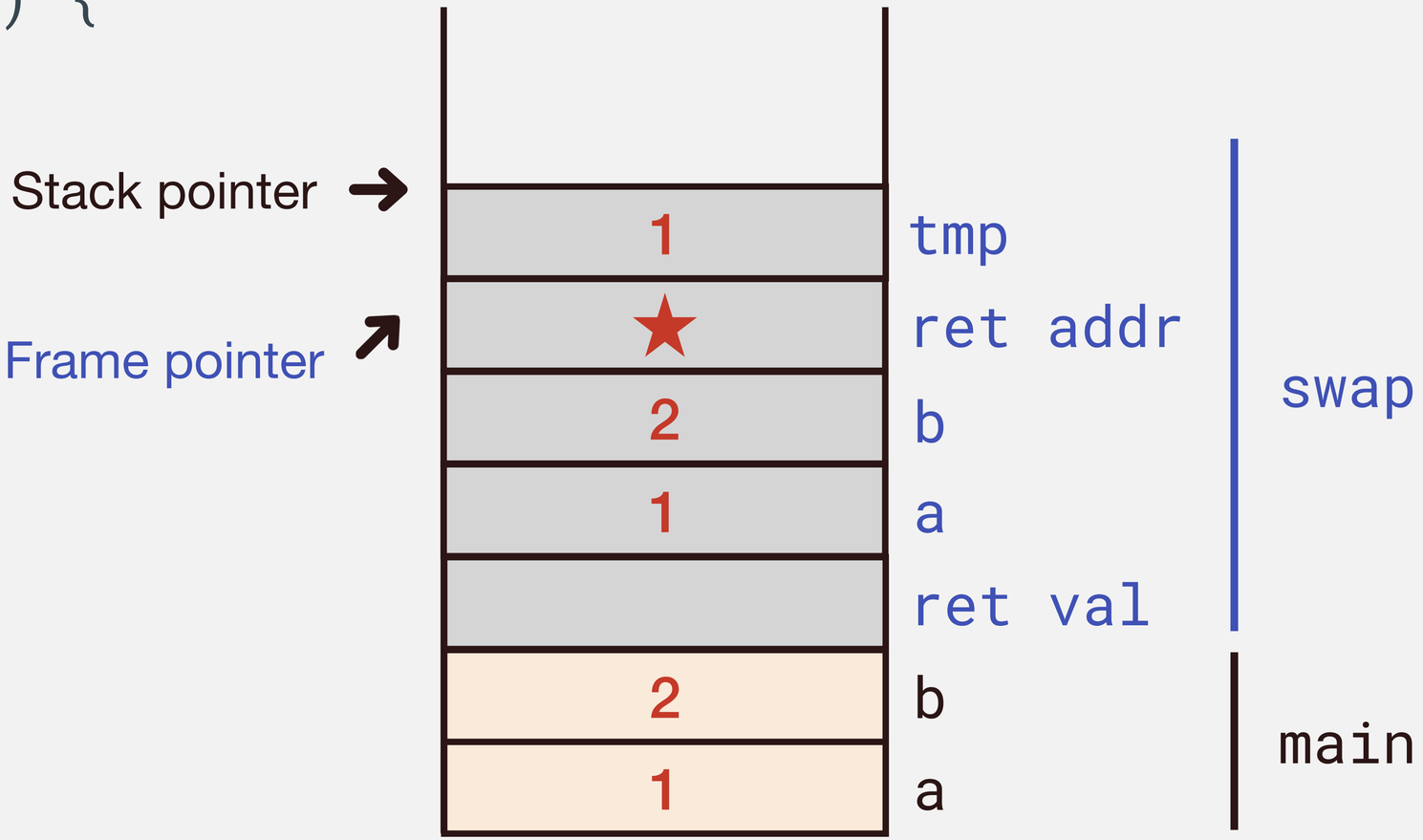

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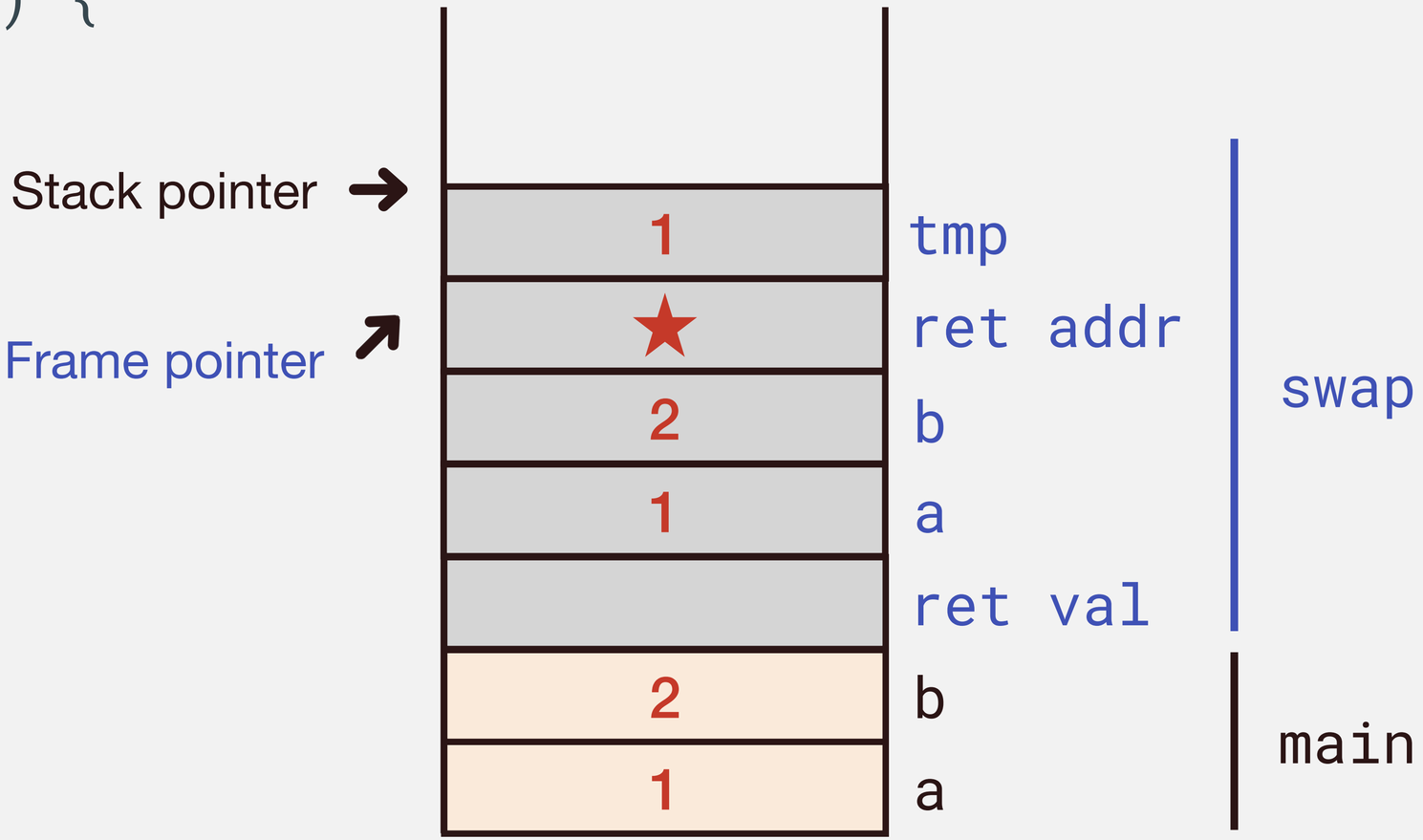

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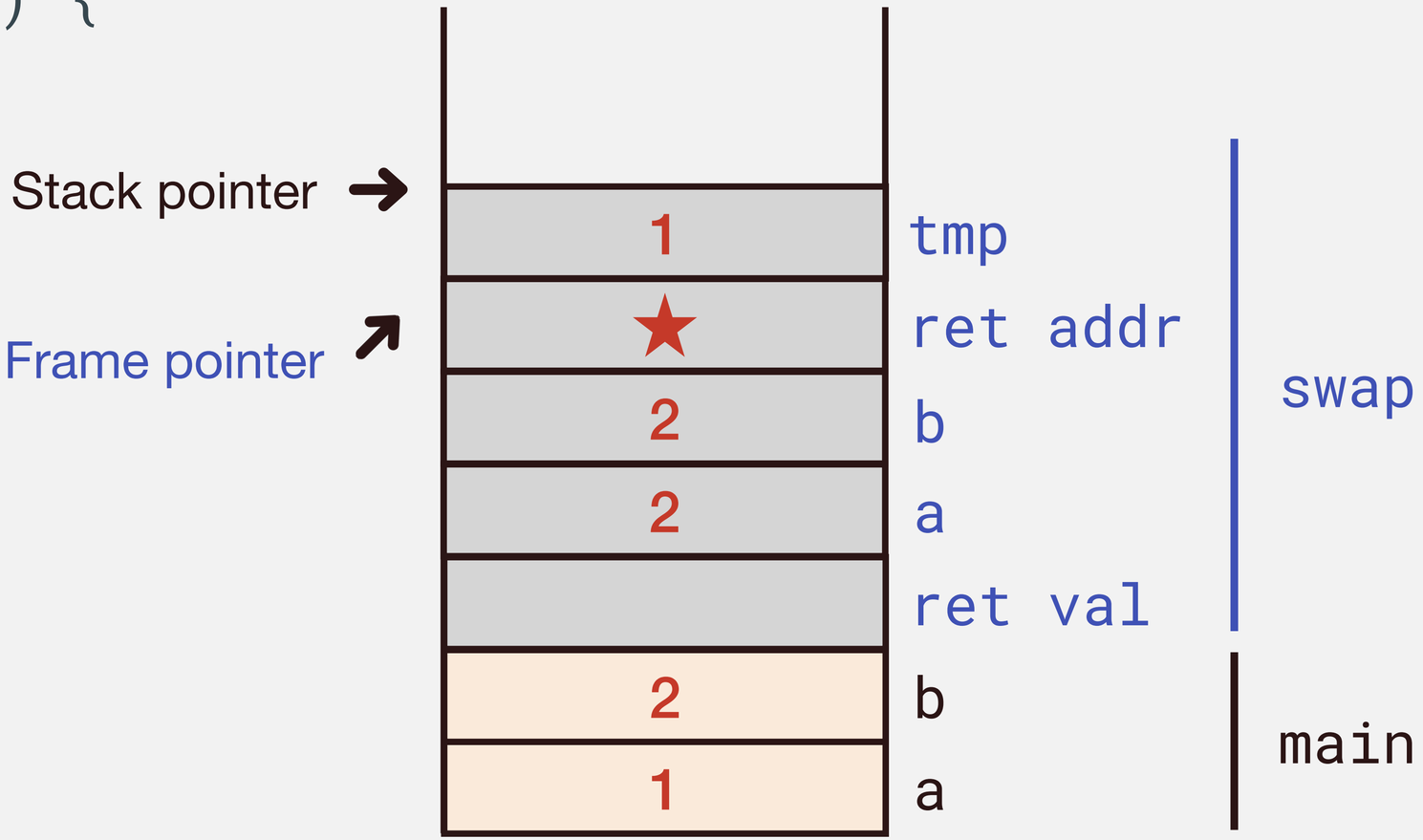

Call Stack

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  int tmp = a;
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}

