# Implementing Abstractions

Part One

```
class RandomBag {
public:
    void add(int value);
    int  removeRandom();

    int  size() const;
    bool isEmpty() const;

private:
    Vector<int> elems;
};
```

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    Vector<int> elems;
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```

# Turtles All the Way Down?

- Last time, we implemented a `RandomBag` on top of our library `Vector` type.
- But the `Vector` type is itself a library – what is it layered on top of?
- ***Question:*** What are the fundamental building blocks provided by the language, and how do we use them to build our own custom classes?

# Getting Storage Space

- The `Vector`, `Stack`, `Queue`, etc. all need storage space to put the elements that they store.
- That storage space is allocated using ***dynamic memory allocation***.
- Essentially:
  - You can, at runtime, ask for extra storage space, which C++ will give to you.
  - You can use that storage space however you'd like.
  - You have to explicitly tell the language when you're done using the memory.

Dynamic Allocation Demo

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int main() {
   int numValues = getInteger("How many lines? ");

   string* arr = new string[numValues];
   for (int i = 0; i < numValues; i++) {
      arr[i] = getLine();
   }

   for (int i = 0; i < numValues; i++) {
      cout << i << ": " << arr[i] << endl;
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numValues $\boxed{7}$

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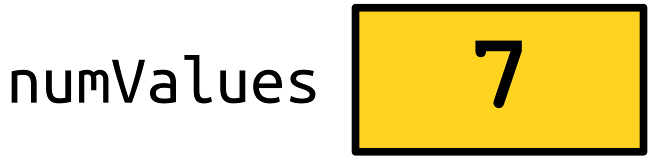

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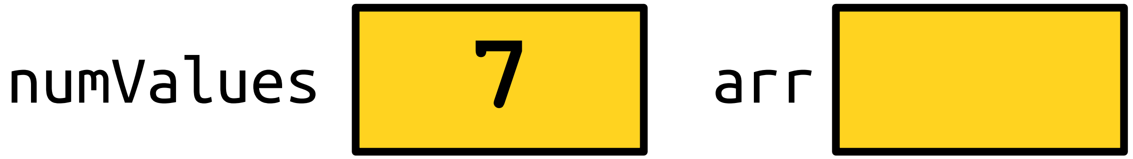

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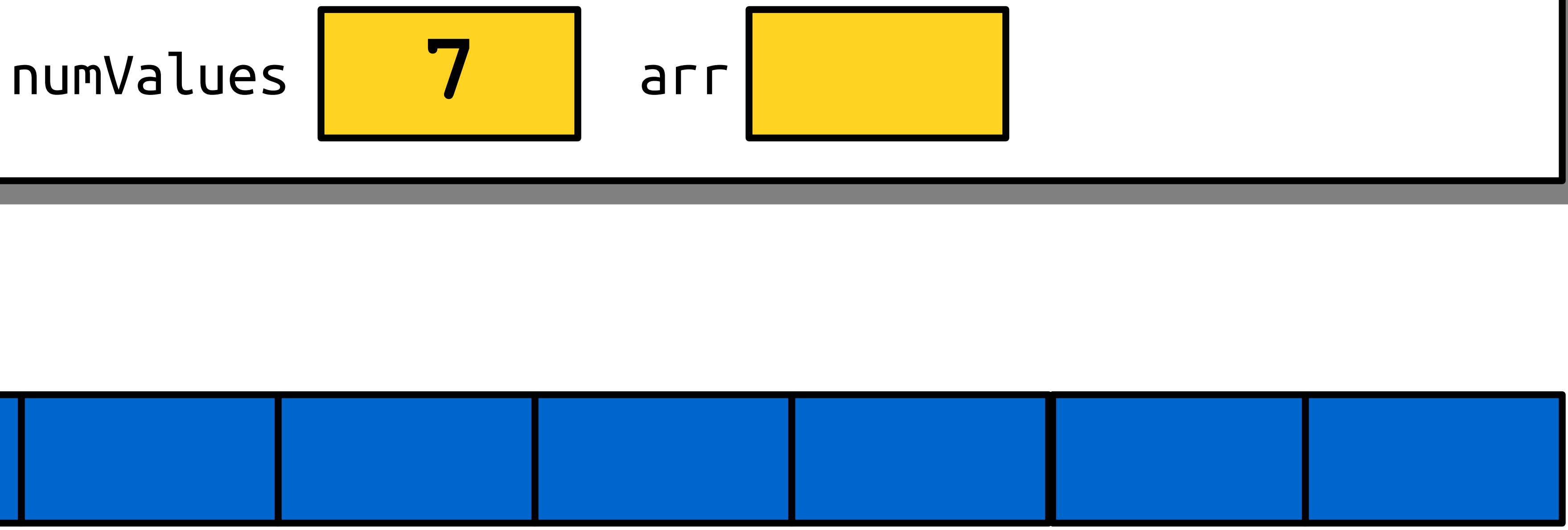

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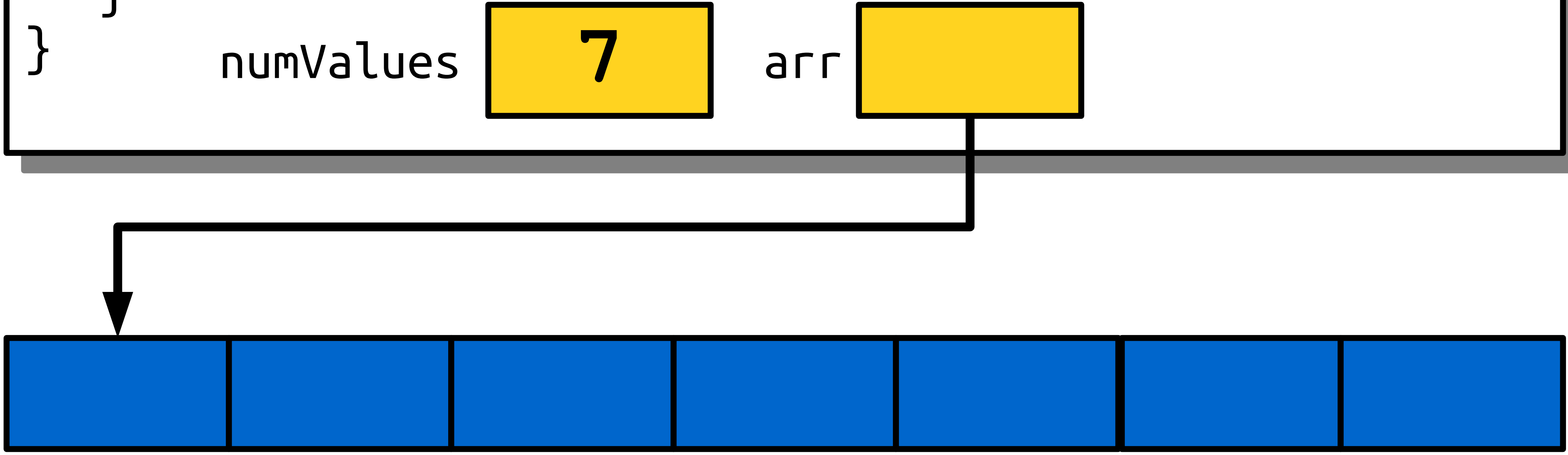

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      cout << i << ":
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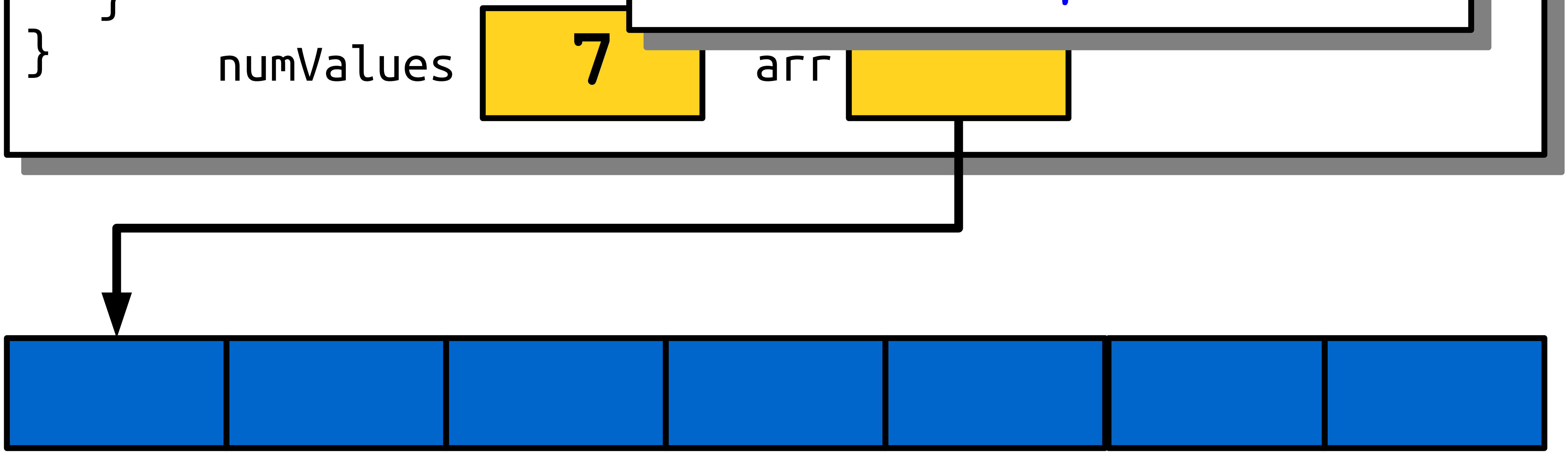
Because the variable arr points to the array, it is called a *pointer*.



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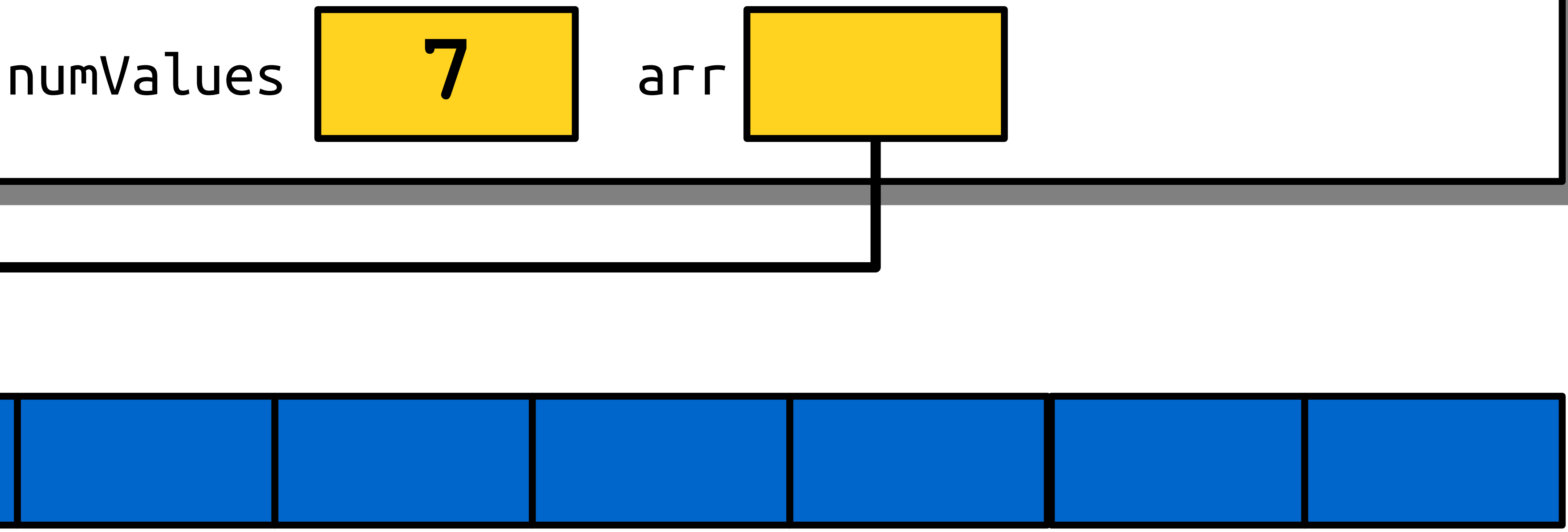

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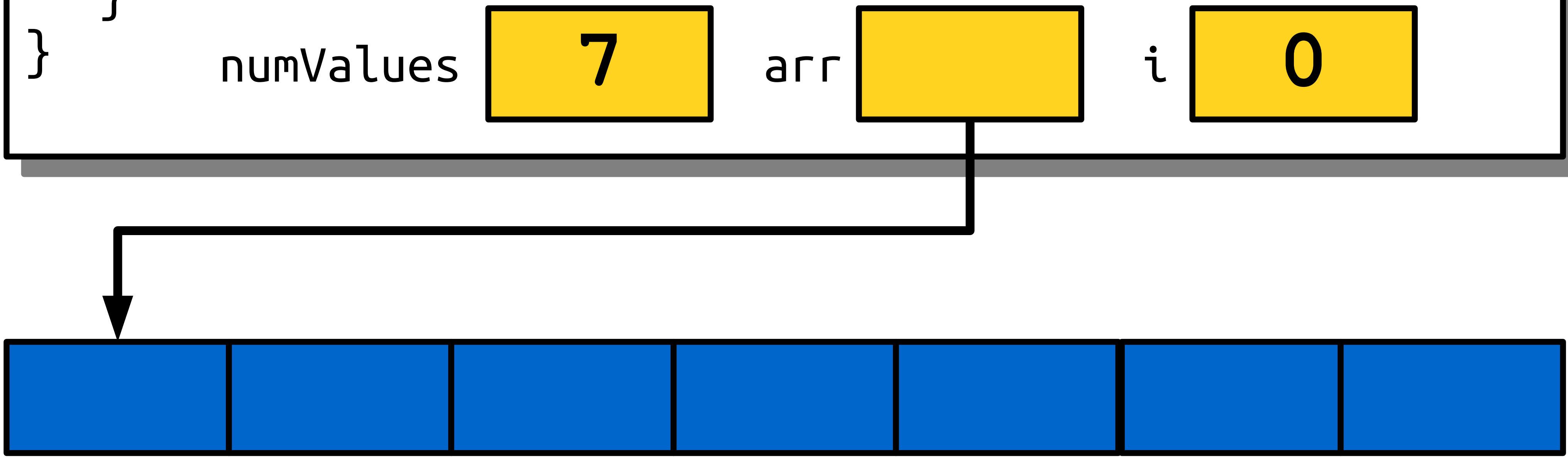

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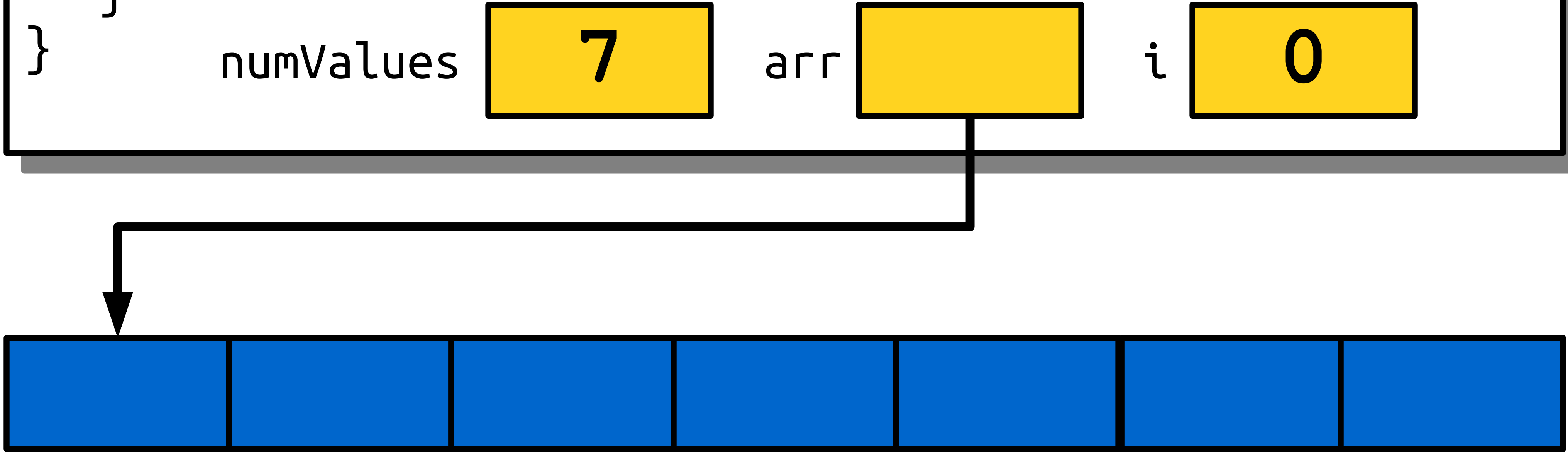

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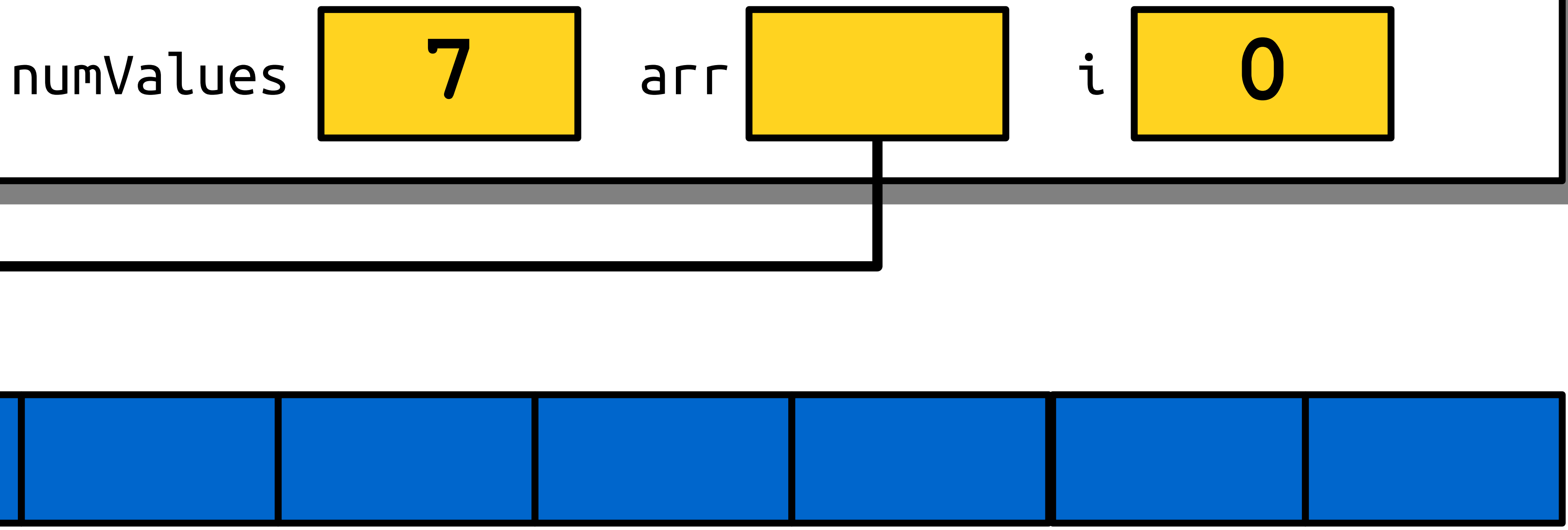

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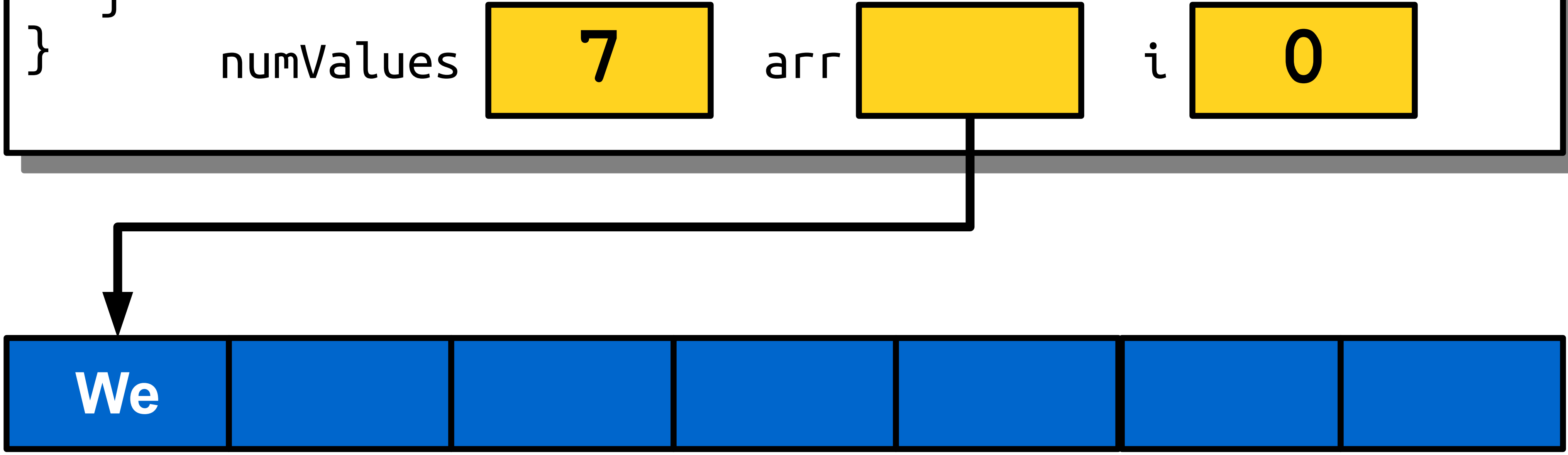

