Implementing Abstractions

Part One

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

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

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

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

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

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

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

```
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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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;
   }
}
```

```
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;
   }
}
```

numValues **7**

```
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 **7**

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

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

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

numValues **7** arr

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

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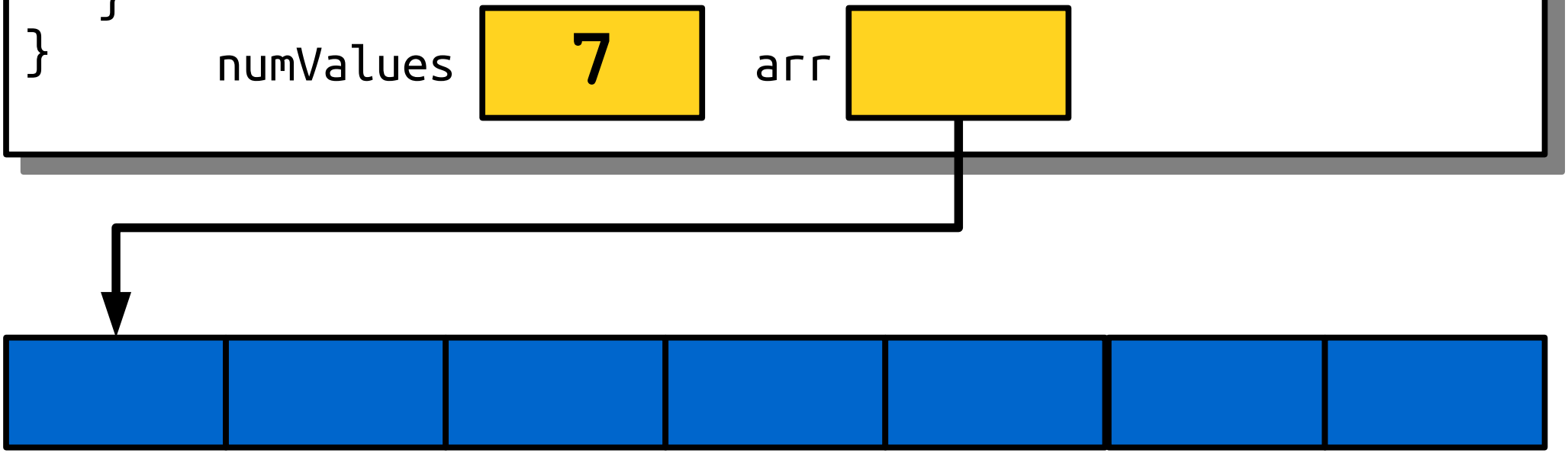
```



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      arr[i] = getLine();
   }

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

Because the variable arr points to the array, it is called a *pointer*.

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

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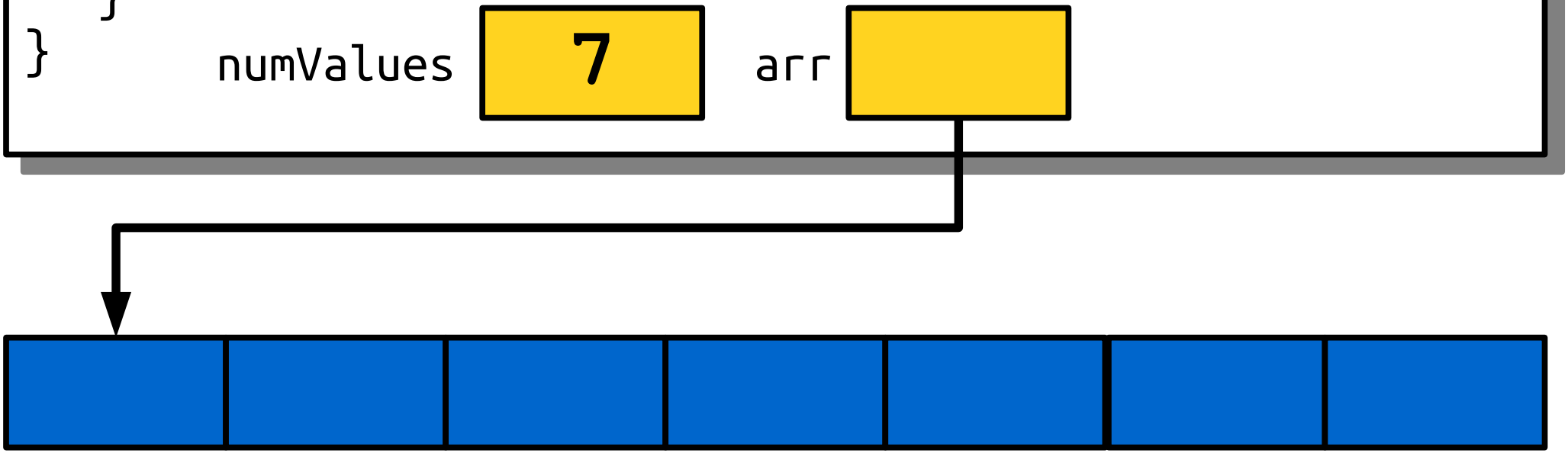

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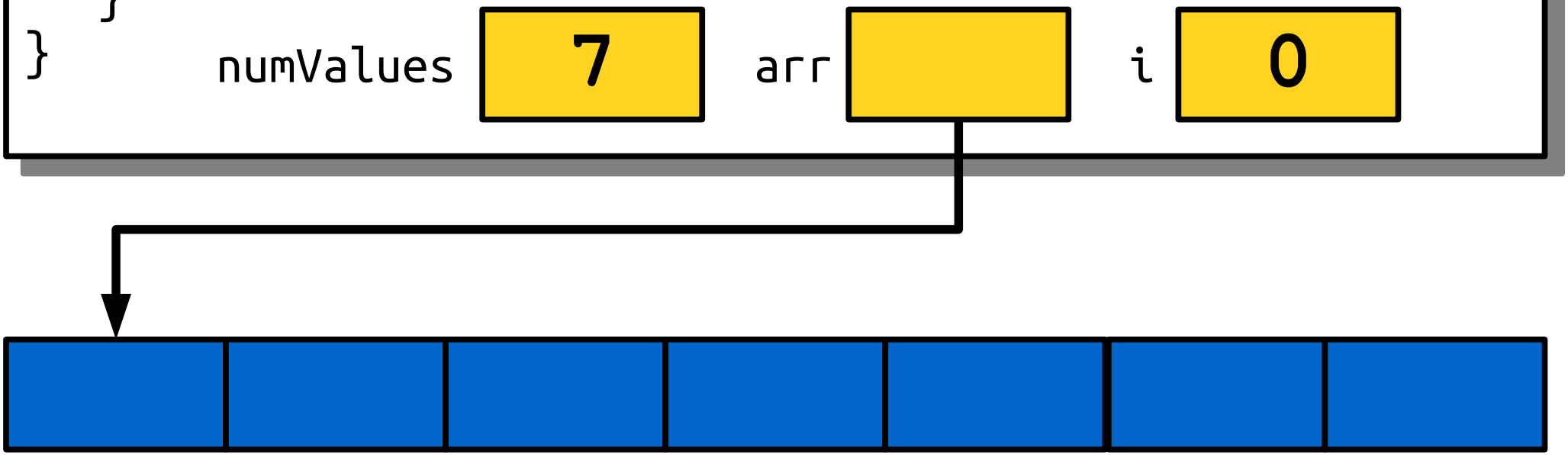

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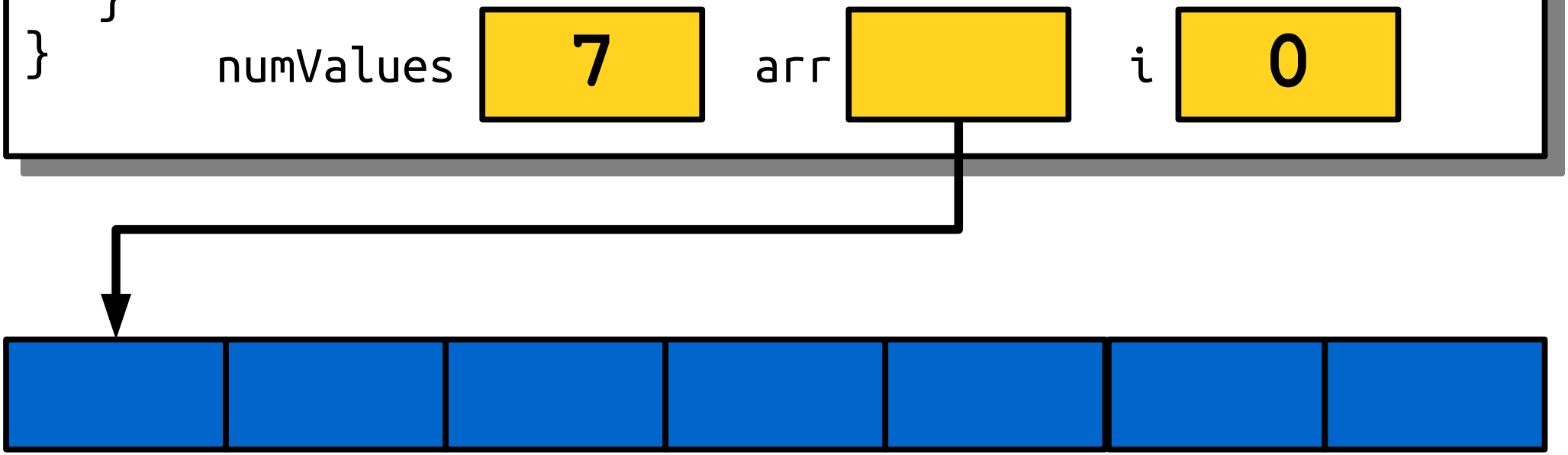

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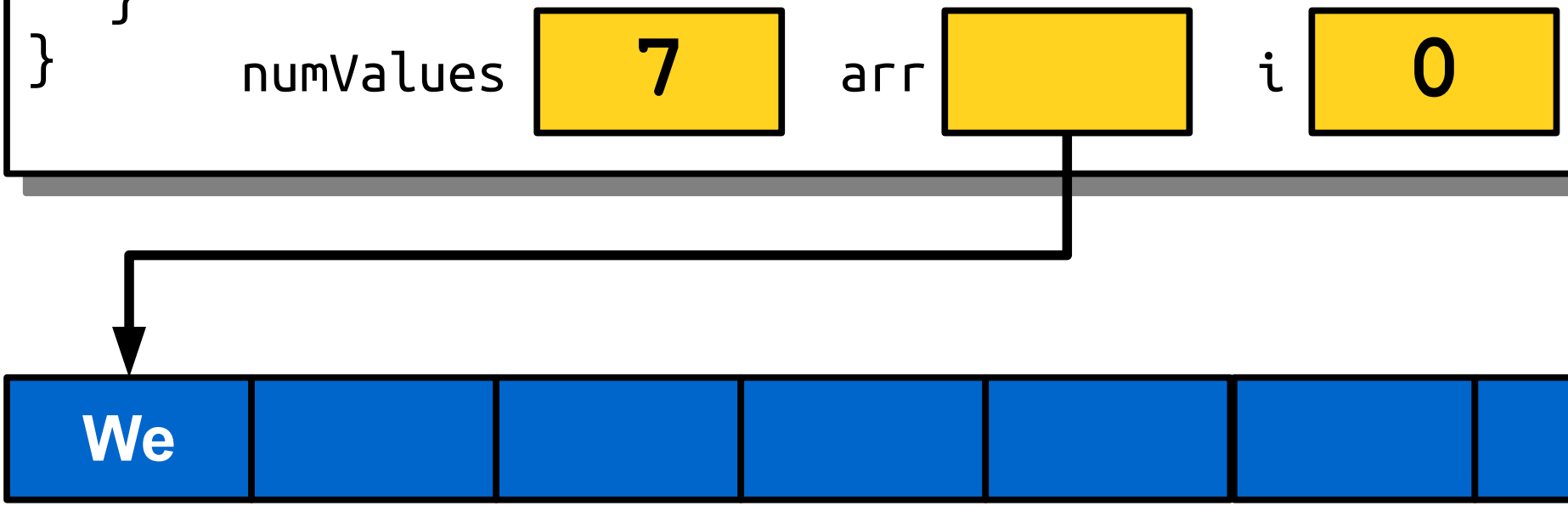