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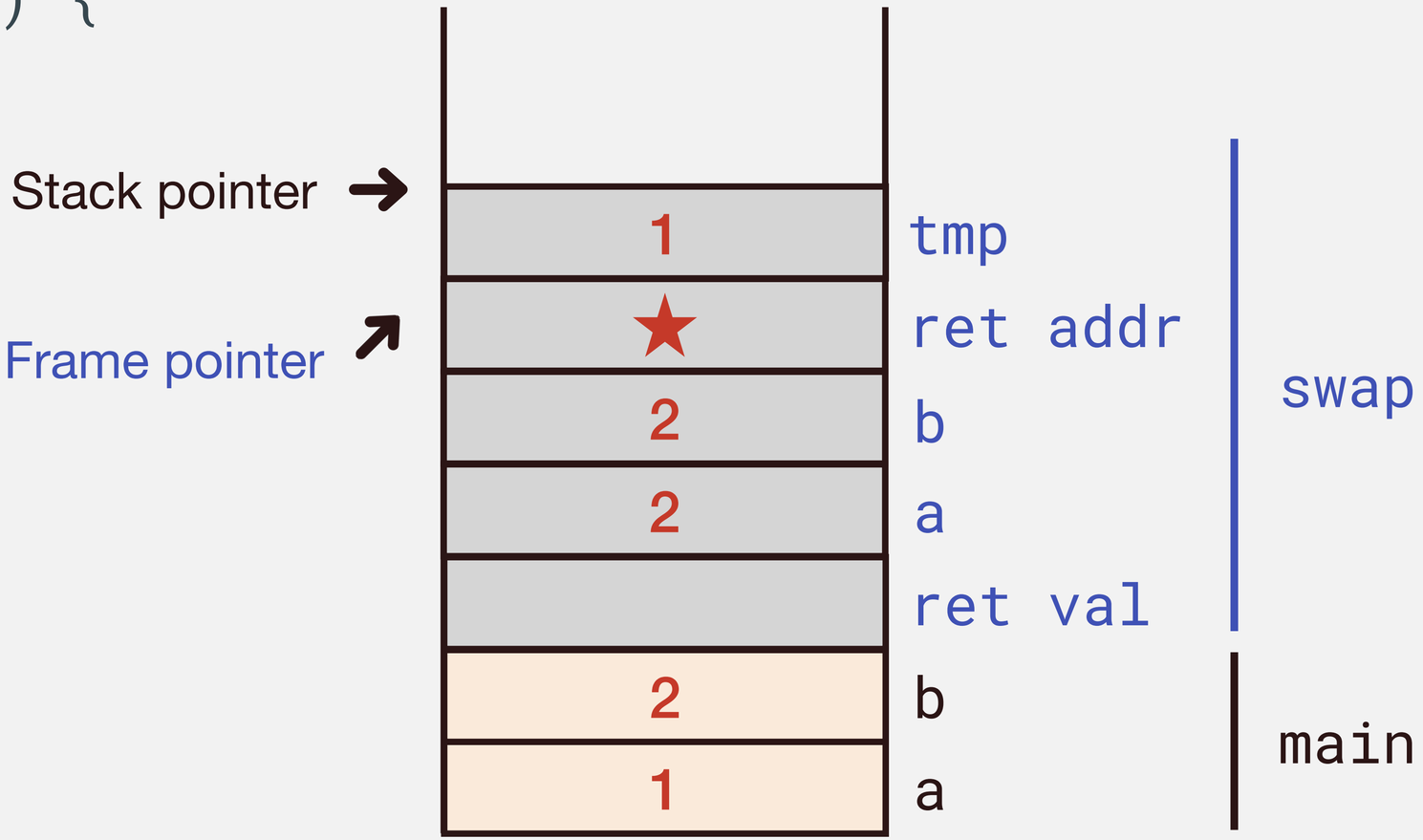
  swap(a, b); ★
}
```



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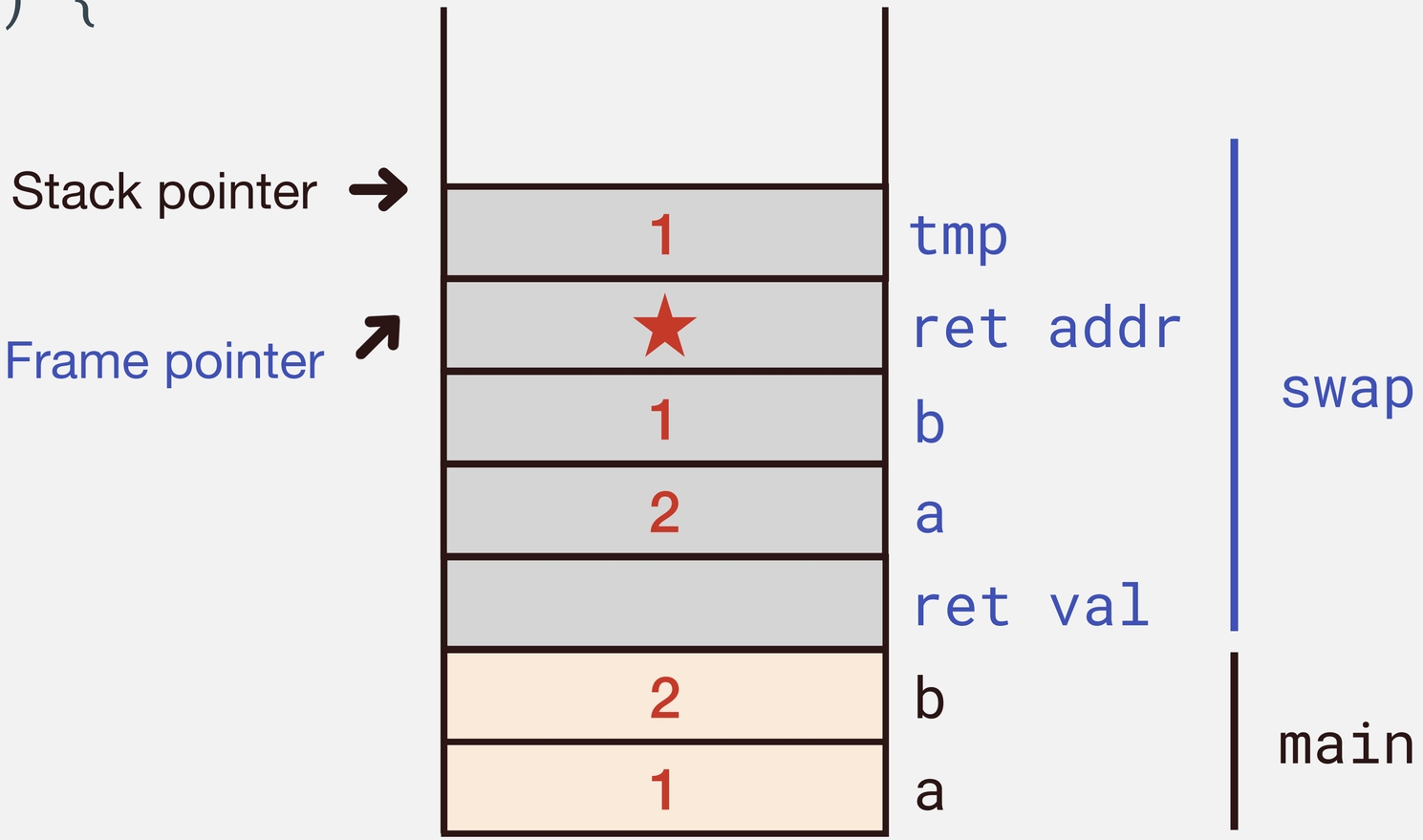

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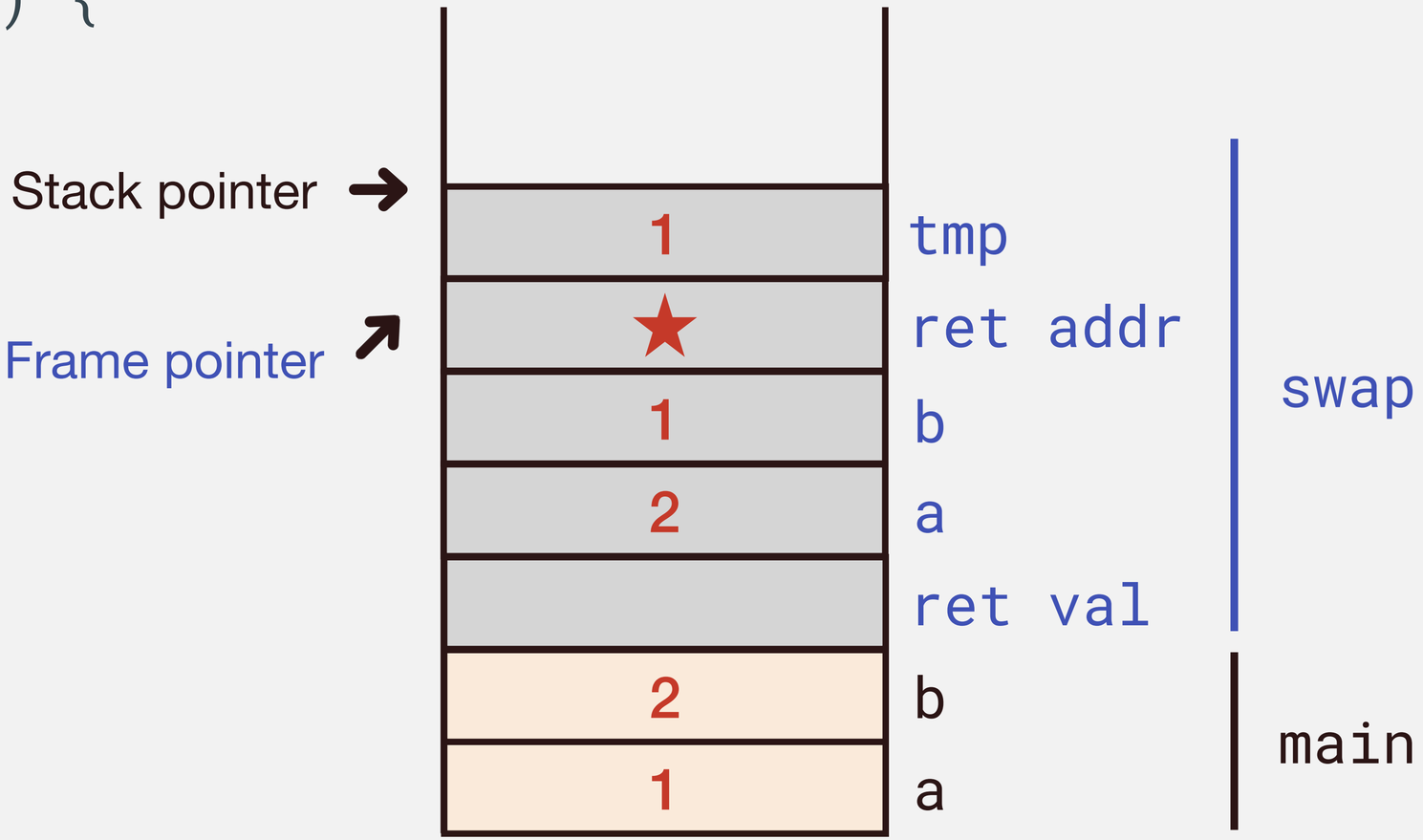

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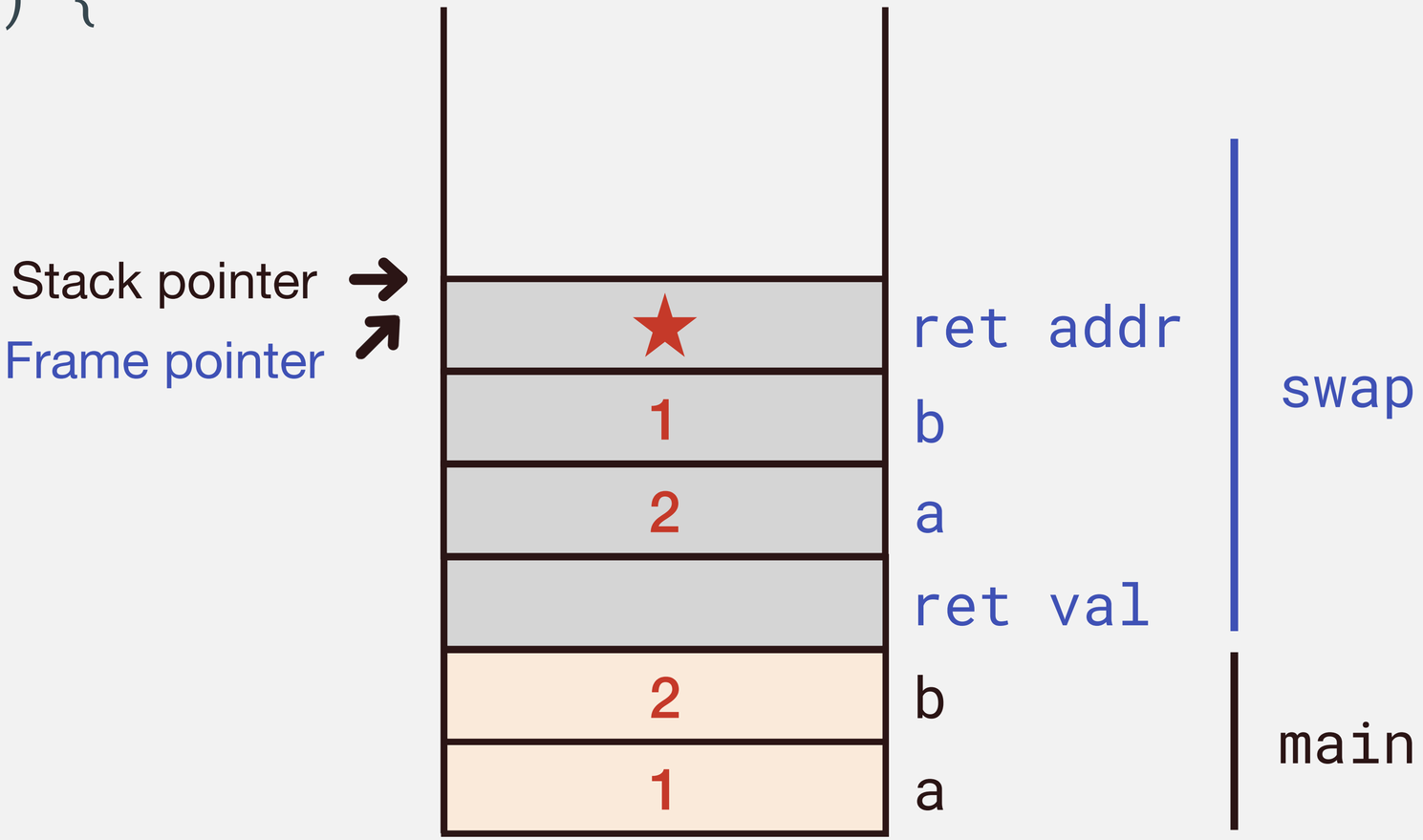

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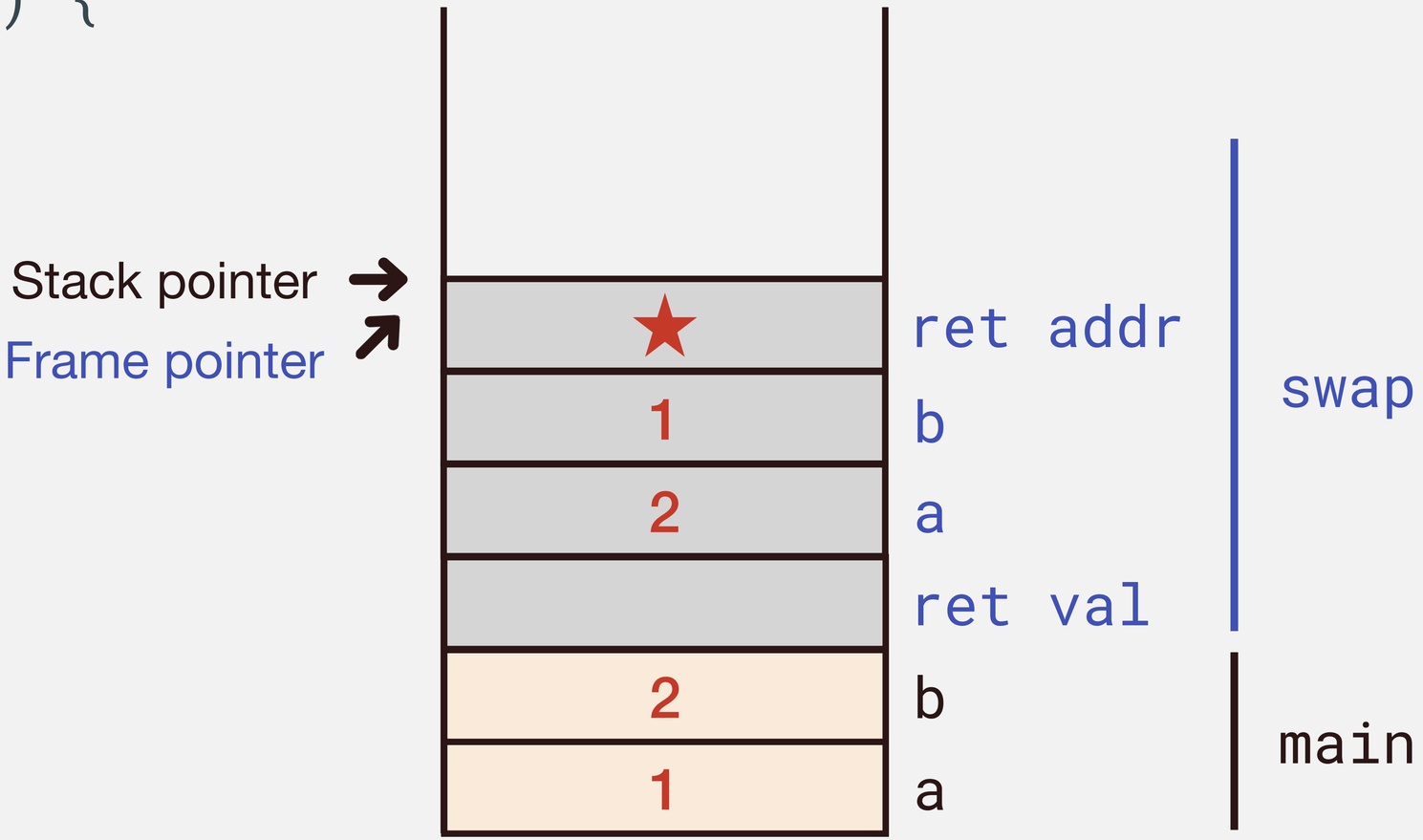

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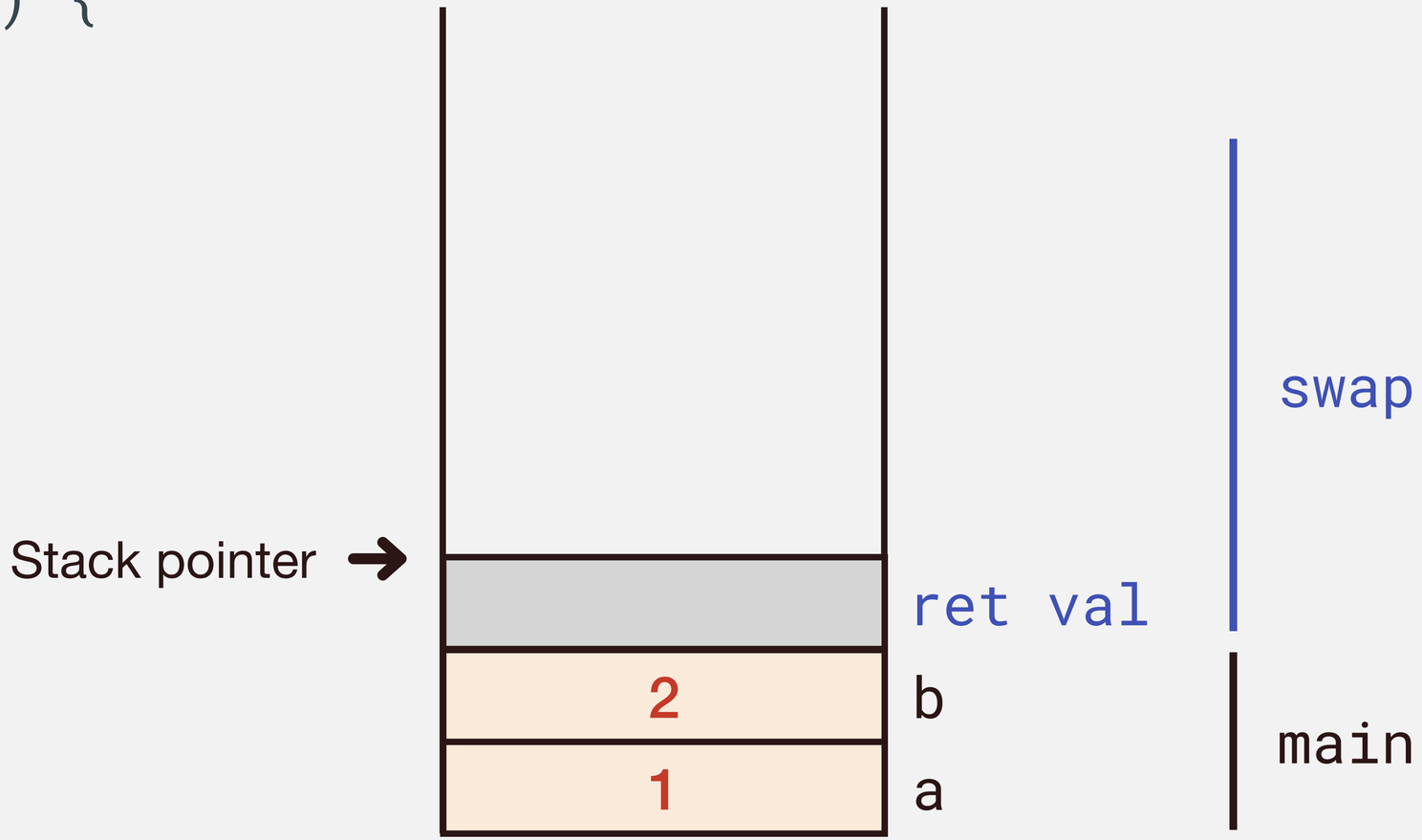

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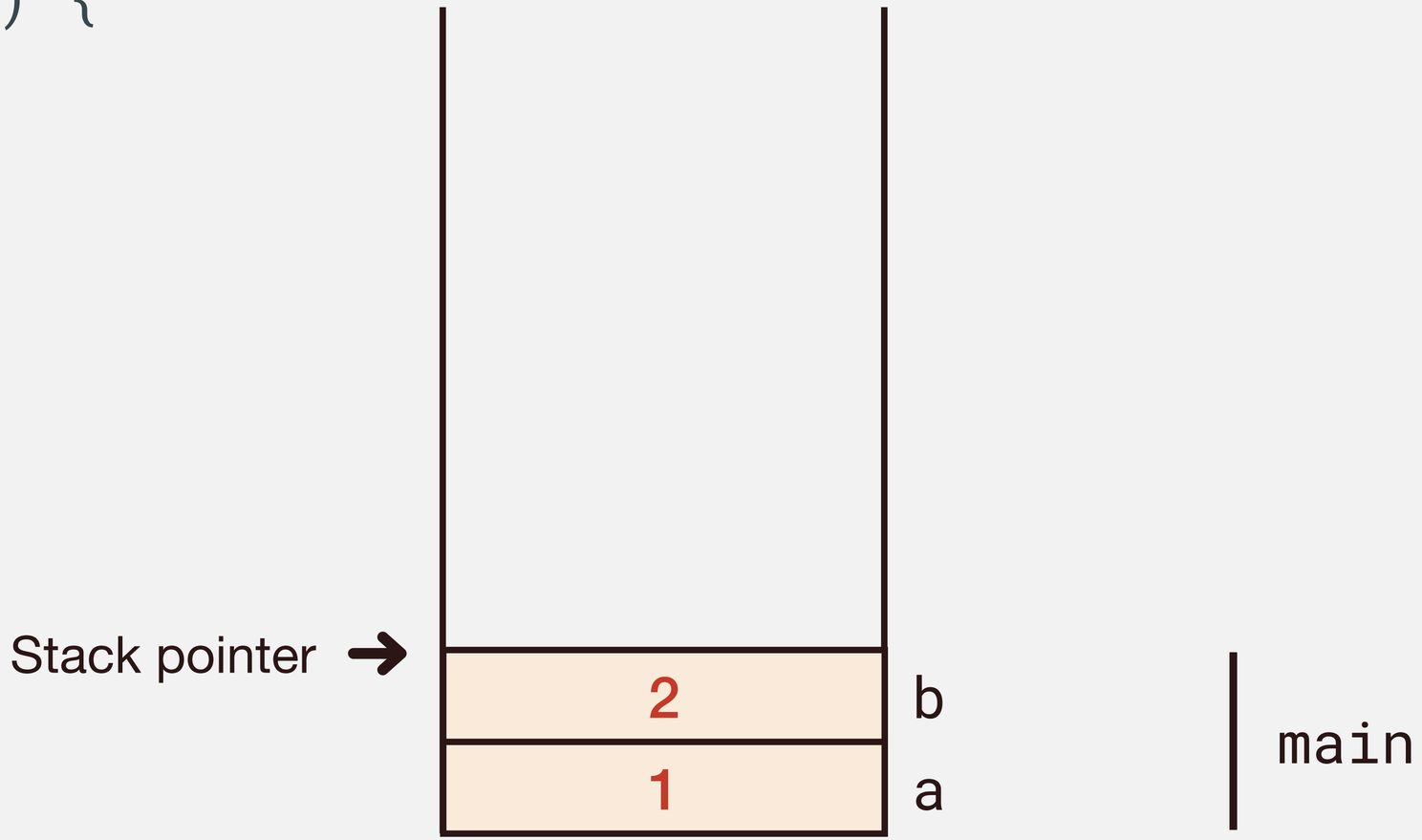

Phenomena Explained by the Stack

1. Why are function arguments **passed by value**?

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Variable Scope

```
int squareSum(int n) {
  int s = 0;
  for (int i = 1; i <= n; i++) {
    int i_sqr = i * i;
    s += i_sqr;
  }
  return s;
}

int main() {
  int n = 100;
  squareSum(n);
}
```

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1. Why are function arguments **passed by value**?
   - Makes a local copy of the passed-in values on stack at function call
2. Why do local variables limited to the **scope** of the function?
   - They no-longer exist on stack after function returns
3. Why don’t local variables need garbage collection?

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2. Why do local variables limited to the **scope** of the function?
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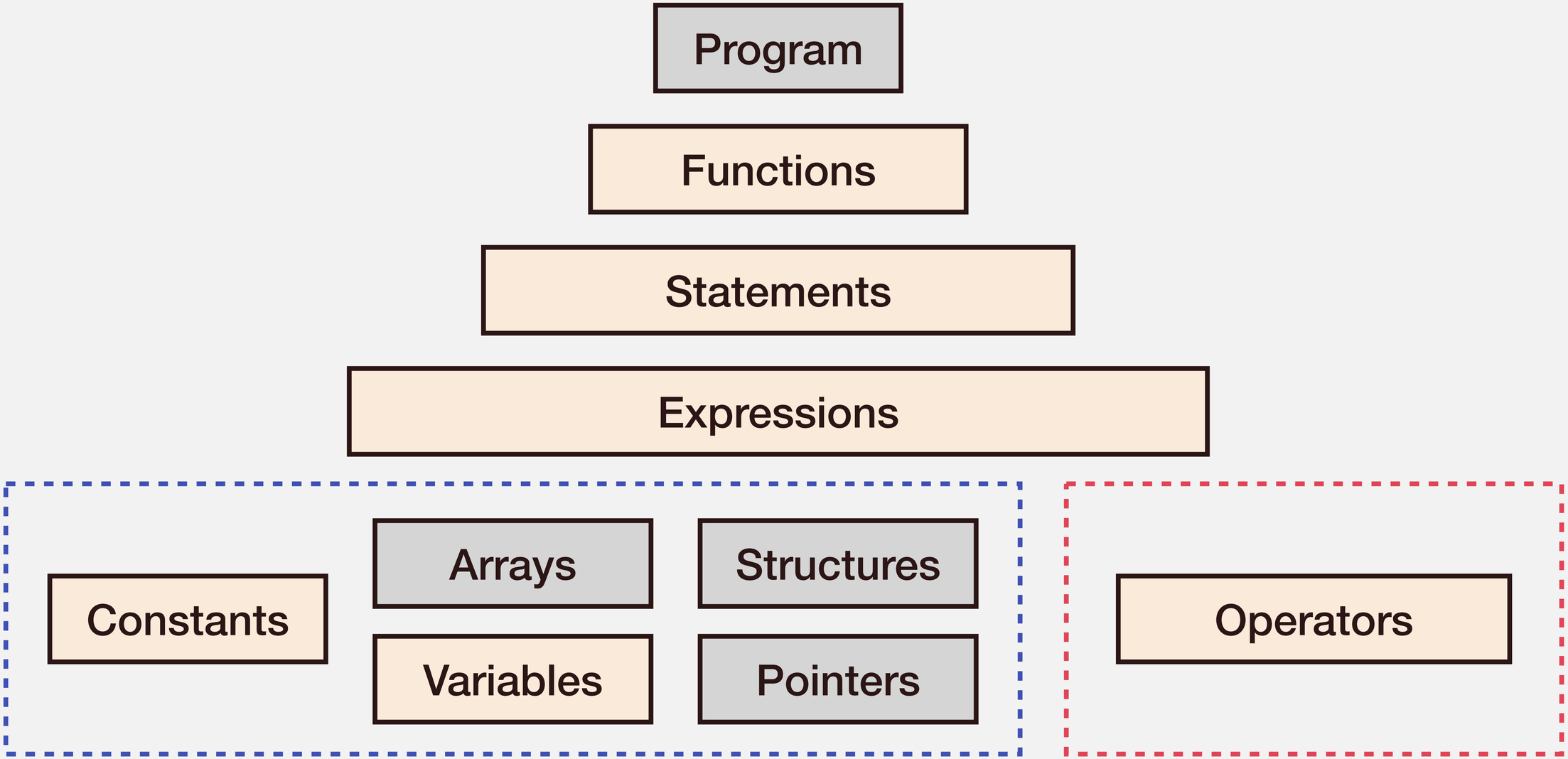
3. Why don’t local variables need garbage collection?
   - Automatically done by the stack

Road Map


Program
Functions
Statements
Expressions
Constants
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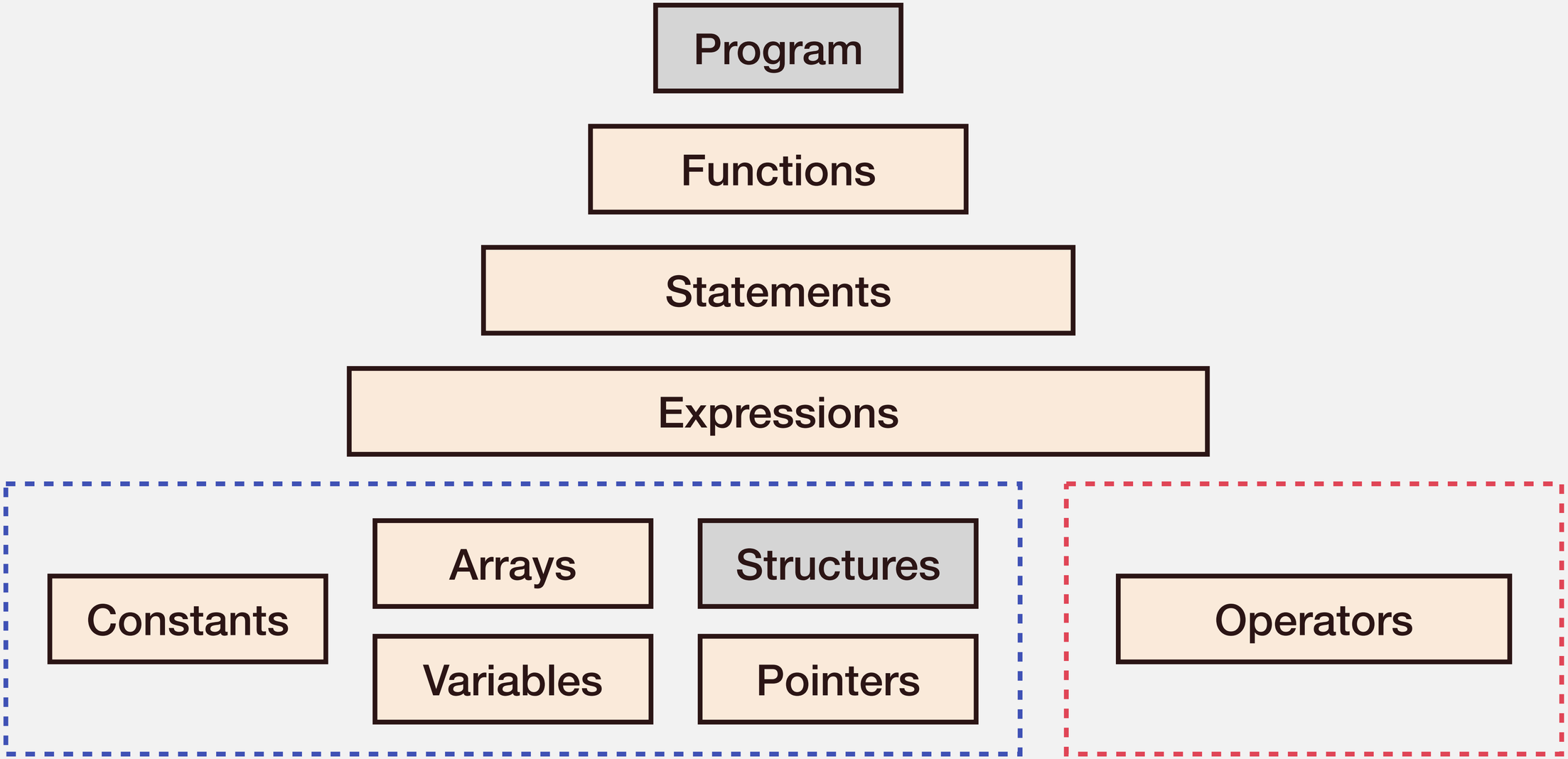
Road Map


Program
Functions
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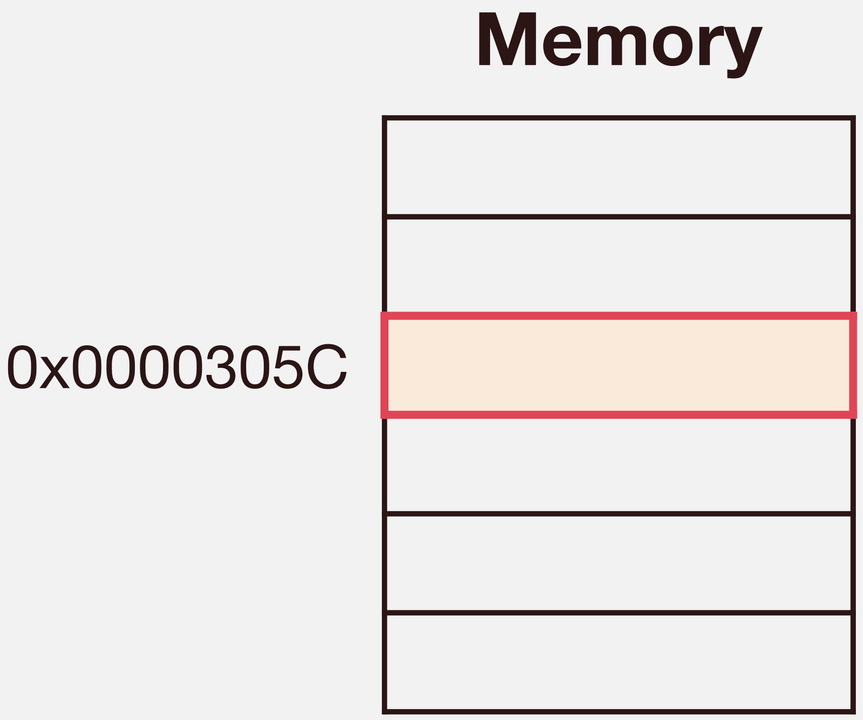
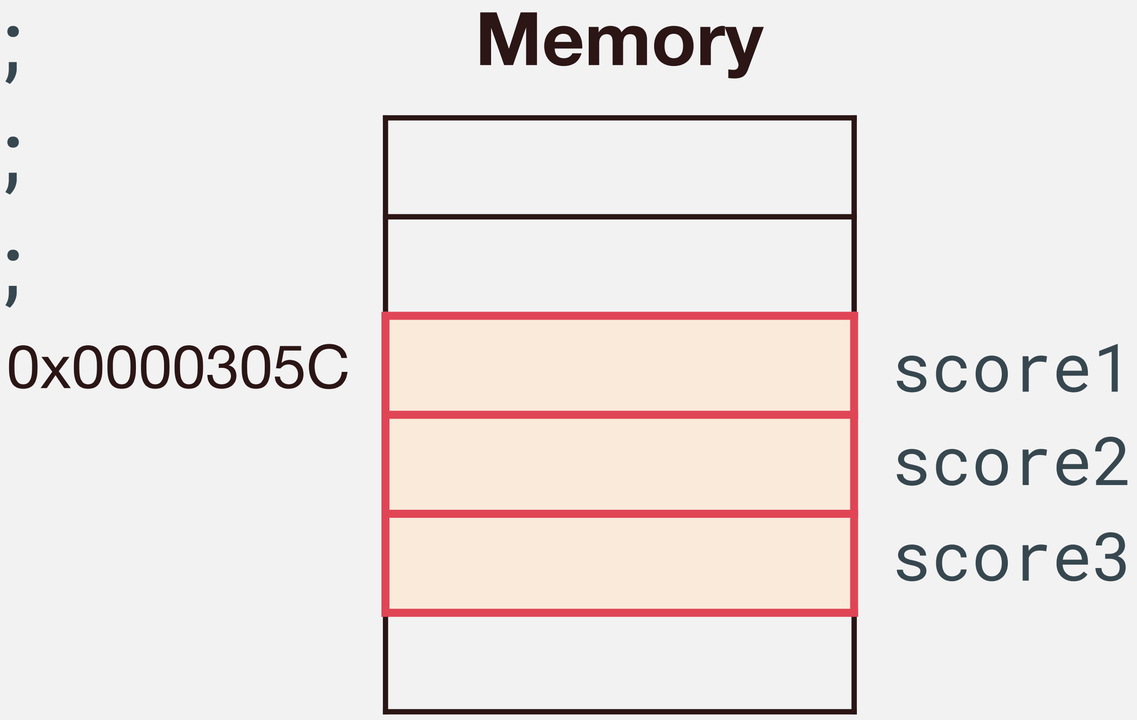
Array Declaration