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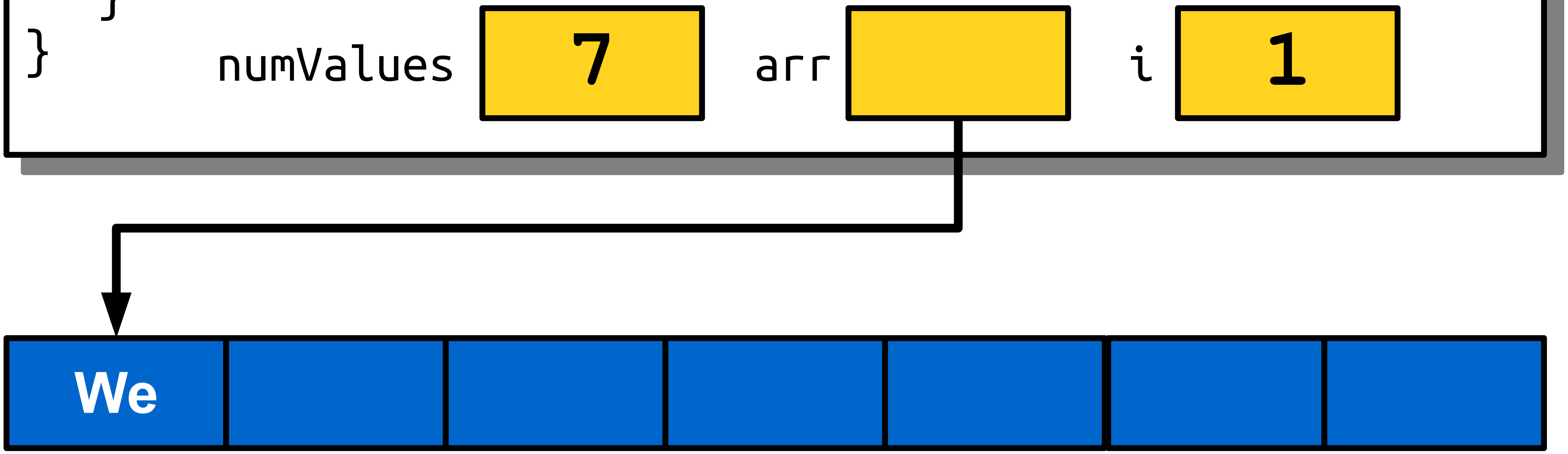

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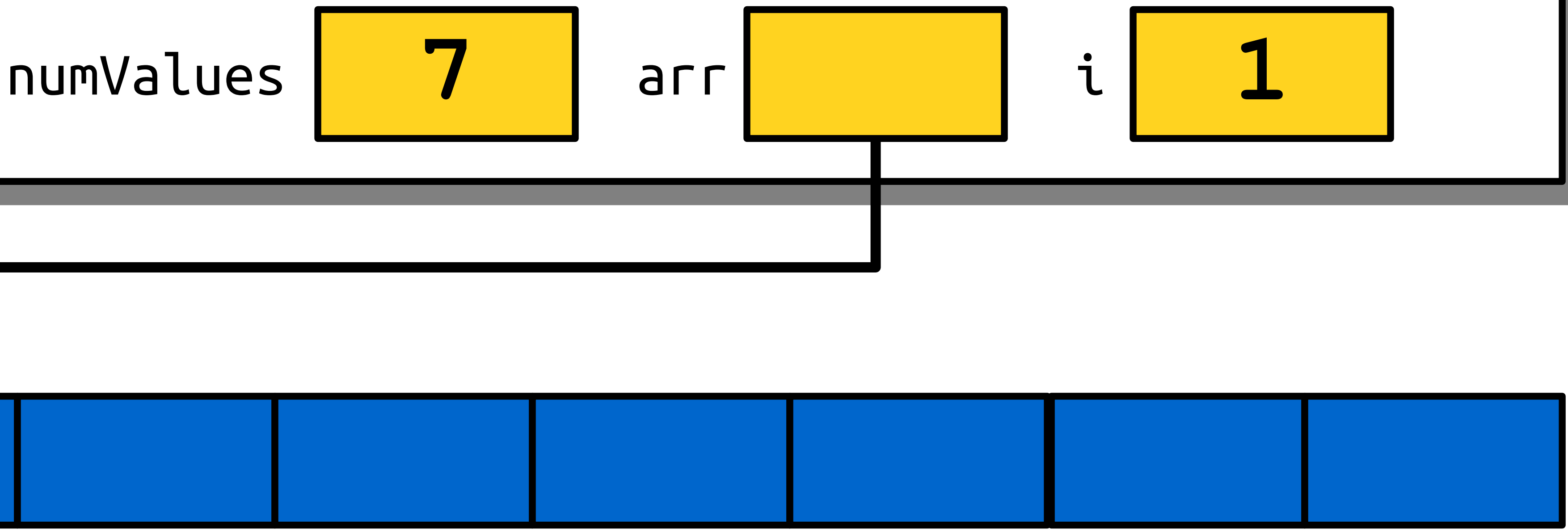

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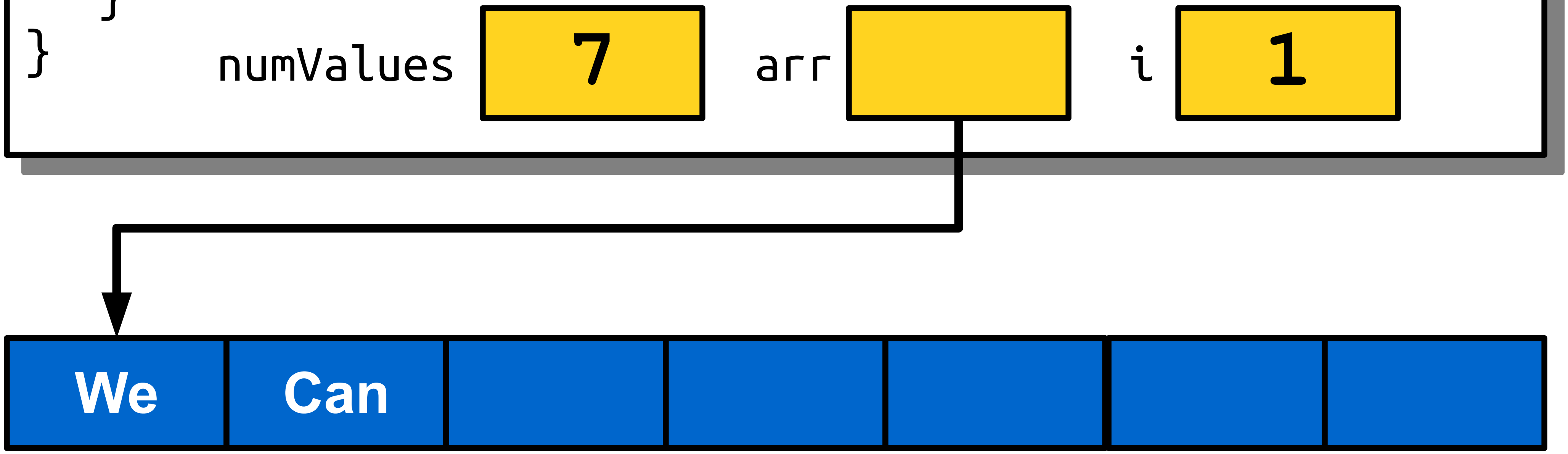

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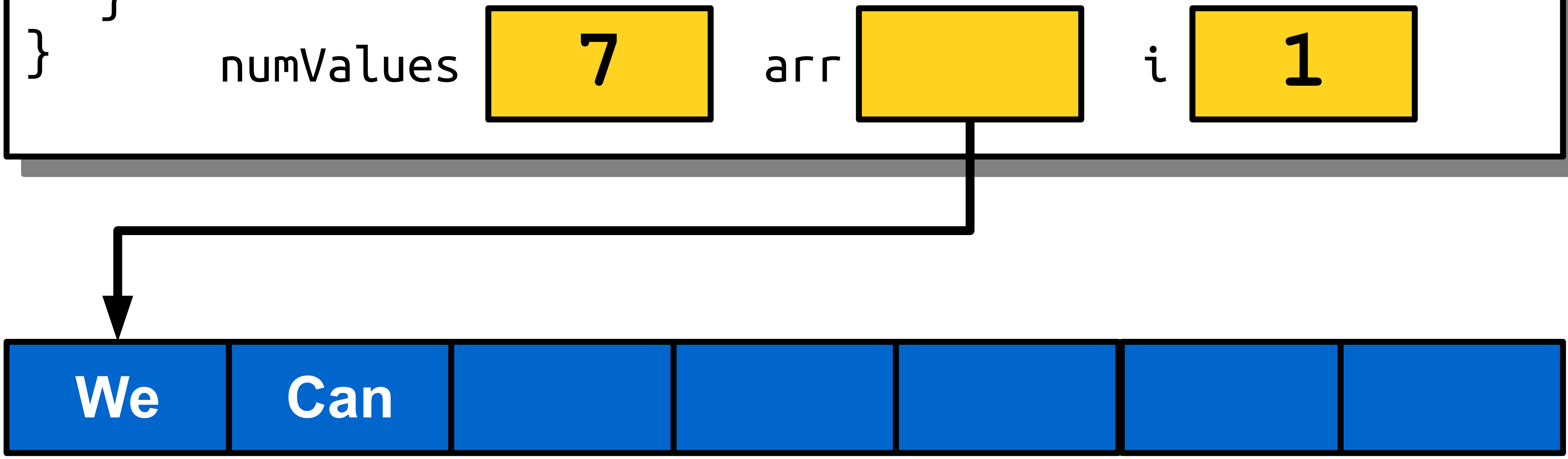

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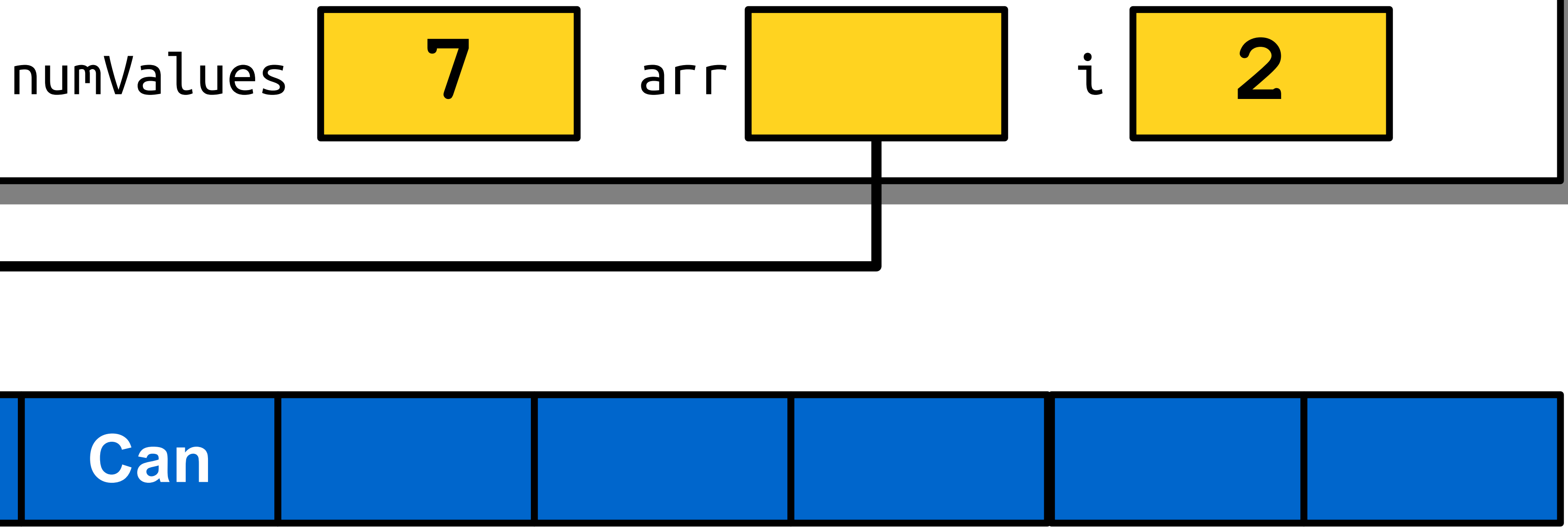

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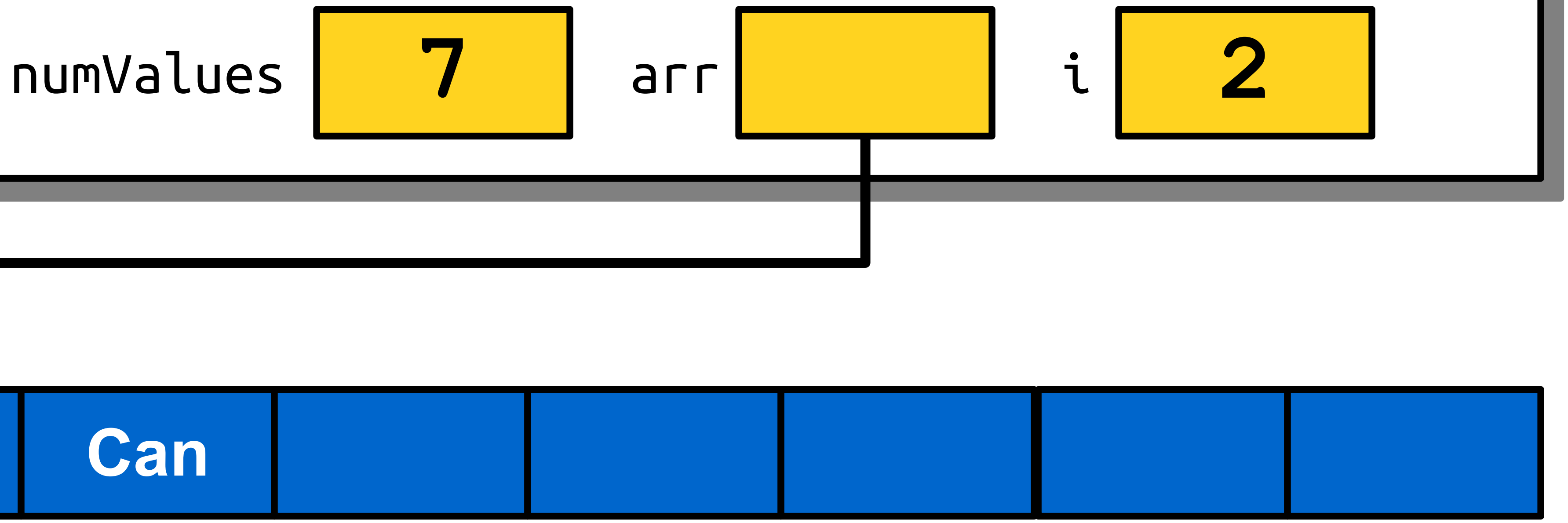

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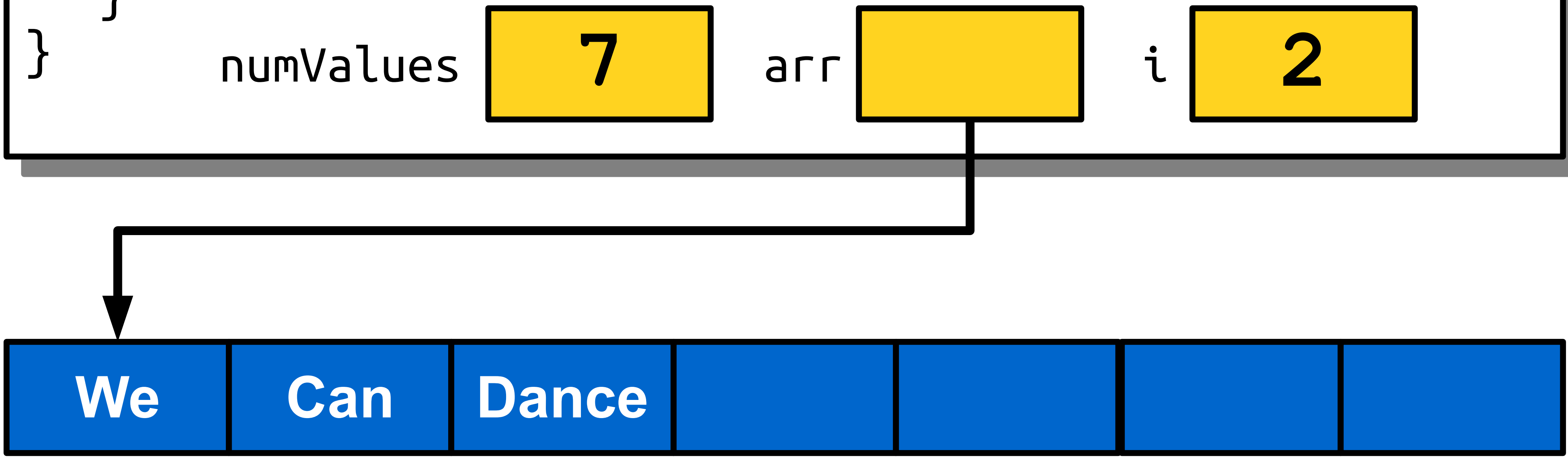

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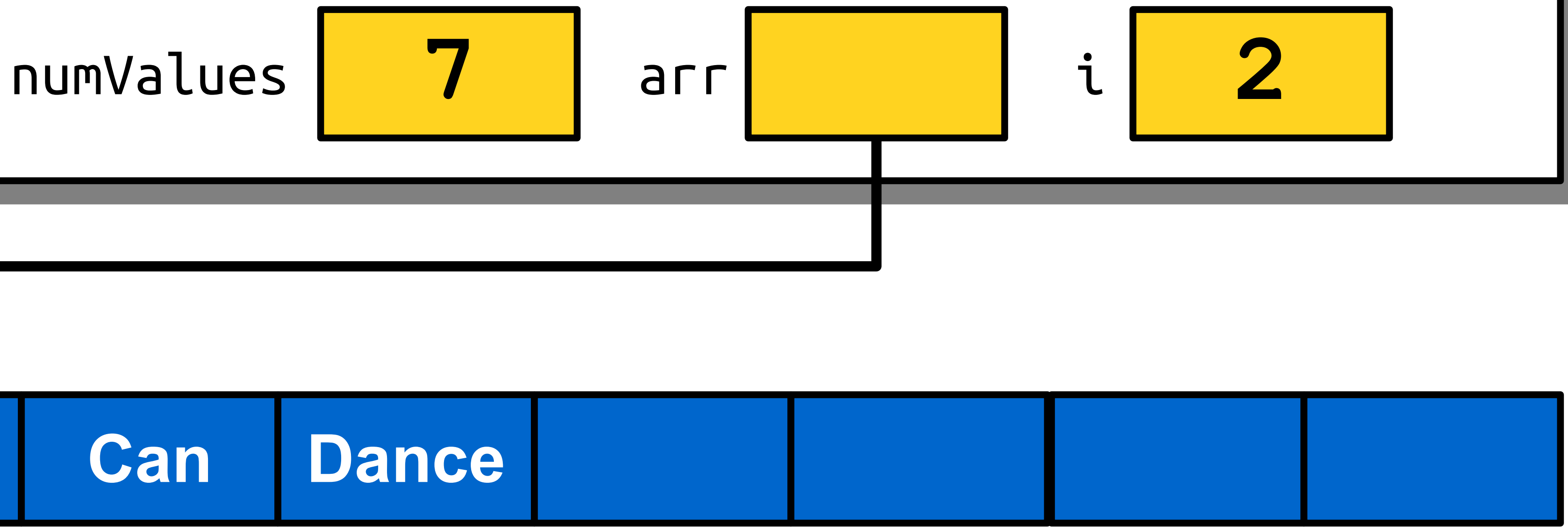

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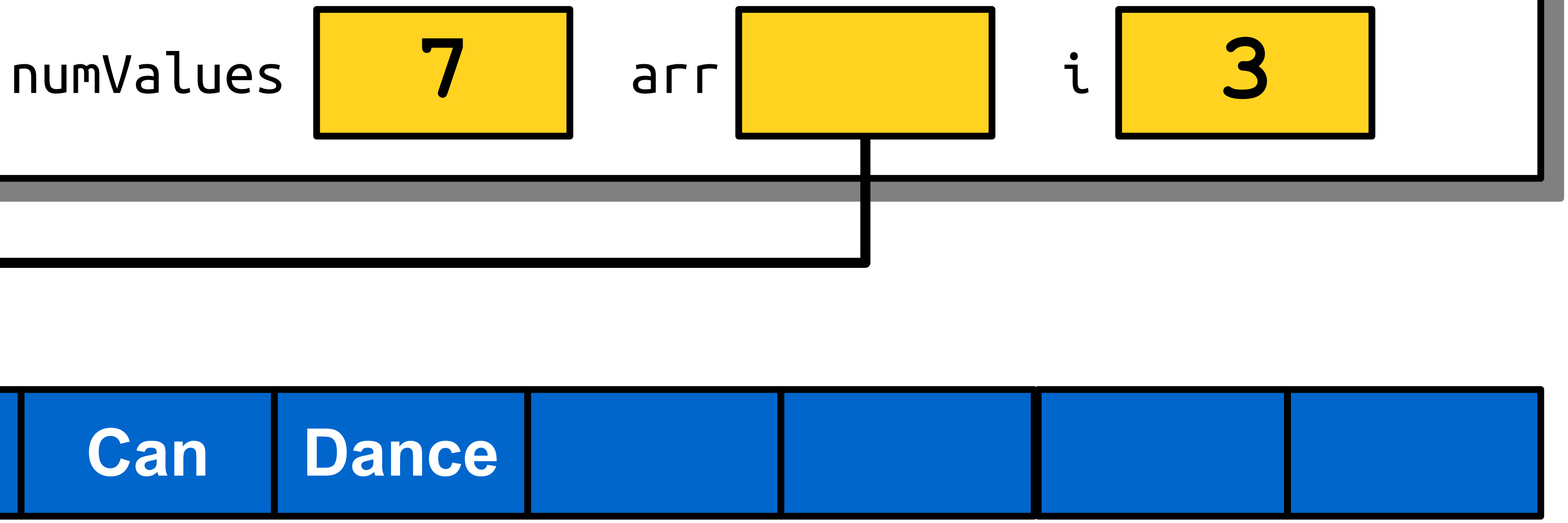