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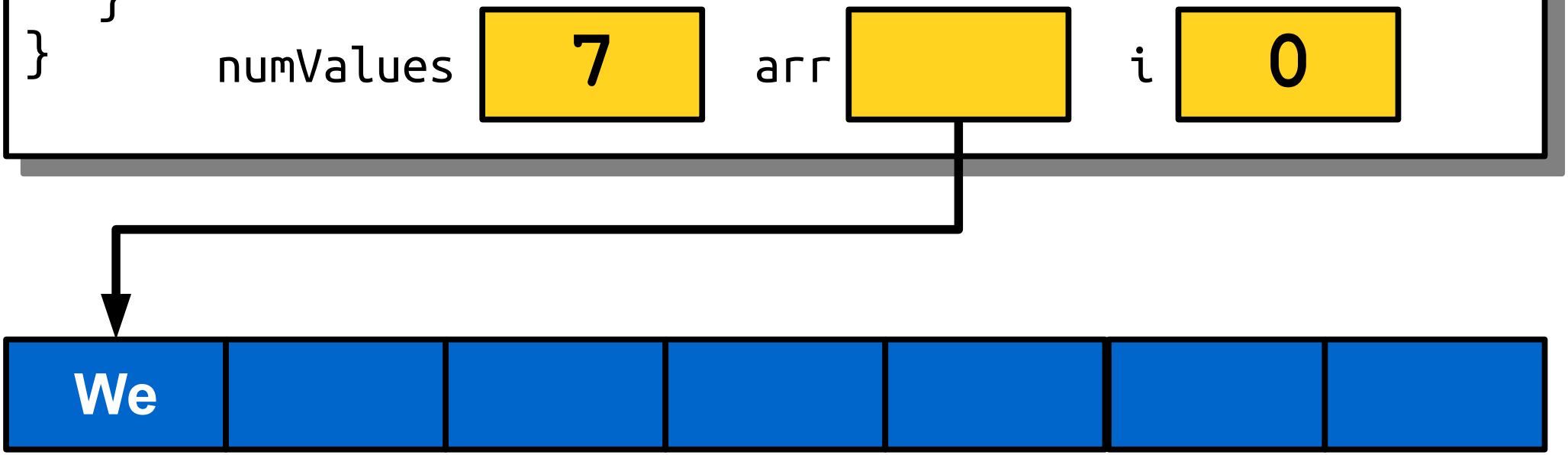

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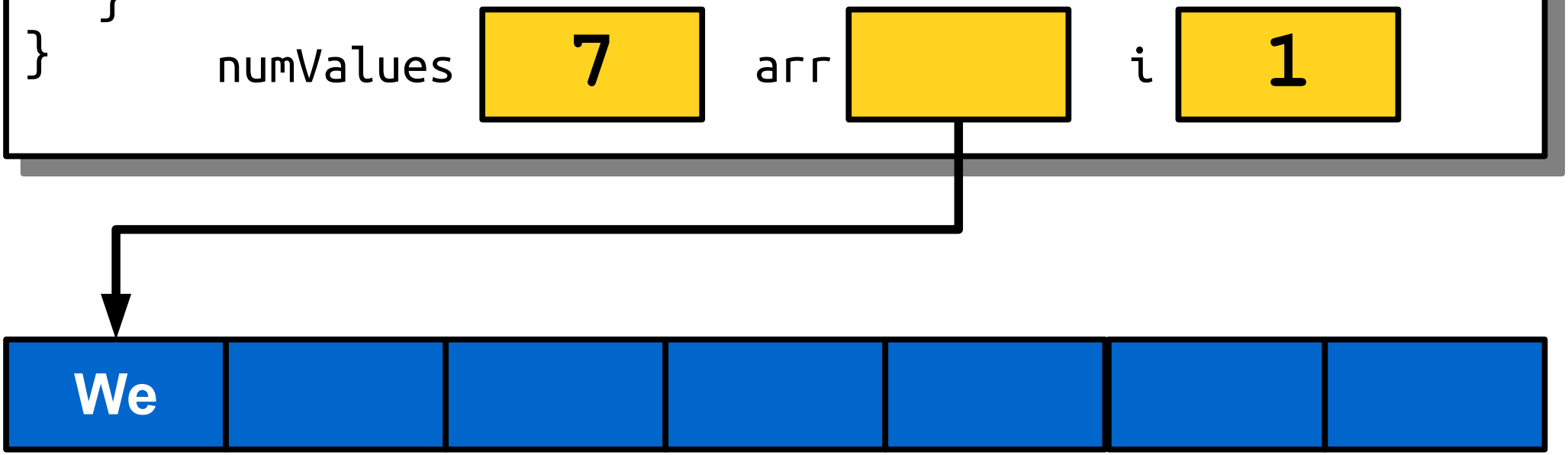

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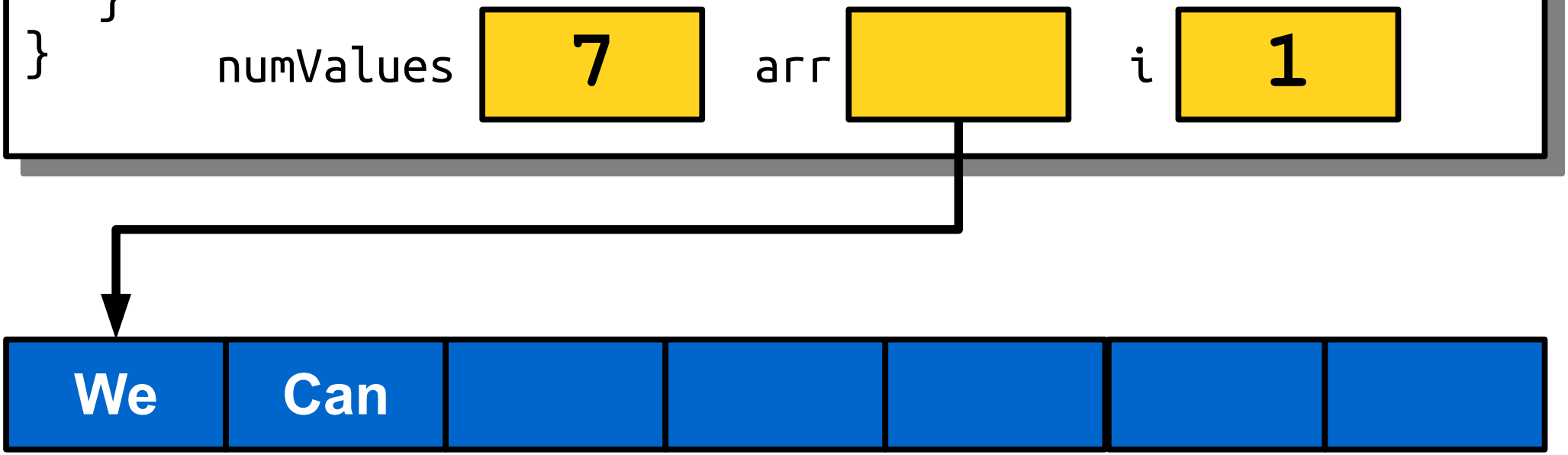

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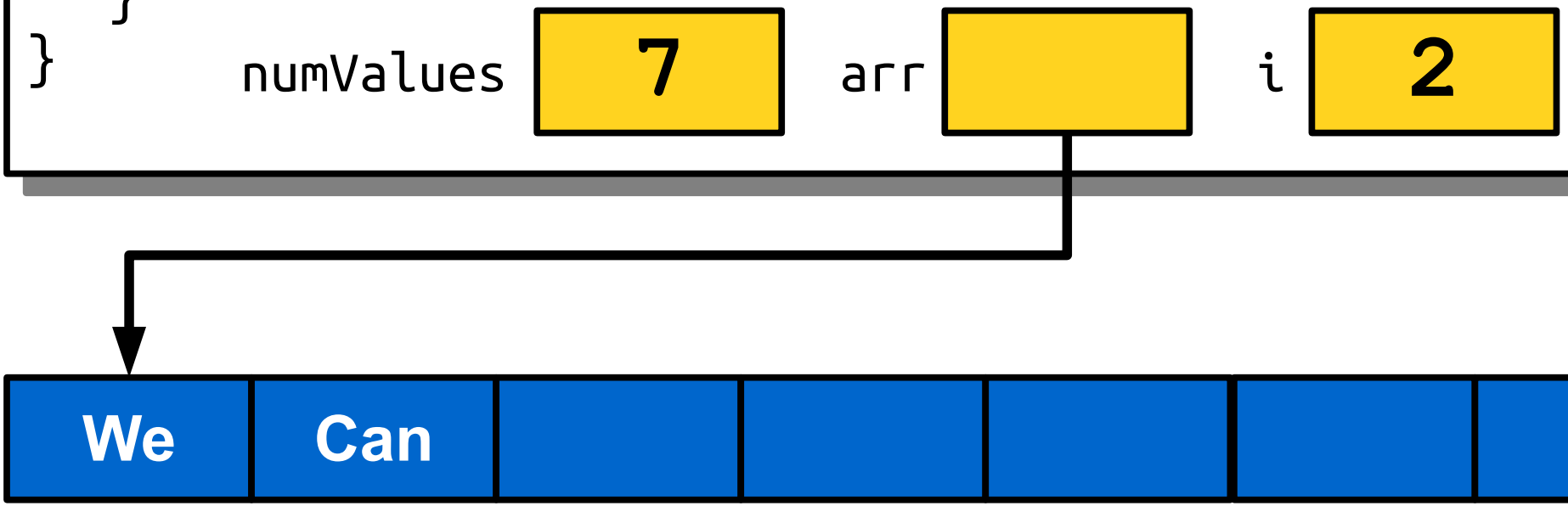

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   }

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

numValues **7** arr i **2**

```
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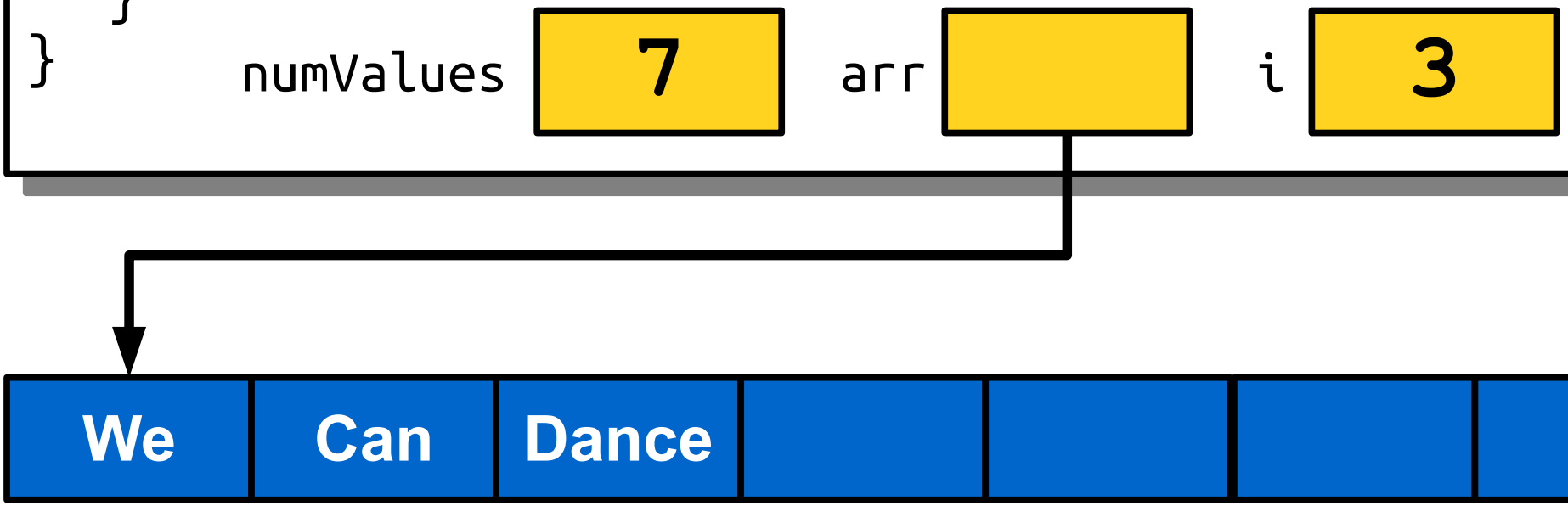

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}
```