```
int score;
```



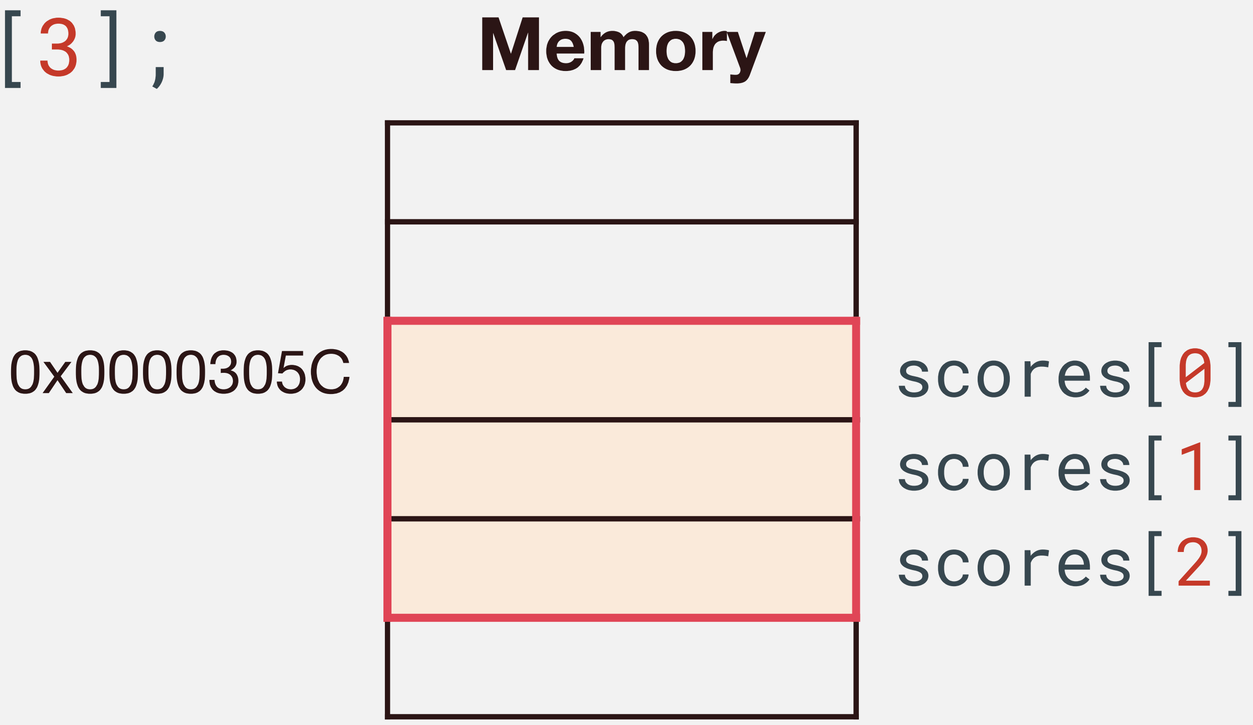
Array Declaration

```
int score1;
int score2;
int score3;
```



Array Declaration

```
int scores[3];
```



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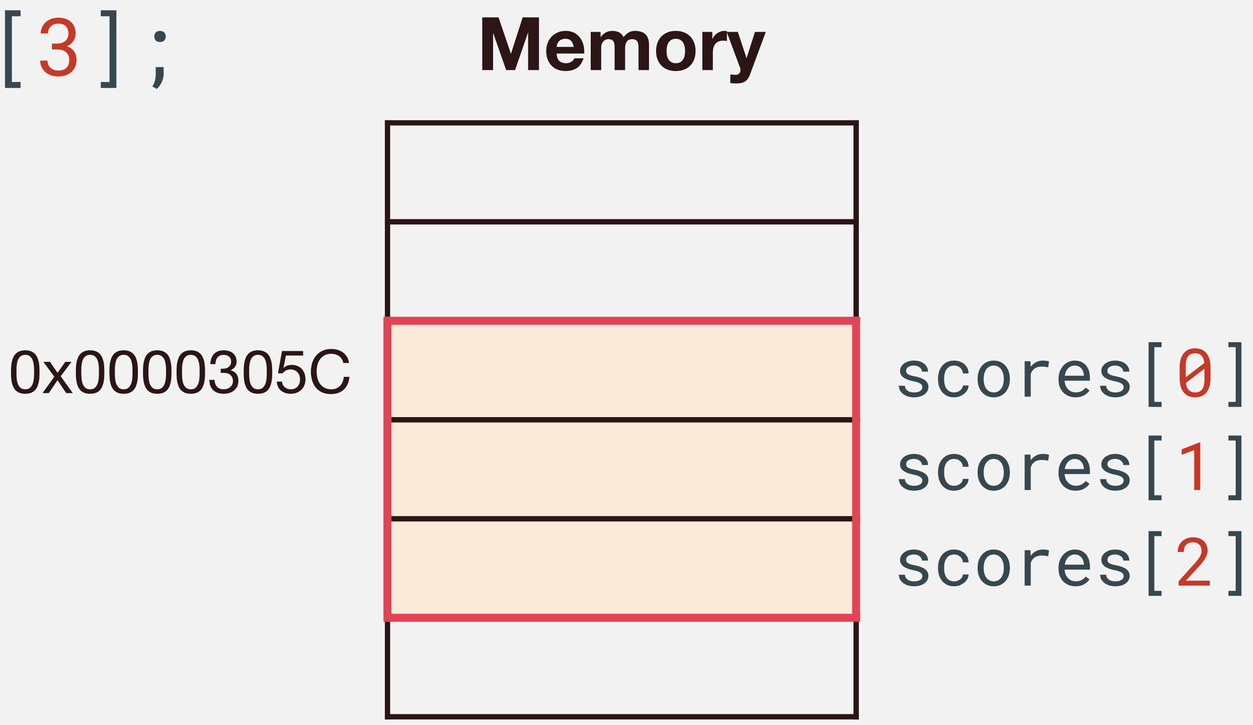


Same Type

Back-to-back

Array Initialization

```
int array[5] = {1, 2, 3, 4, 5}
```

Array Initialization

```
int array[5] = {1, 2, 3, 4, 5}
```

must be **constant**

Array Initialization

```
int array[5] = {1, 2, 3, 4, 5}
```

must be **constant**

```
int n = 5;
int array[n];
```

Array Initialization

```
int array[5] = {1, 2, 3, 4, 5}
```

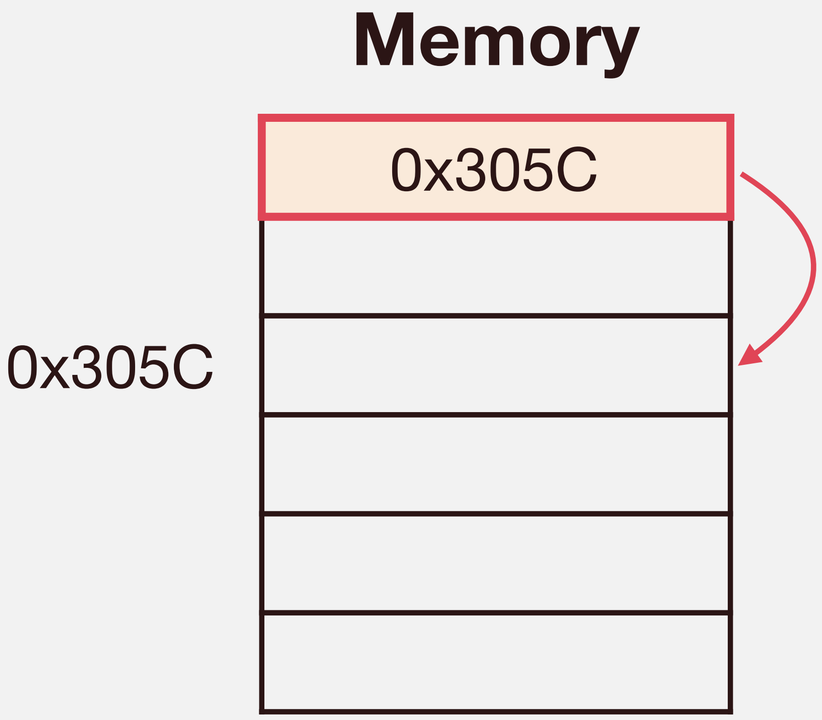
must be **constant**

```
int n = 5;
int array[n];
int i;
for (i = 0; i < n; i++) {
  array[i] = i + 1;
}
```

Pointer Declaration

➜ **Pointer**: a variable that holds the **address** of a memory location

```
int *num_primes;
```



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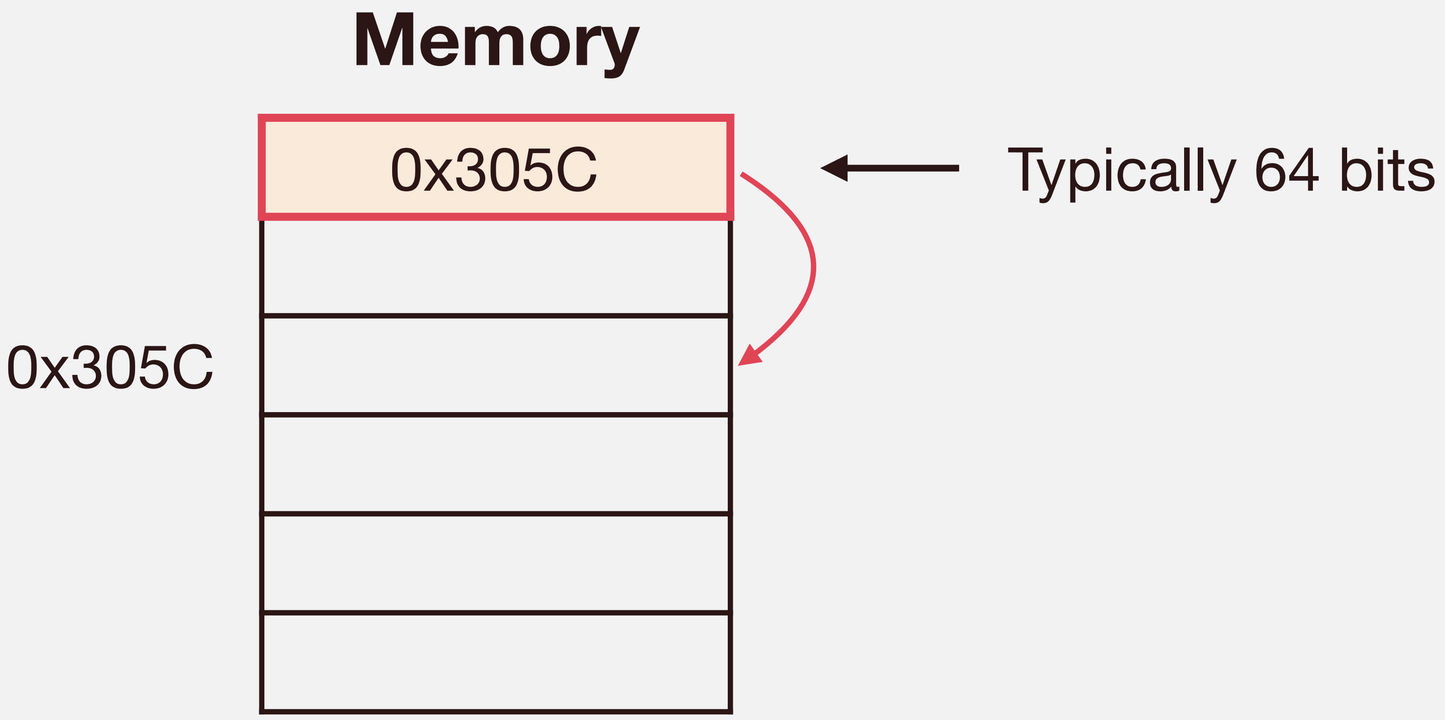
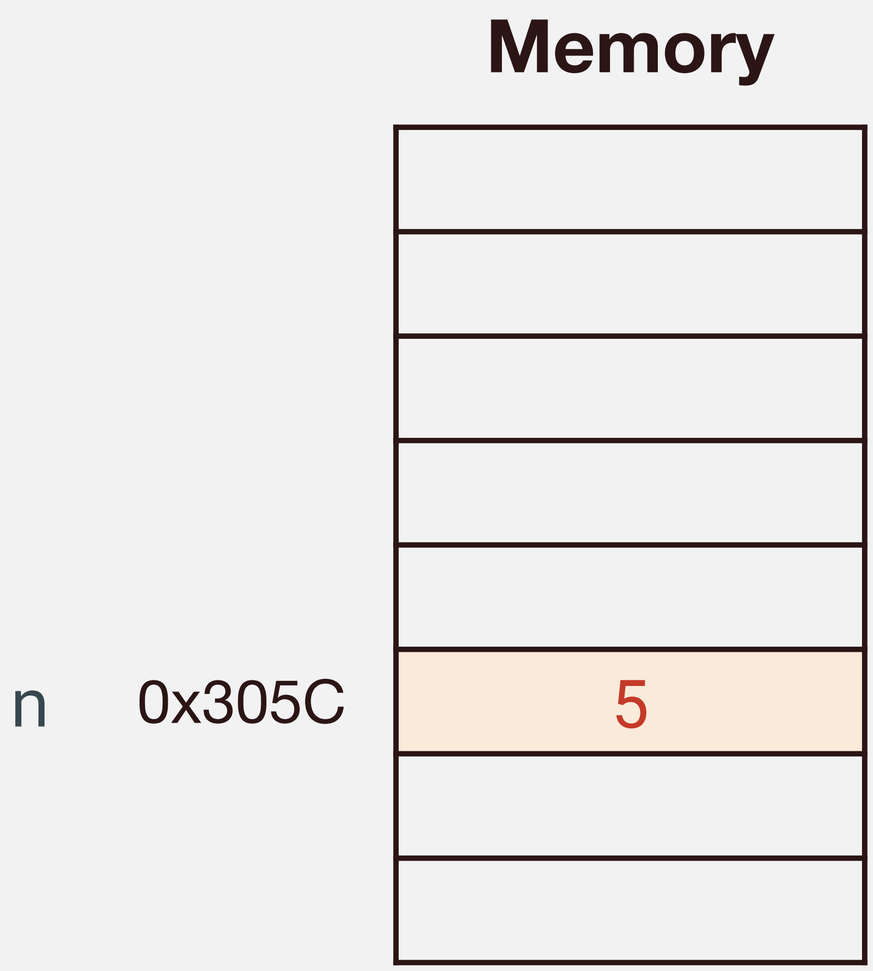


Address <—> Content

```
int main() {
  int n = 5;

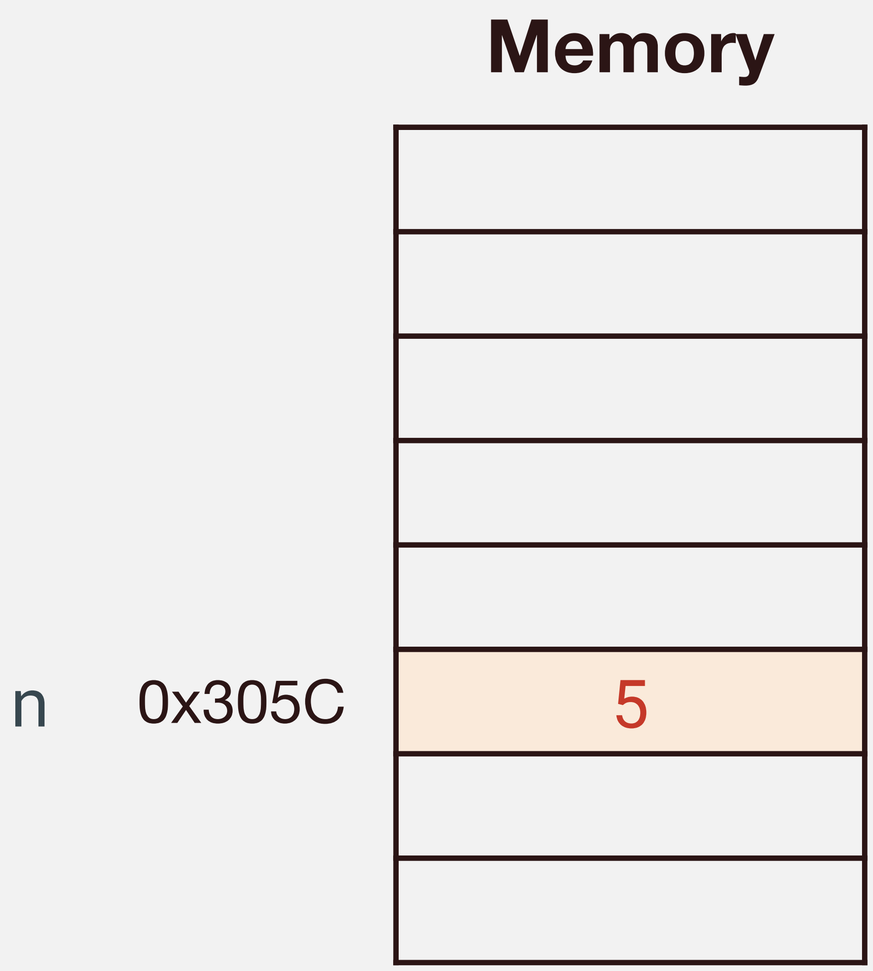
}
```



Address <—> Content

```
int main() {
  int n = 5;
  int *p;