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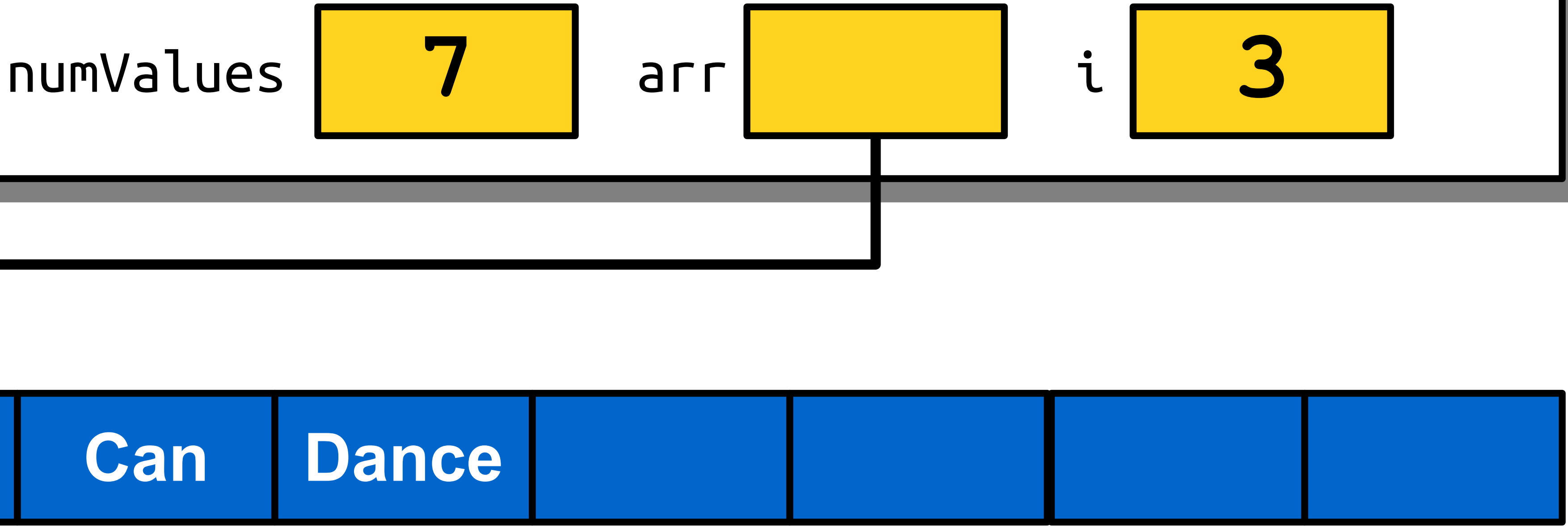

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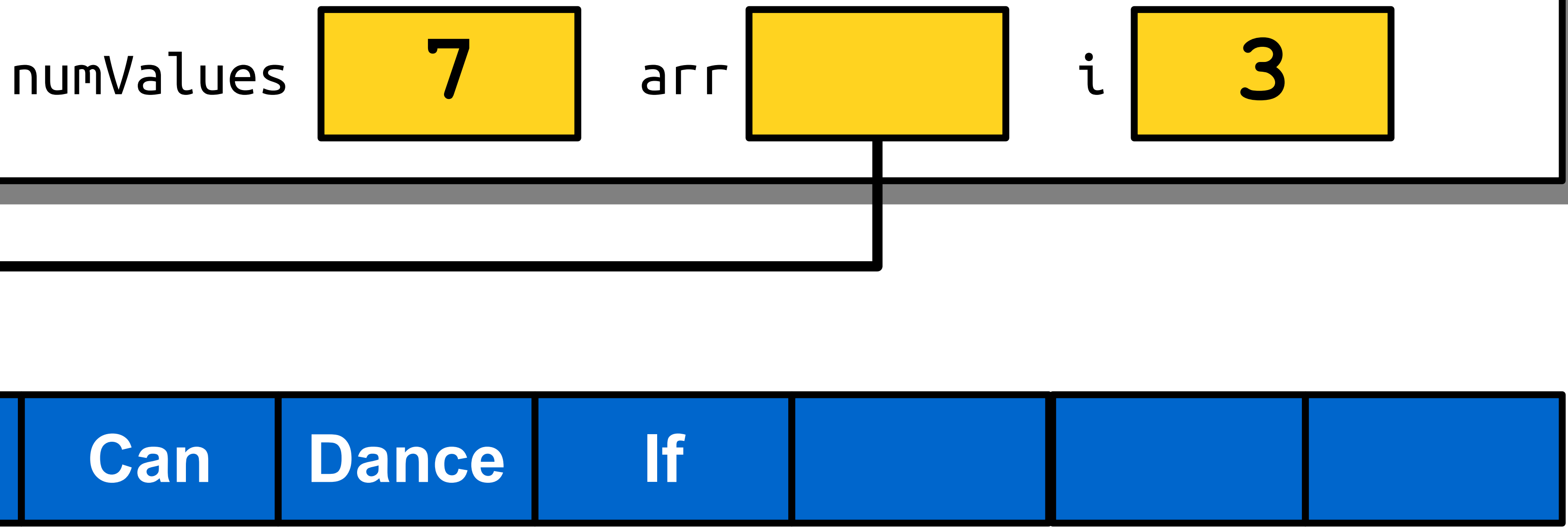

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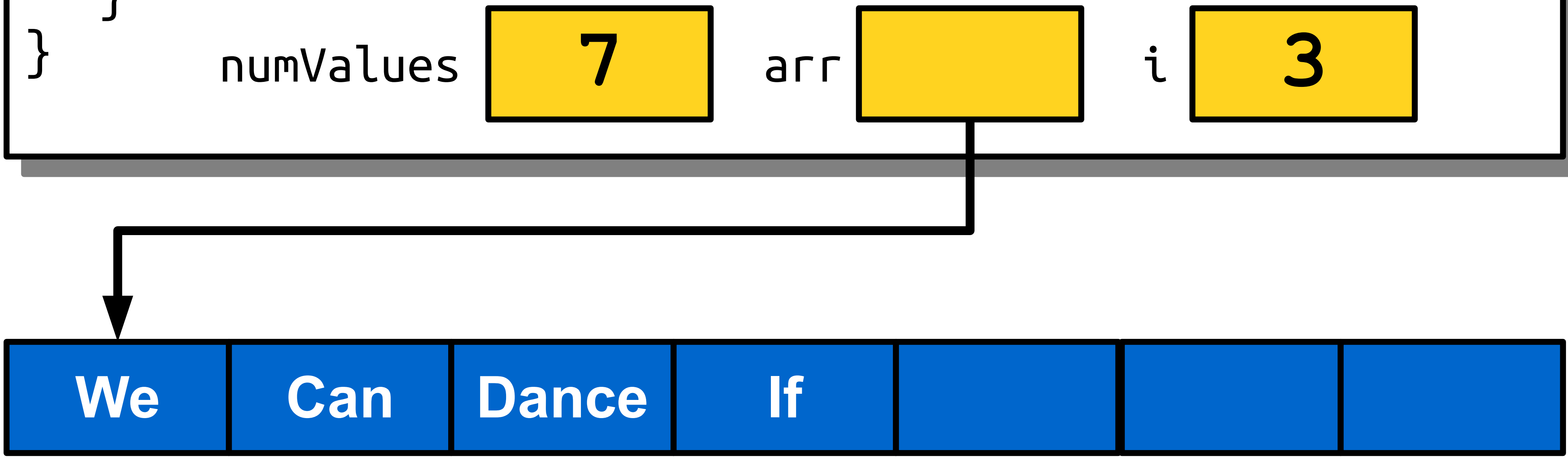

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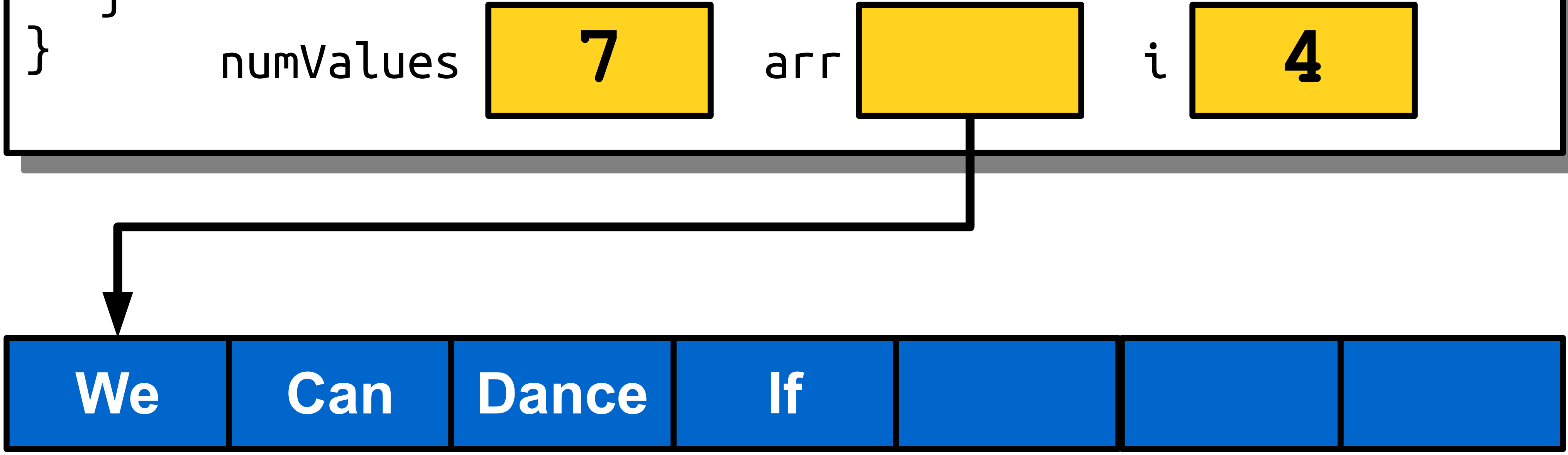

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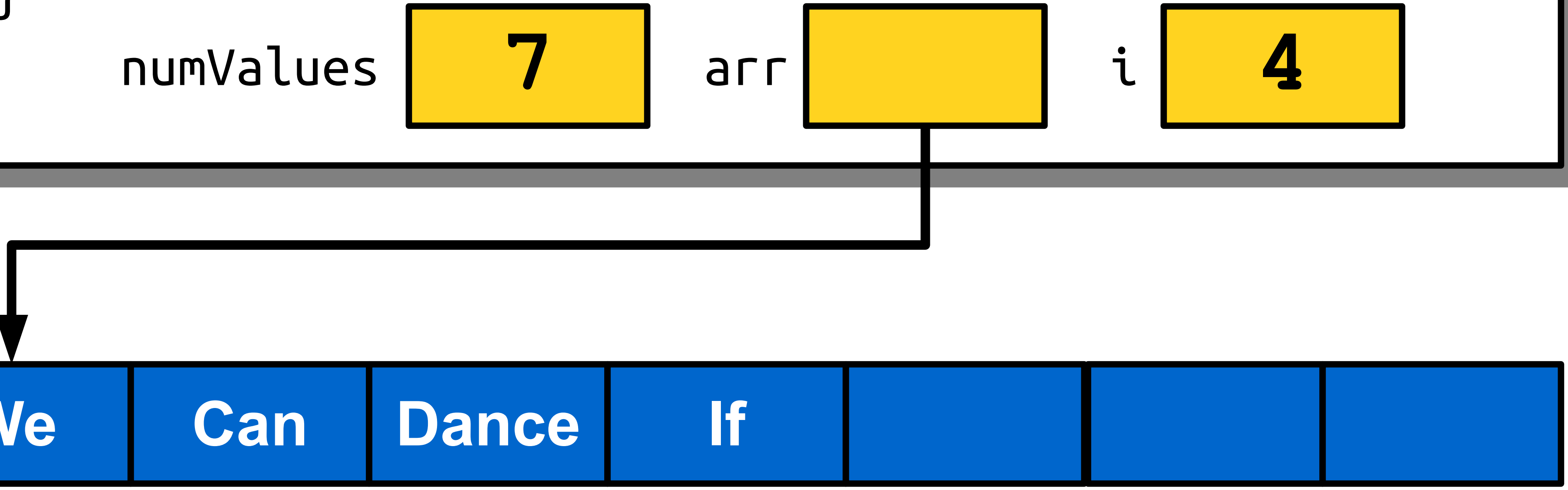

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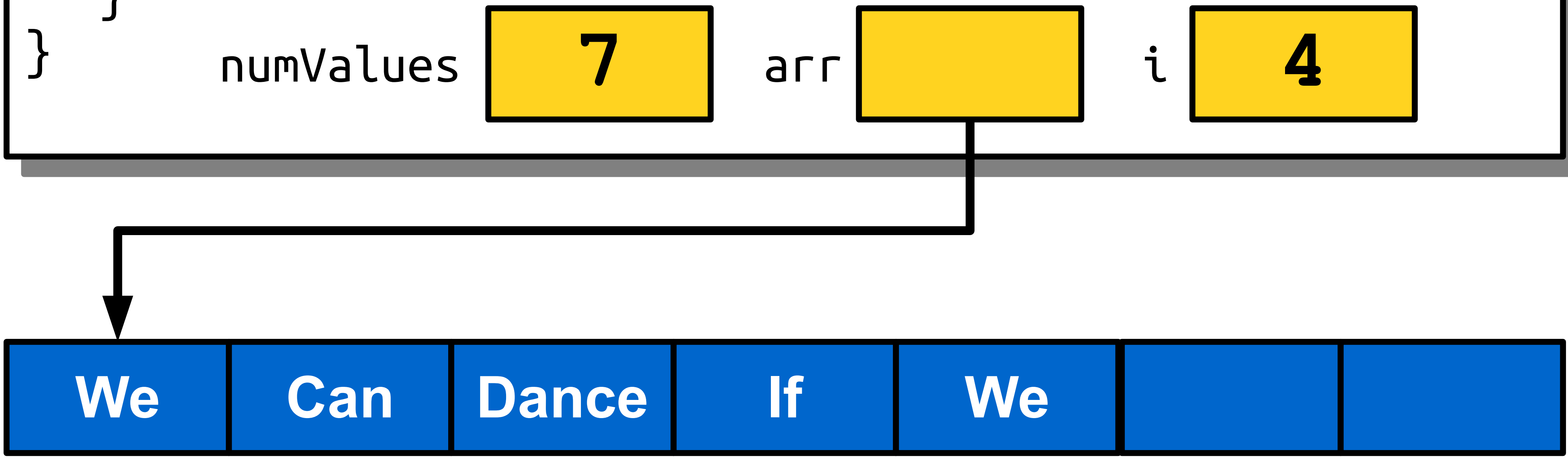

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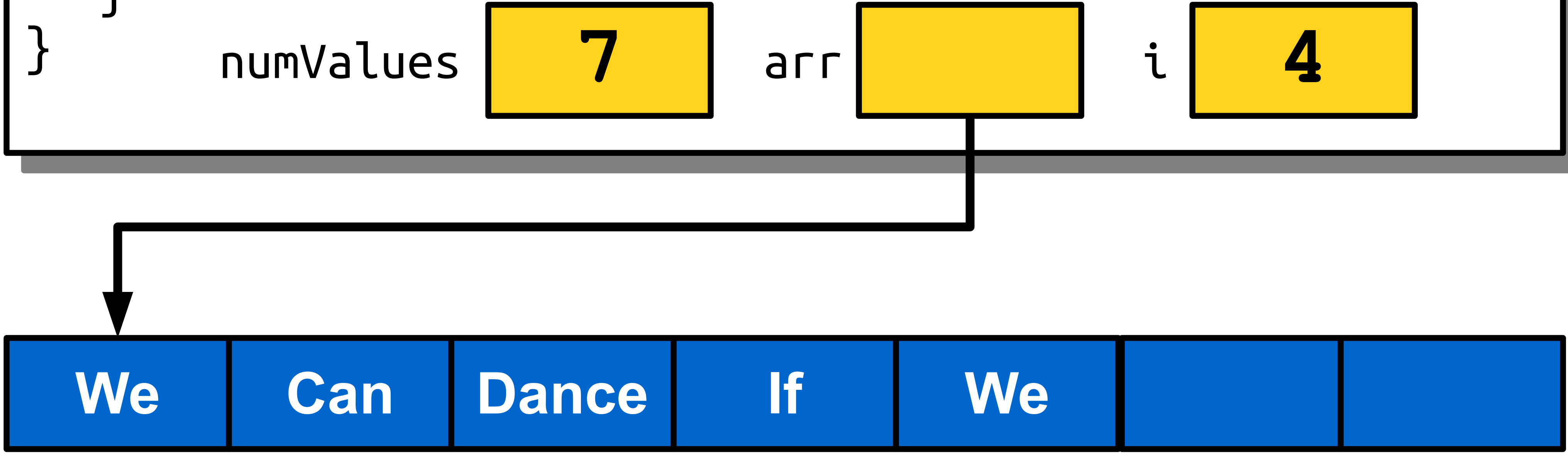

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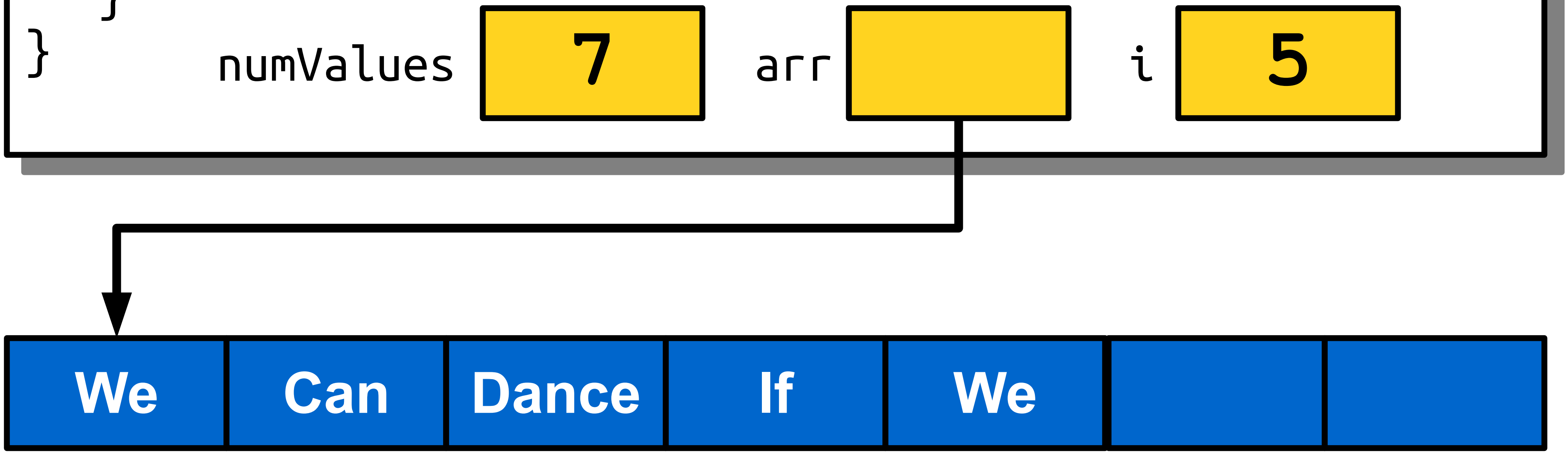

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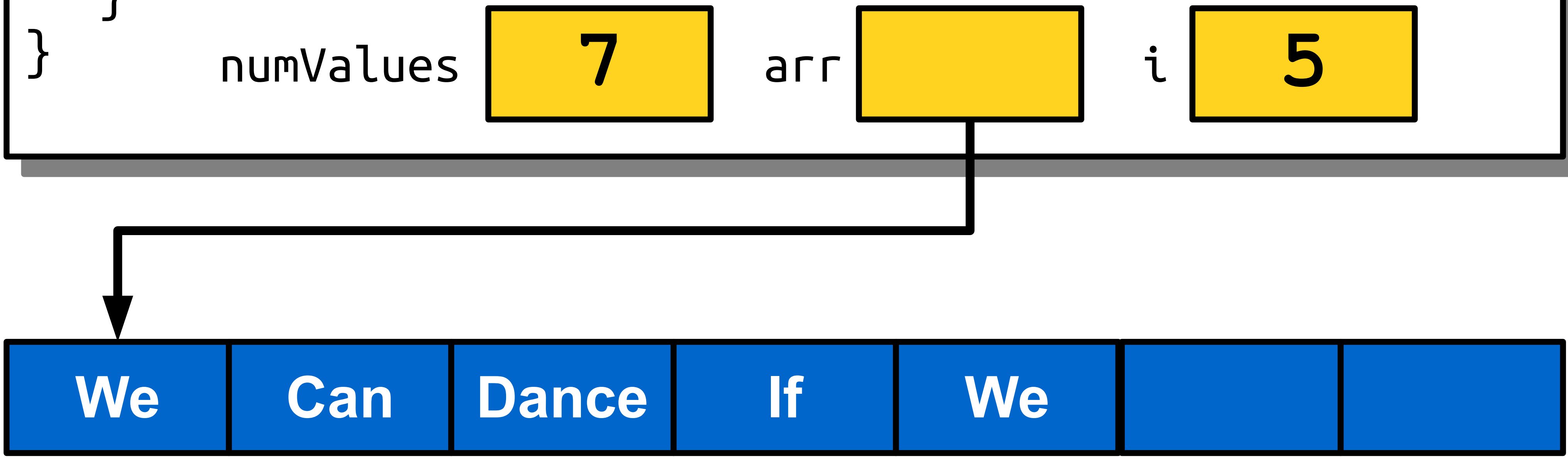