numValues 7 arr i 3

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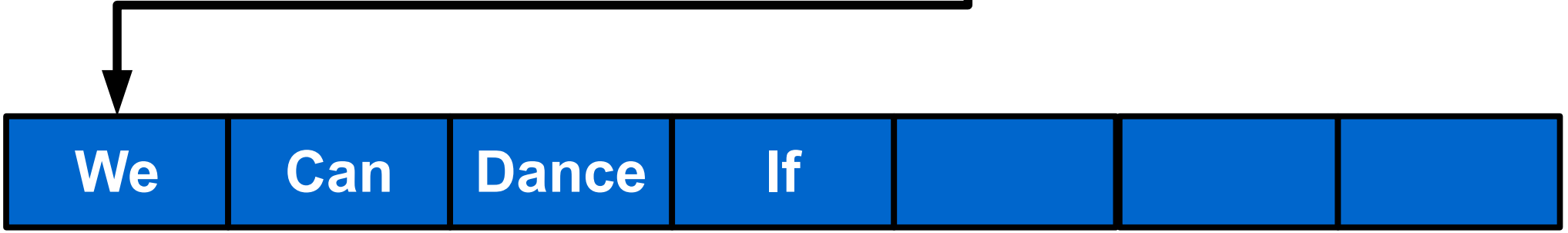
```

numValues 7 arr i 3



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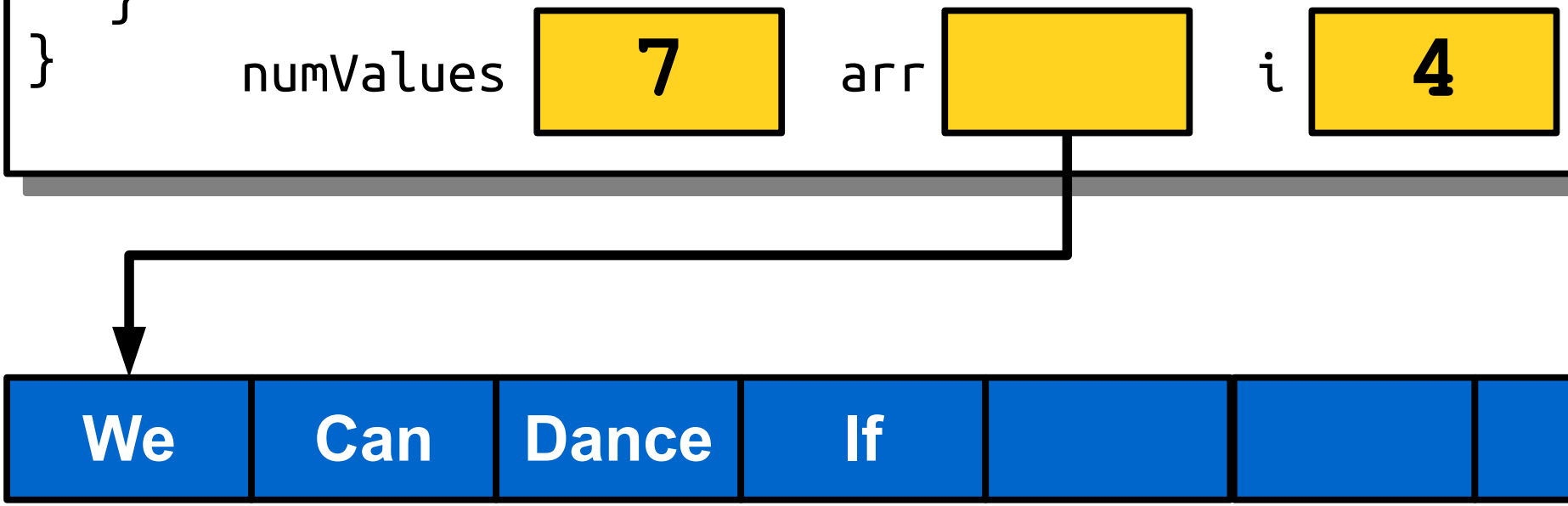

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   }

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

numValues **7** arr i **4**

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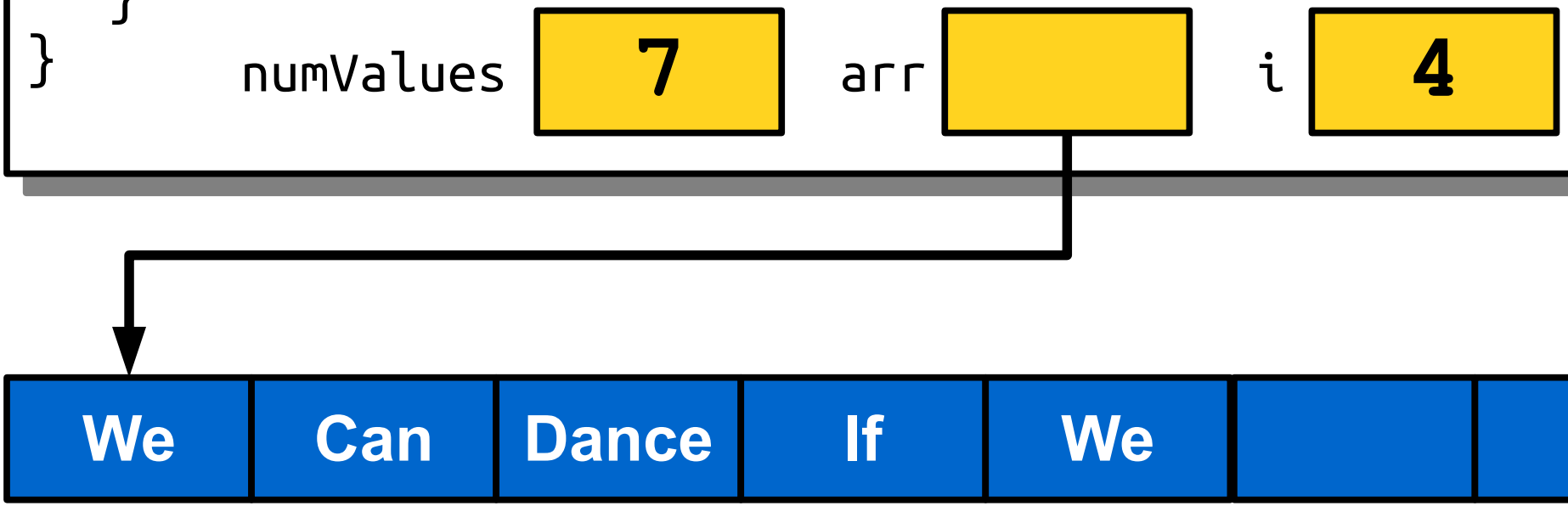
   for (int i = 0; i < numValues; i++) {
      arr[i] = getLine();
   }

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



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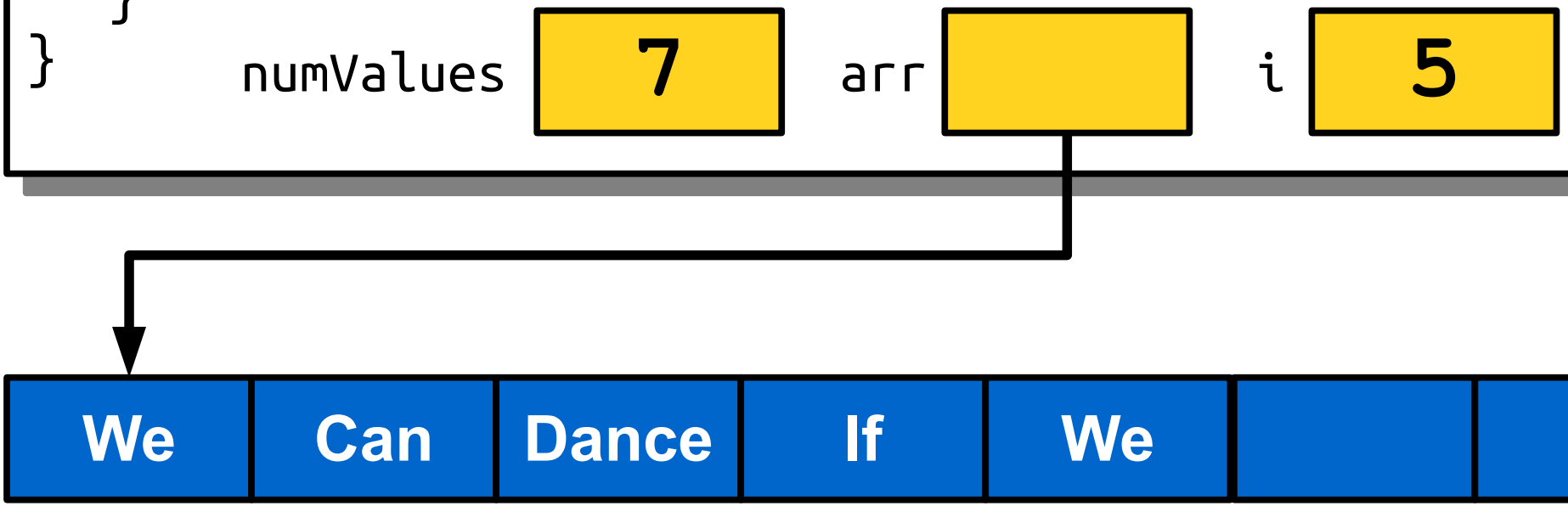

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}
```