}
```



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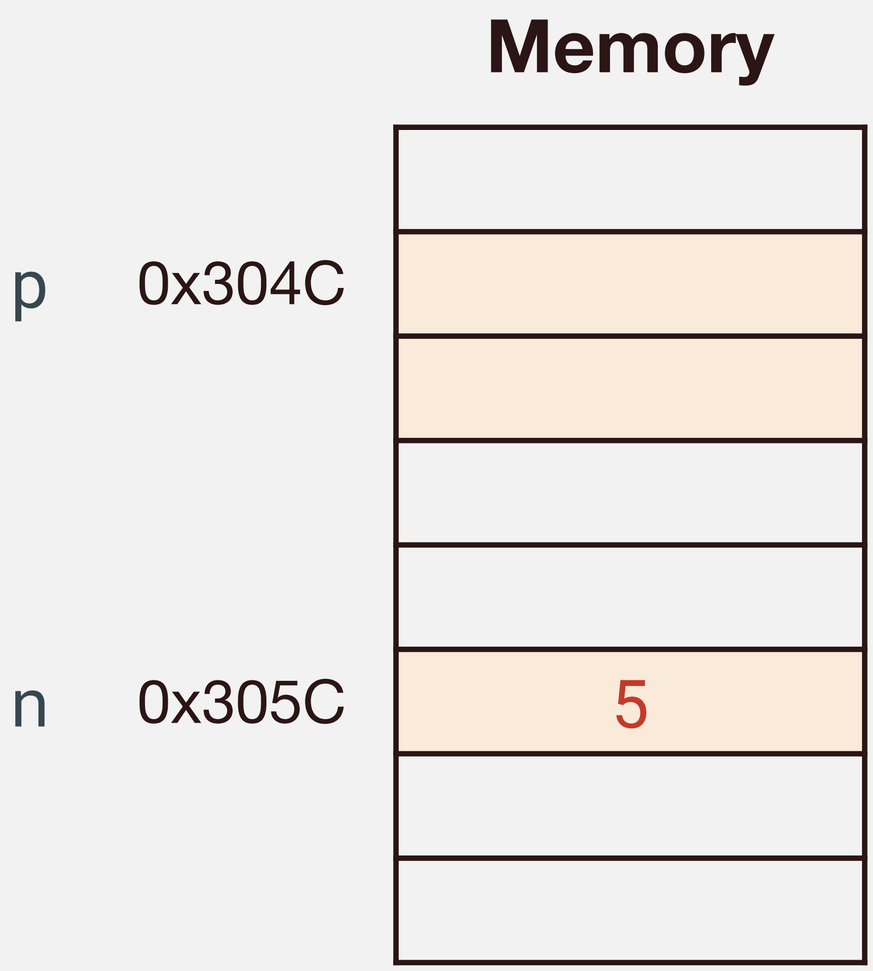
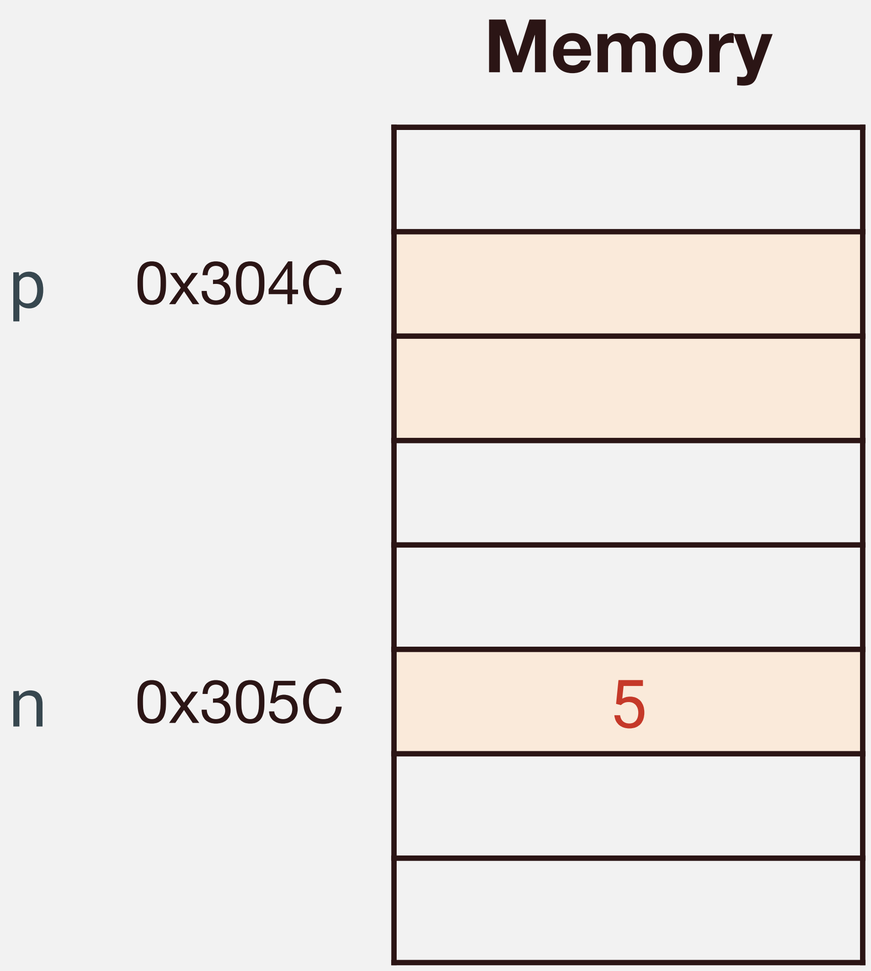


Address <—> Content

```
int main() {
  int n = 5;
  int *p;
  p = &n;



}
```



Address <—> Content

```
int main() {
  int n = 5;
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  p = &n;
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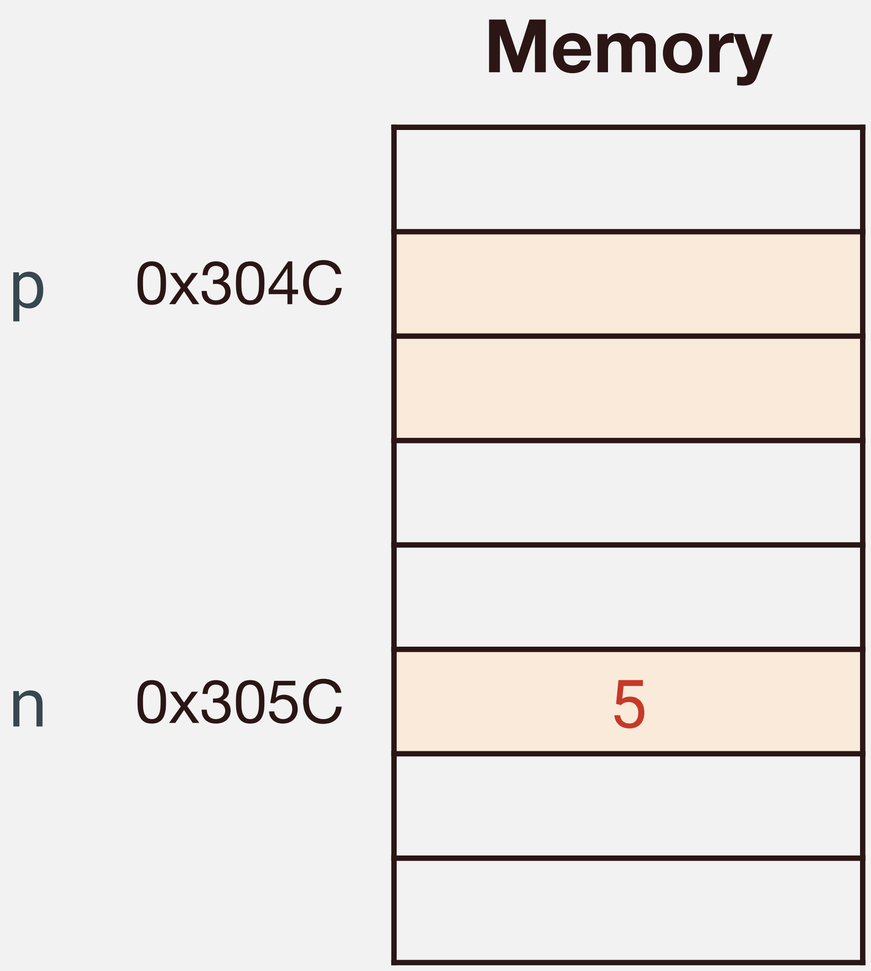
```

← Take the address of



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← Take the address of

Memory

p	0x304C	0x00000000
		0x0000305C
n	0x305C	5

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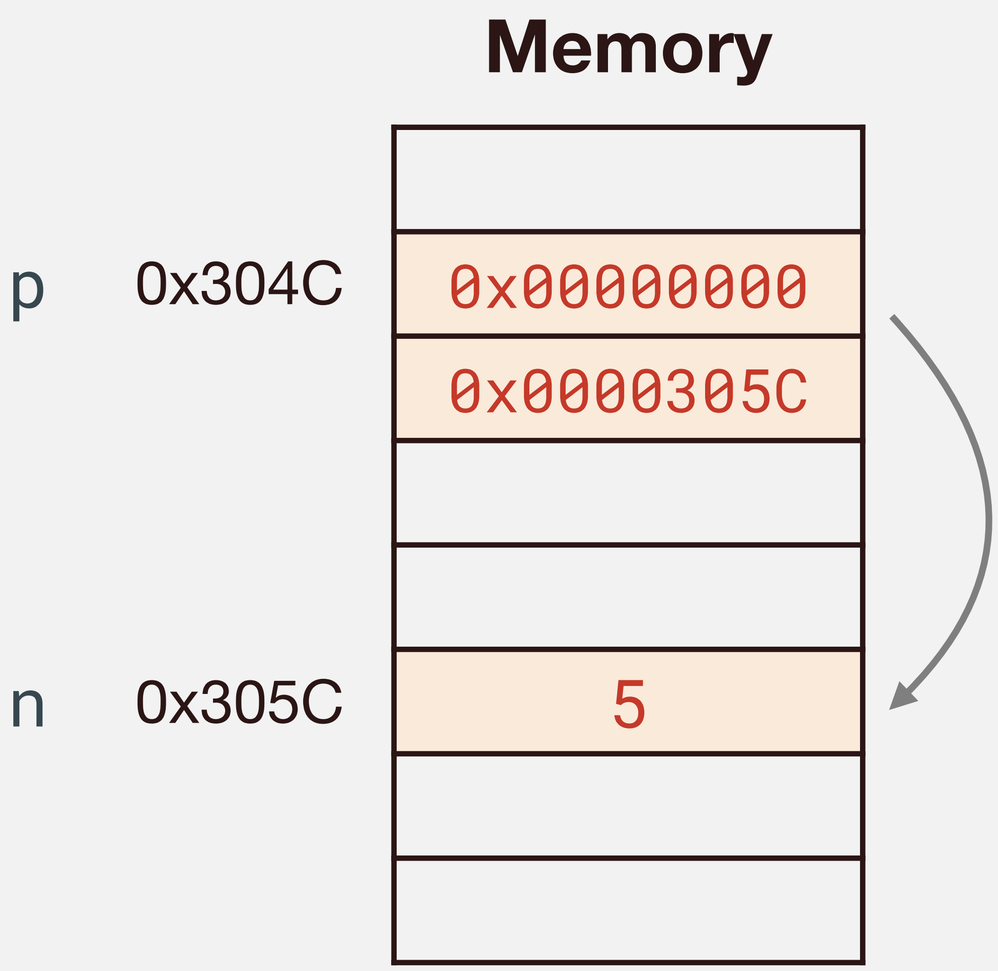
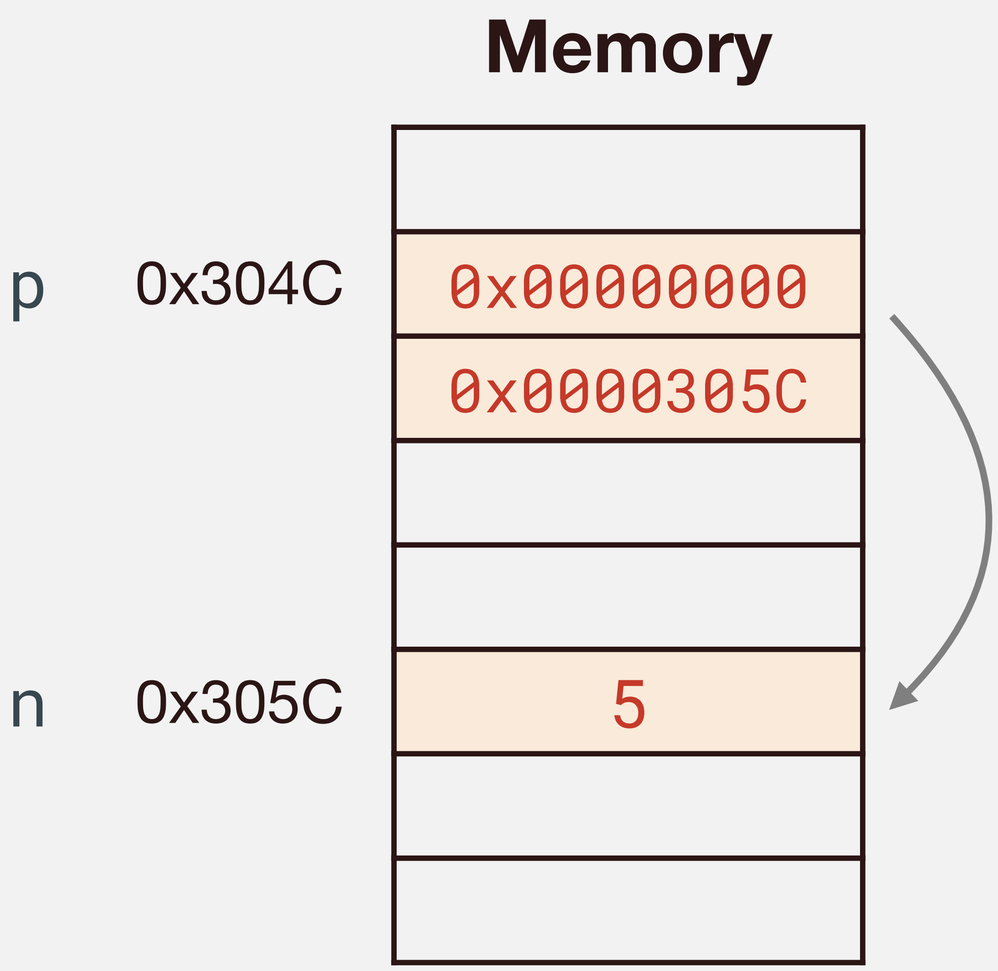


Address <—> Content

```
int main() {
  int n = 5;
  int *p;
  p = &n;
  int t = *p;

}
```

← Take the address of …



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```
int main() {
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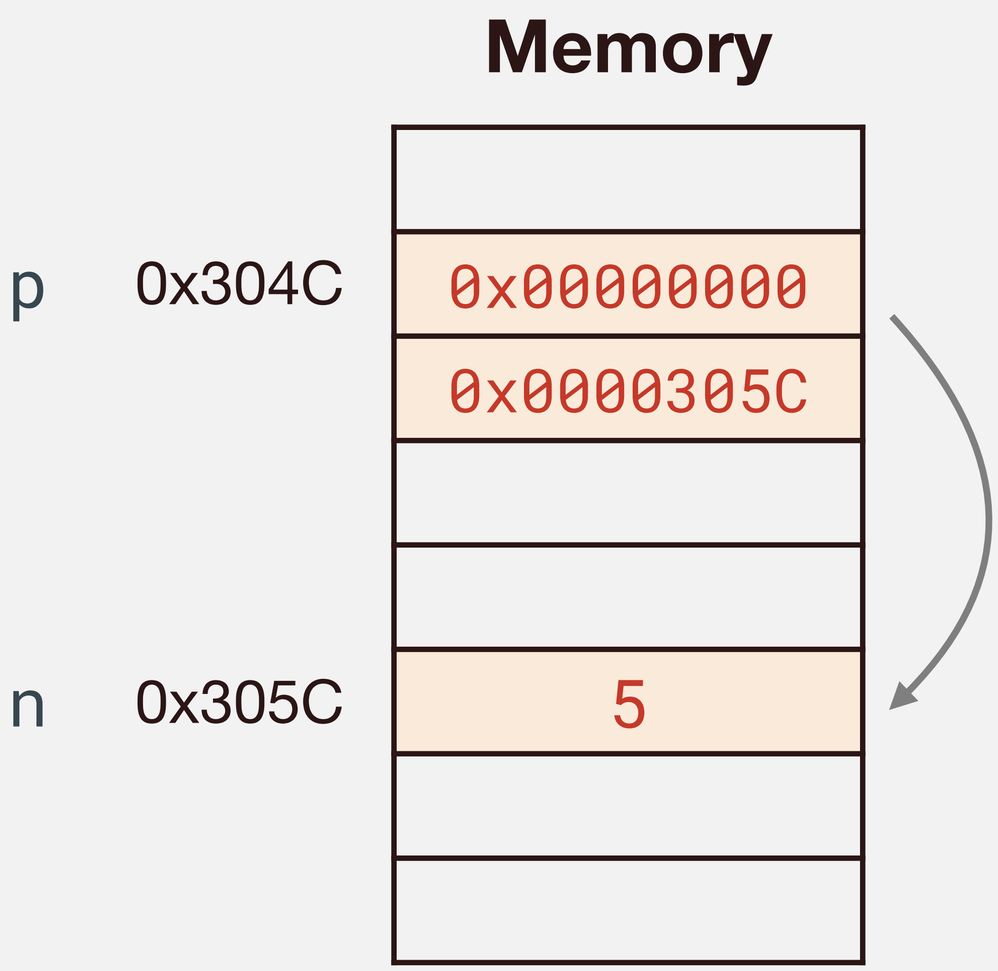
← Take the address of …

← Get the value stored at address …



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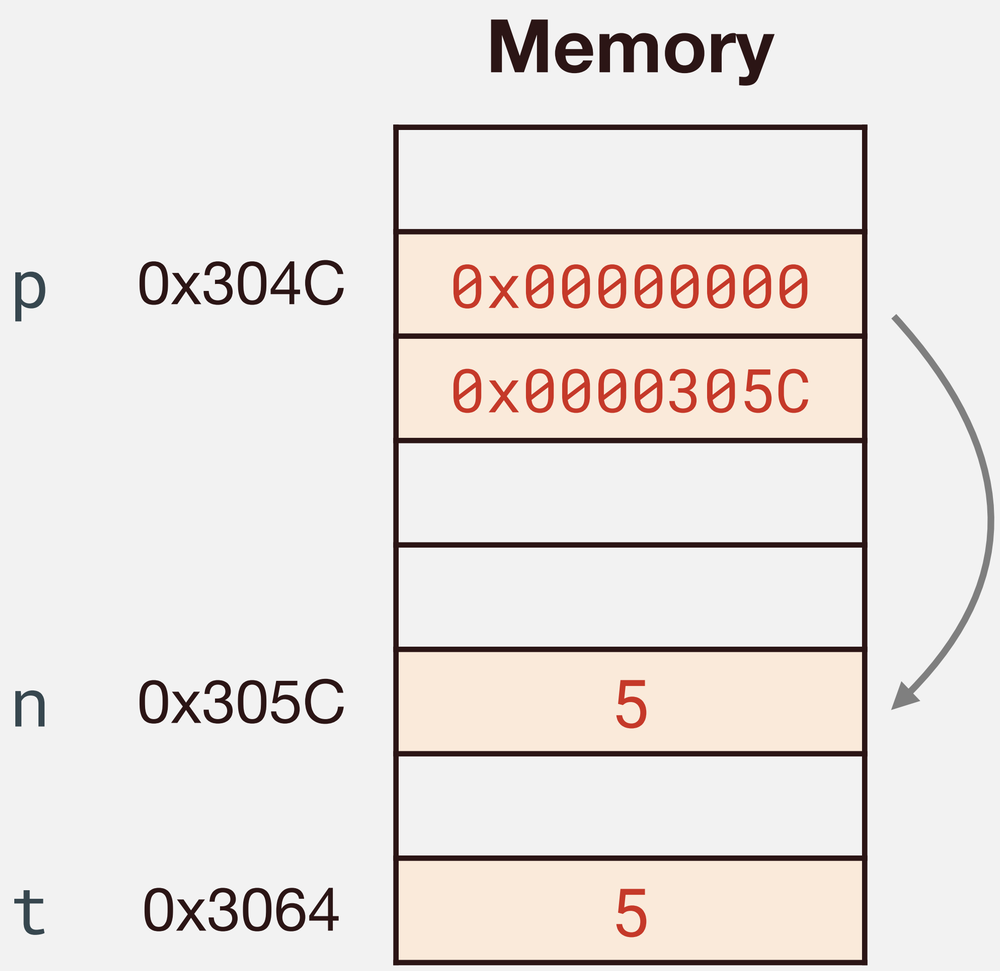


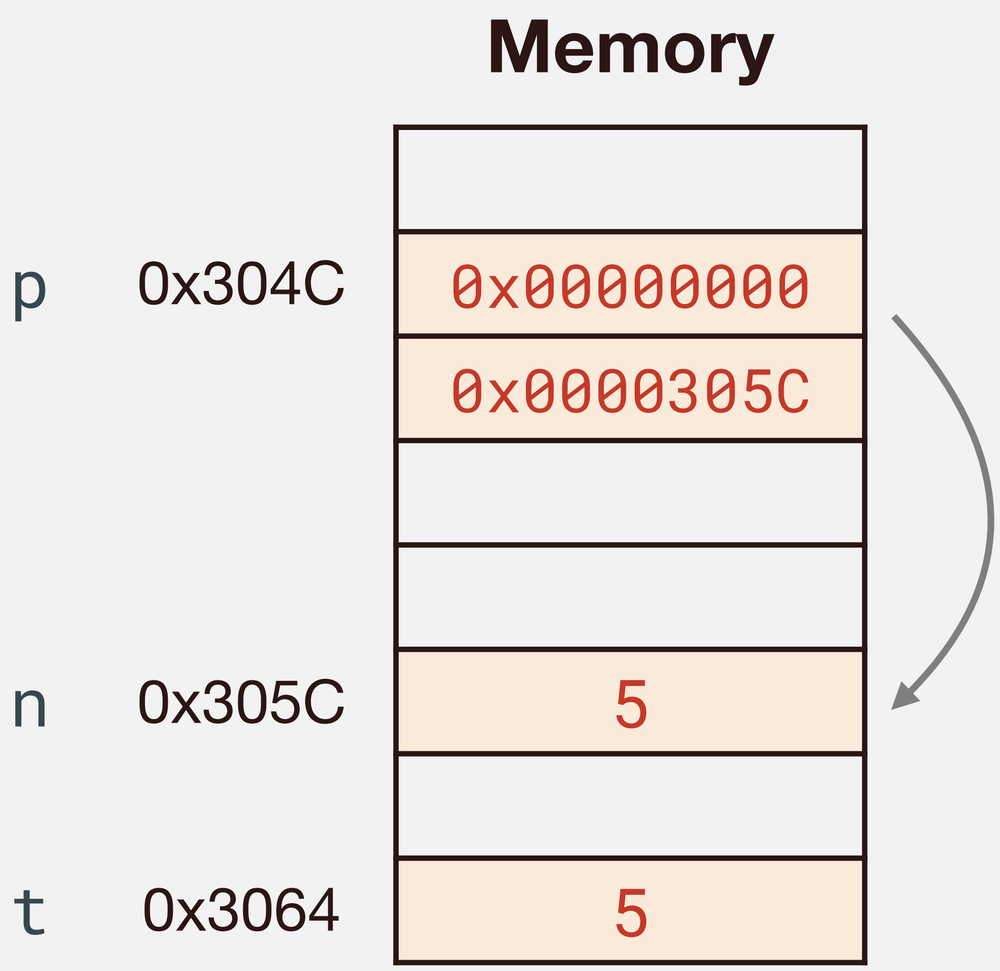
Address <—> Content