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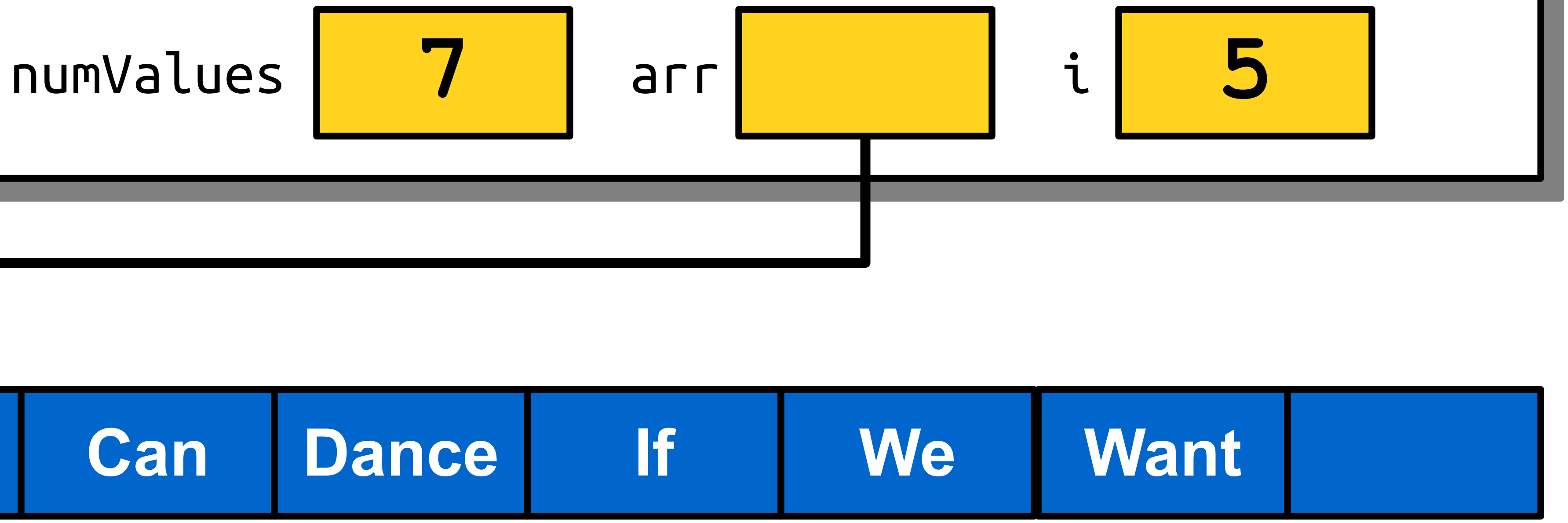

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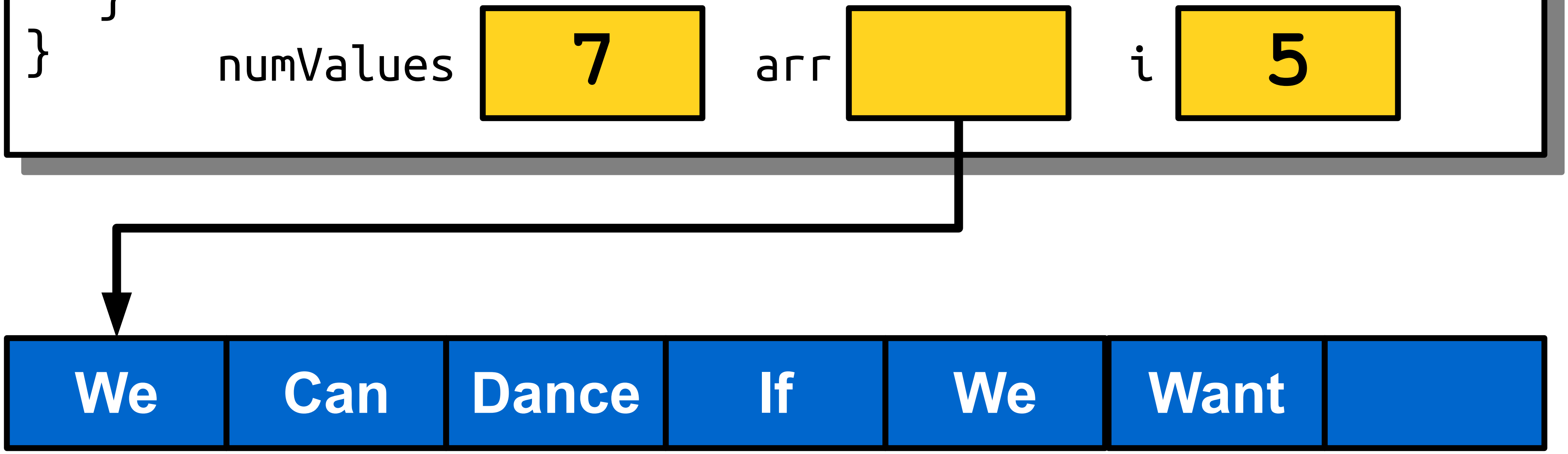

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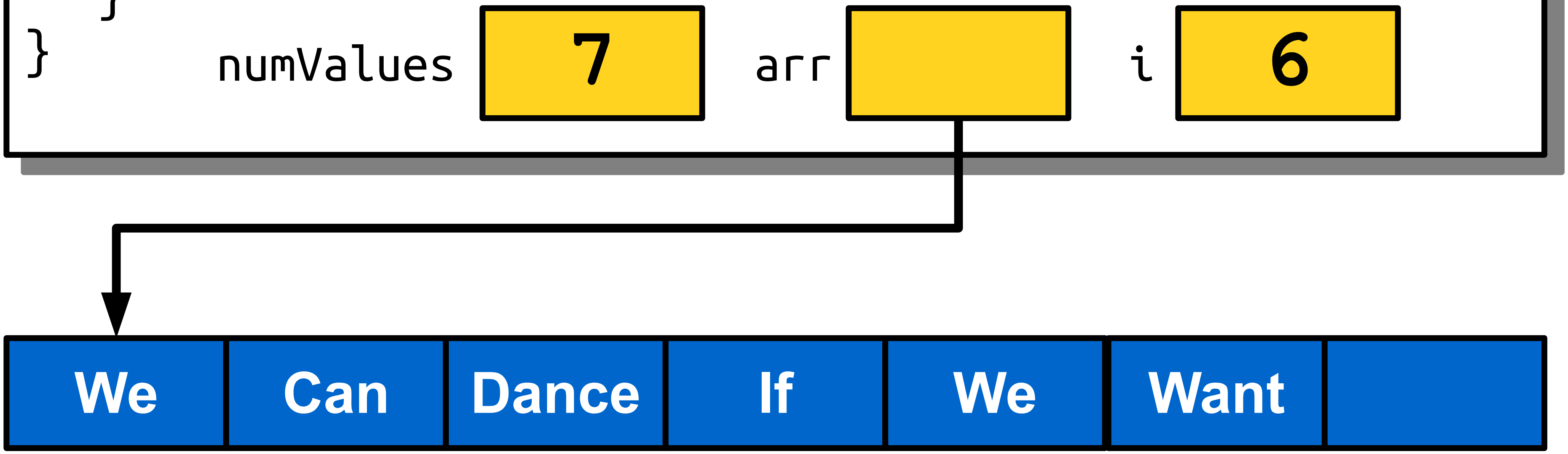

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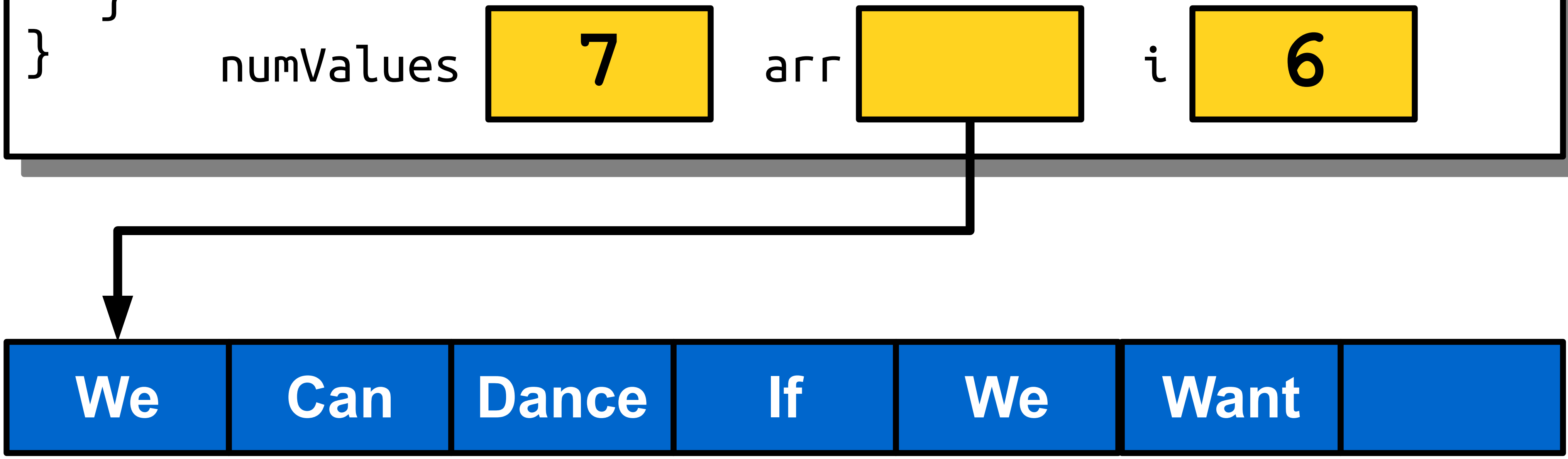

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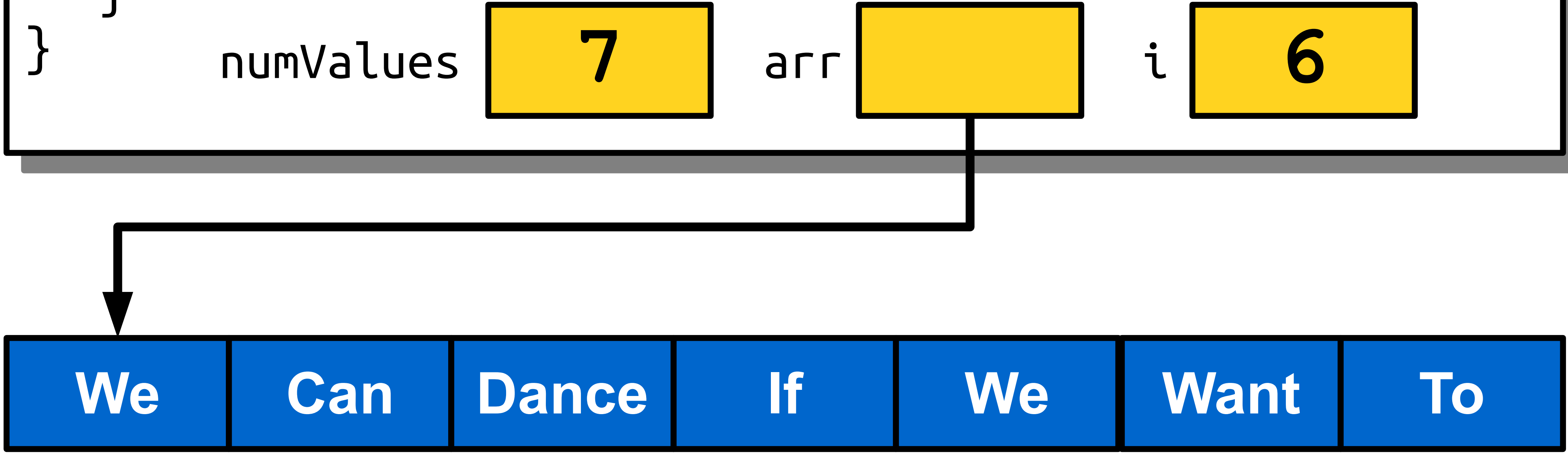

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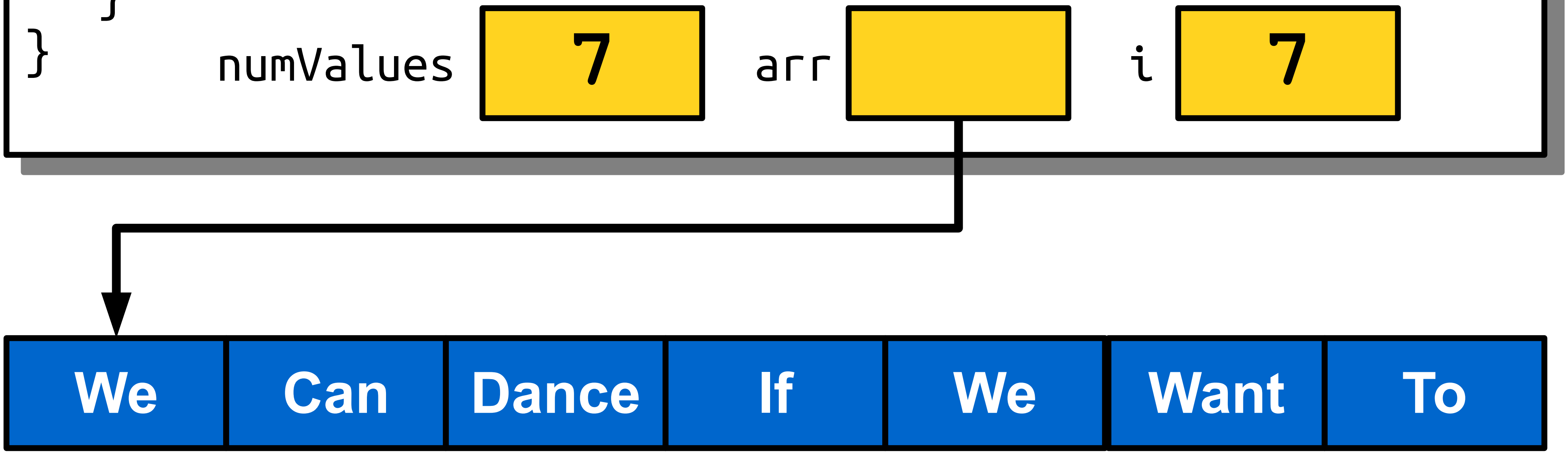

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int main() {
   int numValues = getInteger("How many lines? ");

   string* arr = new string[numValues];
   for (int i = 0; i < numValues; i++) {
      arr[i] = getLine();
   }

   for (int i = 0; i < numValues; i++) {
      cout << i << ": " << arr[i] << endl;
   }
}
```
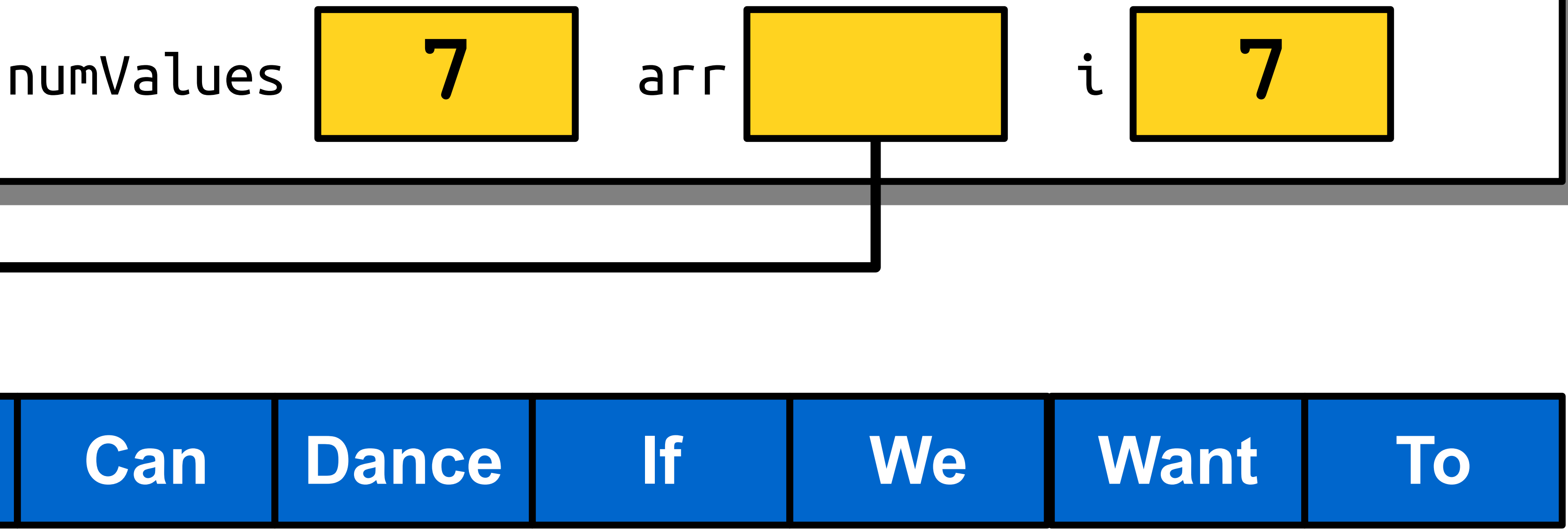



# Dynamically Allocating Arrays

- First, declare a variable that will point at the newly-allocated array. If the array elements have type ***T***, the pointer will have type ***T****.
    - e.g. `int*`, `string*`, `Vector<double>*`
- Then, create a new array with the `new` keyword and assign the pointer to point to it.
- In two separate steps:

```
T* arr;
arr = new T[size];
```

- Or, in the same line:

```
T* arr = new T[size];
```

## Dynamically Allocating Arrays

- C++'s language philosophy prioritizes speed over safety and simplicity.
- The array you get from `new[]` is ***fixed-size***: it can neither grow nor shrink once it's created.
  - The programmer's version of "conservation of mass."
- The array you get from `new[]` has ***no bounds-checking***. Walking off the beginning or end of an array triggers *undefined behavior*.
  - Literally anything can happen: you read back garbage, you crash your program, or you let a hacker take over your computer. Do a search for "buffer overflow" for more details.

# Cleaning Up

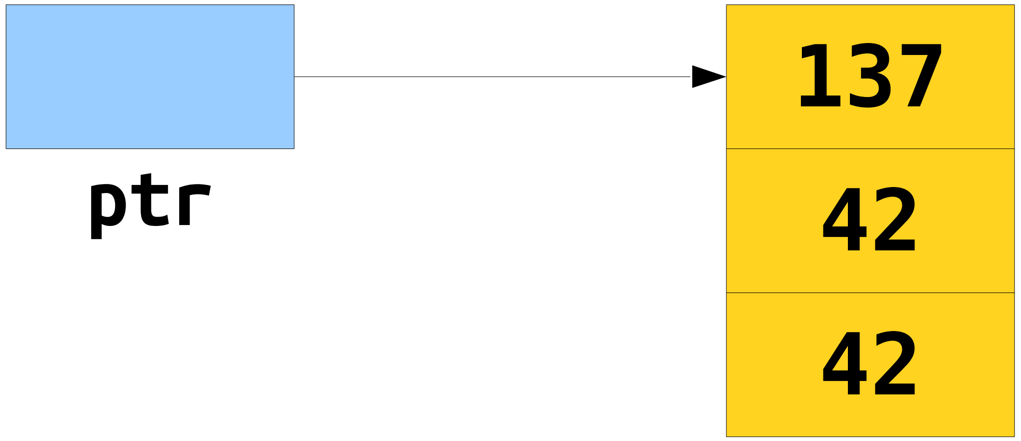
- When declaring local variables or parameters, C++ will automatically handle memory allocation and deallocation for you.
- When using **`new`**, you are responsible for deallocating the memory you allocate.
- If you don't, you get a ***memory leak***. Your program will never be able to use that memory again.
  - Too many leaks can cause a program to crash – it's important to not leak memory!

# Cleaning Up

- You can deallocate memory with the `delete[]` operator:

```
delete[] ptr;
```

- This destroys the array pointed at by the given pointer, not the pointer itself.



# Cleaning Up

- You can deallocate memory with the **delete**[] operator:

```
delete[] ptr;
```

- This destroys the array pointed at by the given pointer, not the pointer itself.

# Cleaning Up

- You can deallocate memory with the **delete**[] operator:

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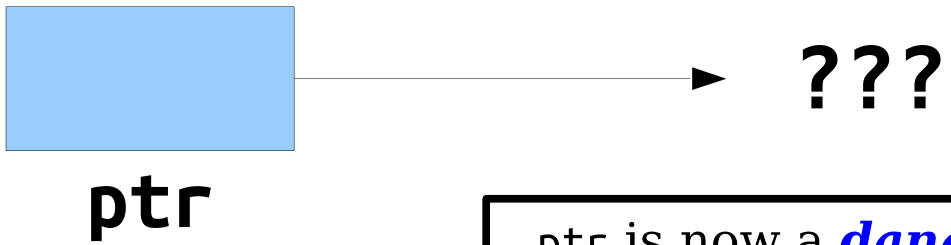

`ptr` is now a ***dangling pointer***. We can reassign it to point somewhere else, but if we try to read from it, it'll do Cruel and Unusual Things!

## To Summarize

- You can create arrays of a fixed size at runtime by using `new[]`.
- C++ arrays don't know their lengths and have no bounds-checking. With great power comes great responsibility.
- You are responsible for freeing any memory you explicitly allocate by calling `delete[]`.
- Once you've deleted the memory pointed at by a pointer, you have a dangling pointer and shouldn't read or write from it.

## Time-Out for Announcements!

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## Midterm Exam

- The midterm exam is next ***Tuesday, February 19*** from ***7:00PM – 10:00PM***.
  - Location TBA.
- It covers topics from Lectures 01 – 12 (up through and including big-O notation) and Assignments 0 – 4.
- The exam is closed-book and limited-note. You may bring one double-sided sheet of 8.5” × 11” of notes to the exam with you.
- If you believe you will be taking the exam at an alternate time and have not yet heard from Kate, you are not actually taking the exam at an alternate time. Ping us ASAP. 😃

## Midterm Exam

- We will be administering the exam using a software tool called ***BlueBook***.
- Visit the CS106B website, click the "BlueBook" link under the "Resources" tab, then download the BlueBook software.
- This week's section handout will be done through BlueBook so that you get a chance to test it out.
- Need a laptop for the exam? Feel free to contact us. We can help out with that.

# Midterm Exam

- ***We want you to do well on this exam***. The purpose of this exam is for you to show us what you've learned, not to separate the elect from the damned.
- We will be holding a practice midterm exam

  ***Tomorrow***,

  ***7PM – 10PM***, in

  ***Room 320-105***.
- The practice exam will be administerd via BlueBook. The practice exam files will be posted on the course website soon. We'll release the password tomorrow at the practice exam.