numValues **7** arr i **5**

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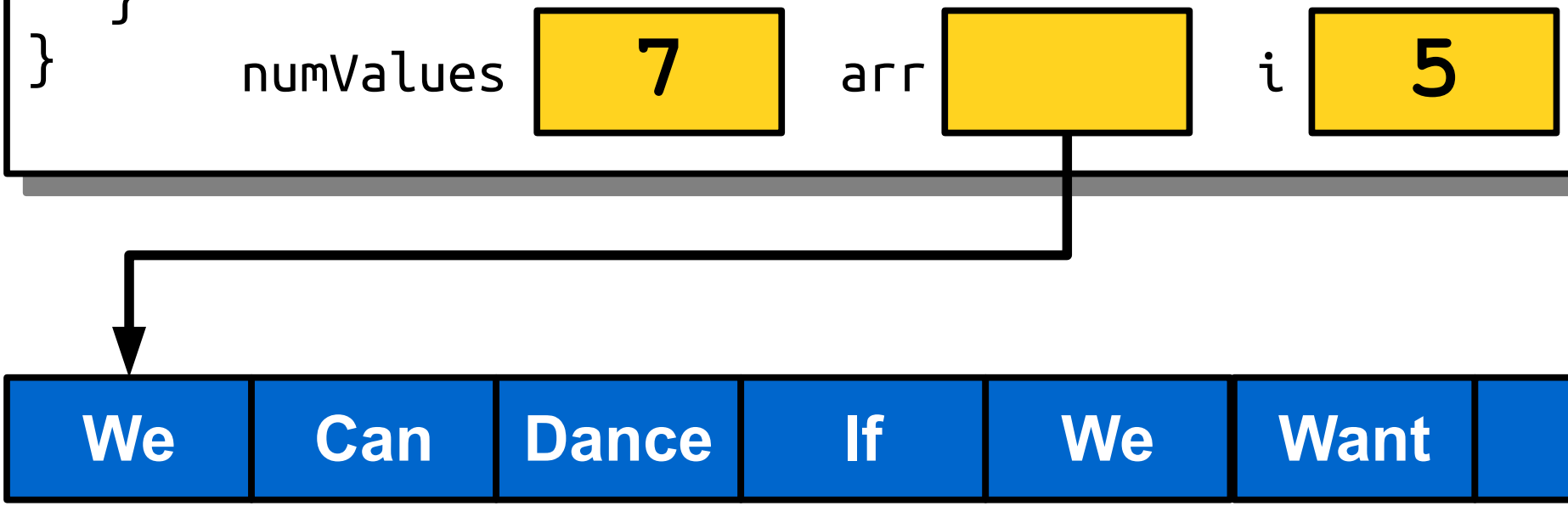
```



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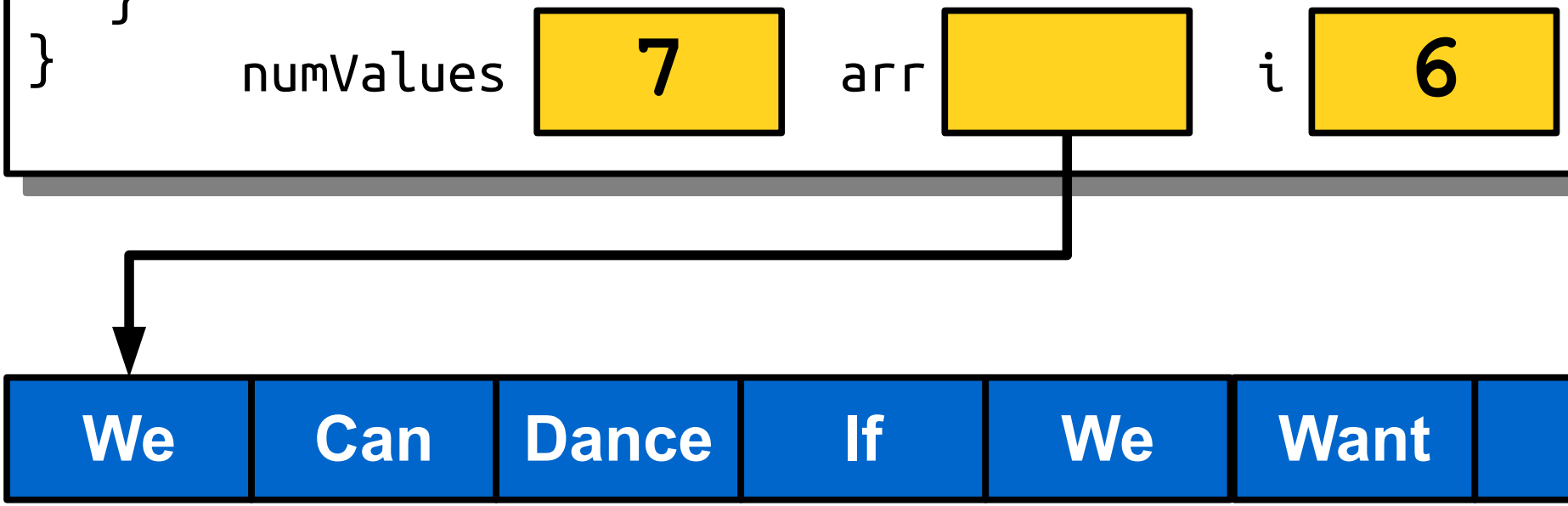

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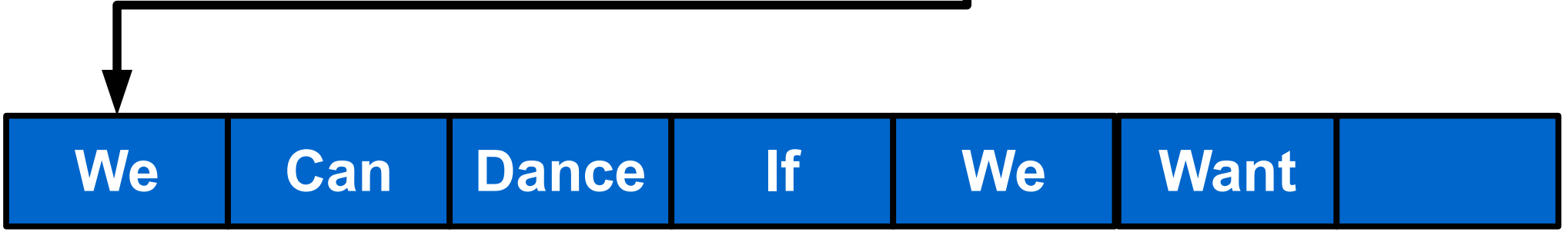
```

numValues **7** arr i **6**



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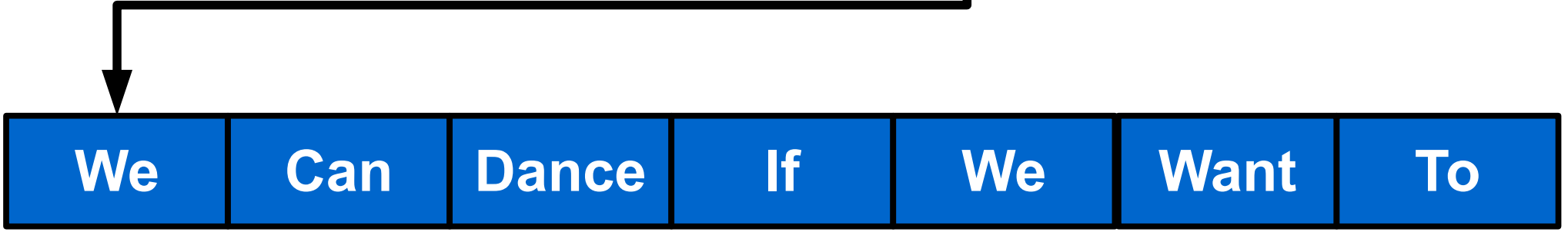
```

numValues **7** arr i **6**



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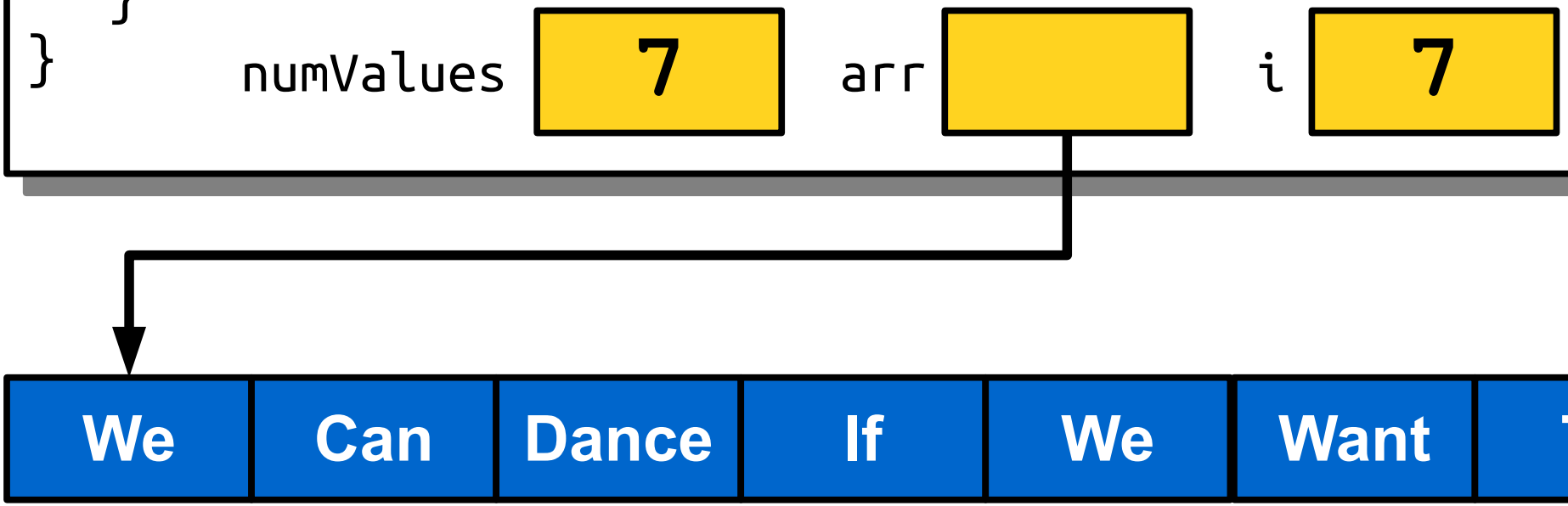

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   }
}
```

numValues **7** arr i **7**

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

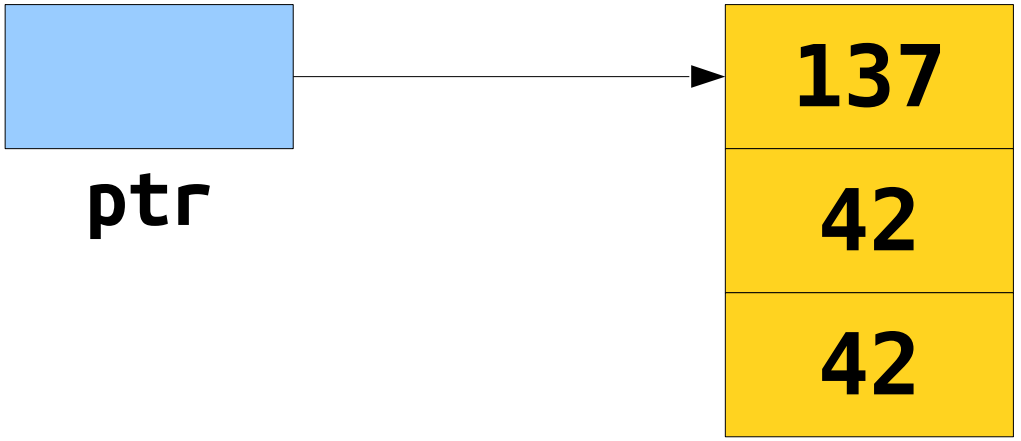
- When declaring local variables or parameters, C++ will automatically handle memory allocation and deallocation for you.
- When using `new`, you are responsible for deallocating the memory you allocate.
- If you don't, you get a ***memory leak***. Your program will never be able to use that memory again.
  - 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.



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

`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.