```
int main() {
  int n = 5;
  int *p;
  p = &n;
  int t = *p;
  *p = 6;

}
```

Take the address of …

Get the value stored at address …



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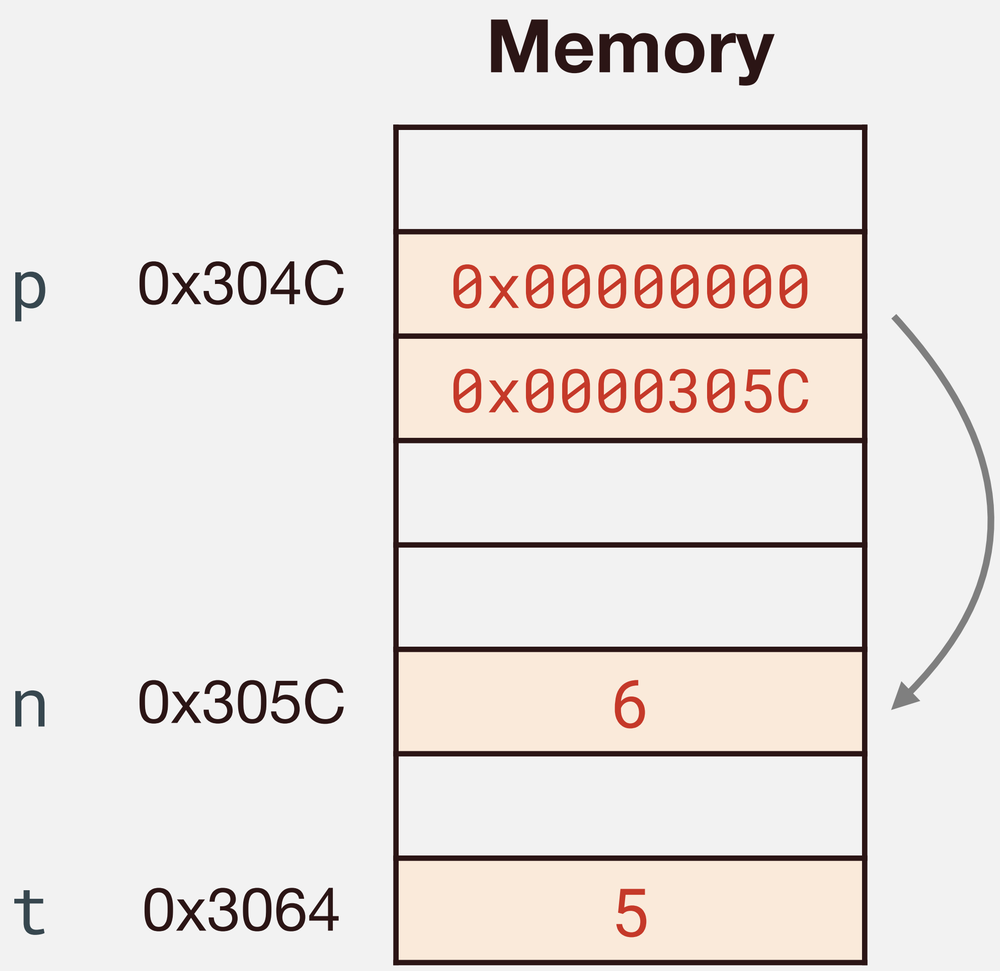

Address <—> Content

```
int main() {
  int n = 5;
  int *p;
  p = &n;
  int t = *p;
  *p = 6;
  printf("%d\n", n);


}
```

← Take the address of …

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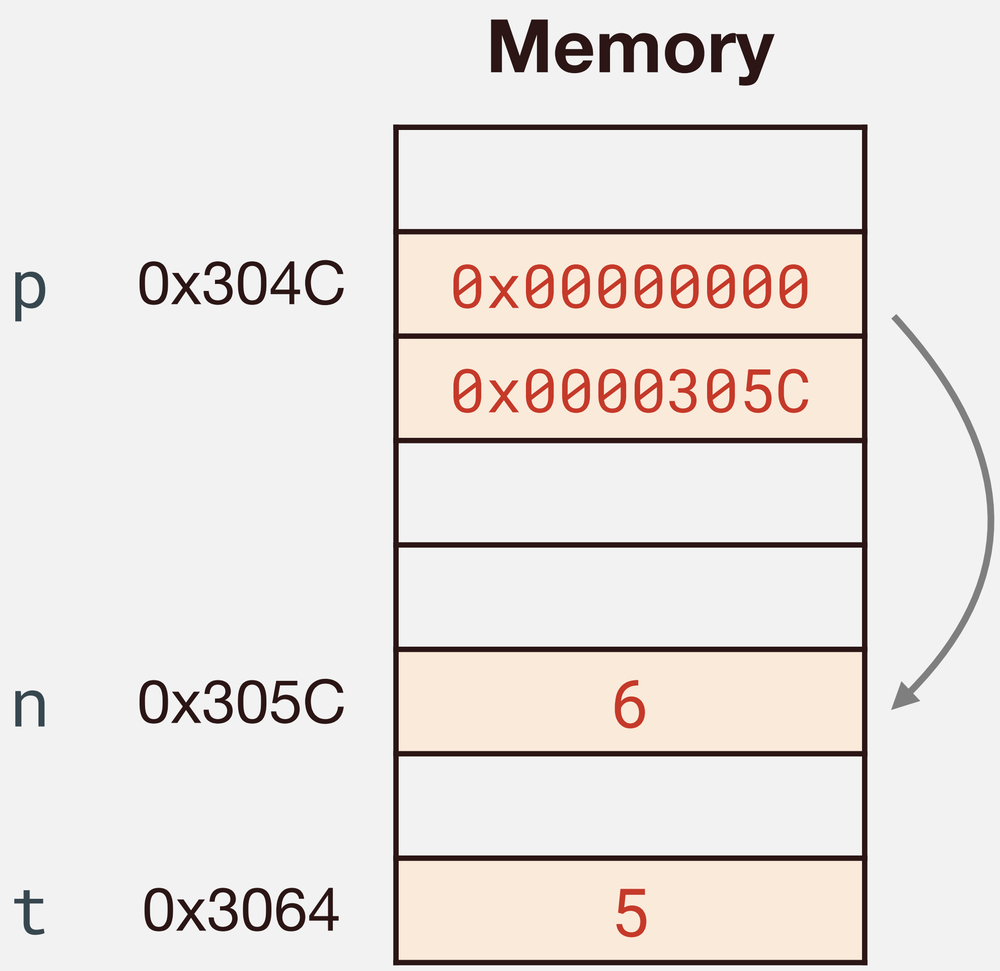

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  p = &n;
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```

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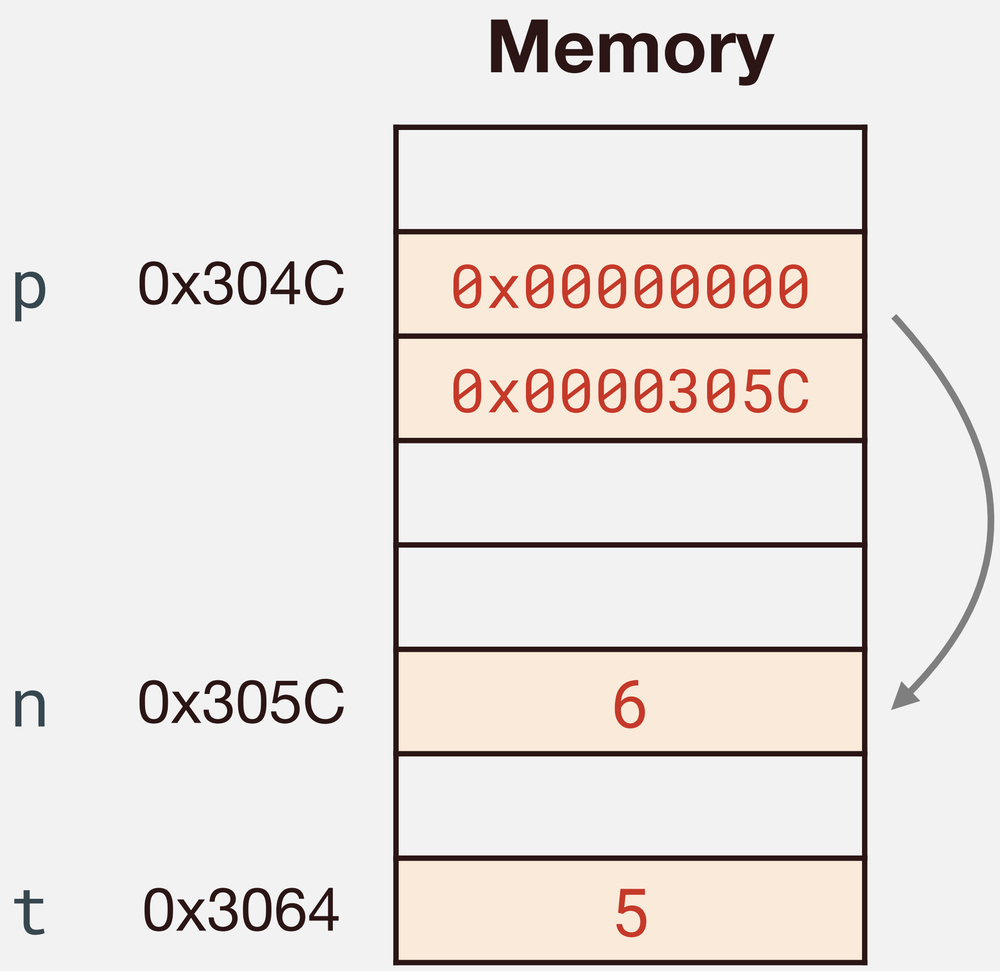

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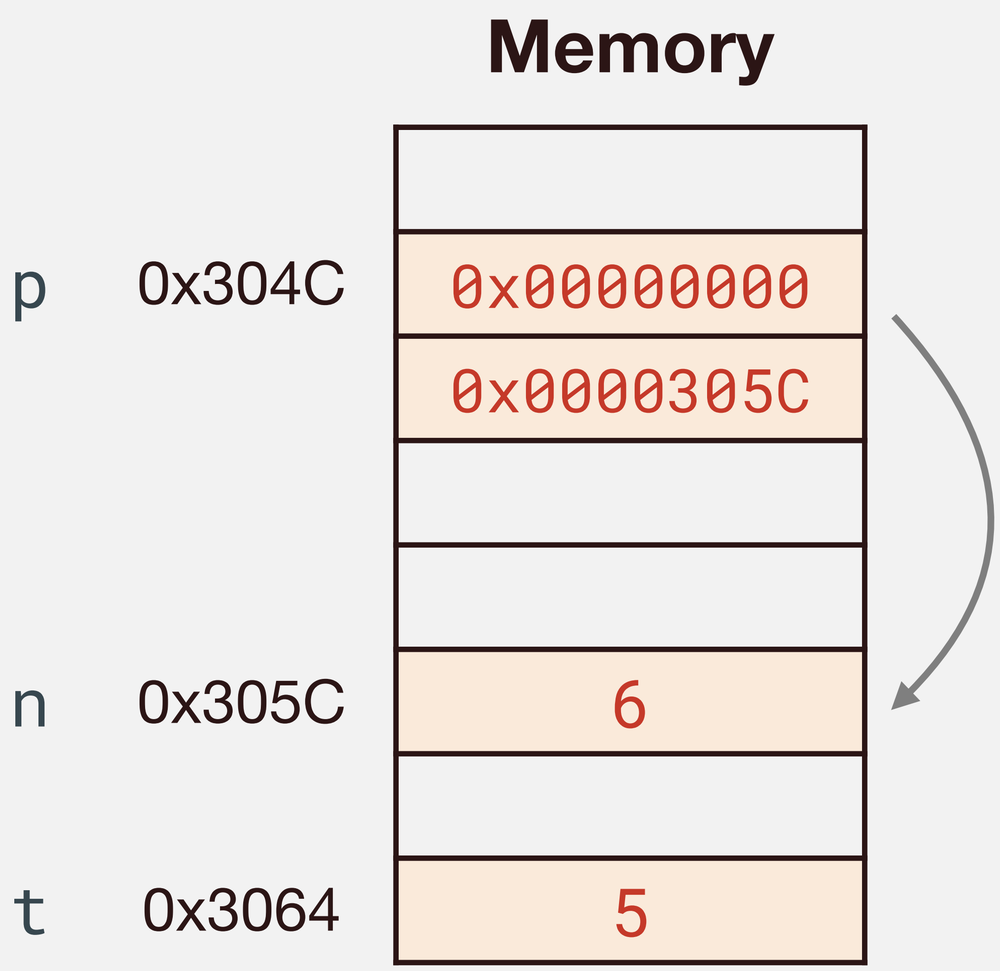

Pointer Declaration Styles

Style 1

```
int *p;
```

Style 2

```
int* p;
```

Pointer Declaration Styles

Style 1

```
int *p;

int *p = &n;
```

Style 2

```
int* p;

int* p = &n;
```

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int *p;

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Pointer Declaration Styles

Style 1

```
int *p;
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int *p, c;
```

Style 2

```
int* p;
int* p = &n;
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Pointer Declaration Styles

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```

Pointers as Function Arguments

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

int main() {
  int a = 1;
  int b = 2;
  swap(a, b);
}
```

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```

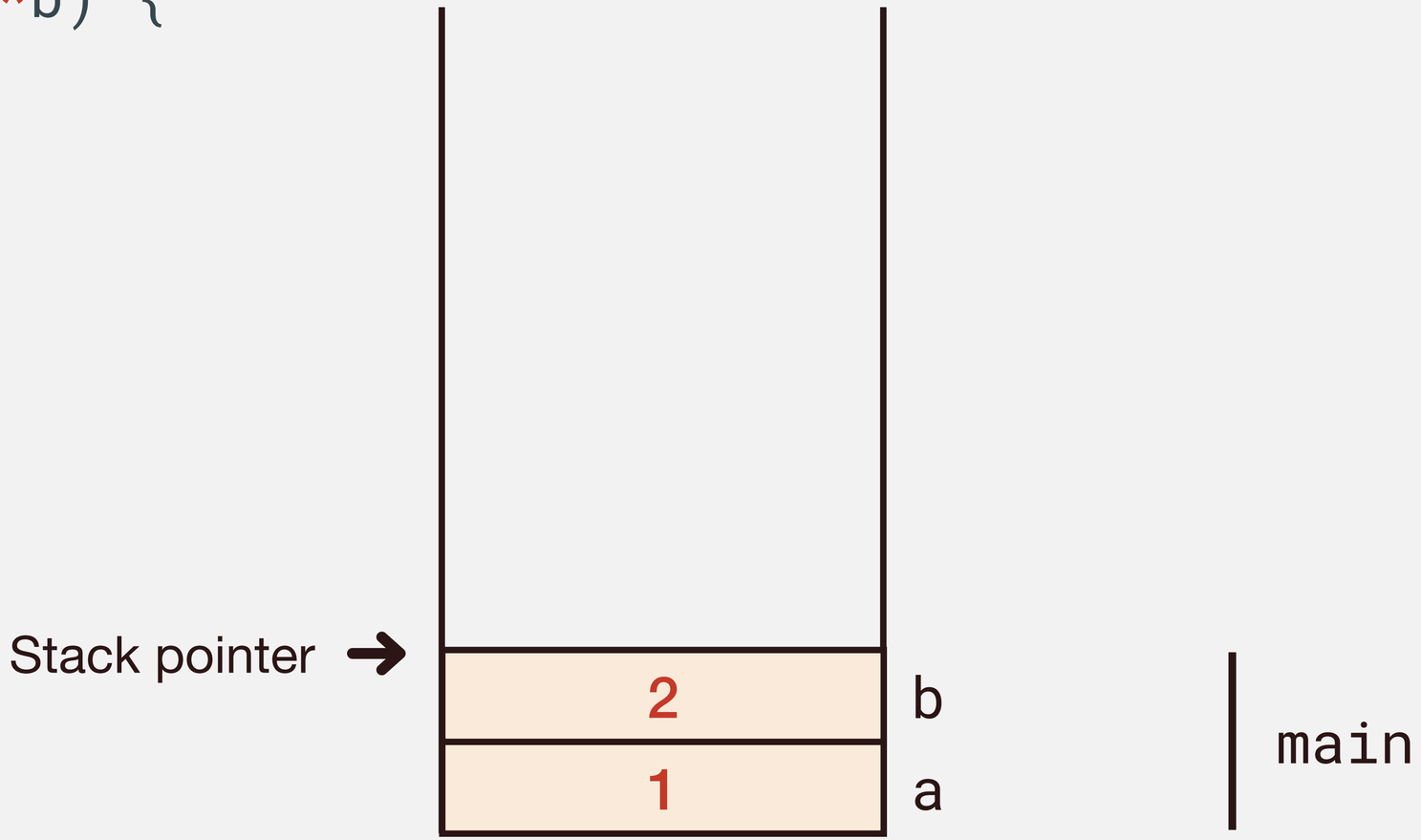

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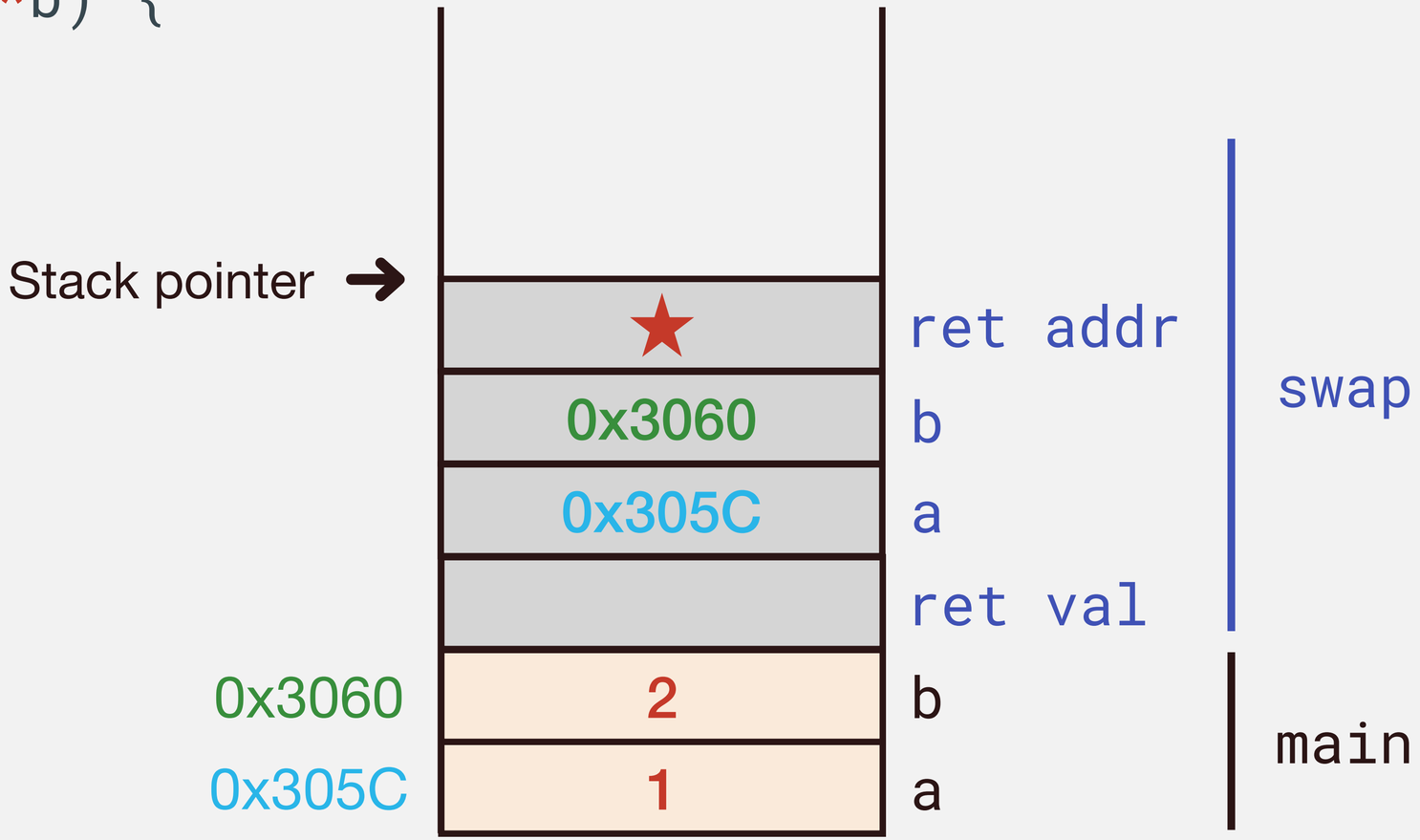
```