```
continue;
```

## Implementing `Stack`

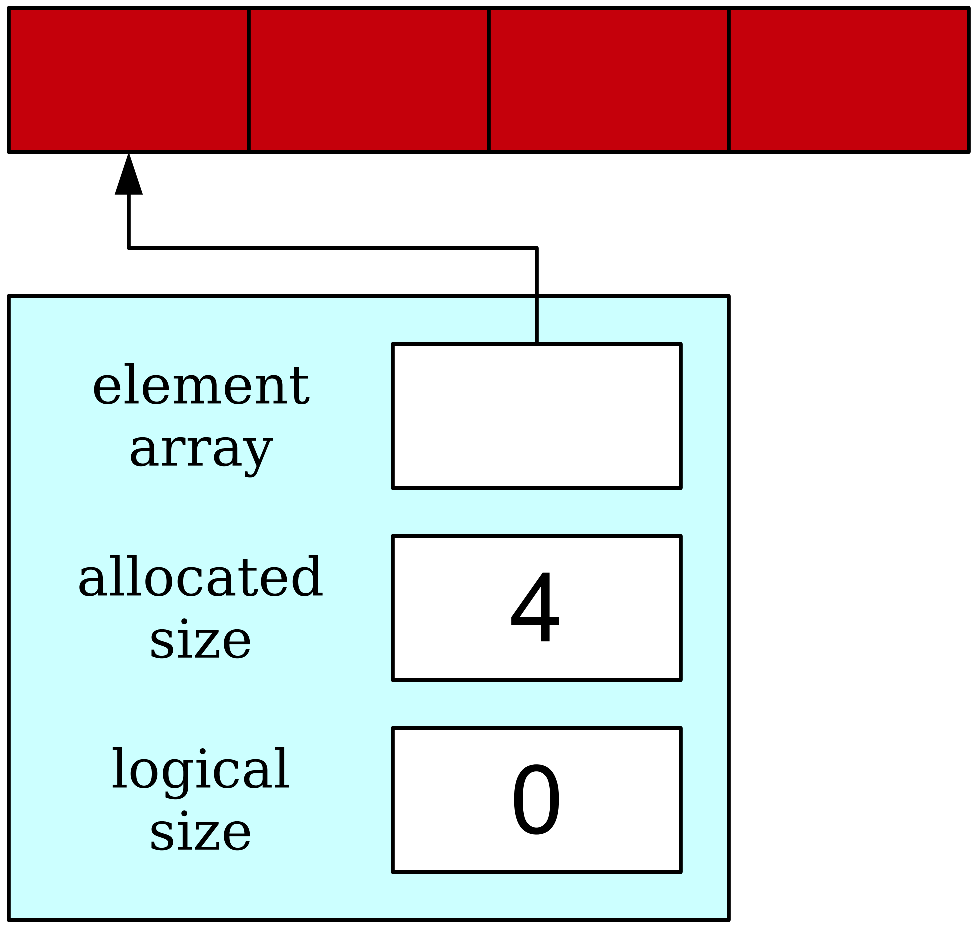
# Implementing `Stack`

- Last time, we saw how to implement `RandomBag` in terms of `Vector`.
- We could also implement `Stack` in terms of `Vector`.
- What if we wanted to implement the `Stack` without relying on any other collections?
- Let's build the stack directly!

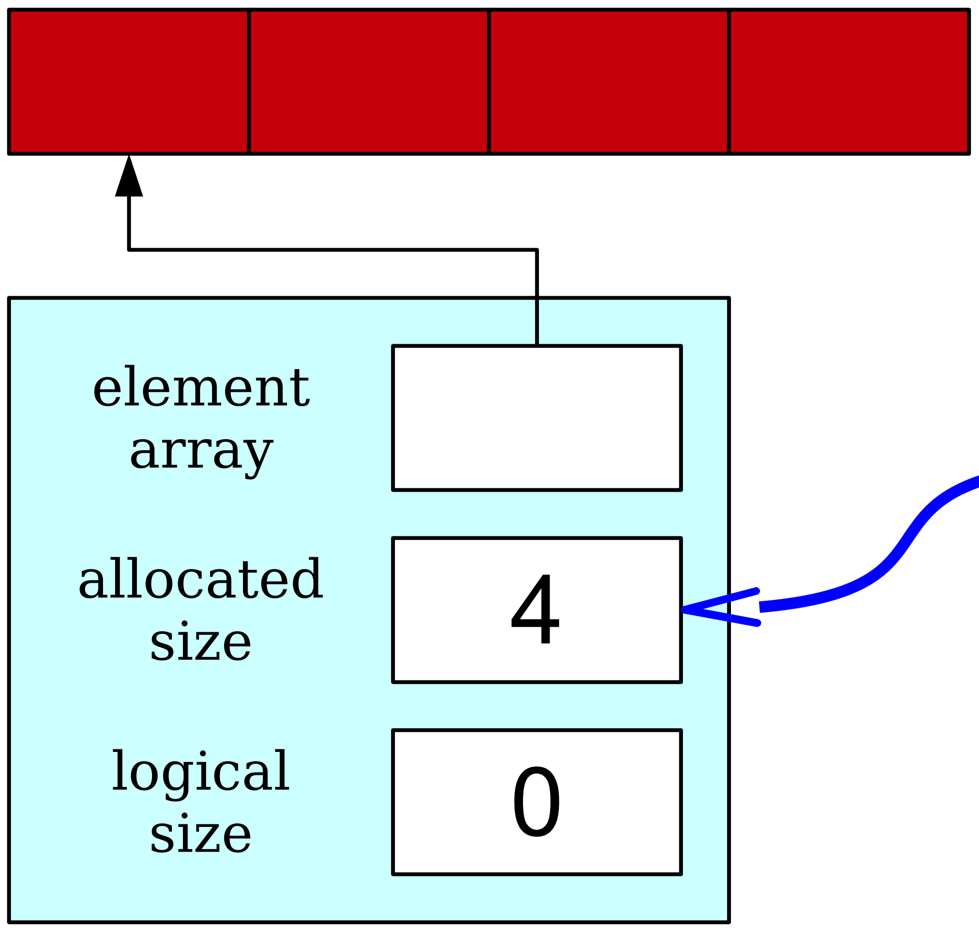
# You Gotta Start Somewhere

- Our initial implementation of the stack will be a *bounded* stack with a maximum capacity.
- We’ll allocate a fixed amount of storage space for the elements, then write them into the array as they’re pushed.
- If we run out of space, we’ll report an error.
- Next time, we’ll update this code so that we can have a stack without any fixed maximum capacity.

# An Initial Idea

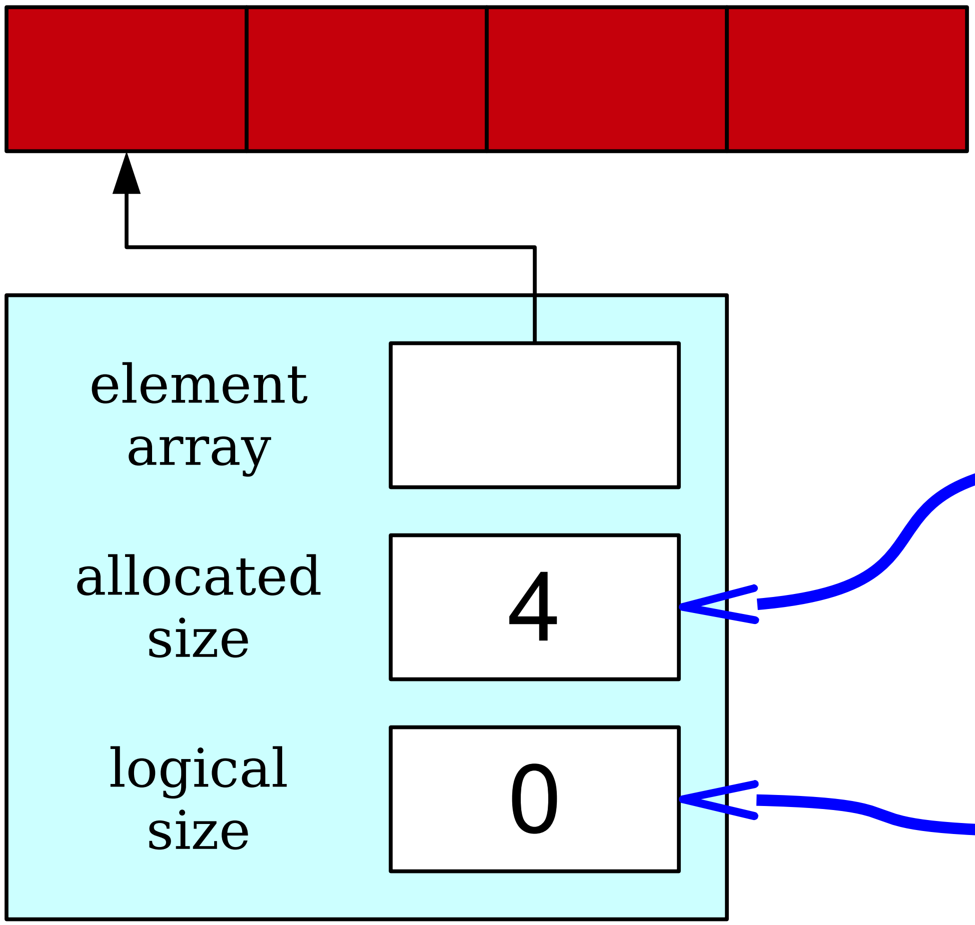


# An Initial Idea



The stack's ***allocated size*** is the number of slots in the array. Remember – arrays in C++ cannot grow or shrink.

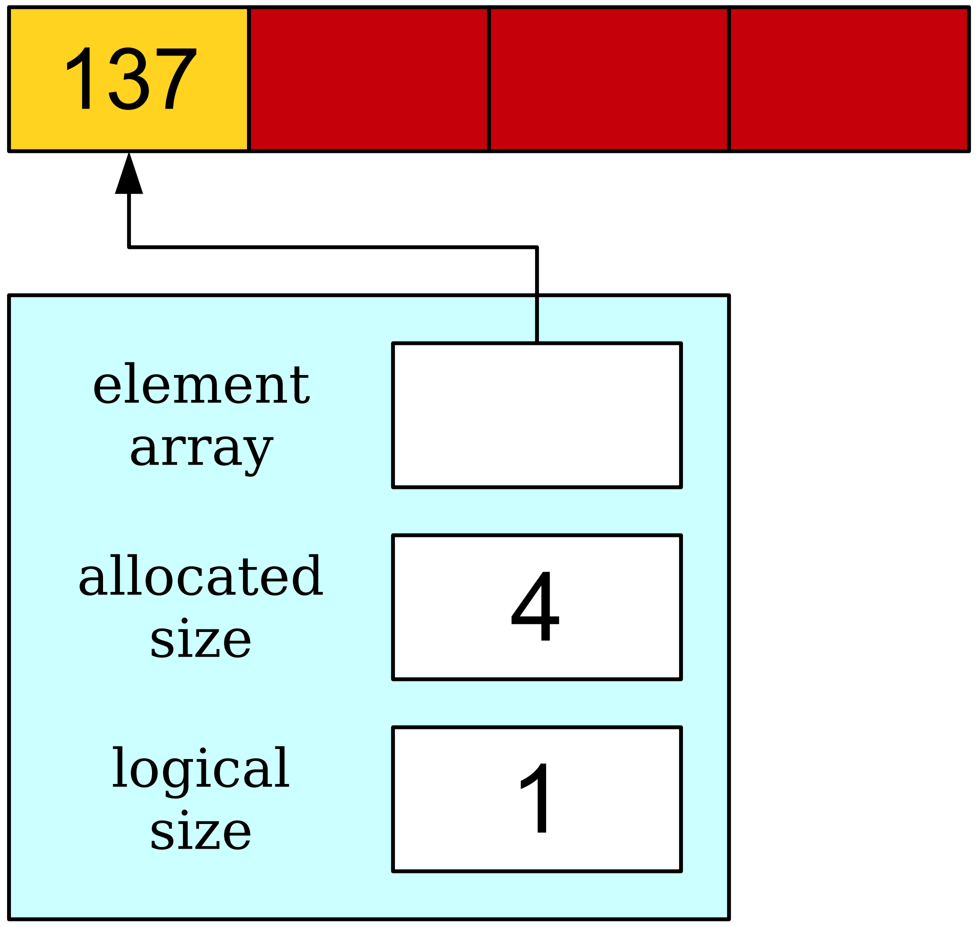
## An Initial Idea



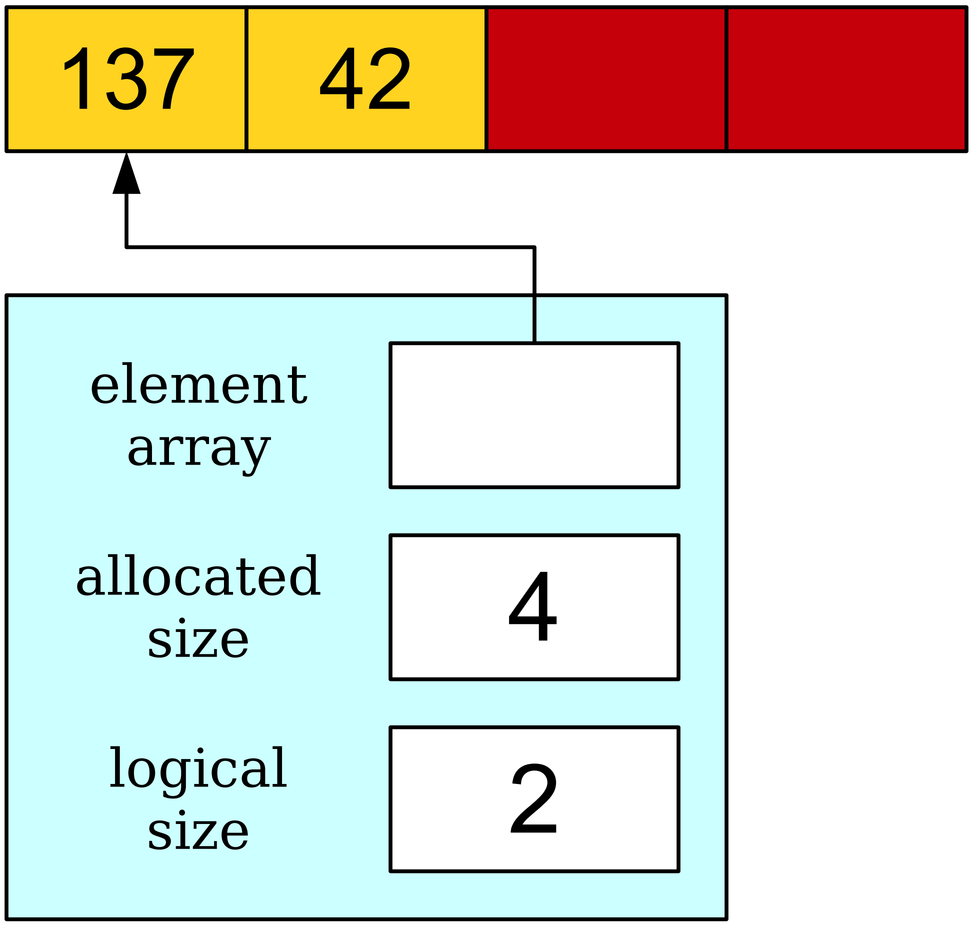
The stack's ***allocated size*** is the number of slots in the array. Remember – arrays in C++ cannot grow or shrink.

The stack's ***logical size*** is the number of elements actually stored in the stack. This lets us track how much space we're actually using.

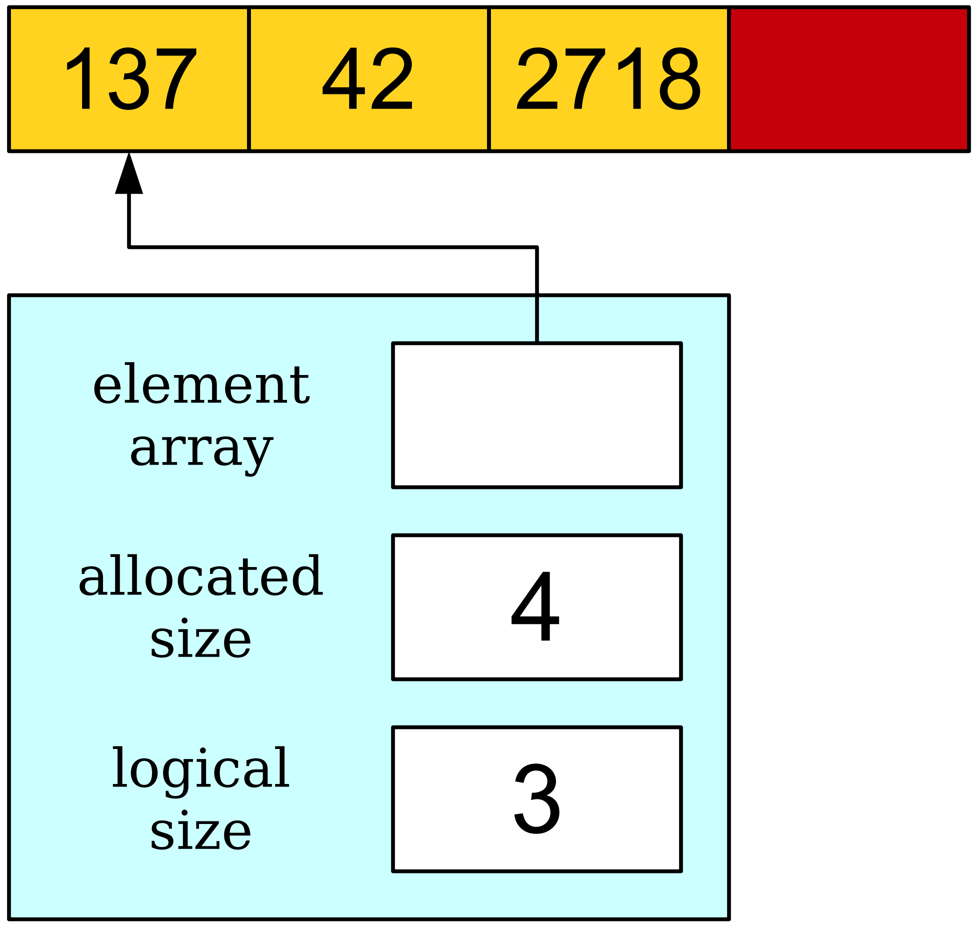
# An Initial Idea



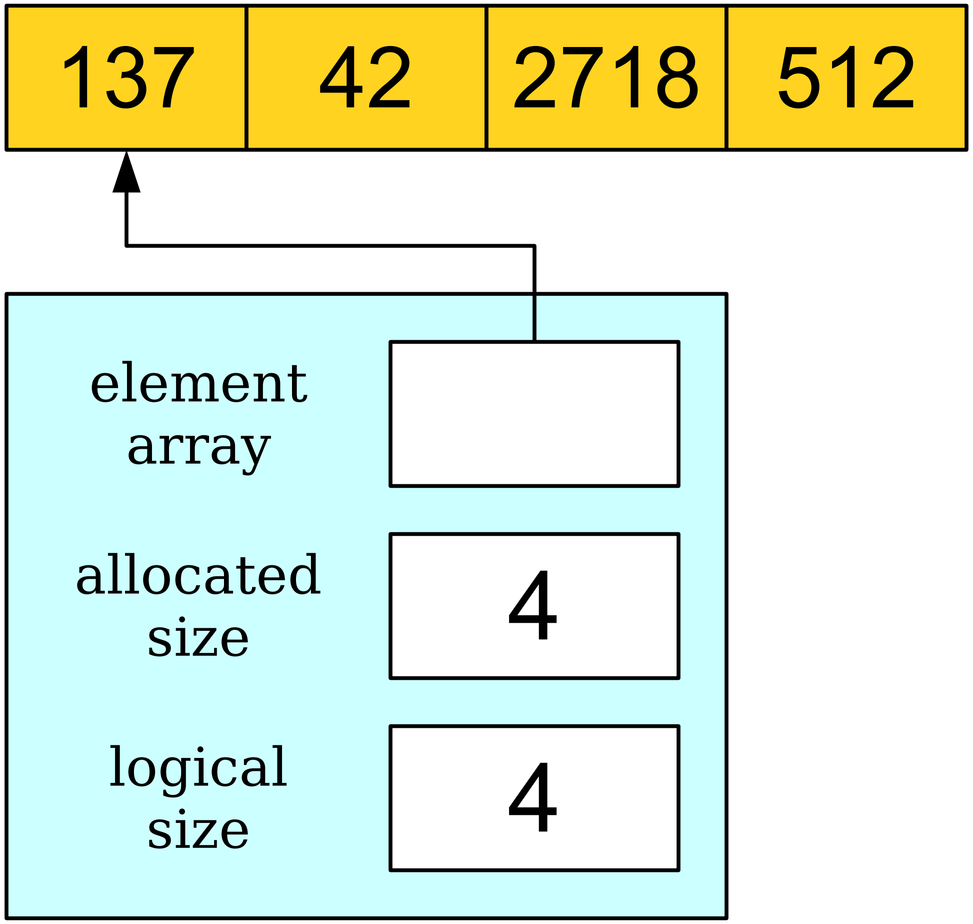
# An Initial Idea



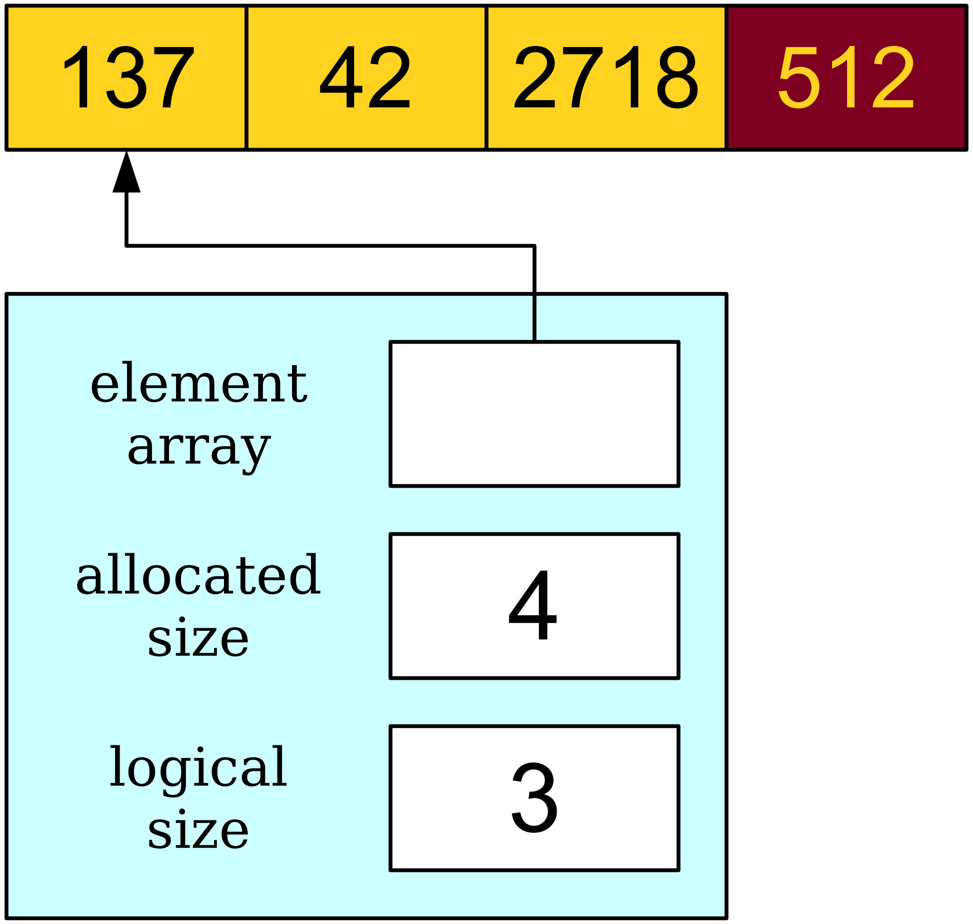
# An Initial Idea



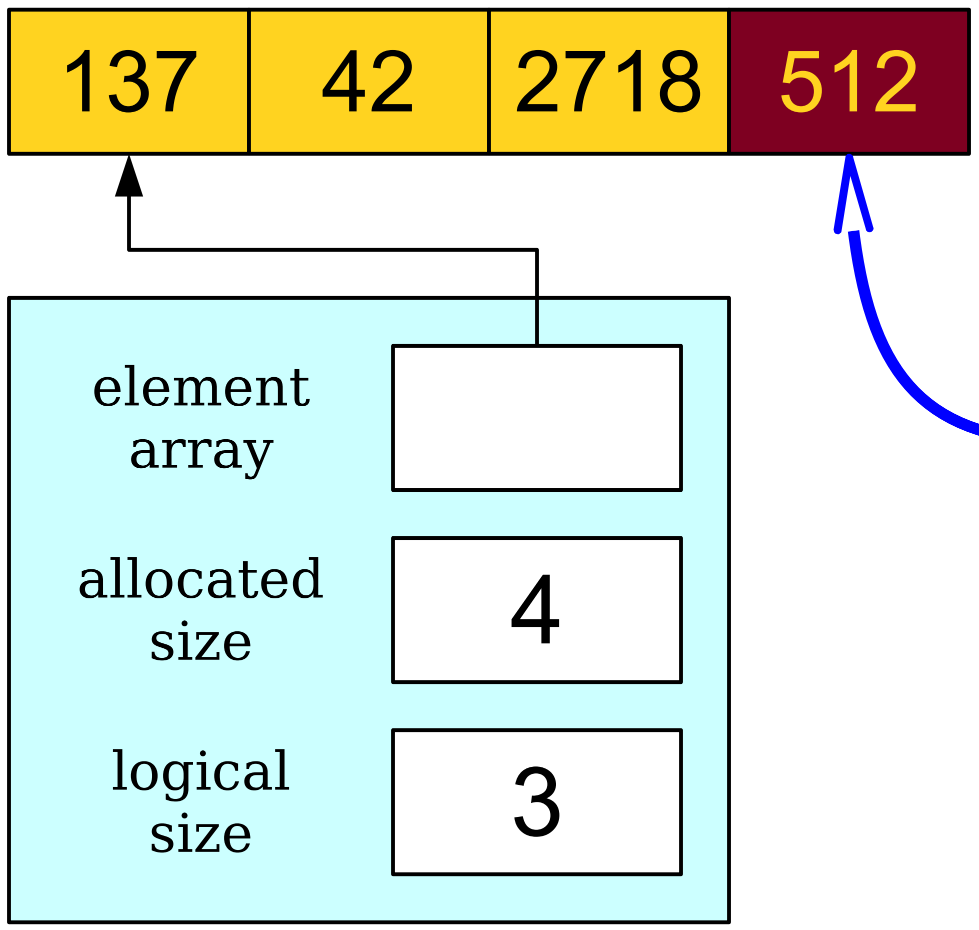
# An Initial Idea



## An Initial Idea

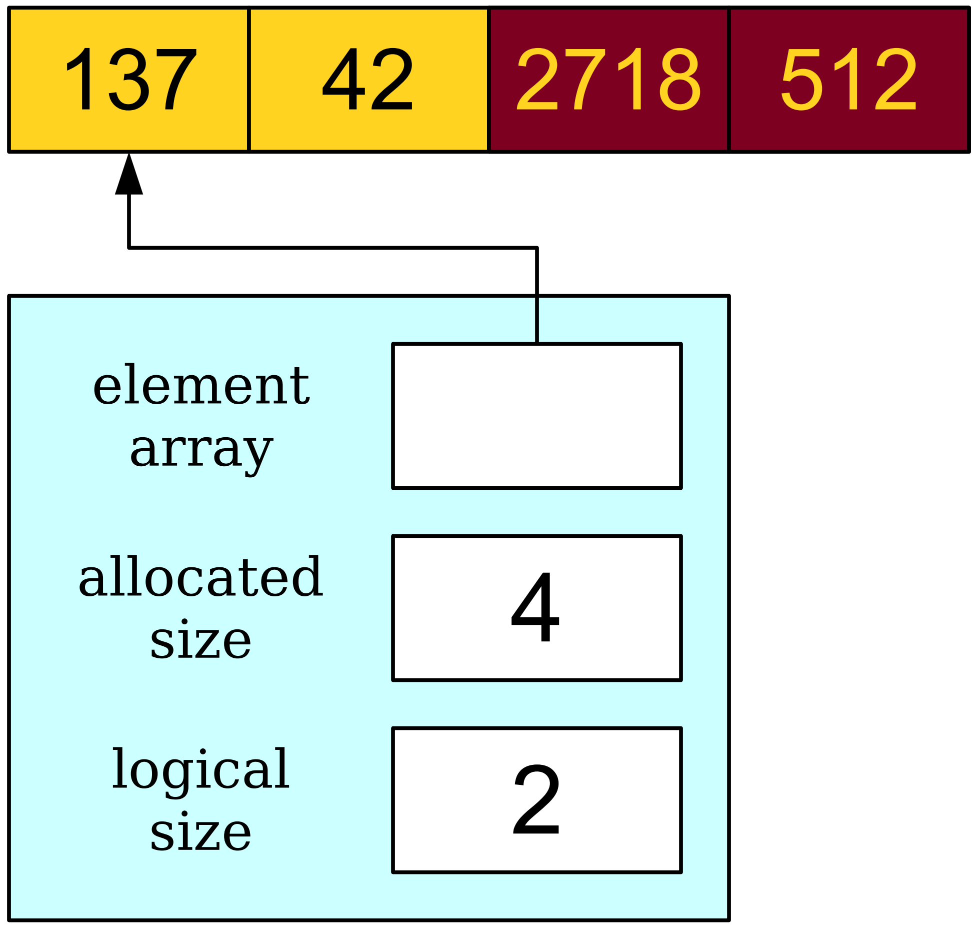


# An Initial Idea

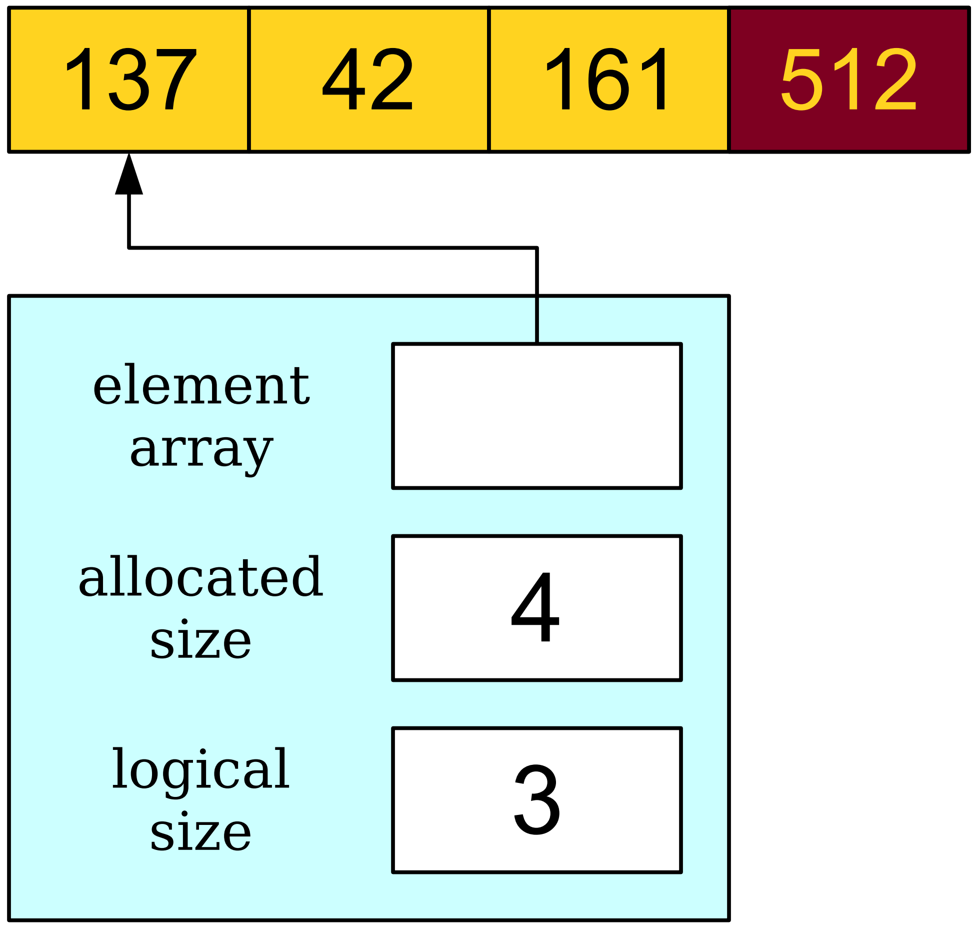


Arrays cannot grow or shrink, so this older value is still technically there in the array. We're just going to pretend it isn't.

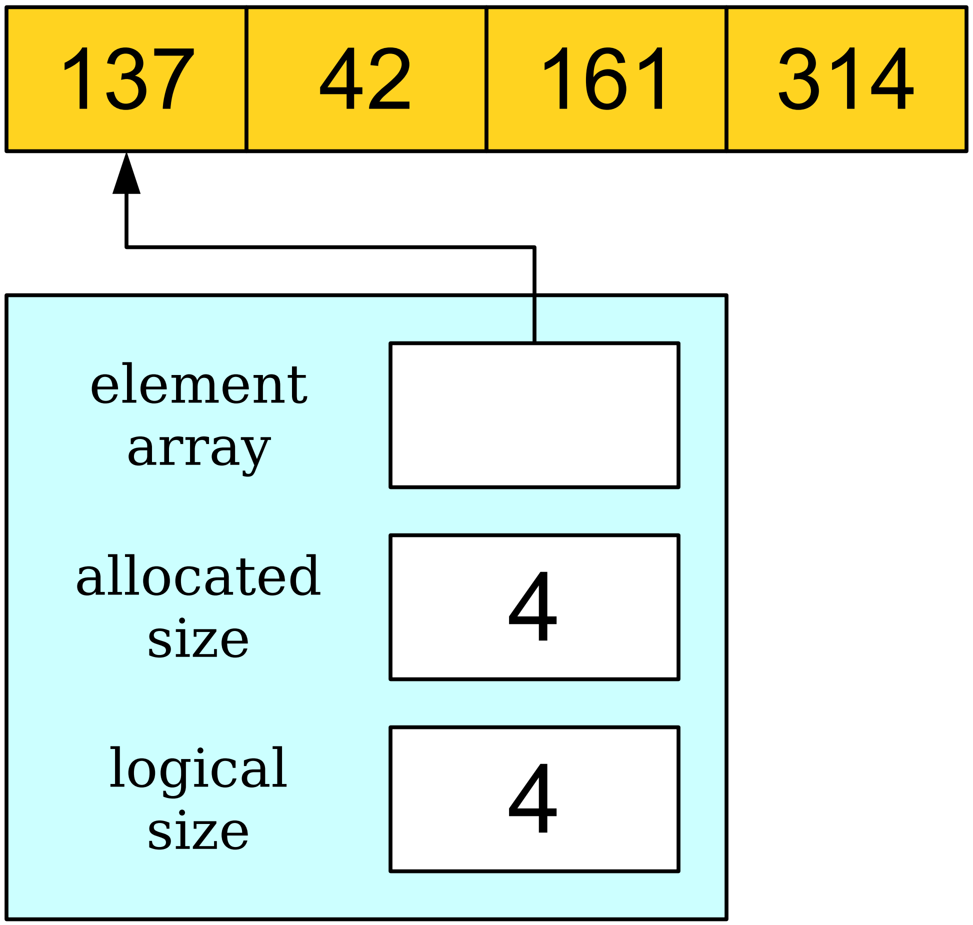
# An Initial Idea



# An Initial Idea



# An Initial Idea



## What We Have

## Before We Start: A Problem

## Cradle to Grave