Implementing `Stack`

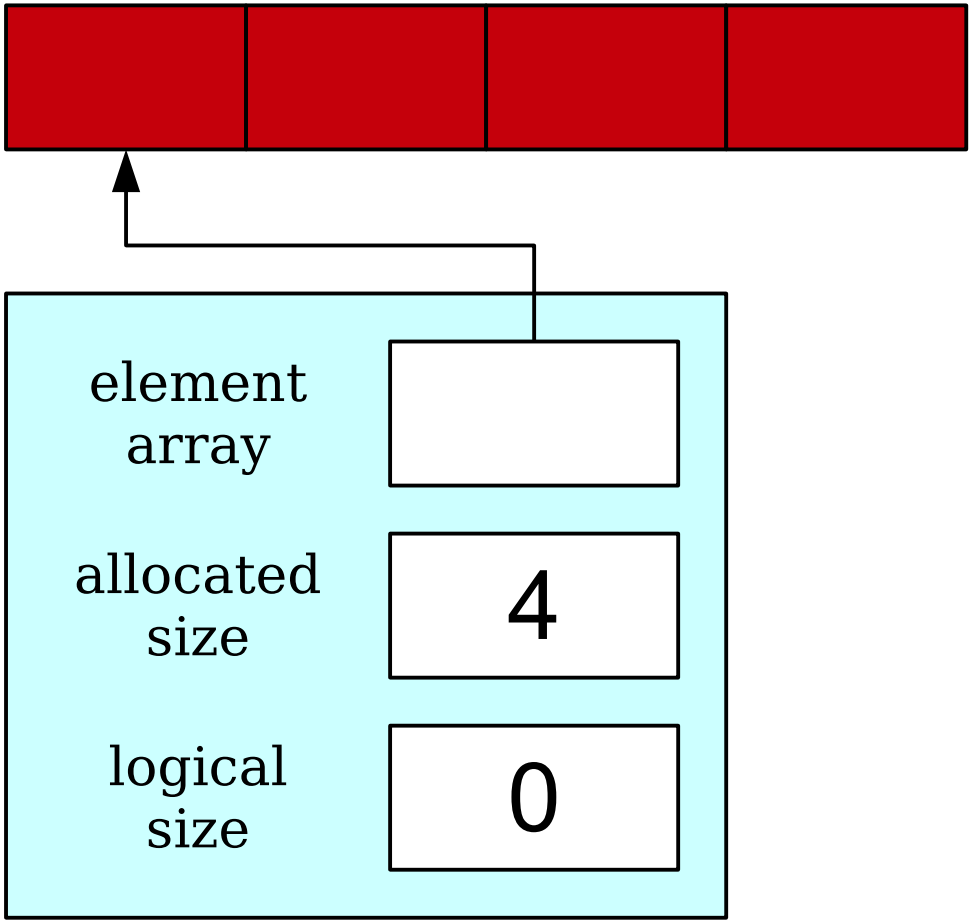
Implementing `Stack`

- 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



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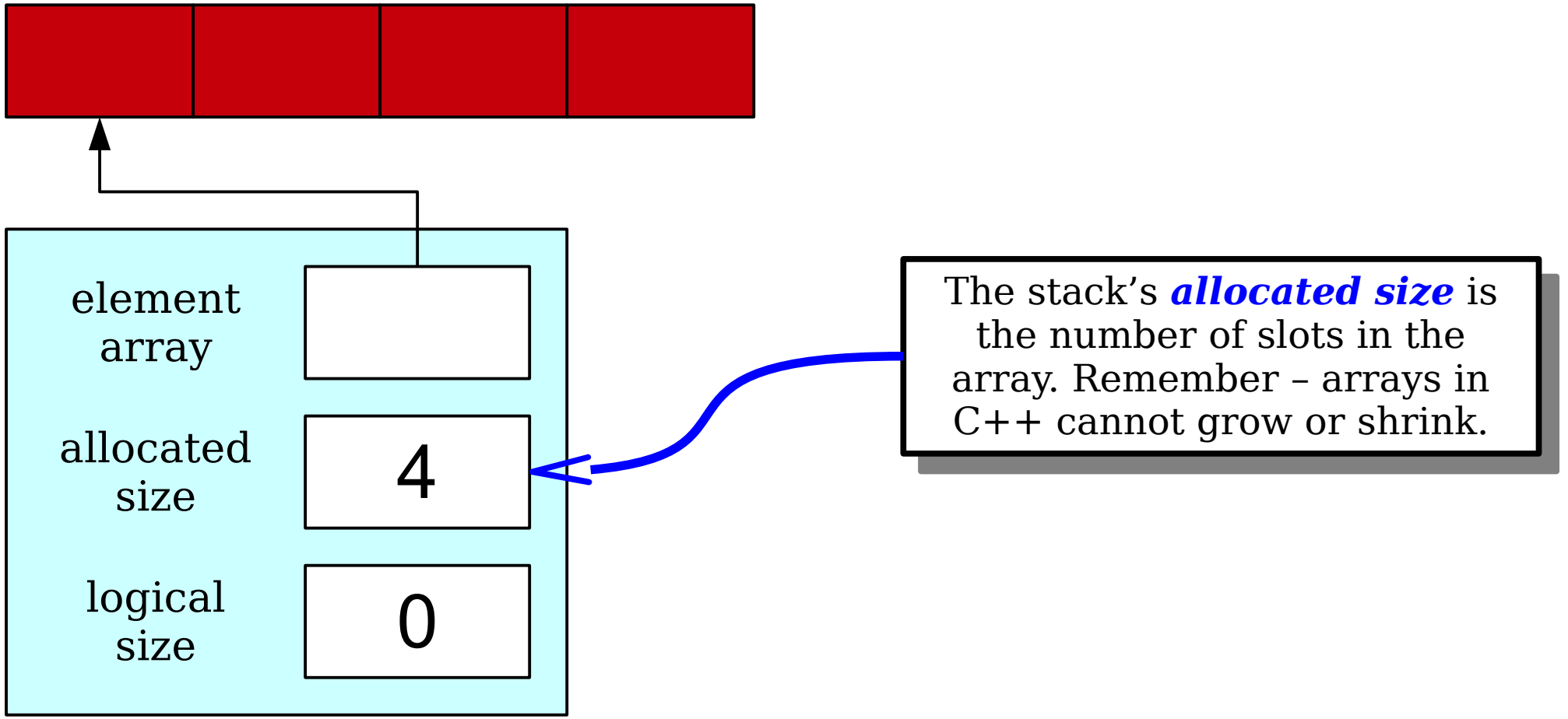

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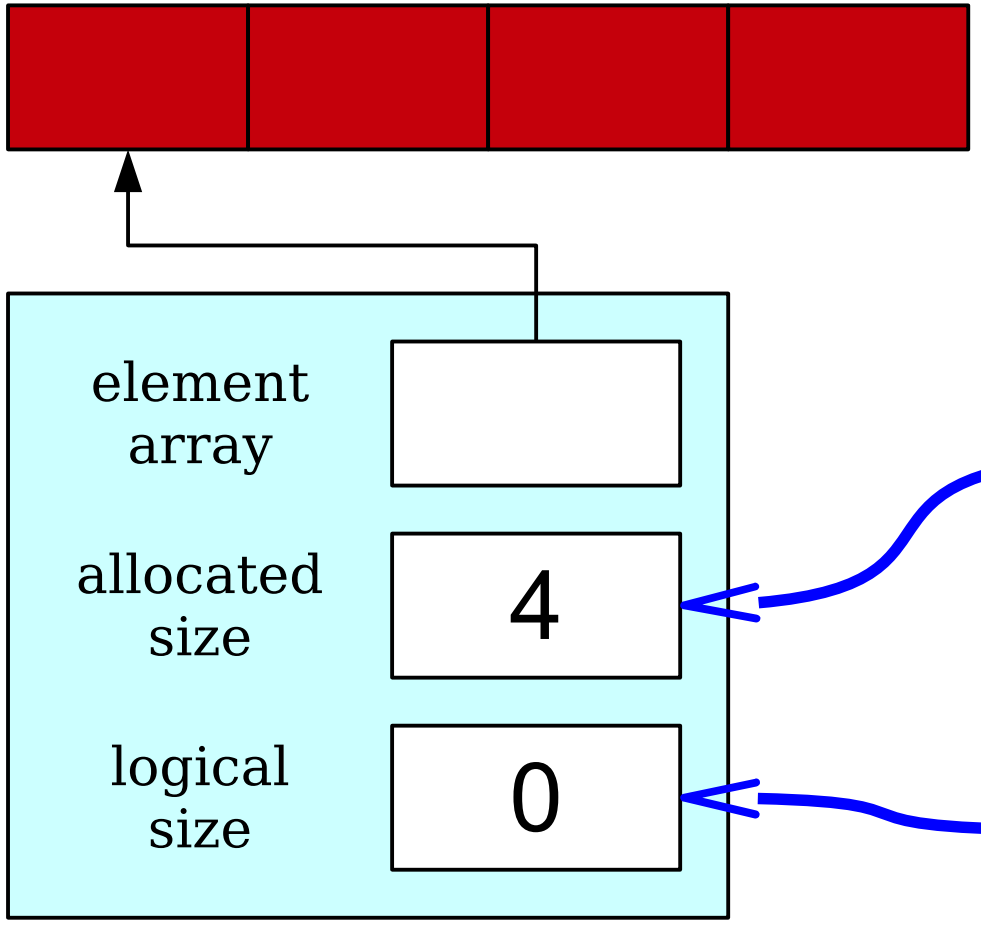
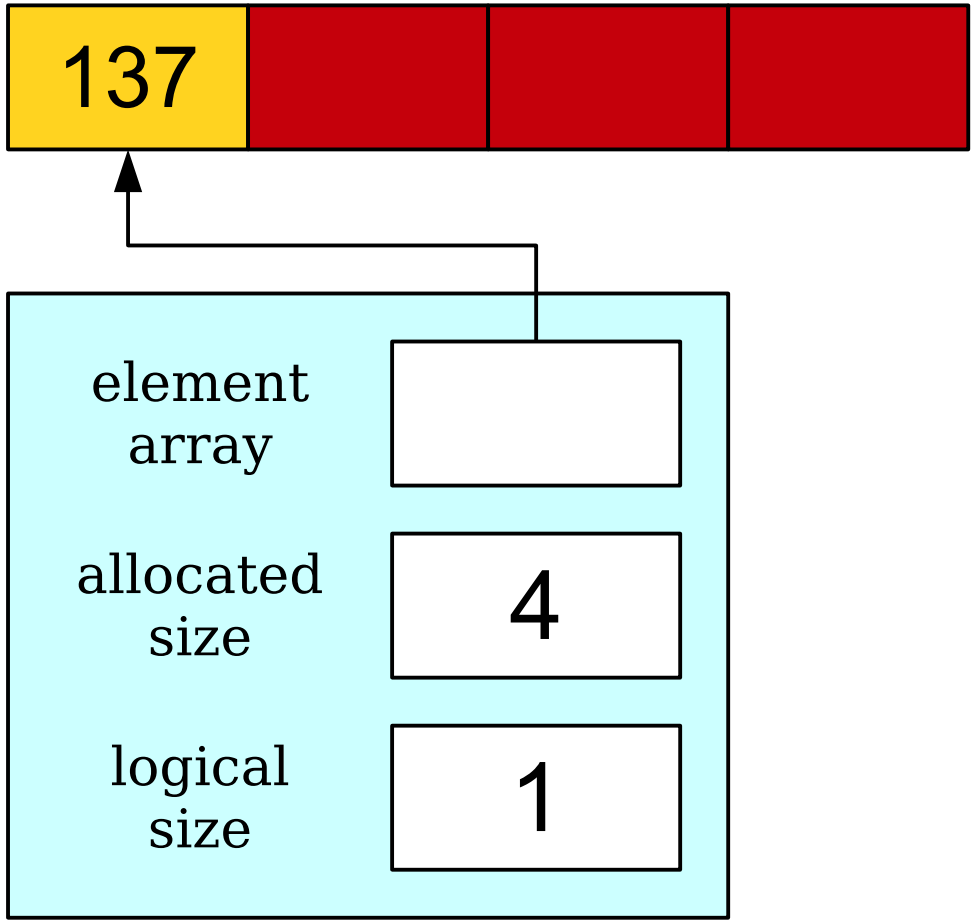


The stack's ***allocated size*** is the number of slots in the array. Remember – arrays in C++ cannot grow or shrink.

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



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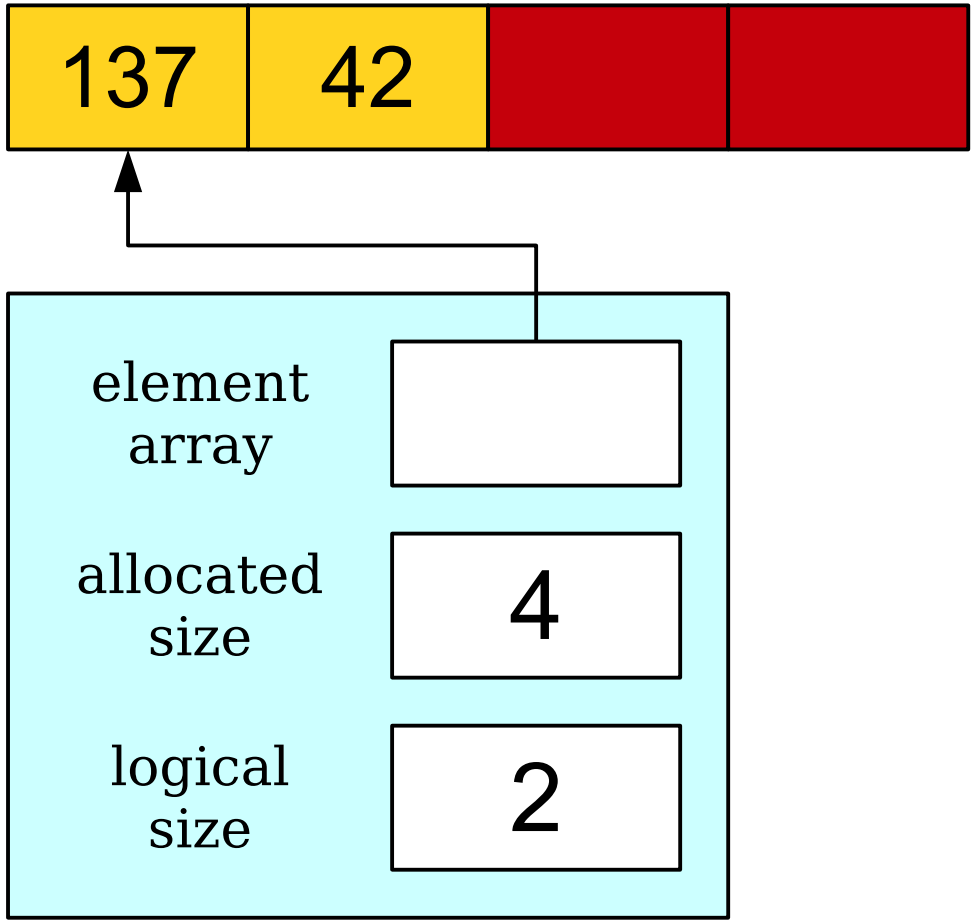