Pointers as Function Arguments

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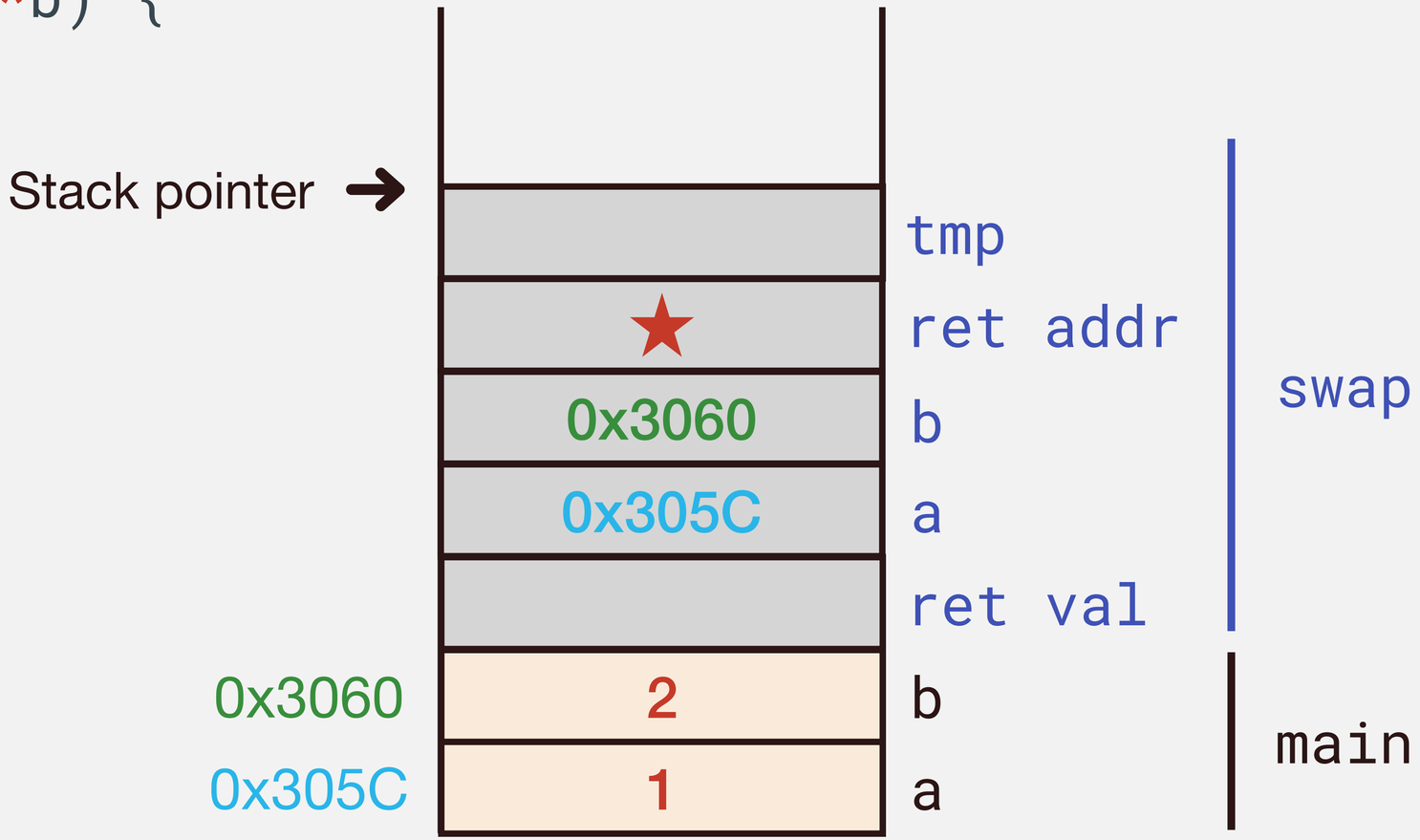

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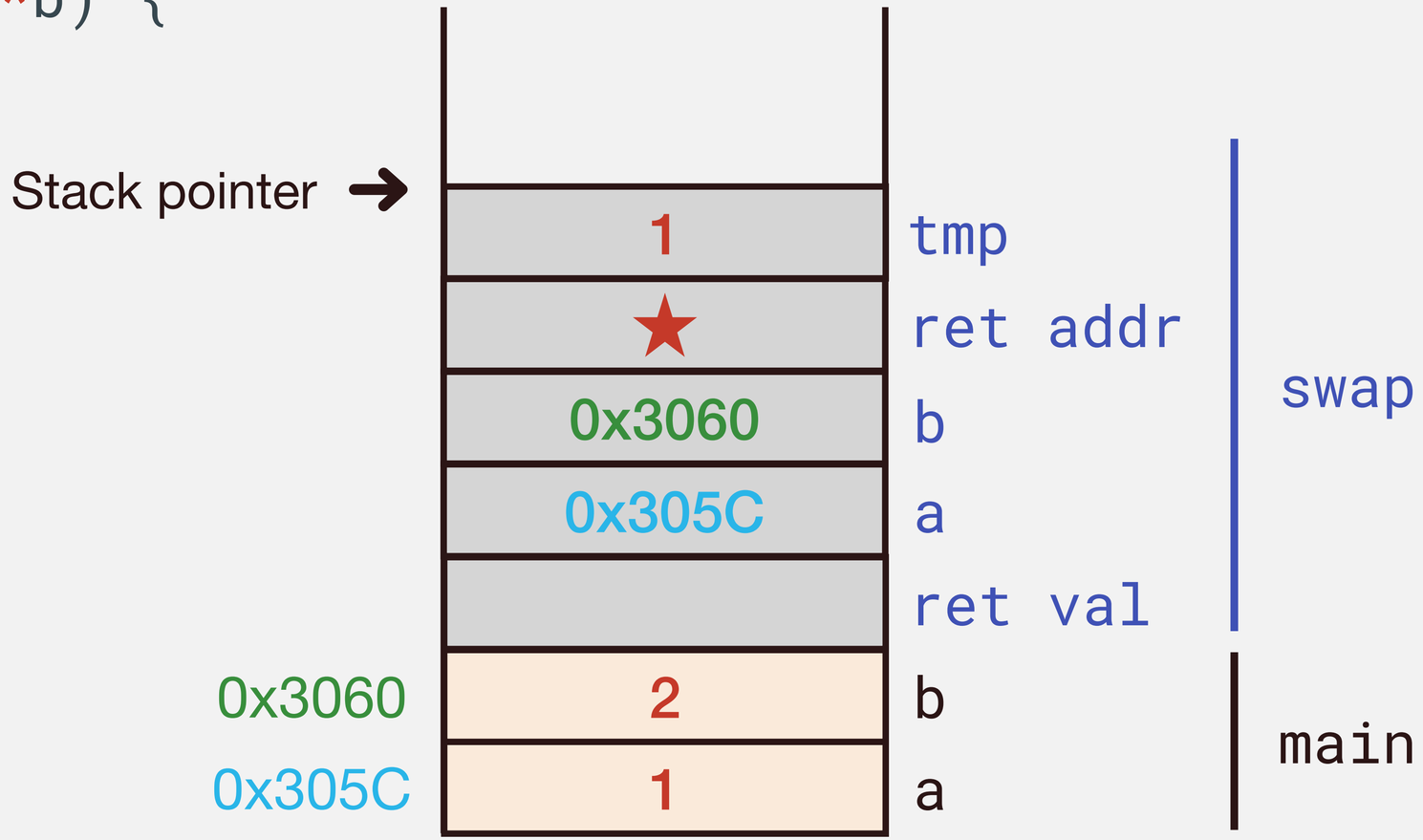

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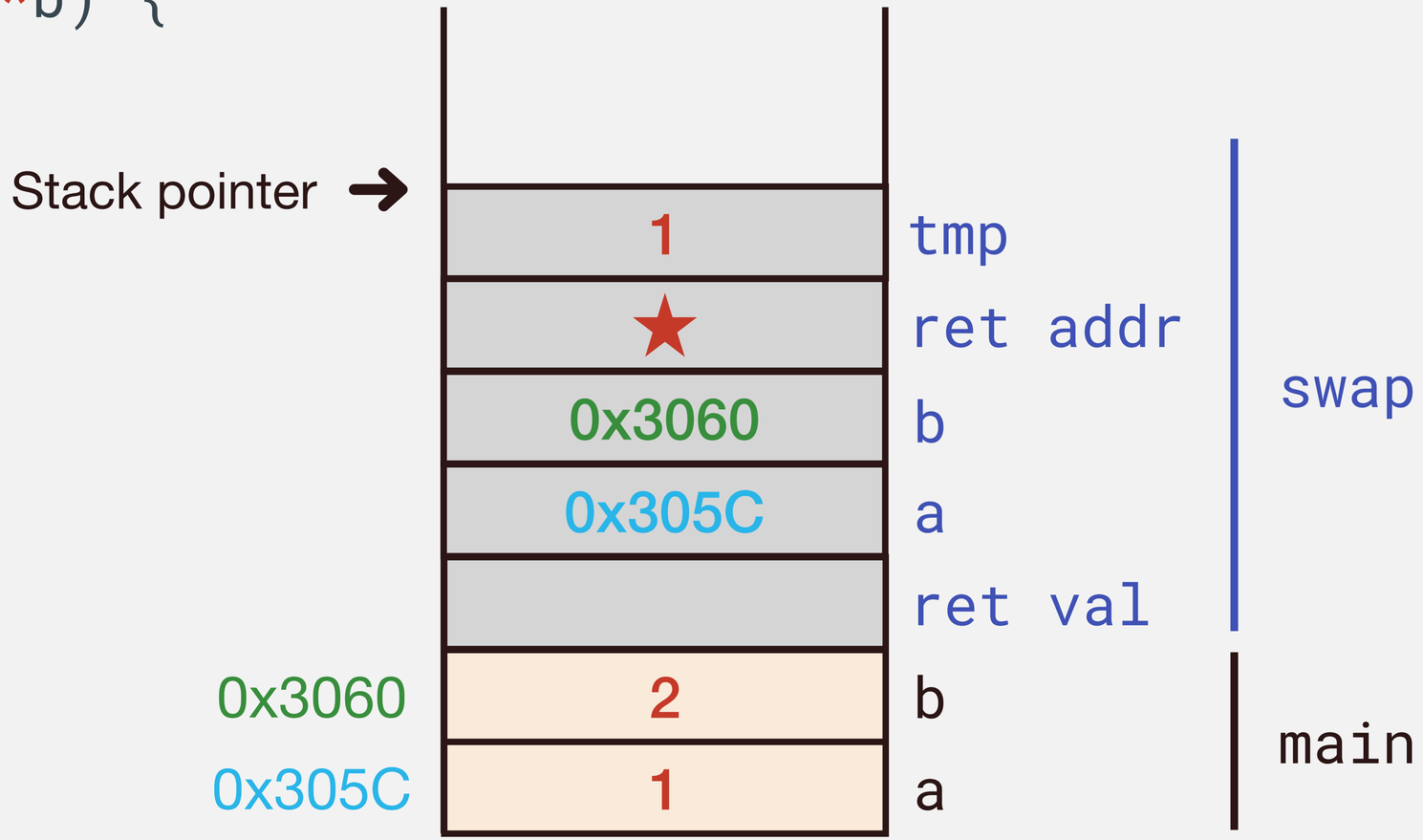

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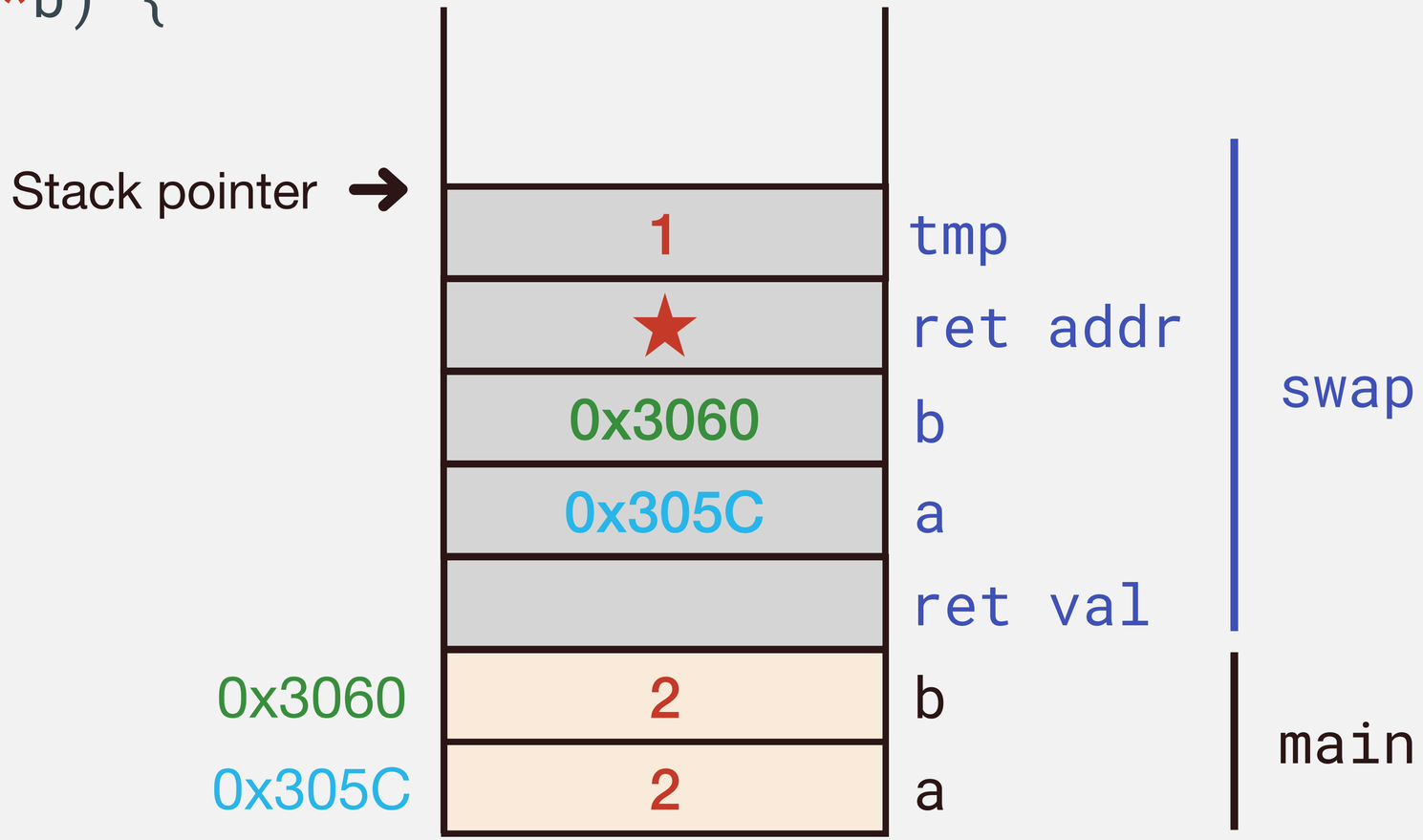

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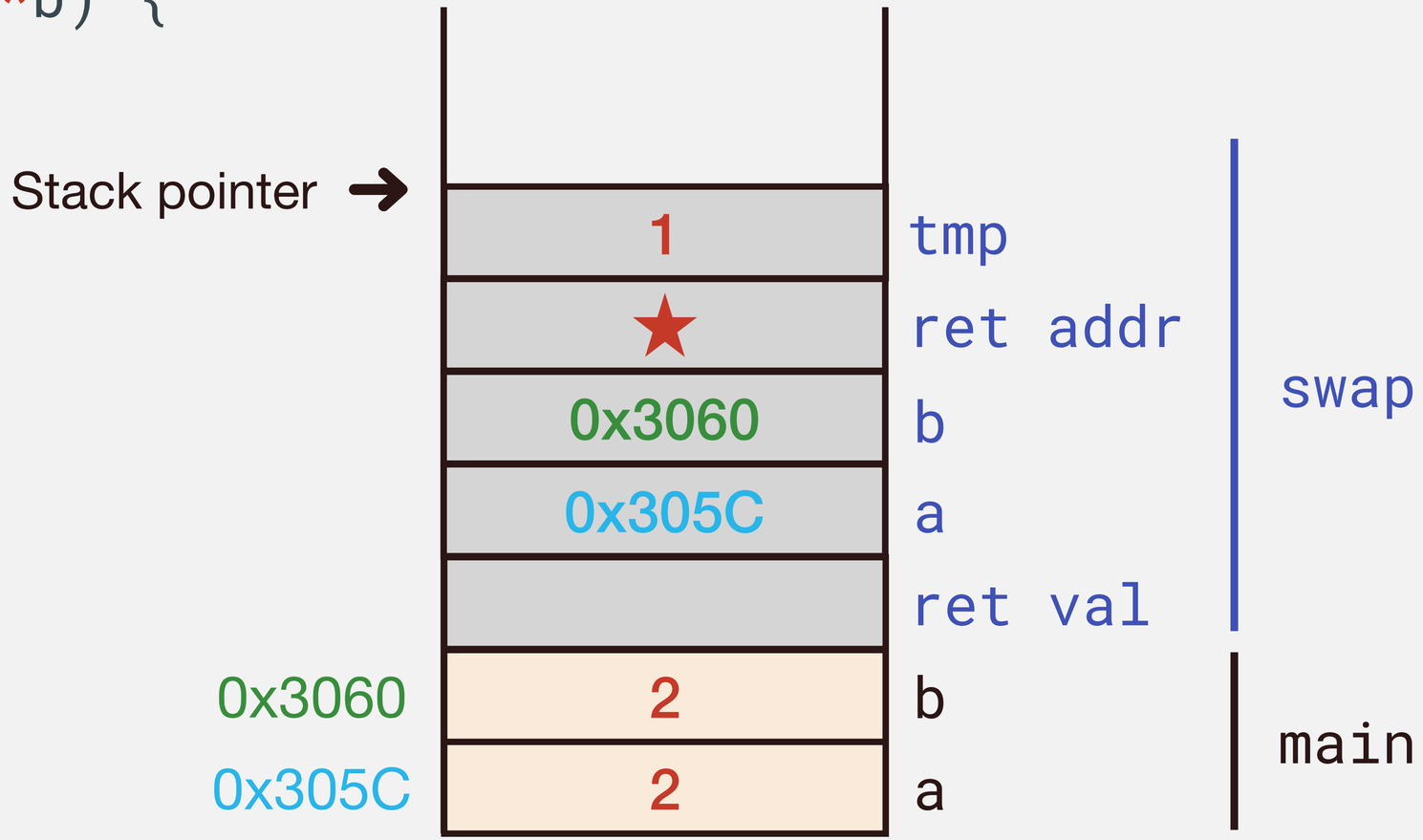

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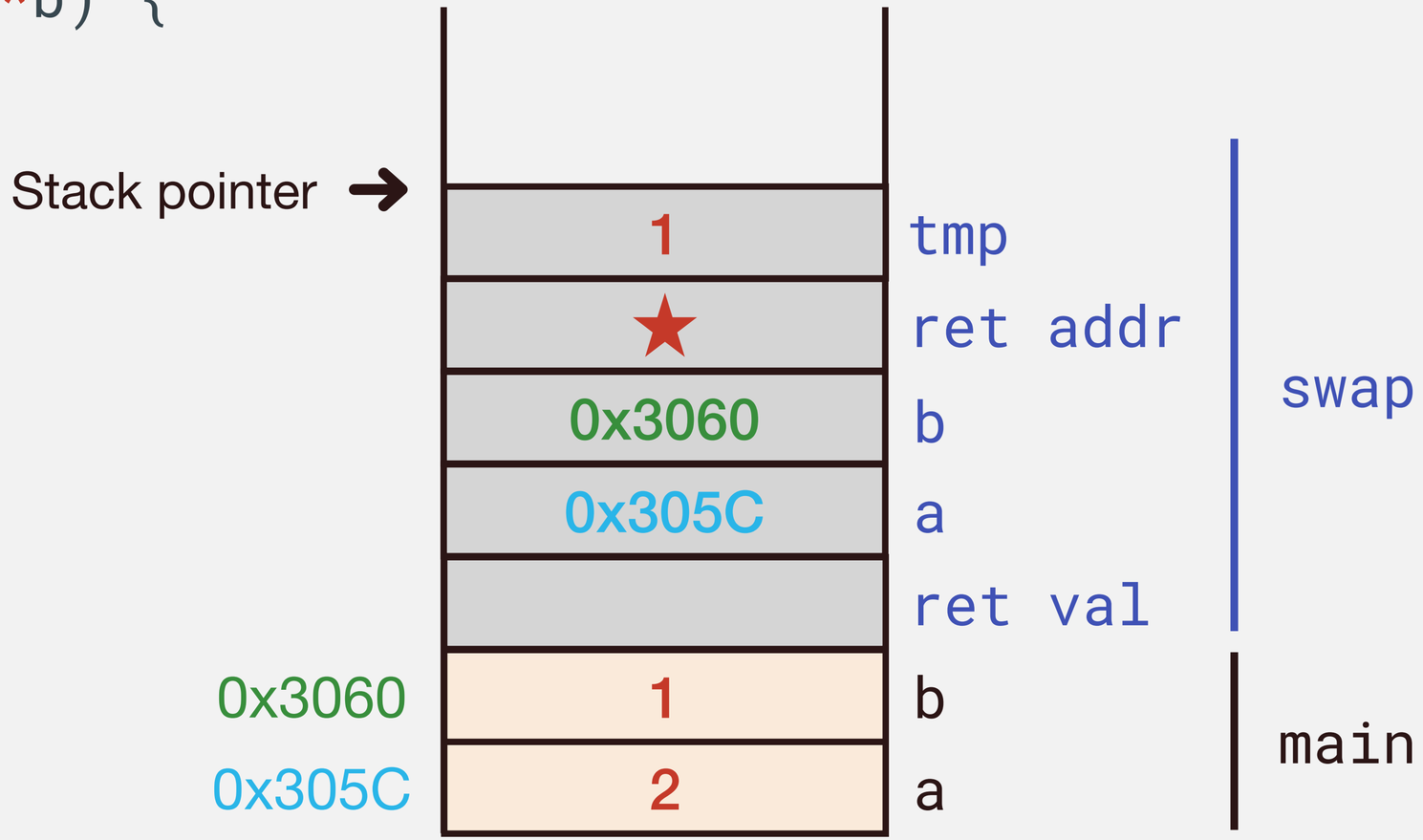