```
int main() {
    OurStack stack;

    /* The stack lives a rich, happy,
     * fulfilling life, the kind we
     * all aspire to.
     */

    return 0;
}
```

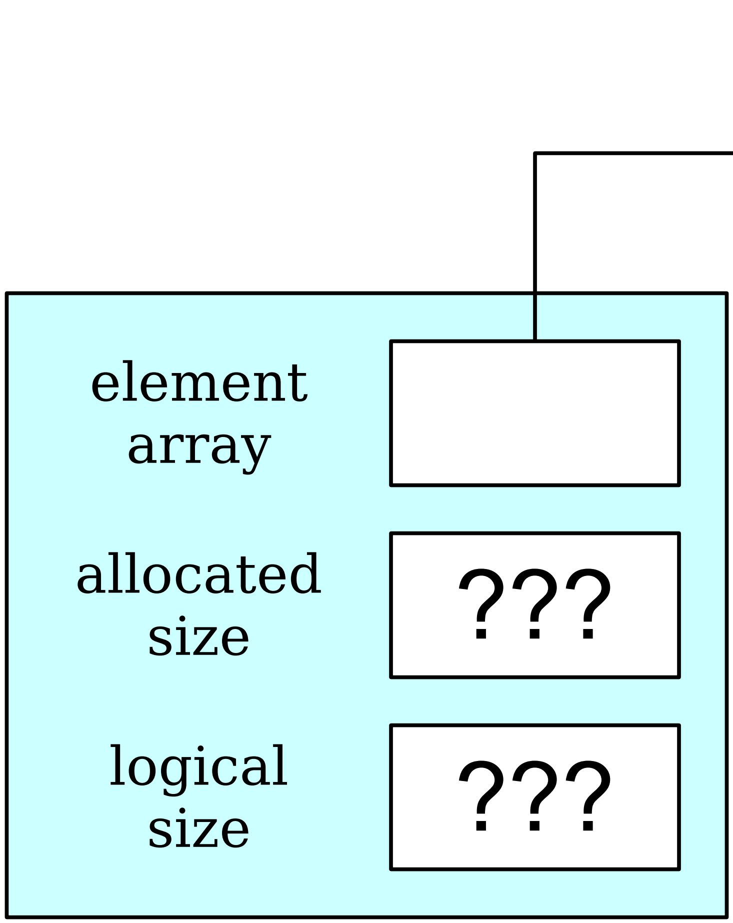
# Cradle to Grave

```
int main() {
    OurStack stack;

    /* The stack lives a rich, happy,
     * fulfilling life, the kind we
     * all aspire to.
     */

    return 0;
}
```

# Cradle to Grave



```
int main() {
    OurStack stack;

    /* The stack lives a rich, happy,
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     */

    return 0;
}
```
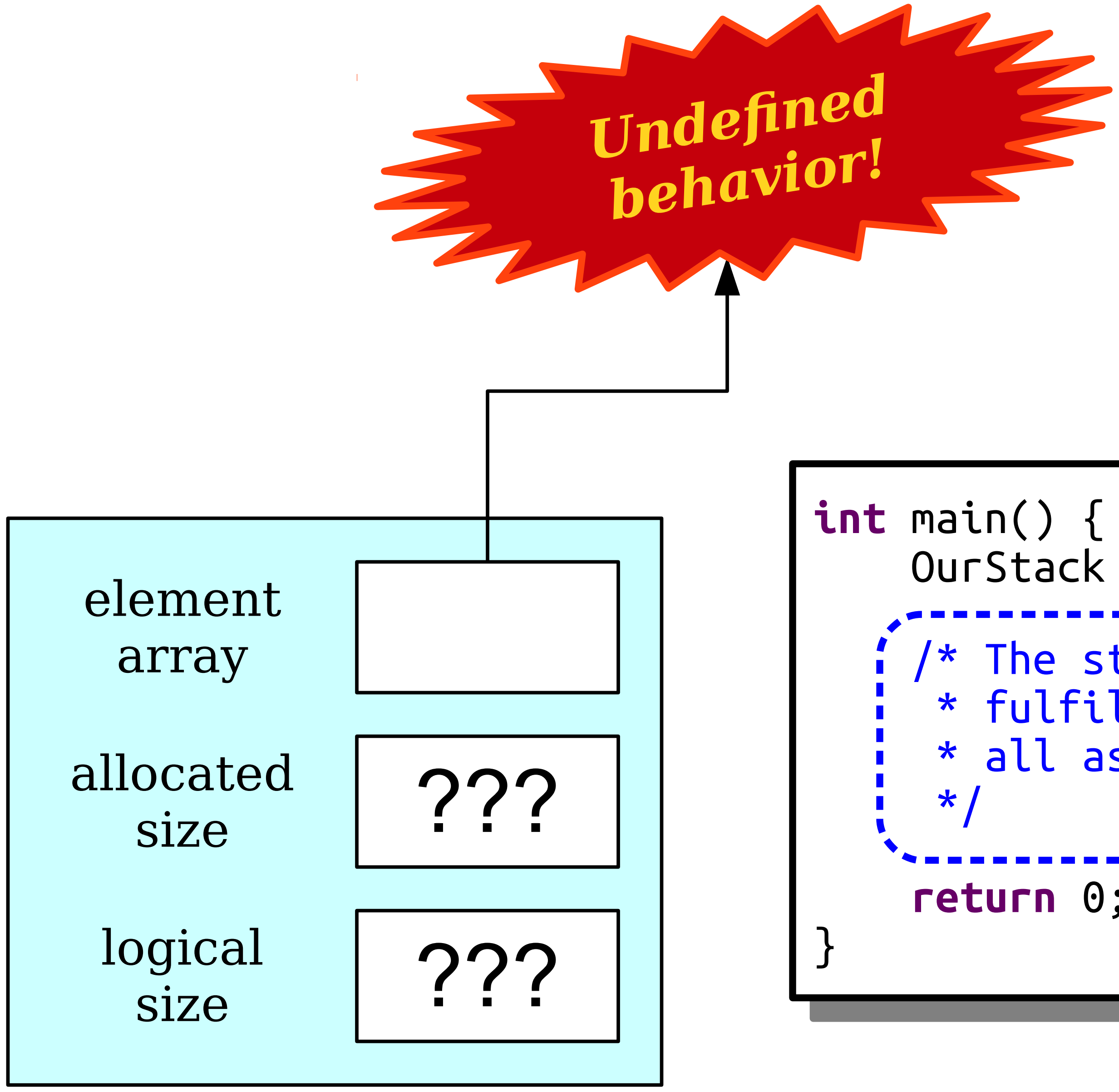

# Cradle to Grave



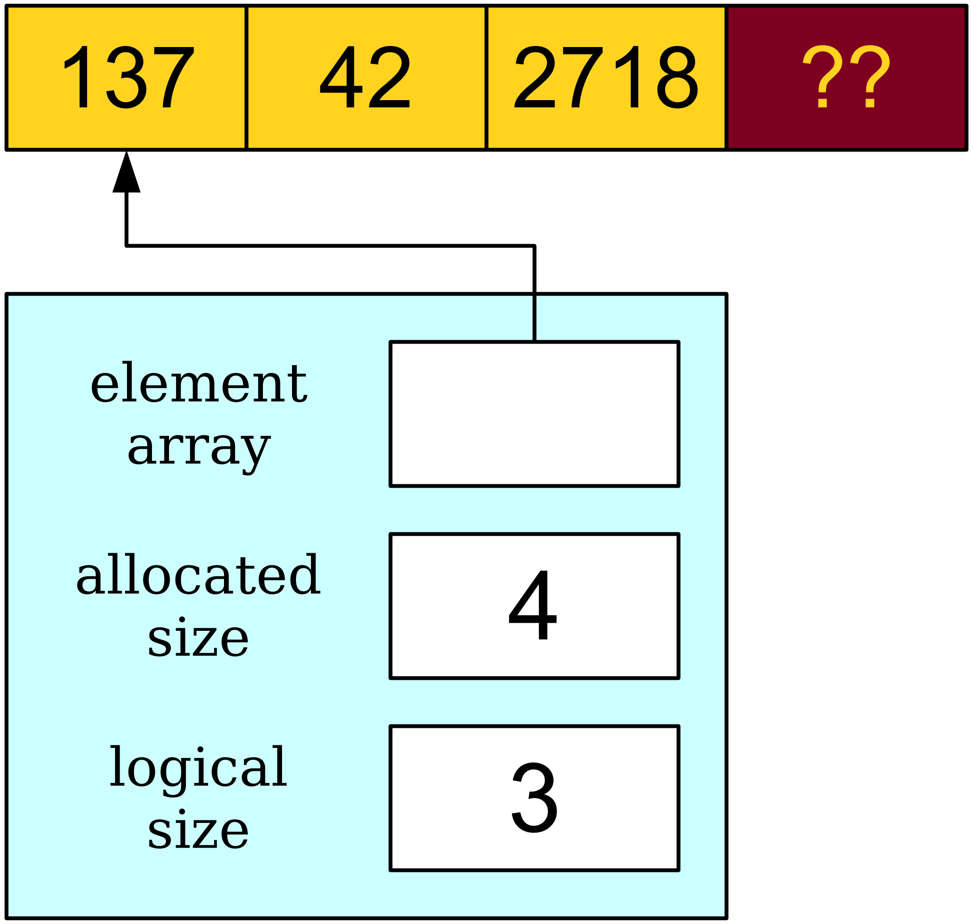
```
int main() {
    OurStack stack;