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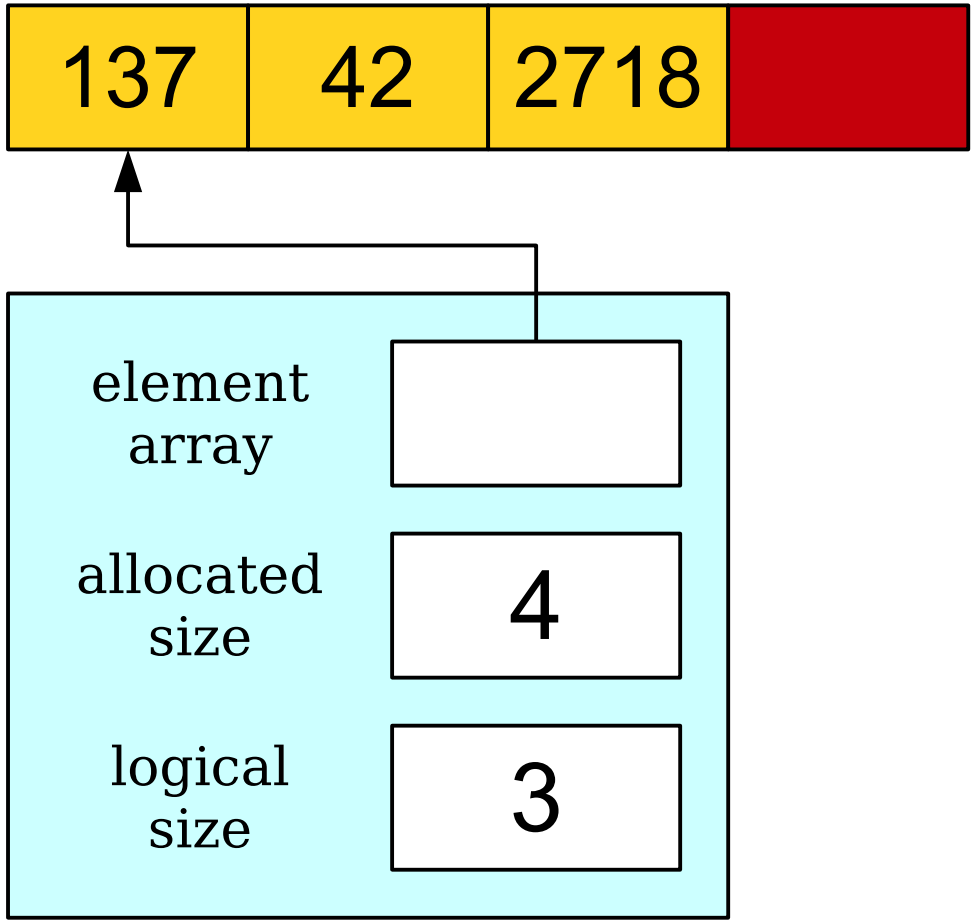

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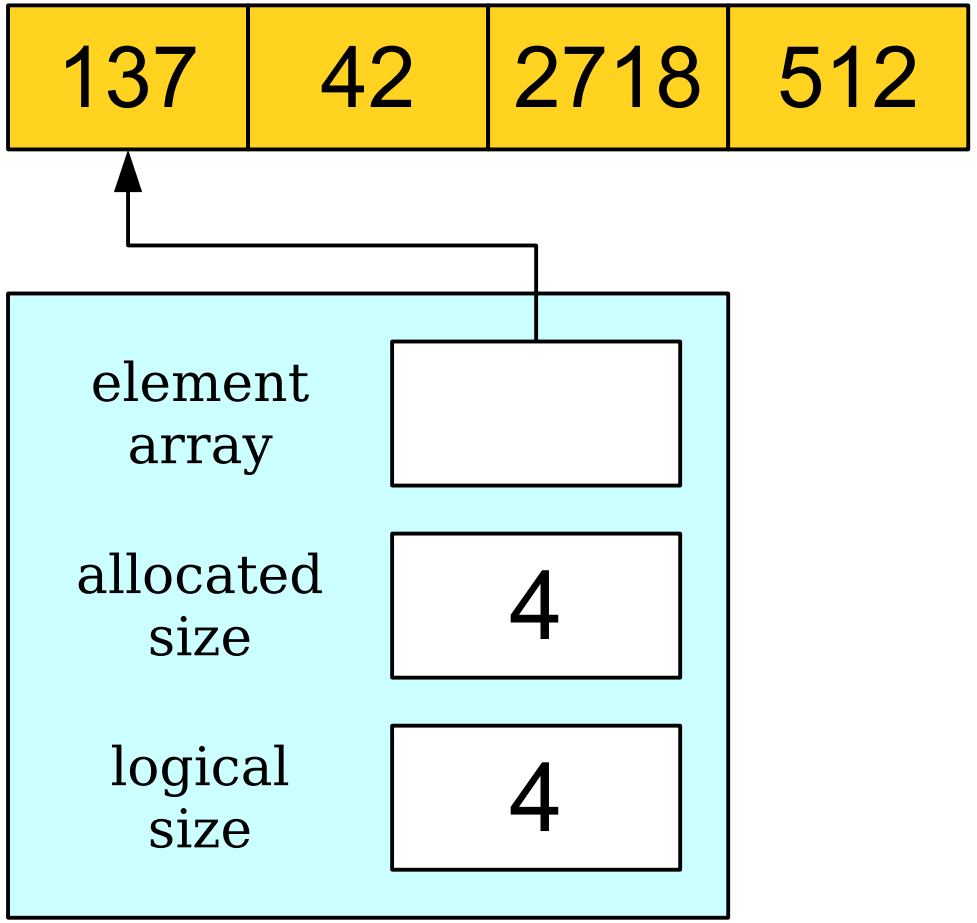

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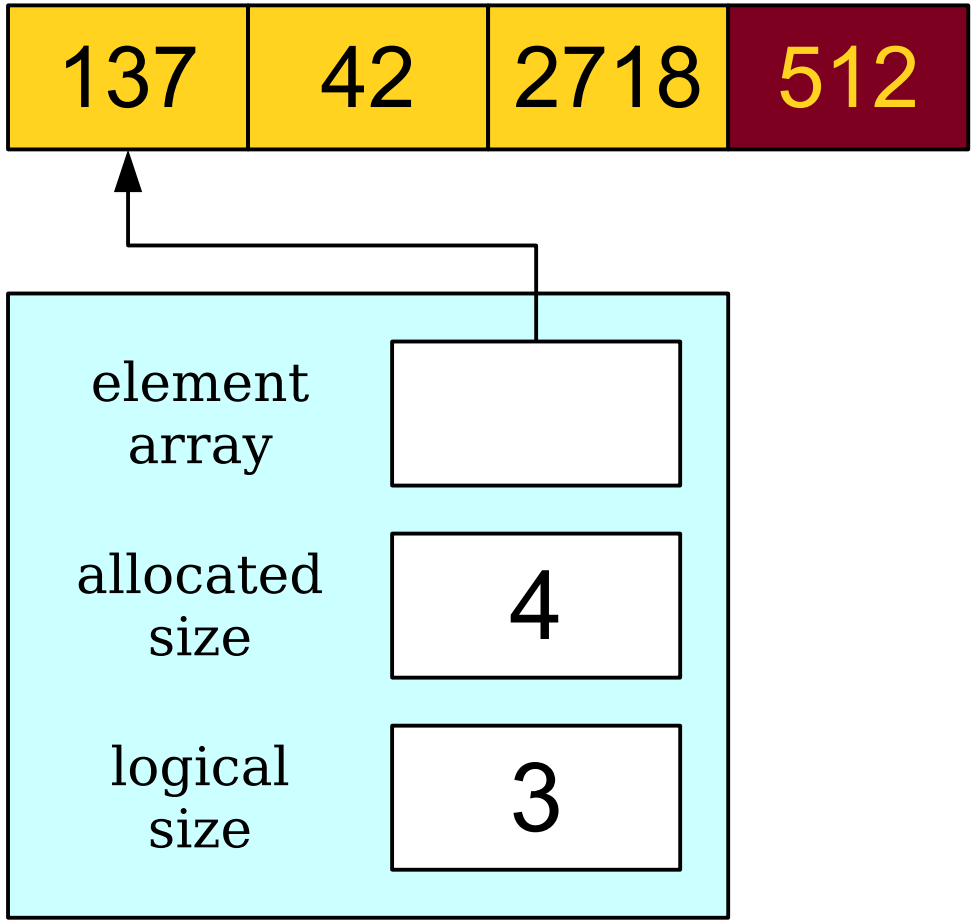

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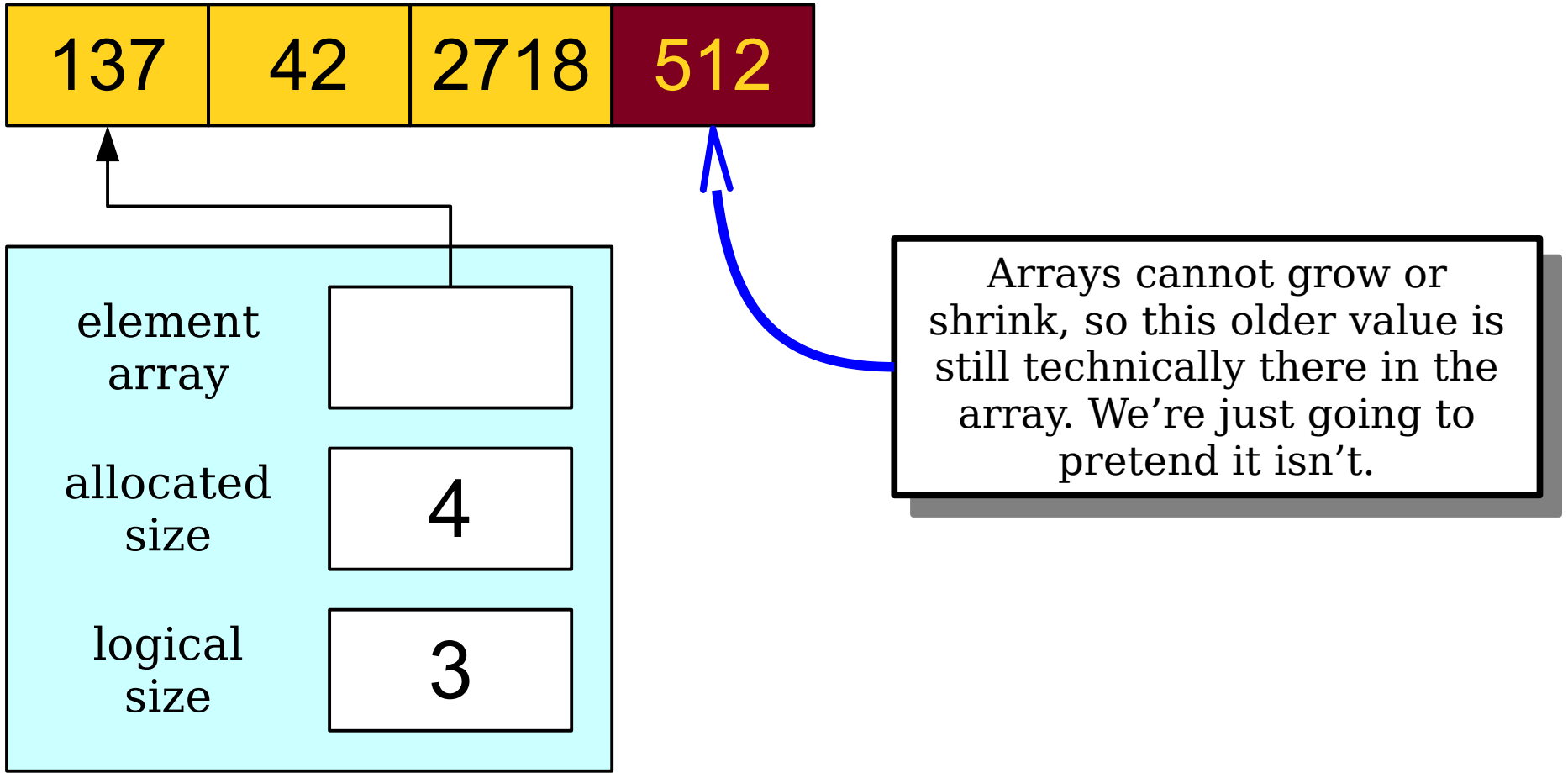