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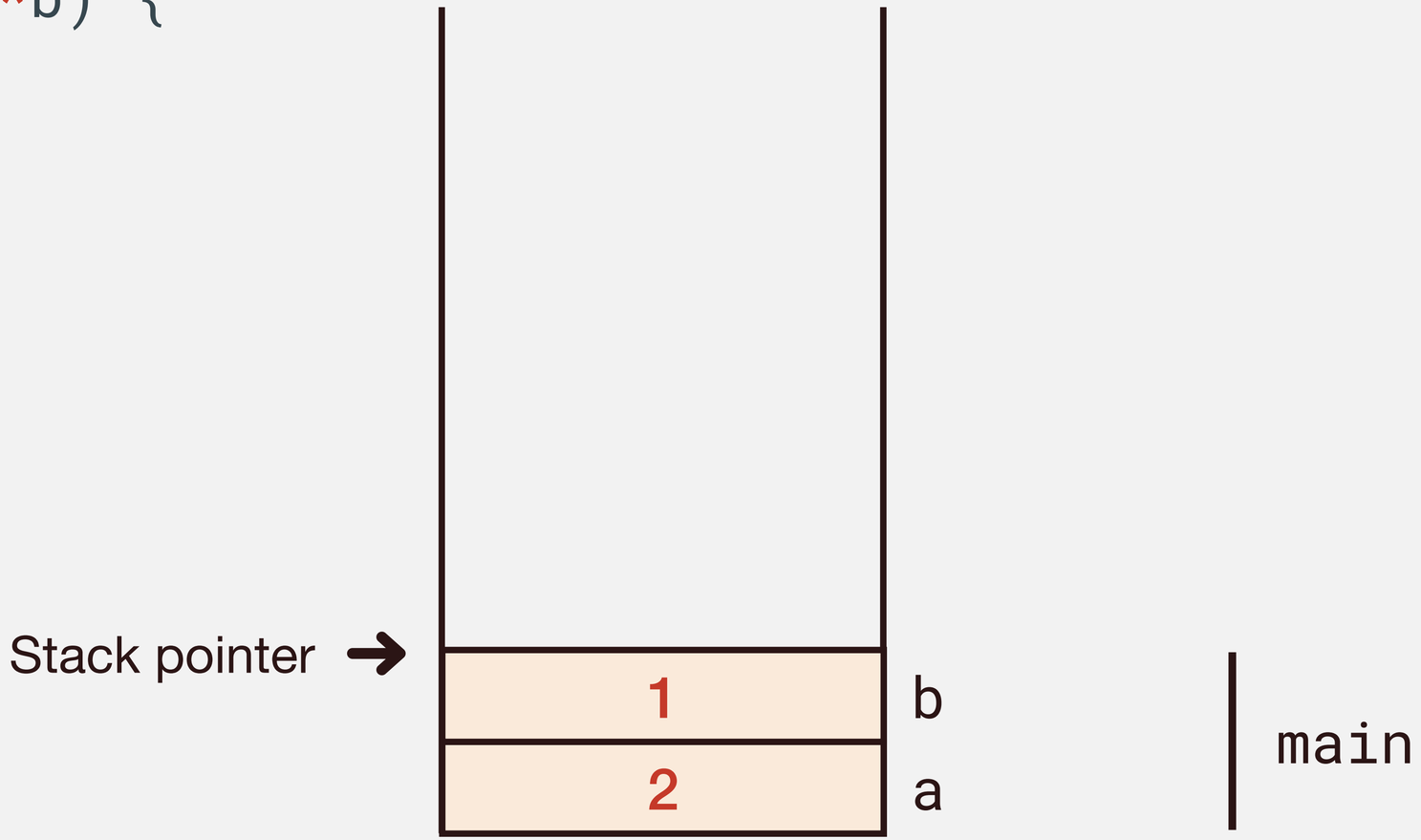
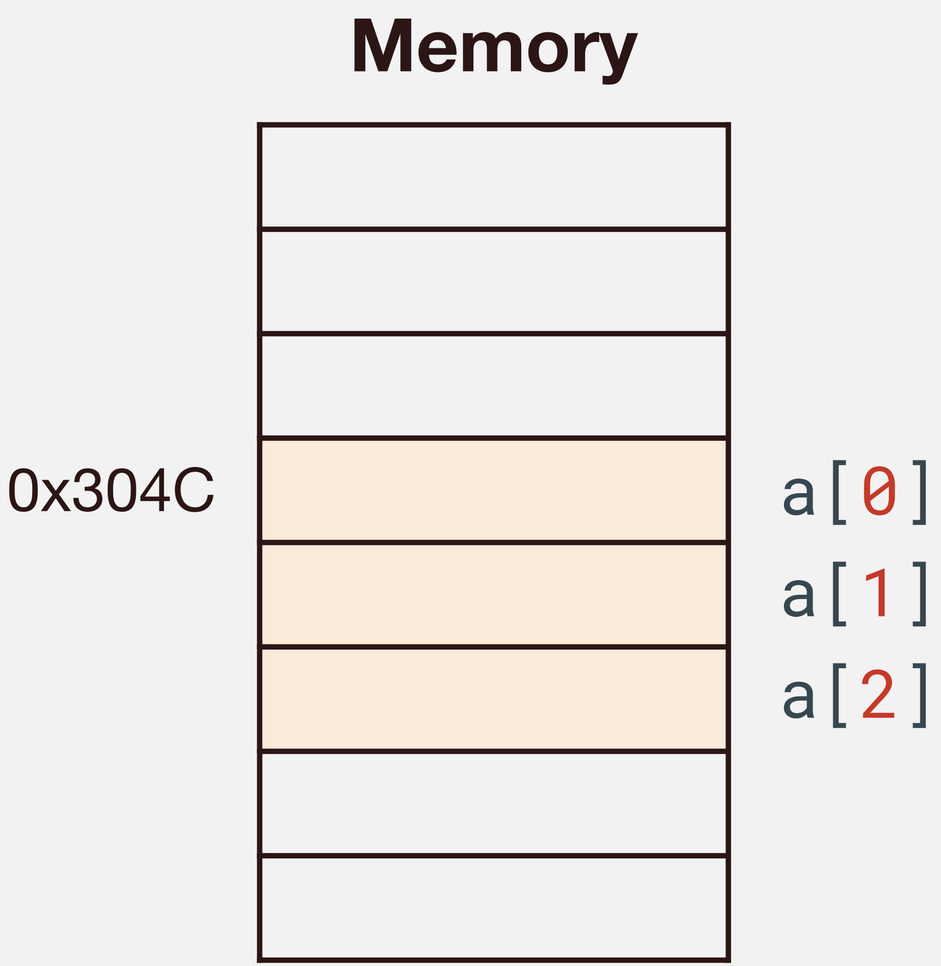
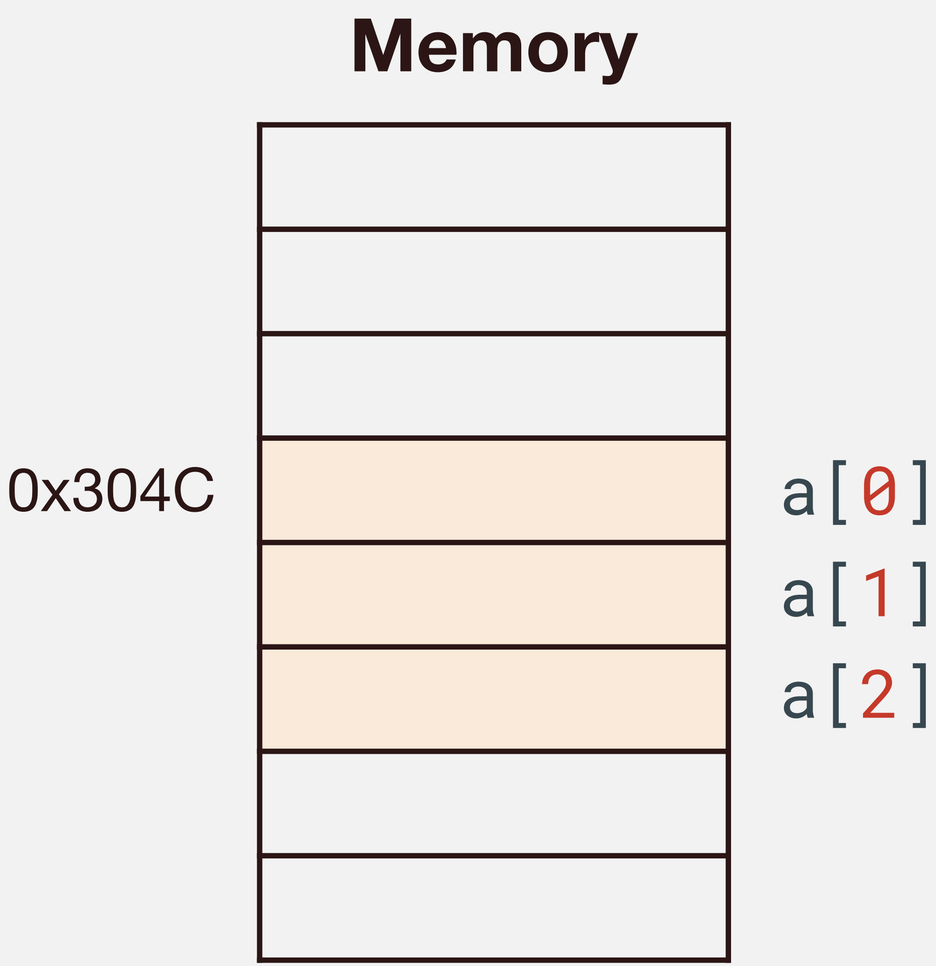


Pointers and Arrays




```
int a[3];
```

Pointers and Arrays

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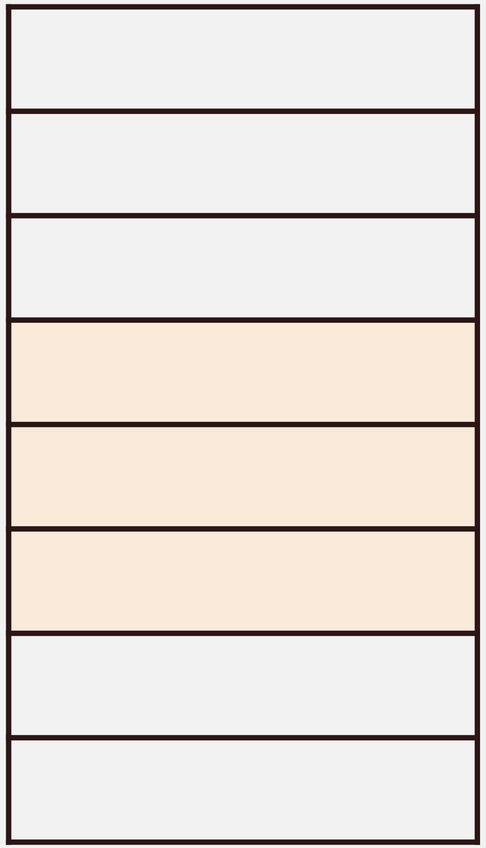
pointer to the first element

Pointers and Arrays

Memory



0x304C

```
int a[3];
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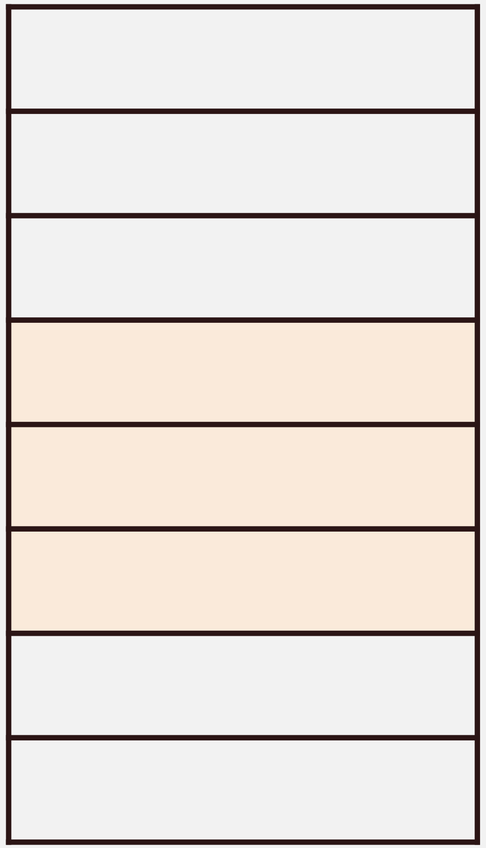
pointer to the first element

```
a[0] ⟷ *a
a[1]
a[2]
```

Pointers and Arrays

Memory



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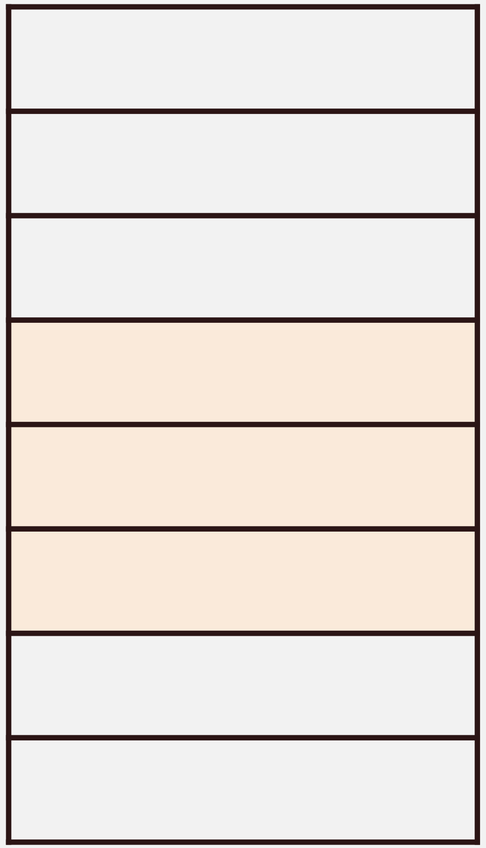
Pointers and Arrays

Memory



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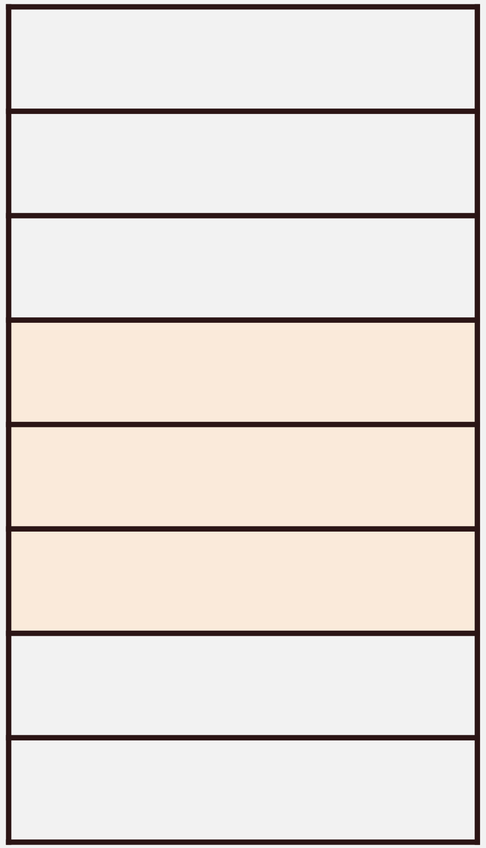

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```
a[0] ⟷ *a
a[1] ⟷ *(a + 1)
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```
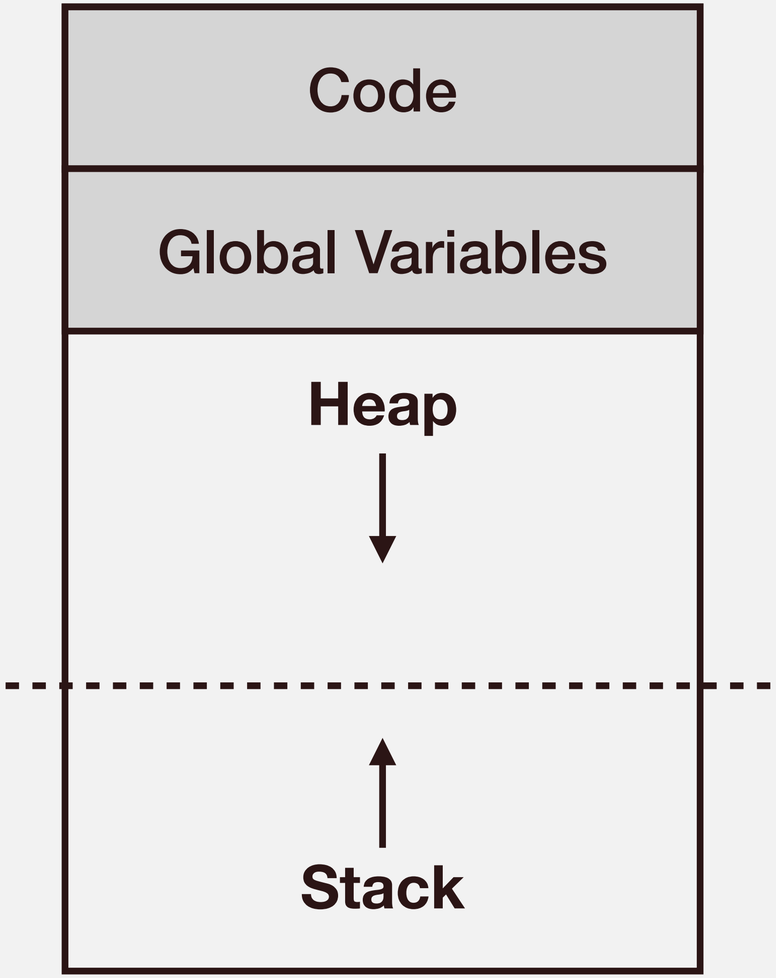

pointer arithmetic

```
a + 1
0x304C + 1 * sizeof(int)
```

Memory Layout



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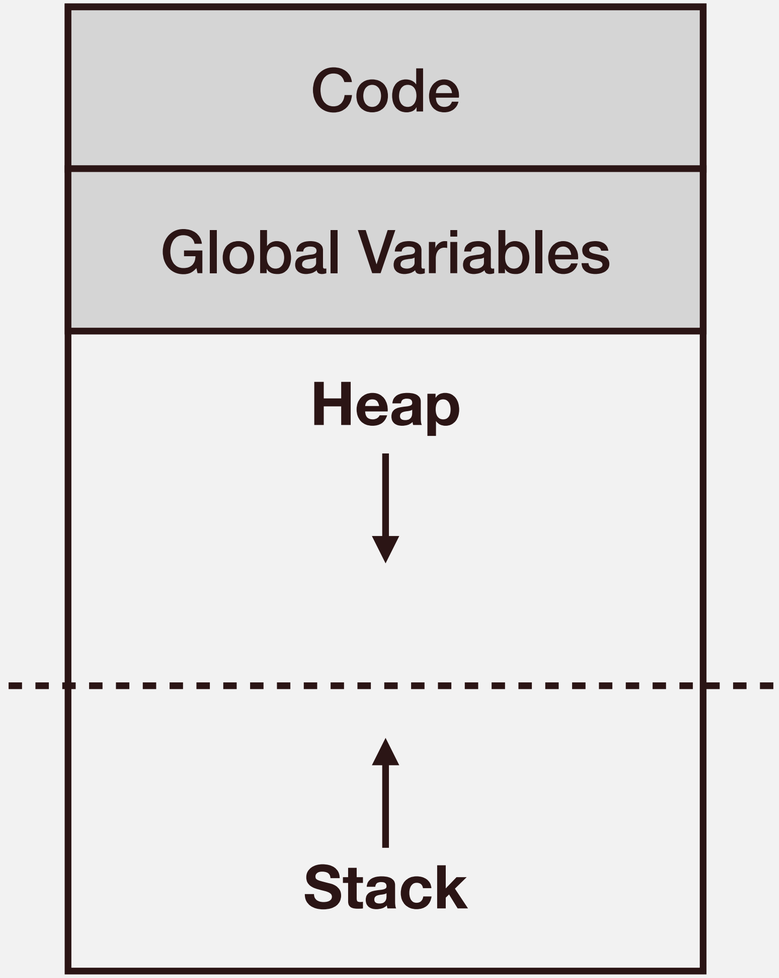
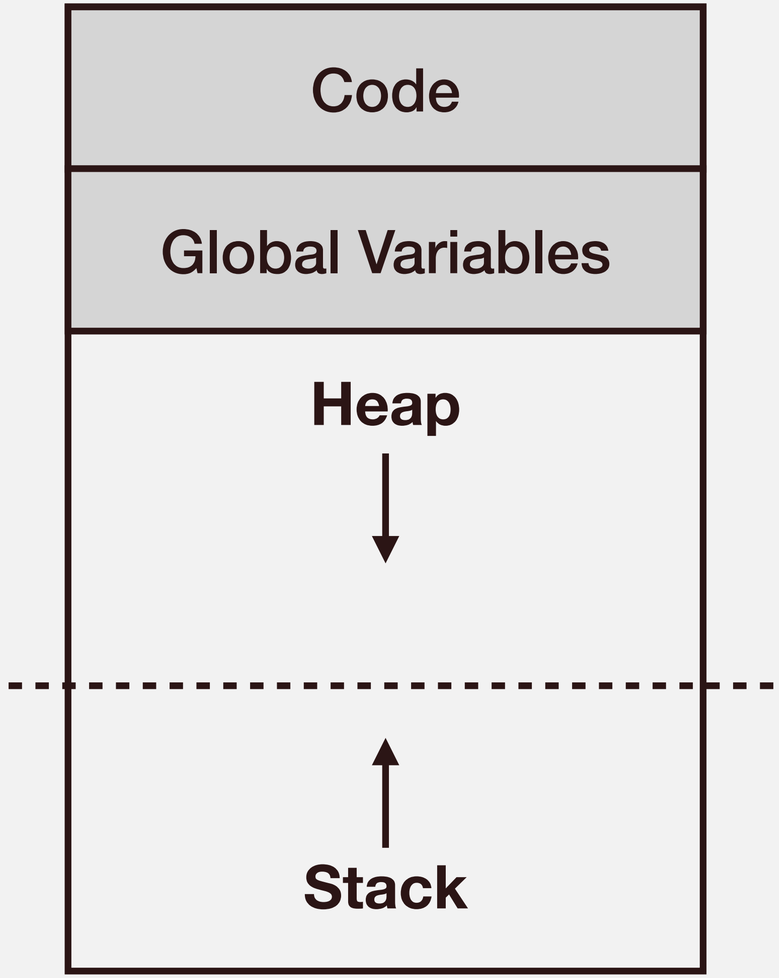