    /* The stack lives a rich, happy,
     * fulfilling life, the kind we
     * all aspire to.
     */

    return 0;
}
```

# Constructors

- A ***constructor*** is a special member function used to set up the class before it is used.
- The constructor is automatically called when the object is created.
- The constructor for a class named ***ClassName*** has signature

```
ClassName(args);
```

## Implementing our Operations



```
class OurStack {
public:
    OurStack();

    int  peek() const;
    void push(int value);
    int  pop();

    int  size() const;
    bool isEmpty() const;

private:
    int* elems;
    int  allocatedSize;
    int  logicalSize;
};
```

## So… we’re done?

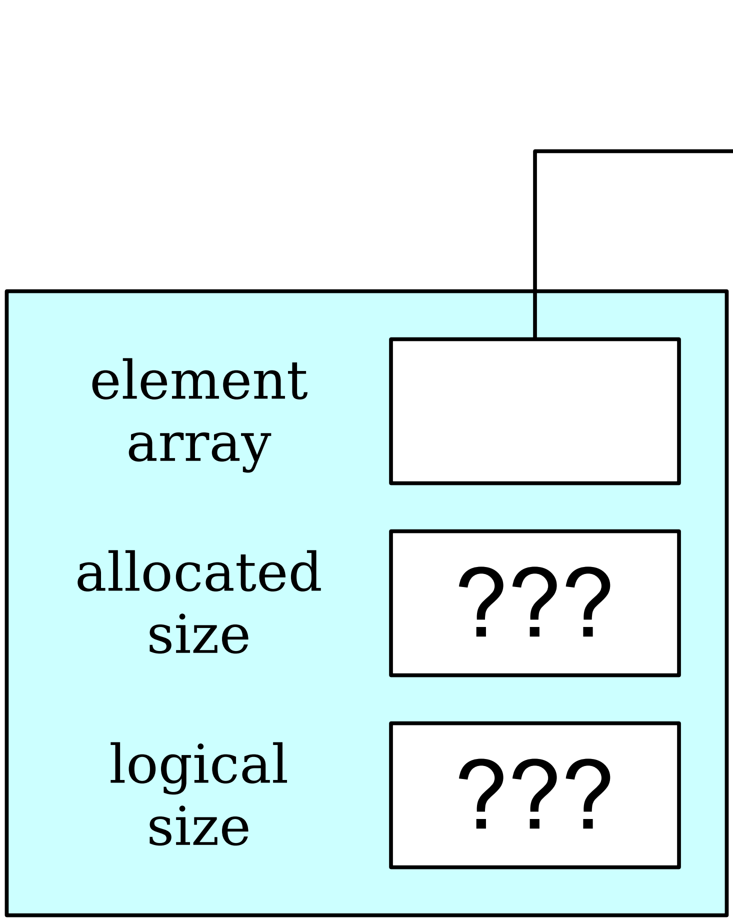
# Cradle to Grave, Take II

```
int main() {
    OurStack stack;

    /* The stack lives a rich, happy,
     * fulfilling life, the kind we
     * all aspire to.
     */

    return 0;
}
```

## Cradle to Grave, Take II

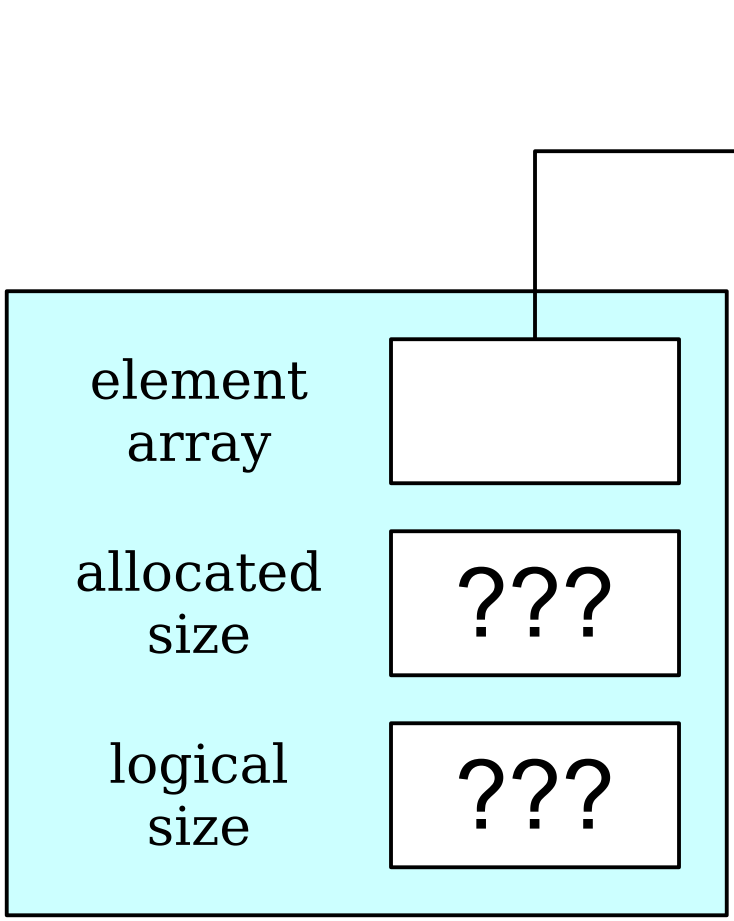
```
int main() {
    OurStack stack;

    /* The stack lives a rich, happy,
     * fulfilling life, the kind we
     * all aspire to.
     */

    return 0;
}
```

# Cradle to Grave, Take II



```
int main() {
    OurStack stack;

    /* The stack lives a rich, happy,
     * fulfilling life, the kind we
     * all aspire to.
     */

    return 0;
}
```

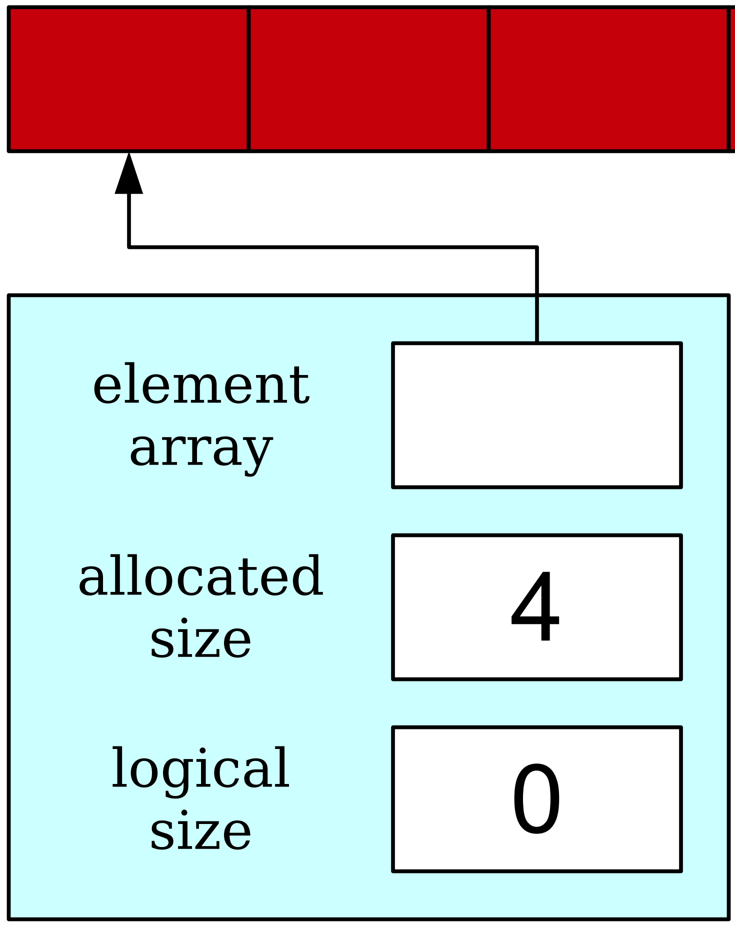
# Cradle to Grave, Take II



```
int
}
```

```
OurStack::OurStack() {
    logicalSize = 0;
    allocatedSize = kInitialSize;
    elems = new int[allocatedSize];
}
```

# Cradle to Grave, Take II

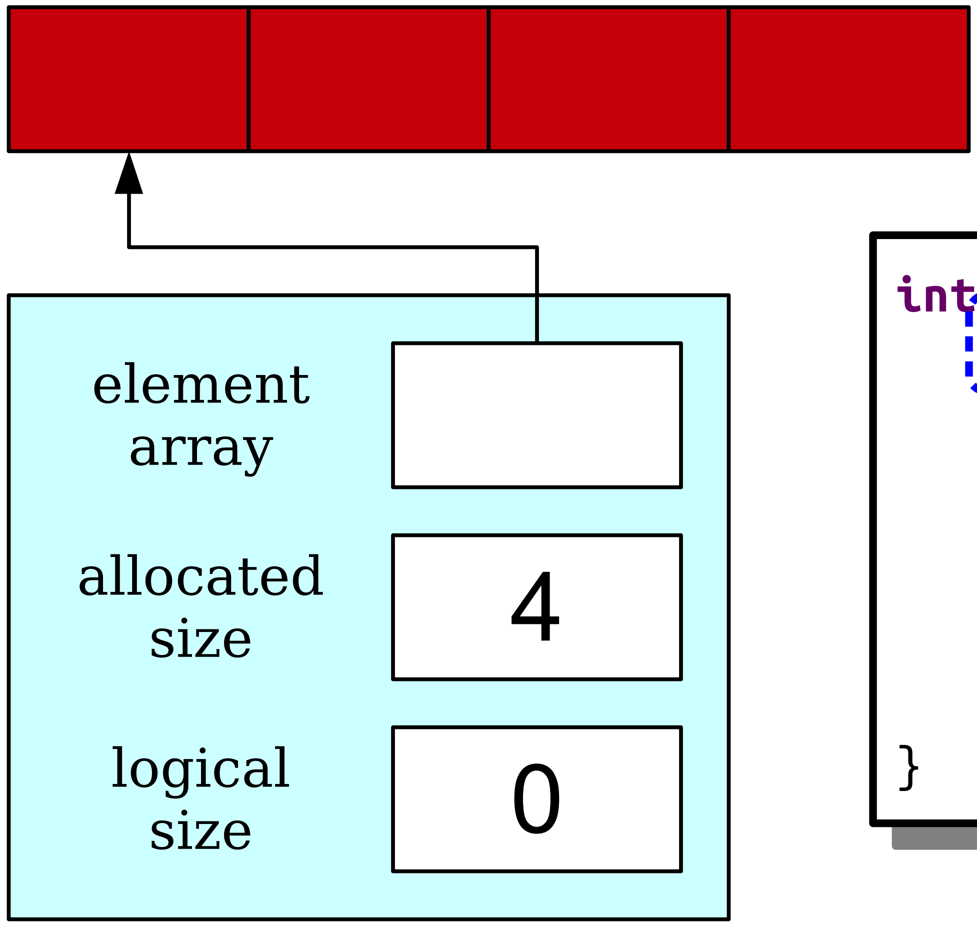


```
int
```

```
OurStack::OurStack() {
    logicalSize = 0;
    allocatedSize = kInitialSize;
    elems = new int[allocatedSize];
}
```

```
}
```

# Cradle to Grave, Take II



```
int main() {
    OurStack stack;

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     */

    return 0;
}
```
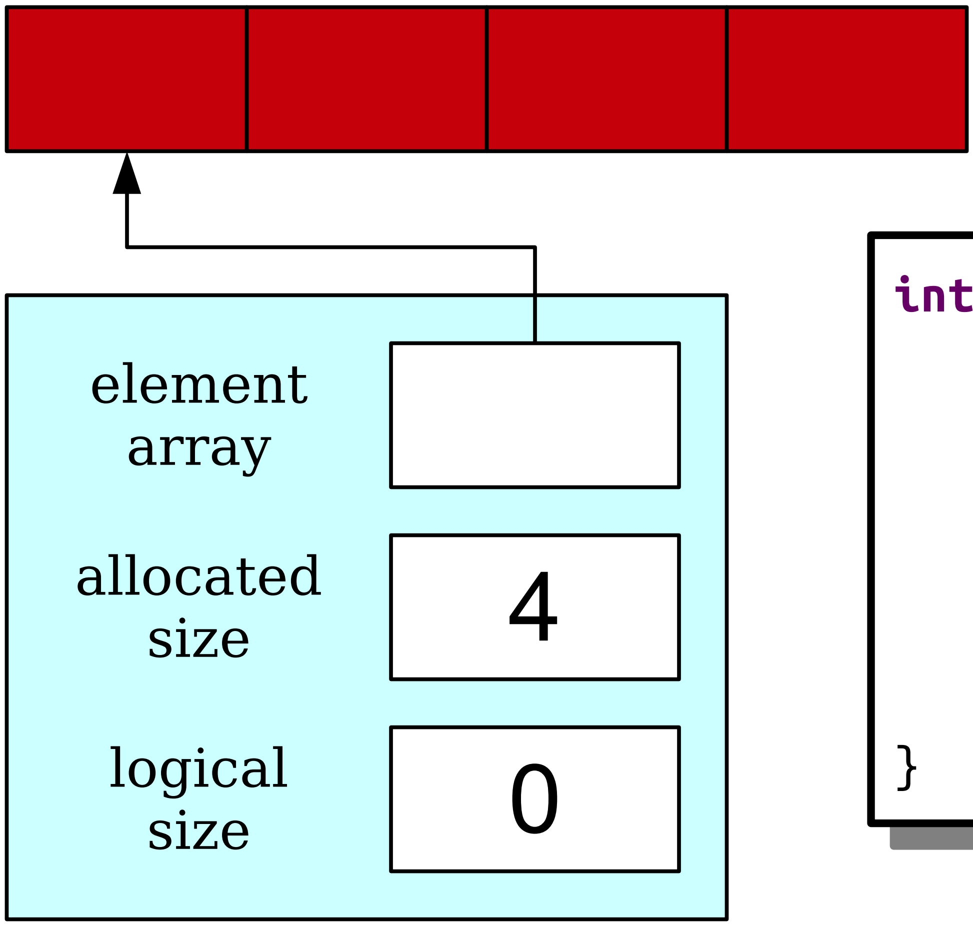

# Cradle to Grave, Take II



```
int main() {
    OurStack stack;

    /* The stack lives a rich, happy,
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     */

    return 0;
}
```
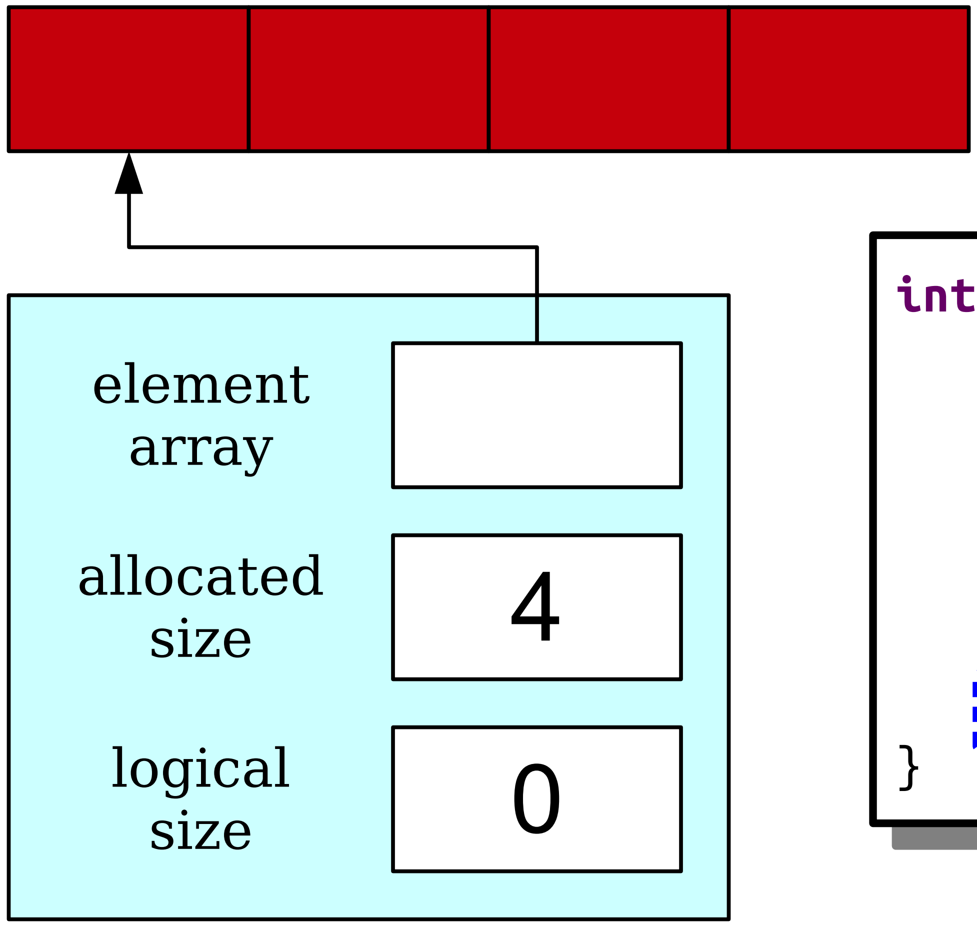

# Cradle to Grave, Take II



```
int main() {
    OurStack stack;

    /* The stack lives a rich, happy,
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     */

    return 0;
}
```
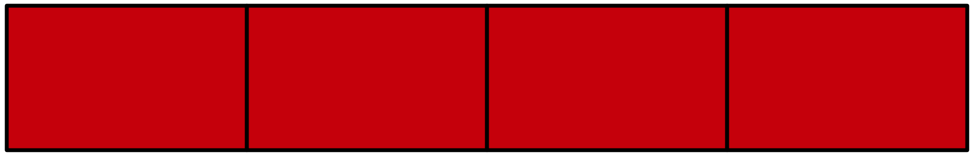

# Cradle to Grave, Take II



```
int main() {
    OurStack stack;

    /* The stack lives a rich, happy,
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     * all aspire to.
     */

    return 0;
}
```
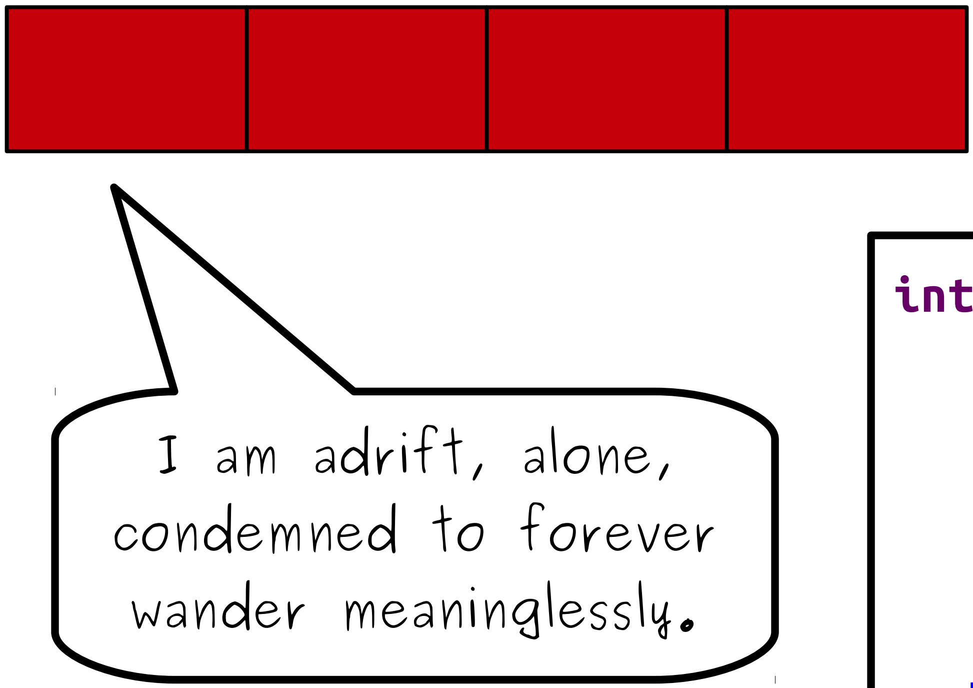

# Cradle to Grave, Take II


I am adrift, alone, condemned to forever wander meaninglessly.