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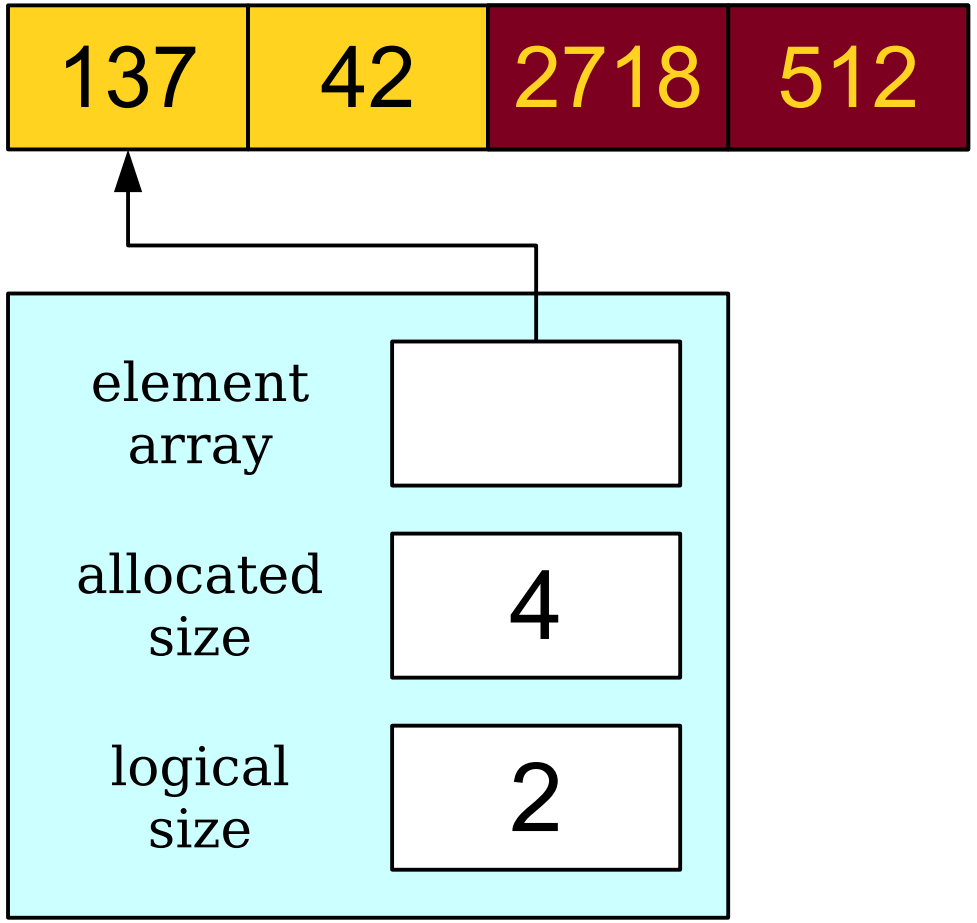

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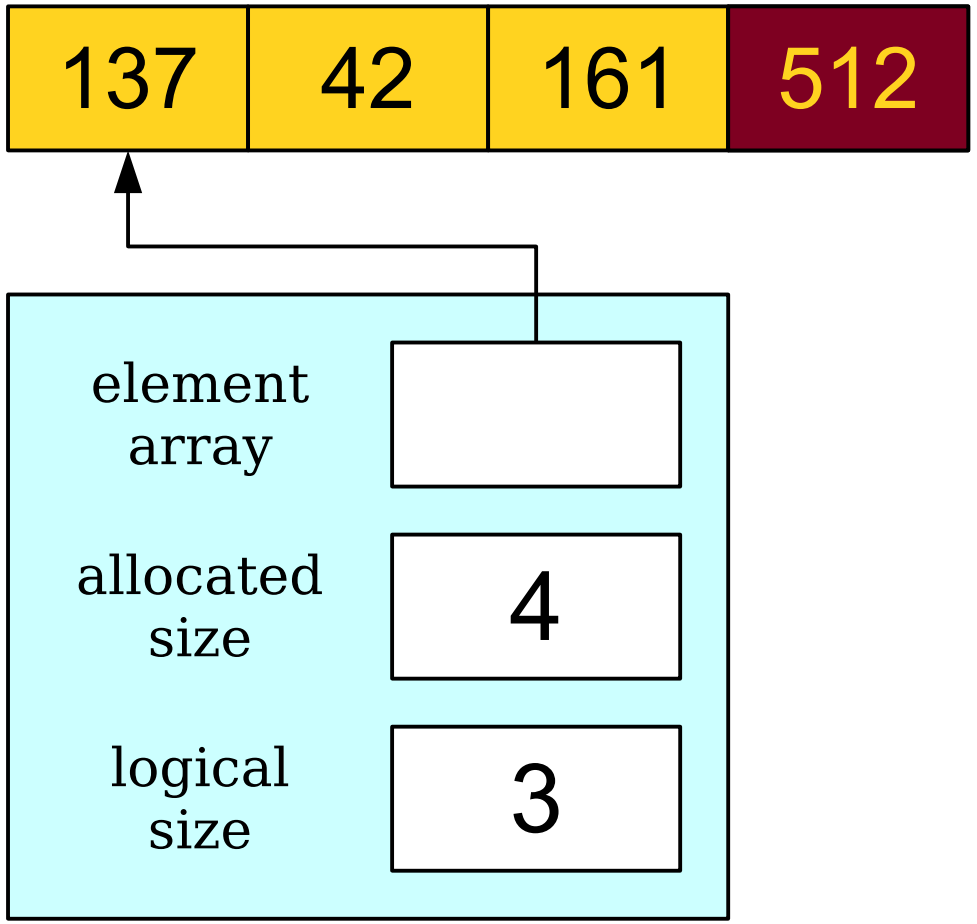

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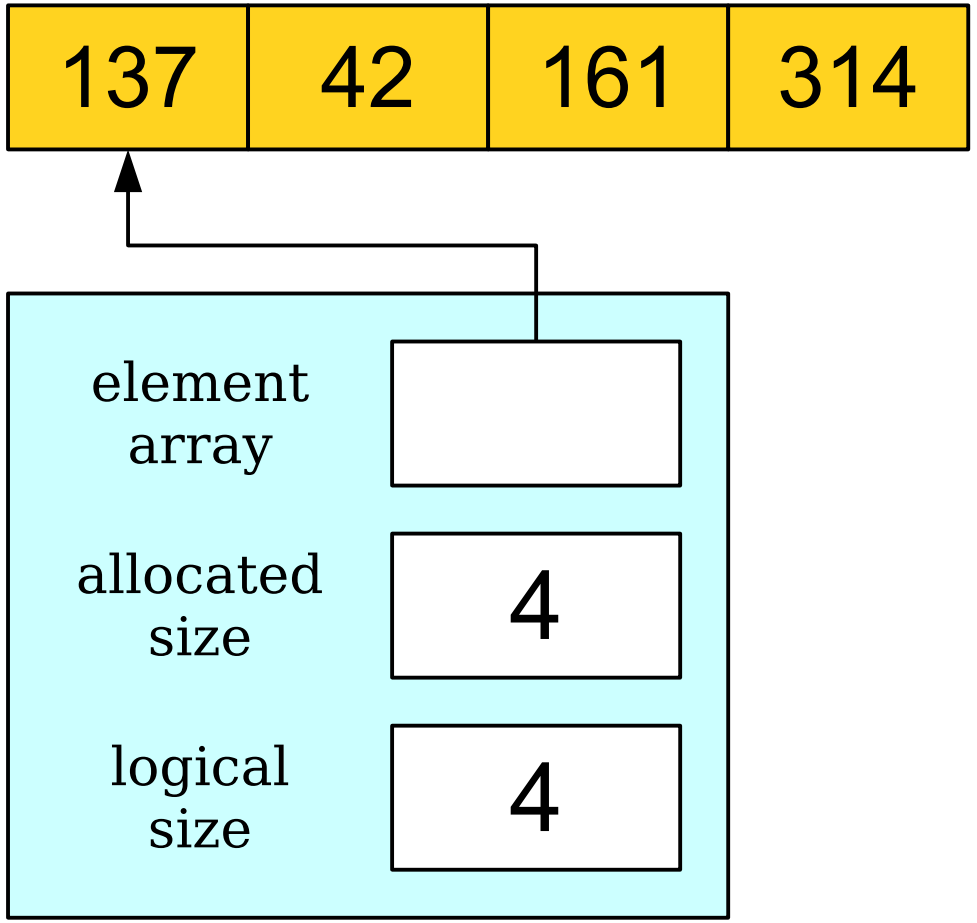

What We Have

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

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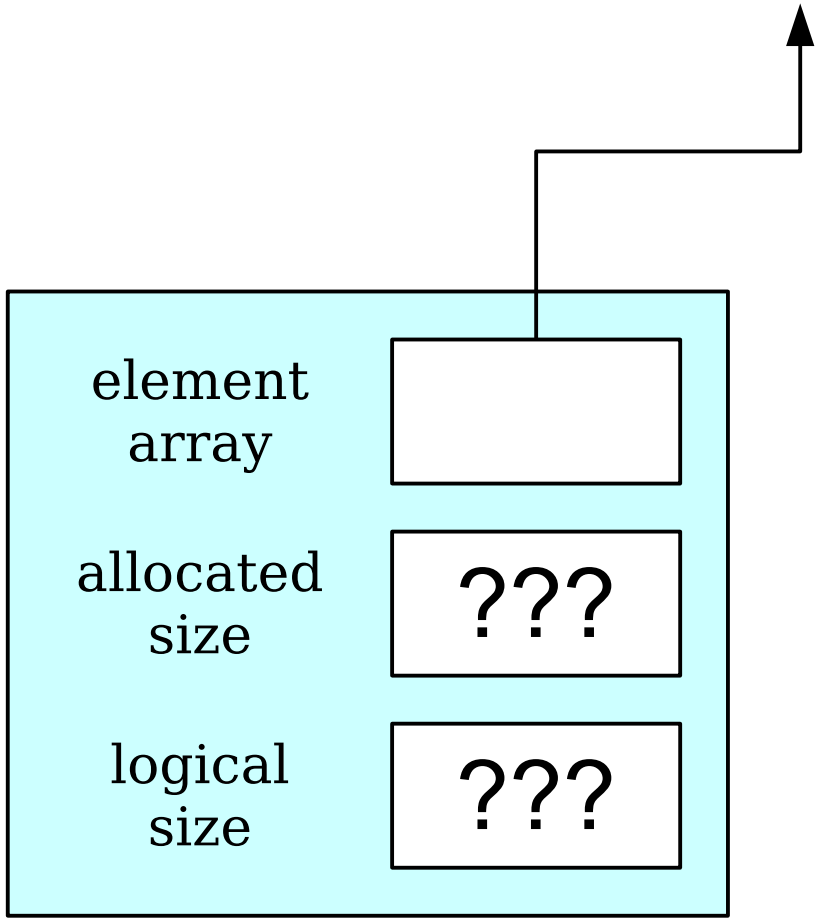