```
int x;
char a[64];
```

Memory Layout




```
int *p = malloc(size)
```

```
int x;
char a[64];
```

Dynamic Memory Allocation

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```
int a[100];
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Stack Array

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int a[100];
```
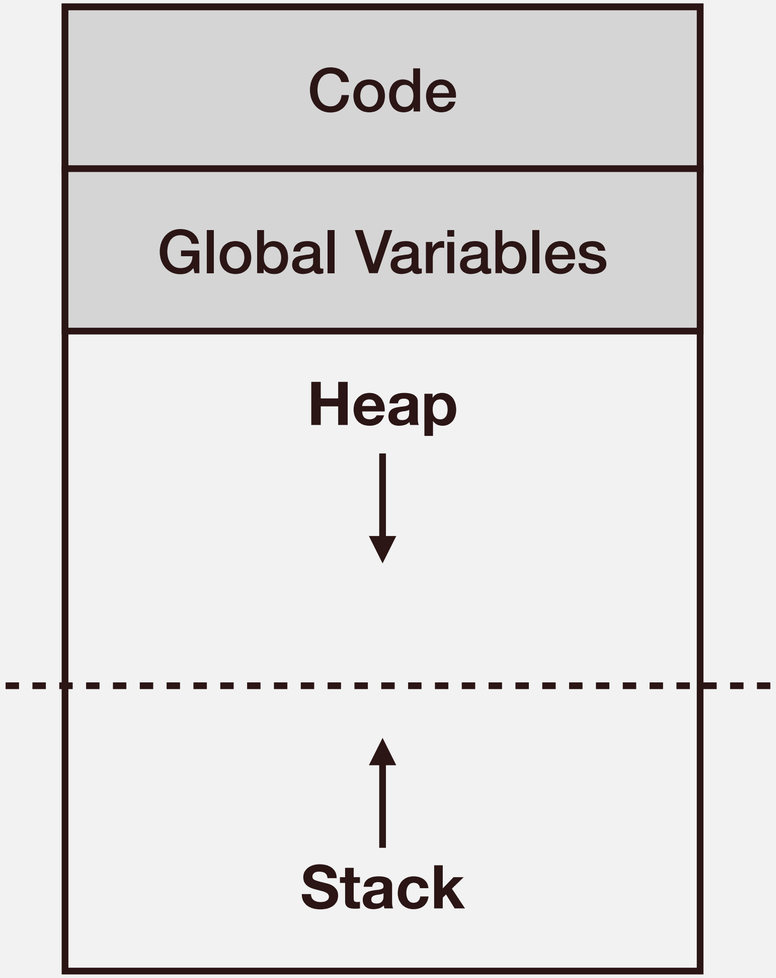
Stack Array

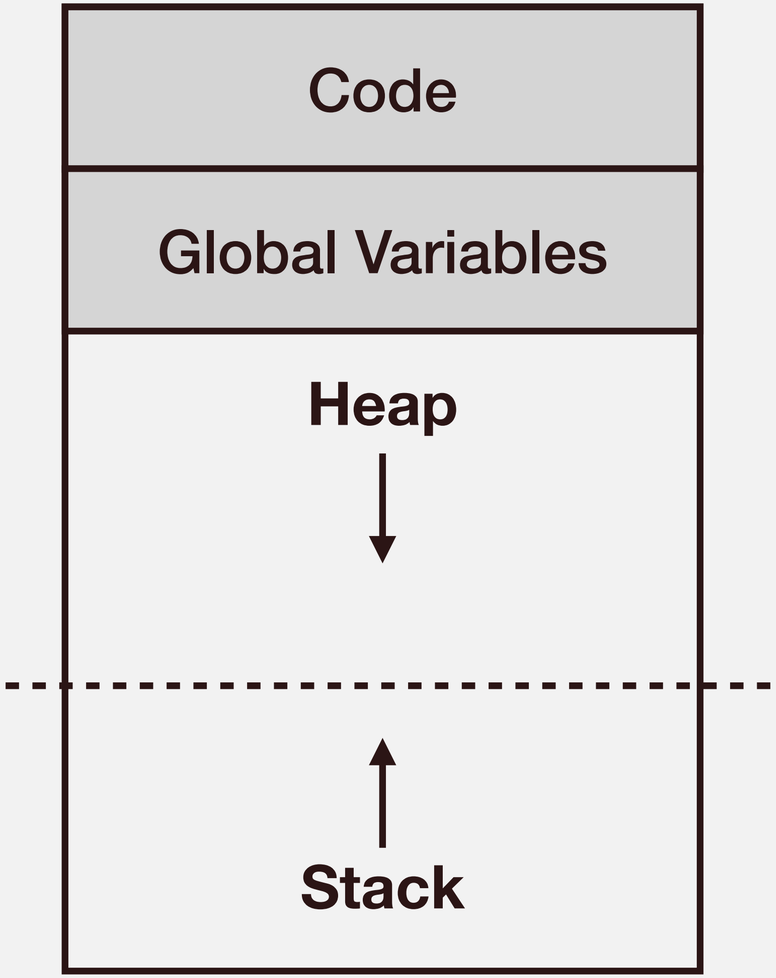
`free(pointer)` → Reclaim the memory for later use

Memory Layout



	Stack	Heap
Scope		
Size Limit		
GC		
Resize?		
Usage		

Memory Layout



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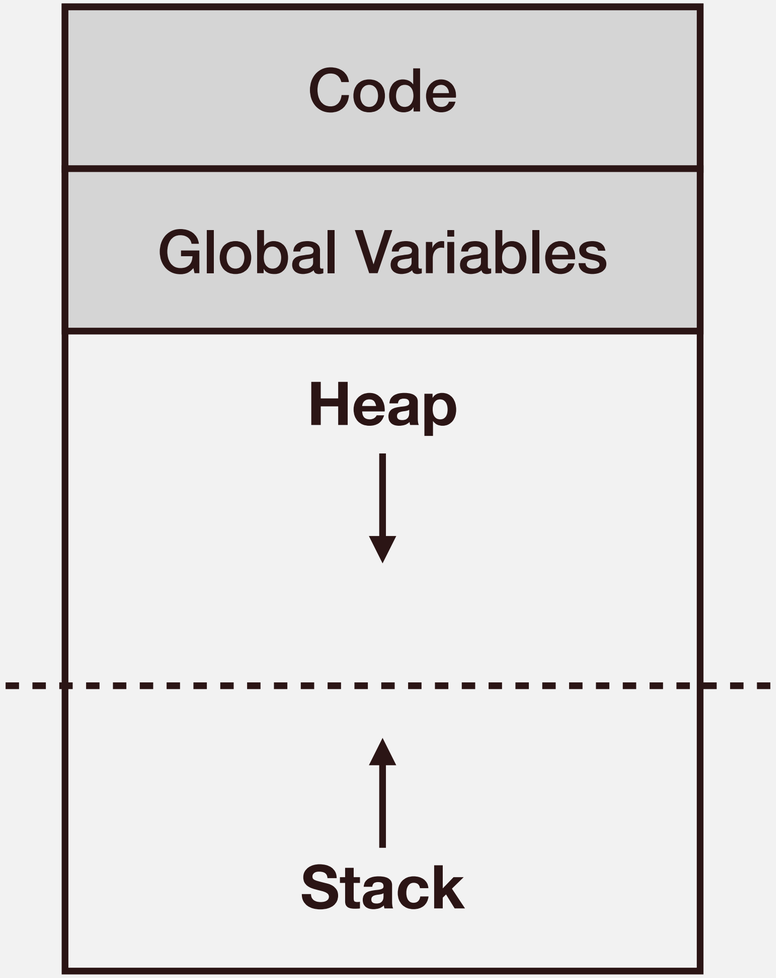

	Stack	Heap
Scope	Local	Global
Size Limit	By OS	Physical Mem
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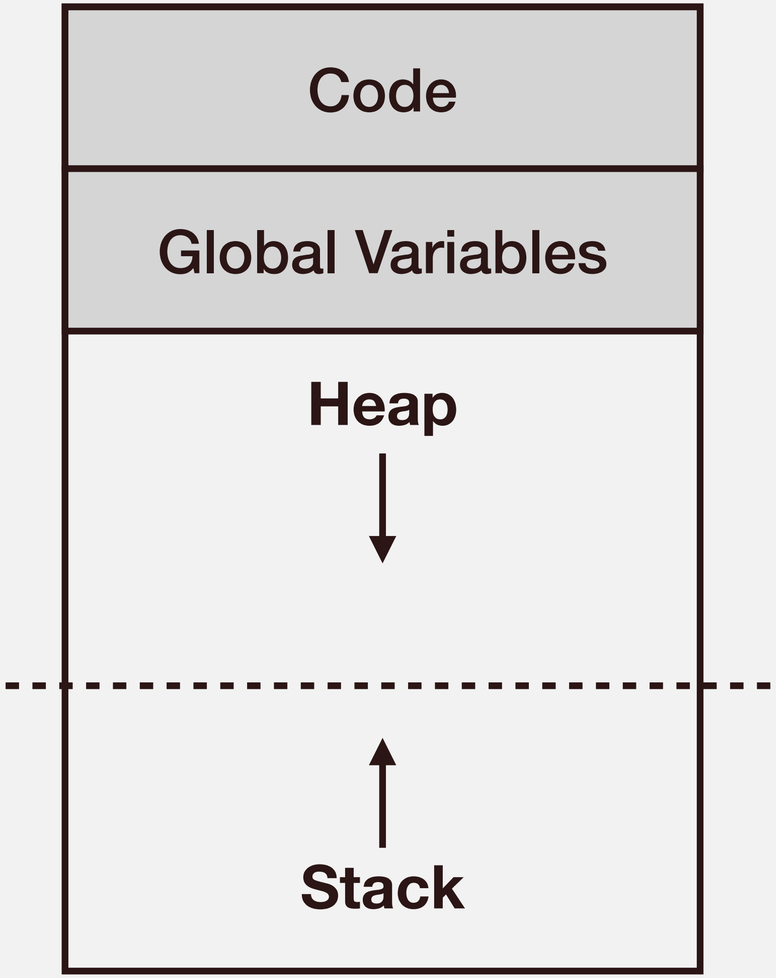
Memory Layout



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Scope	Local	Global
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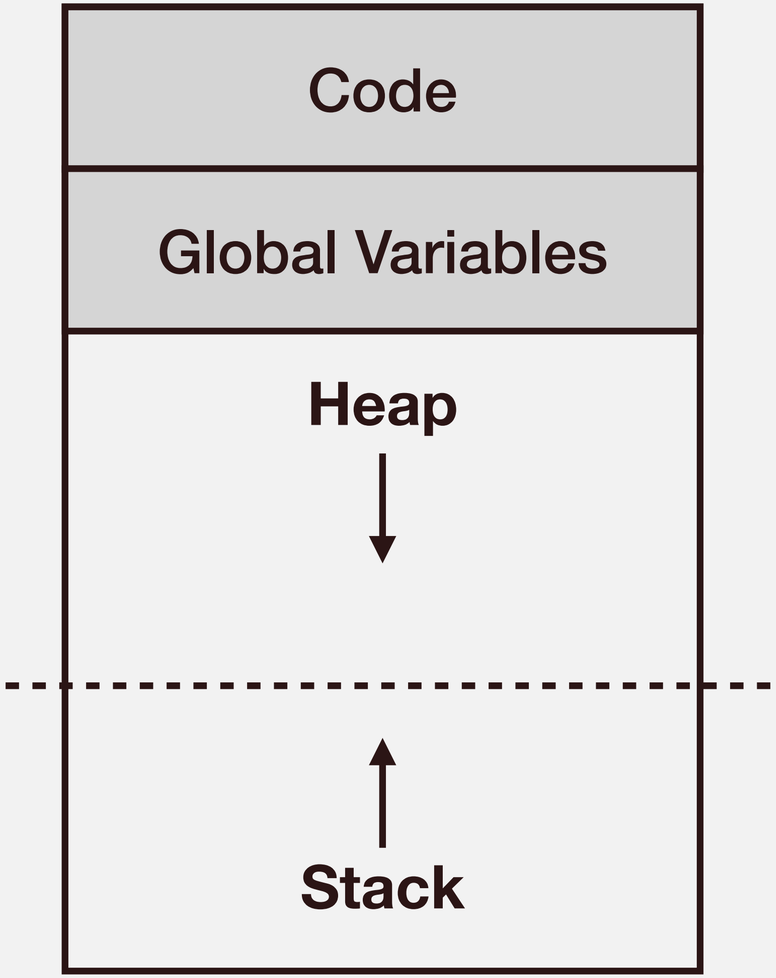

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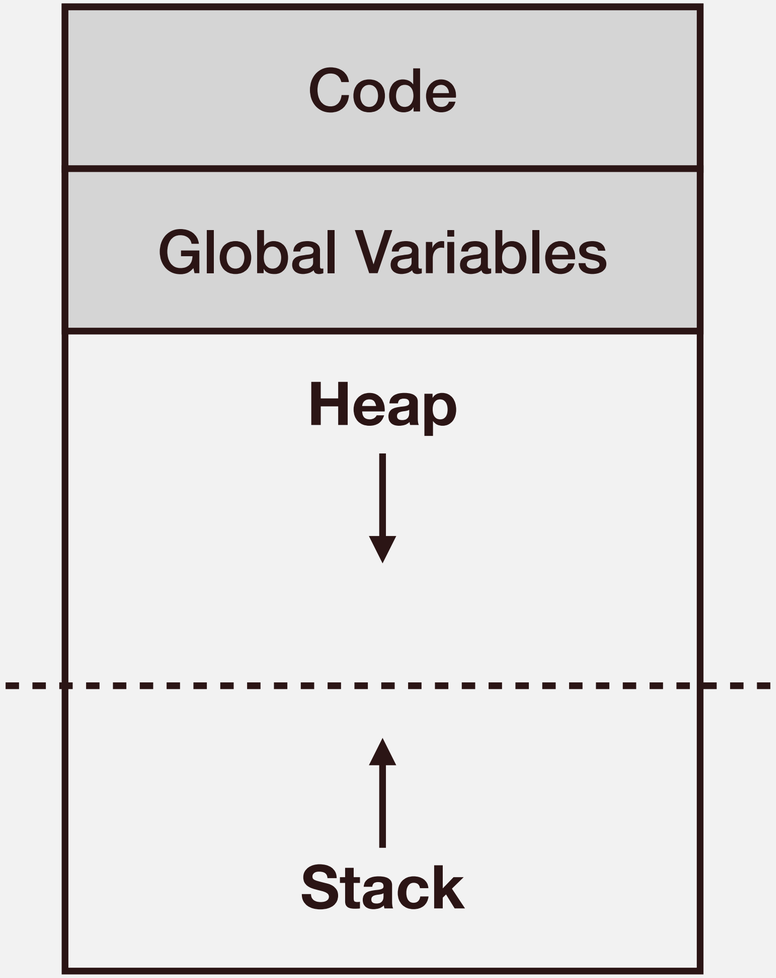

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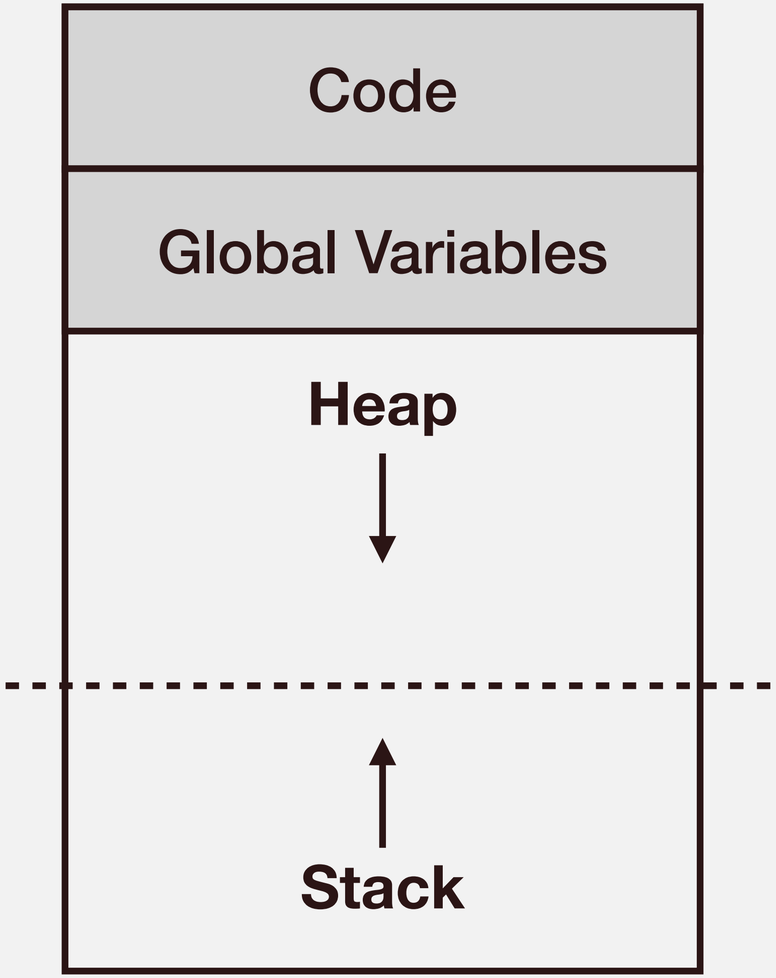

	Stack	Heap
Scope	Local	Global
Size Limit	By OS	Physical Mem
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Resize?	No	Yes
Usage	Local var, function	Global/Large var

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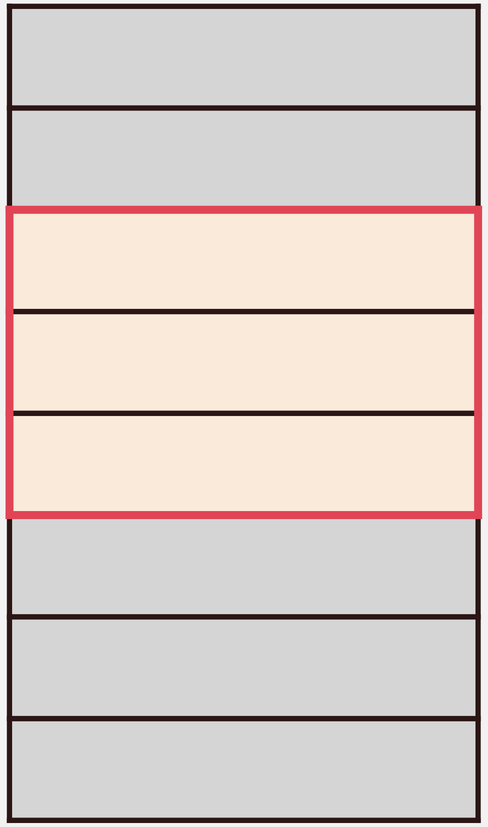
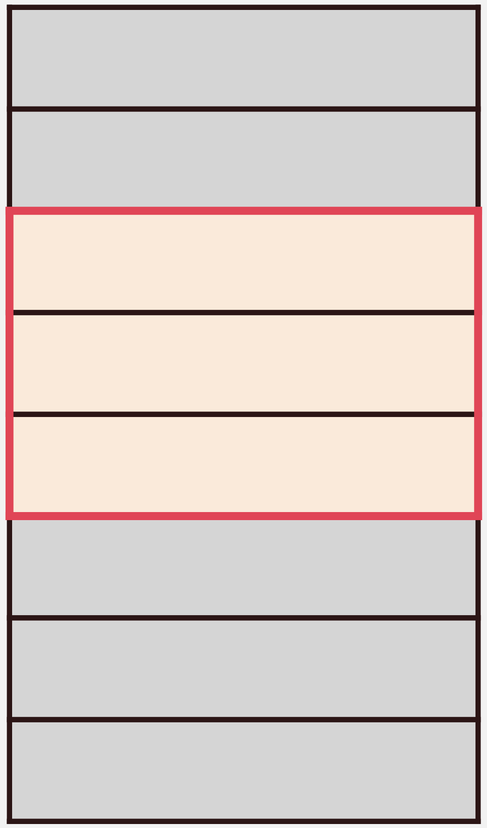
Index Out-of-Bound

Memory



```
array[-1]
array[0]
array[1]
array[2]
array[3]
```

Index Out-of-Bound

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Undefined behavior, super dangerous

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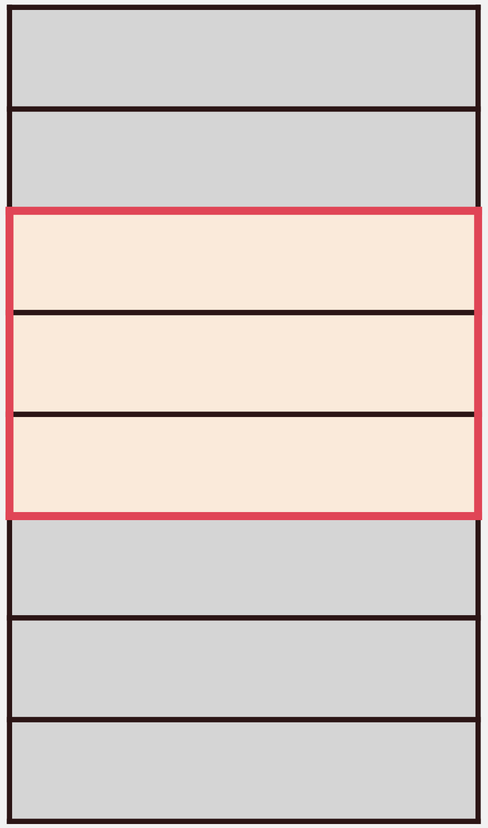


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Undefined behavior, super dangerous

Don’t do that!

Segmentation Fault

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  1. Dereferencing NULL or uninitialized pointers
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- How to debug?
  - `gdb` is your friend!

Common GDB Commands

`gdb prgm`	Enters GDB with program prgm loaded
`Ctrl-x Ctrl-a`	Enters the TUI mode
`[r]un <args>`	Runs the loaded program with command line arguments
`[b]ack[t]race`	Prints the call stack trace
`[b]reak <func_name or file_name:line#>`	Sets a breakpoint
`[d]elete #`	Deletes breakpoint #
`[s]tep`	Steps through a single line of code: INTO function calls
`[n]ext`	Steps through a single line of code: OVER function calls
`[p]rint <expr>`	Prints the current value of the expression
`[k]ill`	Kills the current debugging session
`[q]uit`	Quits GDB

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- There **must be** a `free` for **each** `malloc`
- How to debug?
  - Use `valgrind` (or leaks for MacOS)!

Summary

- **Control Flow**
- **Function Basics**
  - Call stack, pass-by-value, variable scope
- **Array & Pointer**
  - Pointer arithmetic, pointer as function argument, dynamic array
- **Debugging**
  - Segfault, memory leak
  - `gdb, valgrind`