```
int main() {
    OurStack stack;

    /* The stack lives a rich, happy,
     * fulfilling life, the kind we
     * all aspire to.
     */

    return 0;
}
```

# Destructors

- A ***destructor*** is a special member function responsible for cleaning up an object's memory.
- It’s automatically called whenever an object’s lifetime ends (for example, if it’s a local variable that goes out of scope.)
- The destructor for a class named ***ClassName*** has signature

```
~ClassName();
```

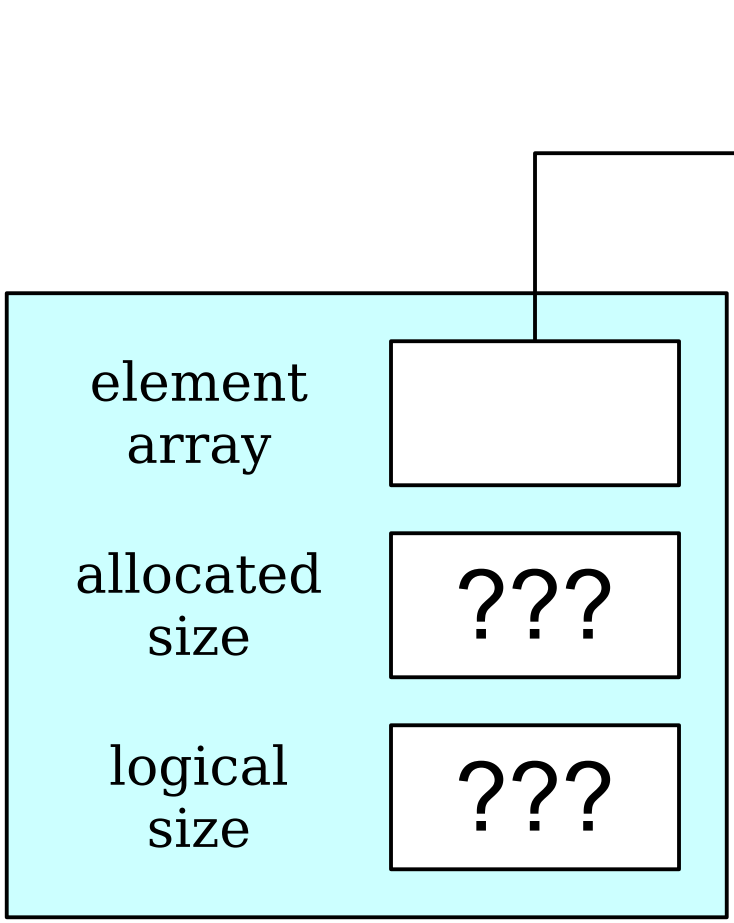
## Cradle to Grave, Take III

```
int main() {
    OurStack stack;

    /* The stack lives a rich, happy,
     * fulfilling life, the kind we
     * all aspire to.
     */

    return 0;
}
```

## Cradle to Grave, Take III

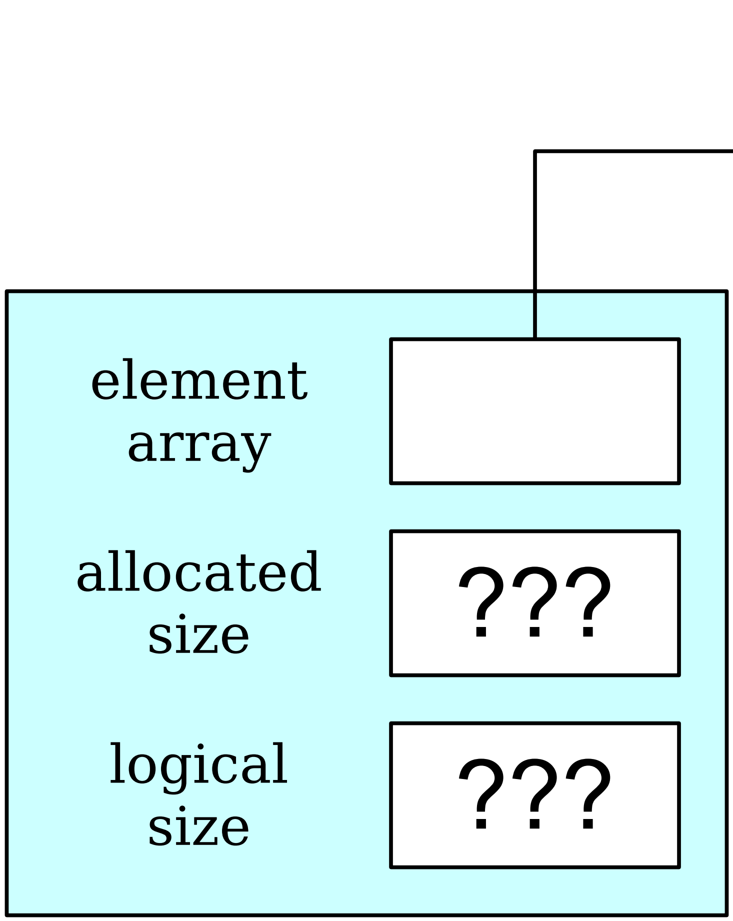
```
int main() {
   OurStack stack;

    /* The stack lives a rich, happy,
     * fulfilling life, the kind we
     * all aspire to.
     */

    return 0;
}
```

# Cradle to Grave, Take III



```
int main() {
    OurStack stack;

    /* The stack lives a rich, happy,
     * fulfilling life, the kind we
     * all aspire to.
     */

    return 0;
}
```

# Cradle to Grave, Take III

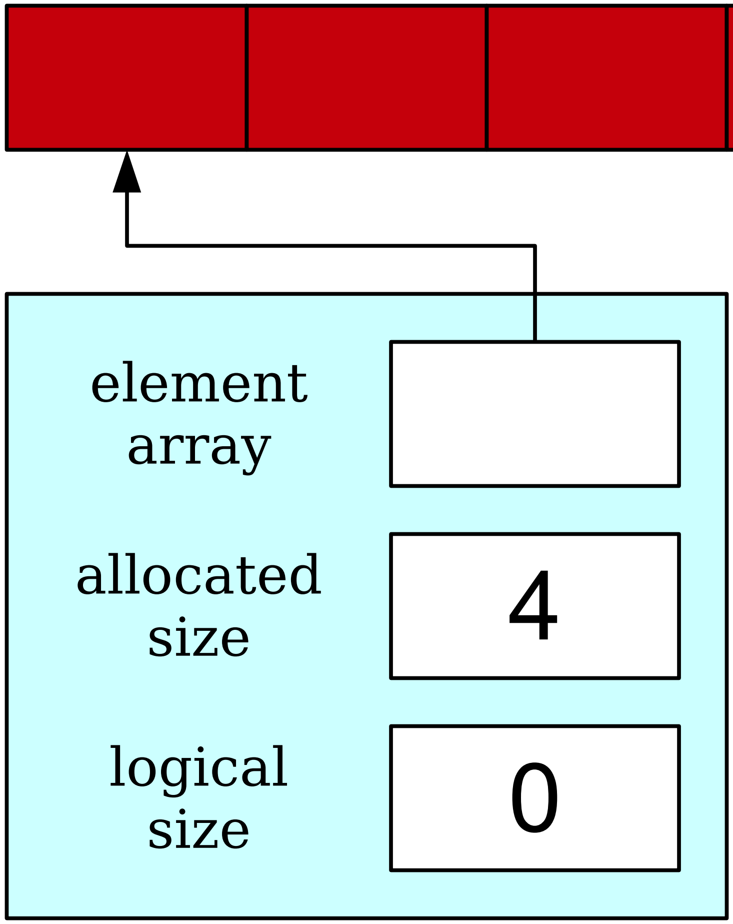


```
int
```

```
OurStack::OurStack() {
    logicalSize = 0;
    allocatedSize = kInitialSize;
    elems = new int[allocatedSize];
}
```

```
}
```

# Cradle to Grave, Take III

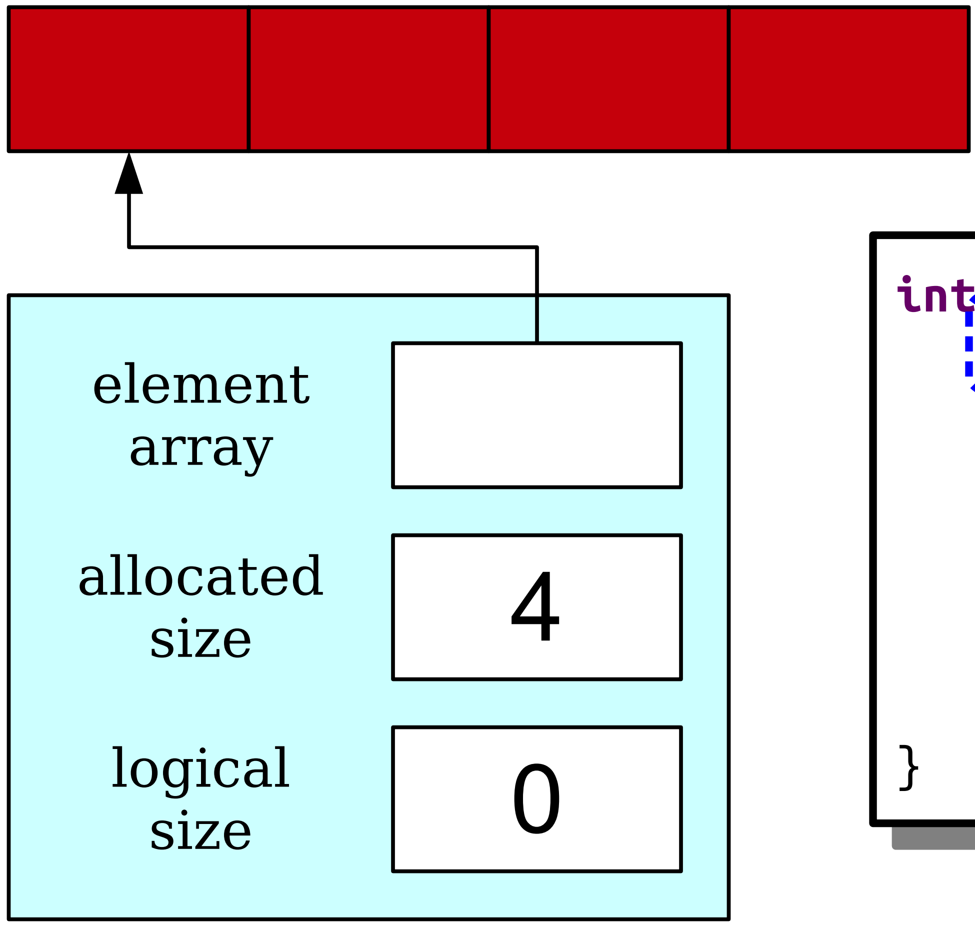


```
int
```

```
OurStack::OurStack() {
    logicalSize = 0;
    allocatedSize = kInitialSize;
    elems = new int[allocatedSize];
}
```

```
}
```

# Cradle to Grave, Take III



```
int main() {
    OurStack stack;

    /* The stack lives a rich, happy,
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     * all aspire to.
     */

    return 0;
}
```
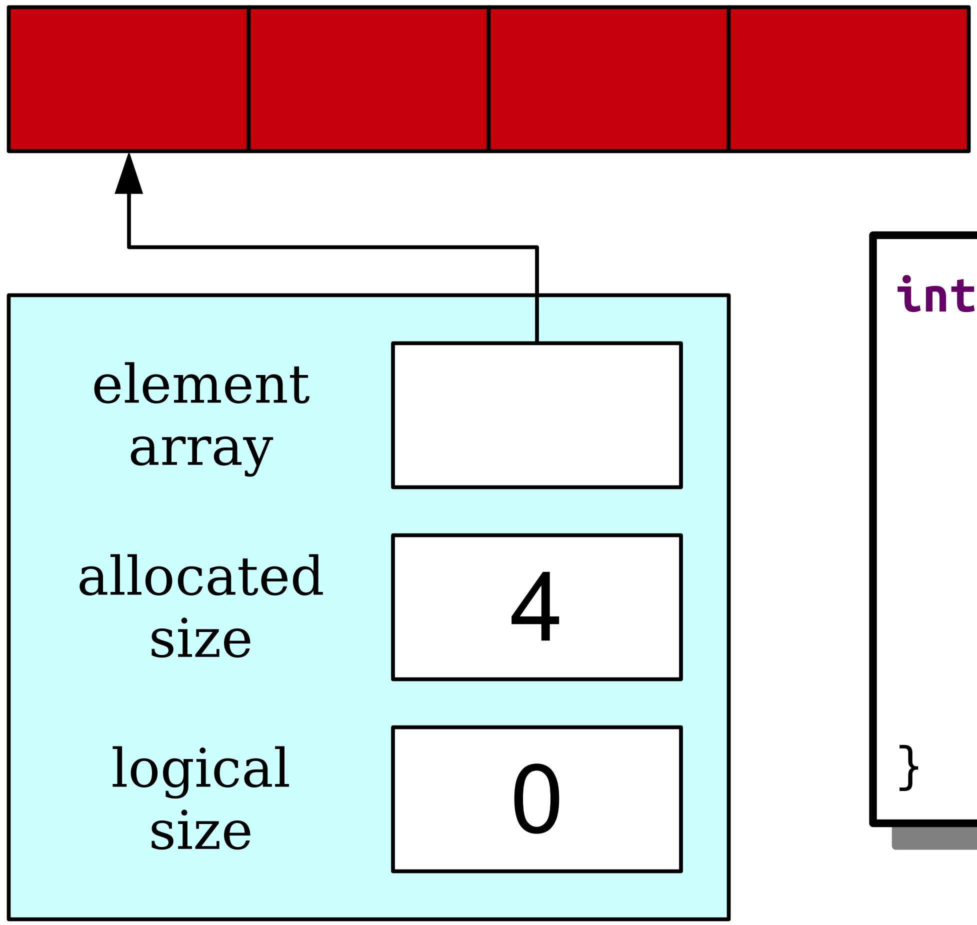
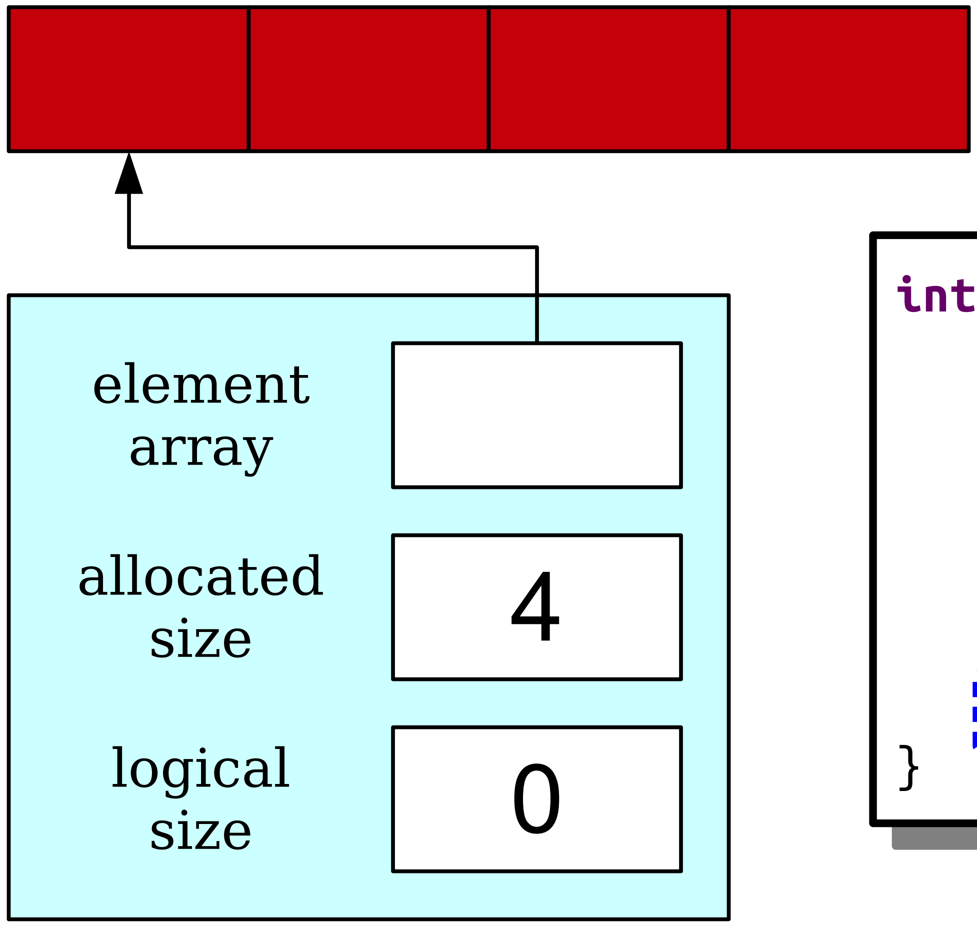

# Cradle to Grave, Take III



```
int main() {
    OurStack stack;
    /* The stack lives a rich, happy,
     * fulfilling life, the kind we
     * all aspire to.
     */
    return 0;
}
```

# Cradle to Grave, Take III



```
int main() {
    OurStack stack;

    /* The stack lives a rich, happy,
     * fulfilling life, the kind we
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     */

    return 0;
}
```
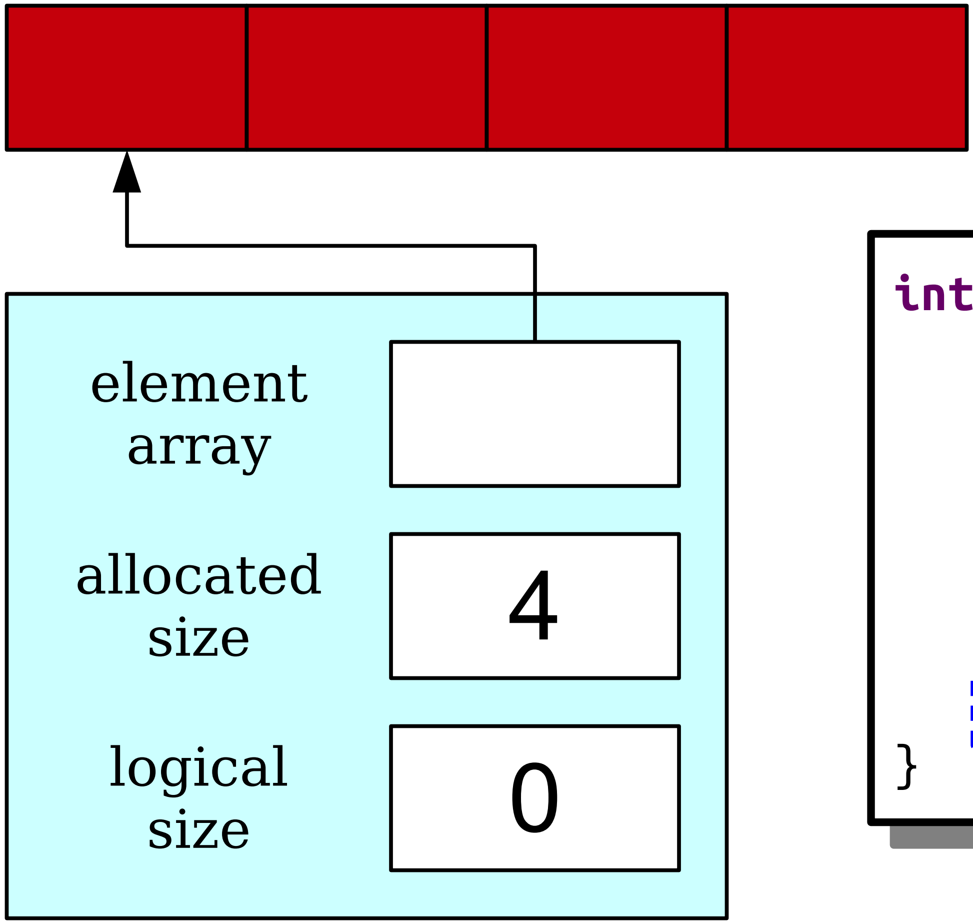
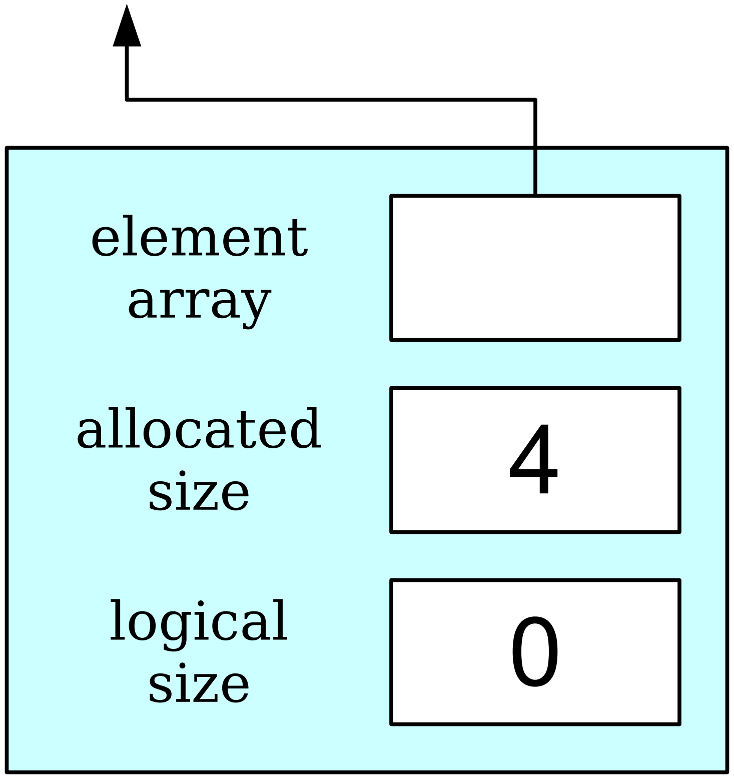

# Cradle to Grave, Take III



```
int main() {

}
```

```
OurStack::~OurStack() {
    delete[] elems;
}
```

# Cradle to Grave, Take III



```
int main() {
    OurStack stack;

    /* The stack lives a rich, happy,
     * fulfilling life, the kind we
     * all aspire to.
     */

    return 0;
}
```

# Cradle to Grave, Take III

```
int main() {
    OurStack stack;

    /* The stack lives a rich, happy,
     * fulfilling life, the kind we
     * all aspire to.
     */

    return 0;
}
```

## To Summarize

- You can create arrays of a fixed size at runtime by using `new[]`.
- You are responsible for freeing any memory you explicitly allocate by calling `delete[]`.
- Constructors are used to set up a class's internal state so that it's in a good place.
- Destructors are used to free resource that a class allocates.

## Your Action Items

- ***Download BlueBook and Section Handout 5.***
  - It’s a good idea to familiarize yourself with these tools before the actual exam.
  - Need a laptop? Ping us! It’s not a problem.
- ***Keep working on Assignment 4.***
  - If you’re following our timetable, you should be mostly done with Disaster Preparations at this point and should start working on Winning the Presidency.

## Next Time

- ***Making Stack Grow!***
  - Different approaches to `Stack` growth.
  - Analysis of these approaches.
  - The reality: *everything is a tradeoff!*
- ***Implementing the Queue***
  - … is not too hard when you have a stack!