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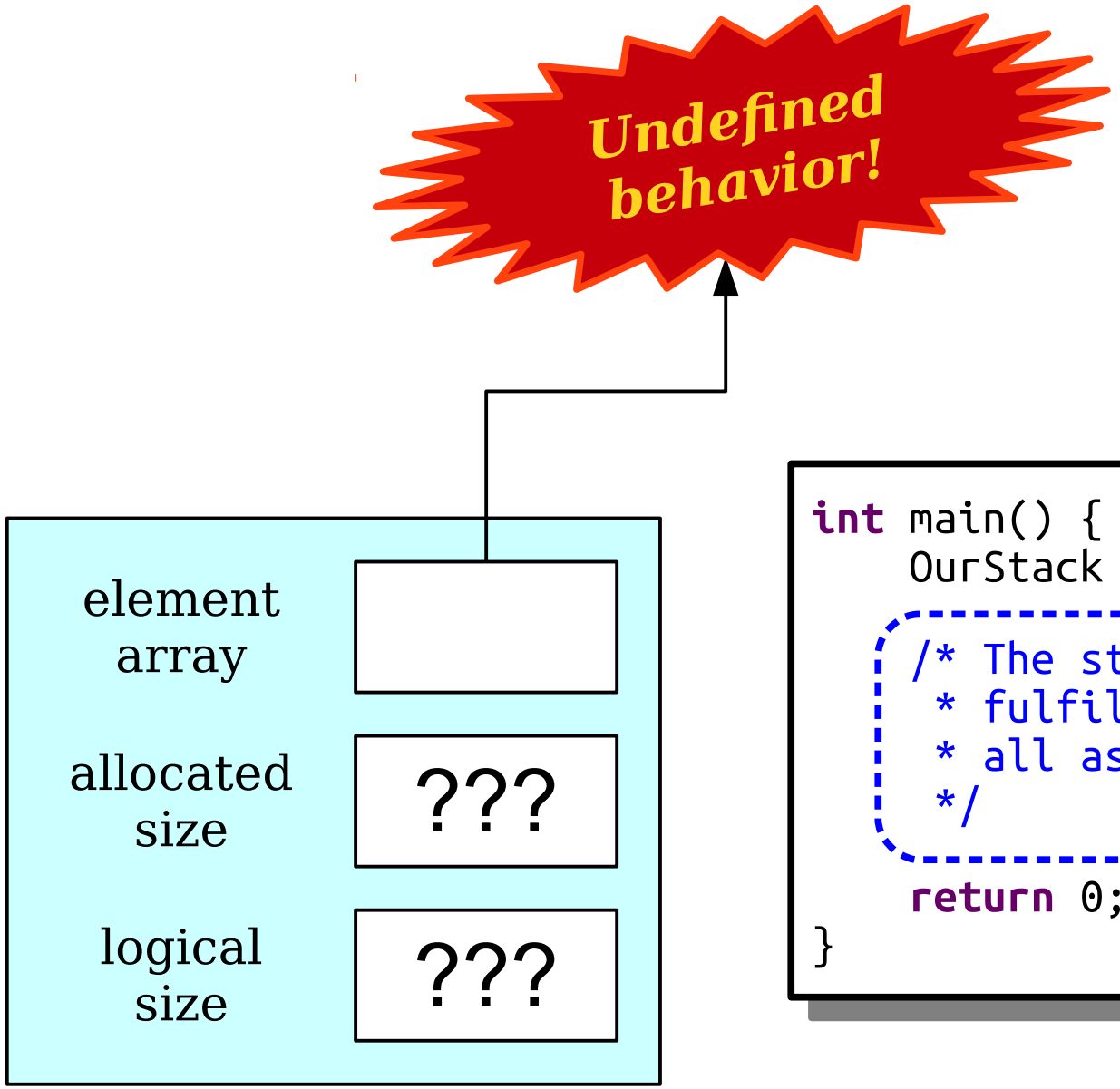


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Constructors

- 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*);**

```
class OurStack {
public:


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

    int  size() const;
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private:
    int* elems;
    int  allocatedSize;
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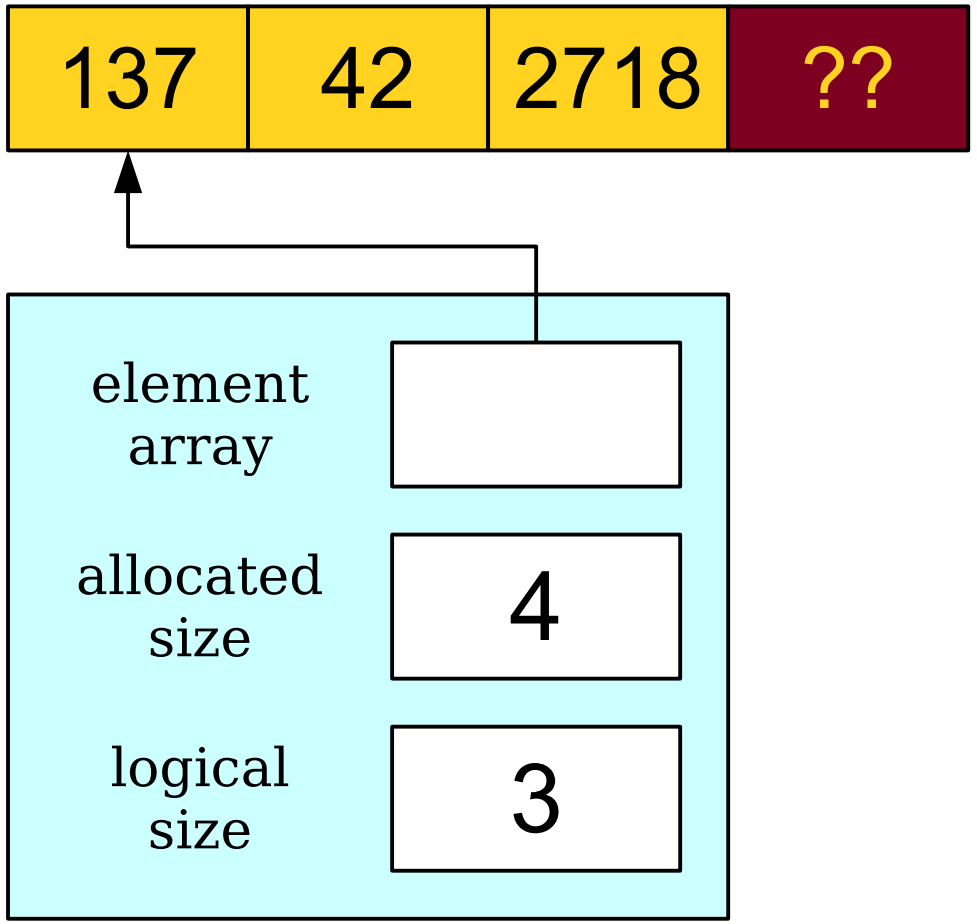
Implementing our Operations

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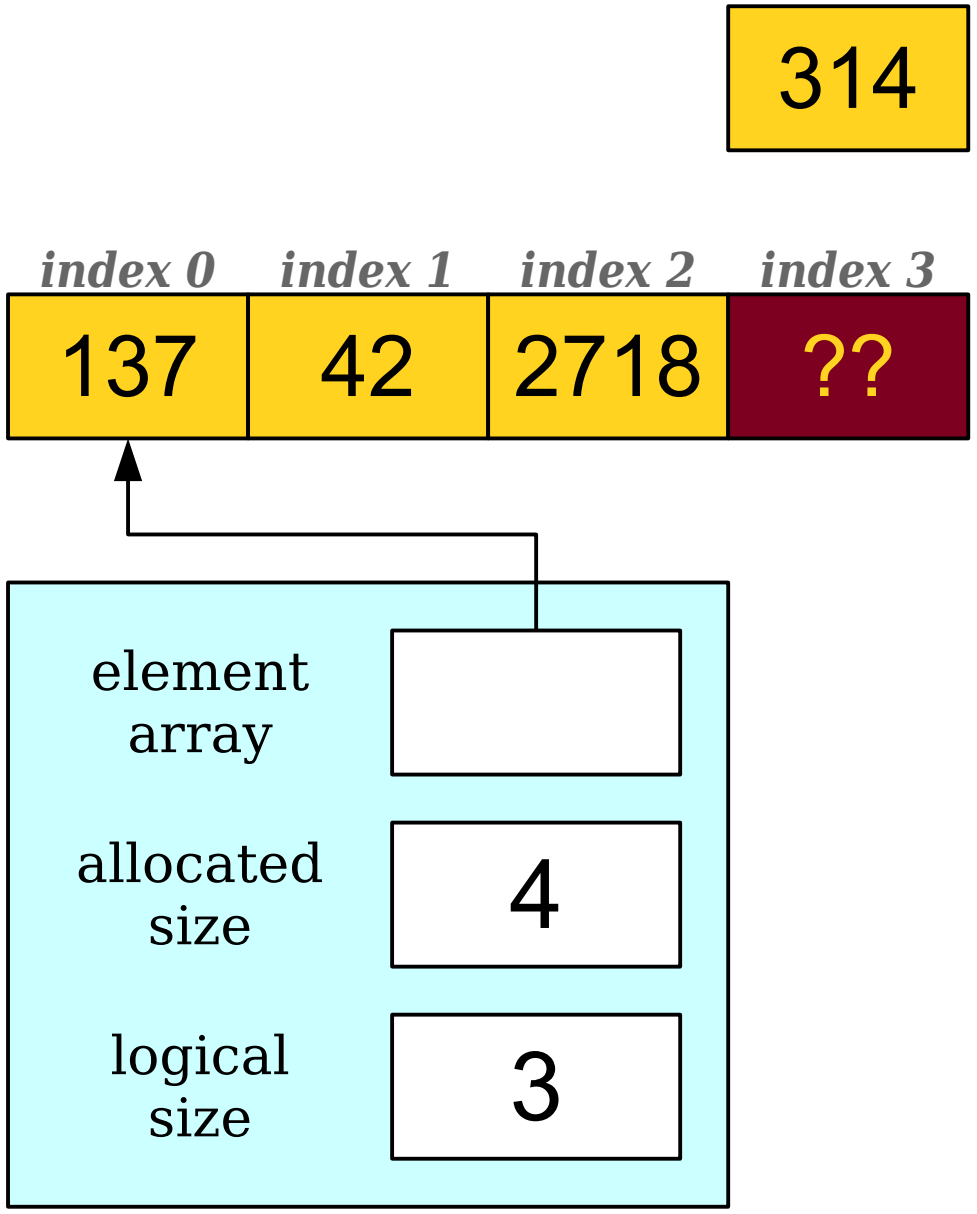


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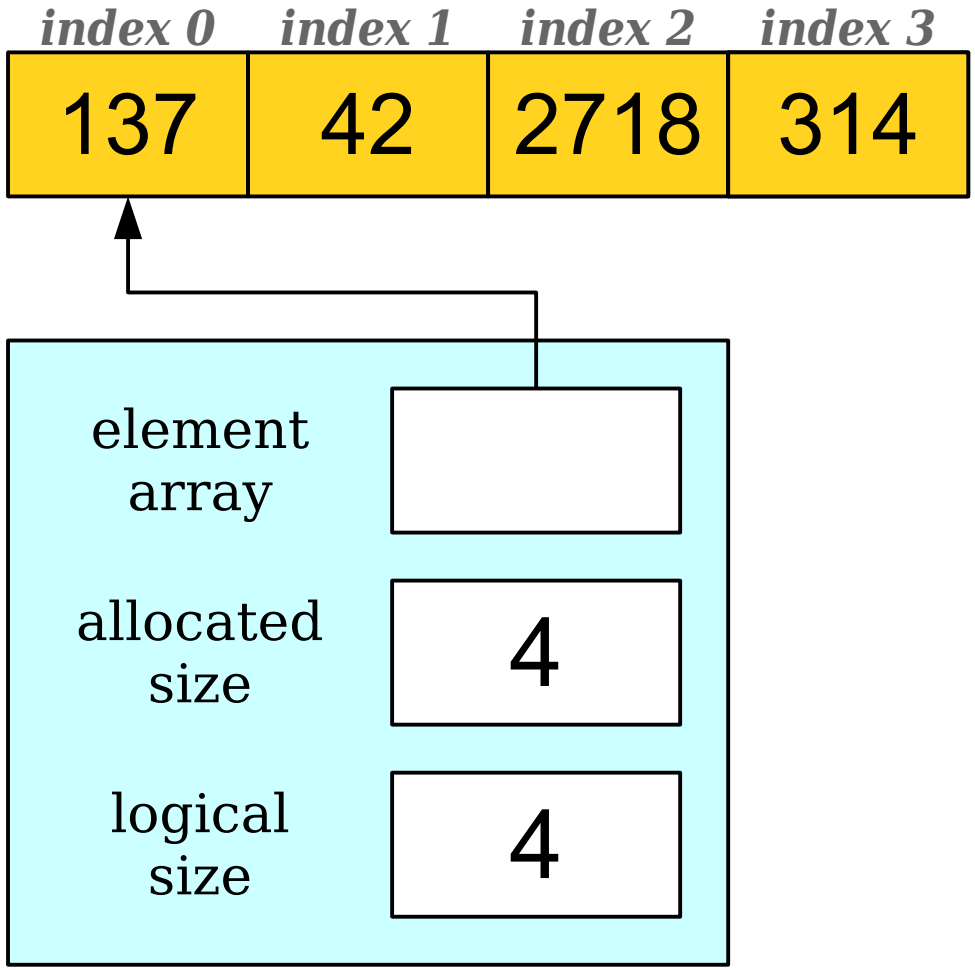


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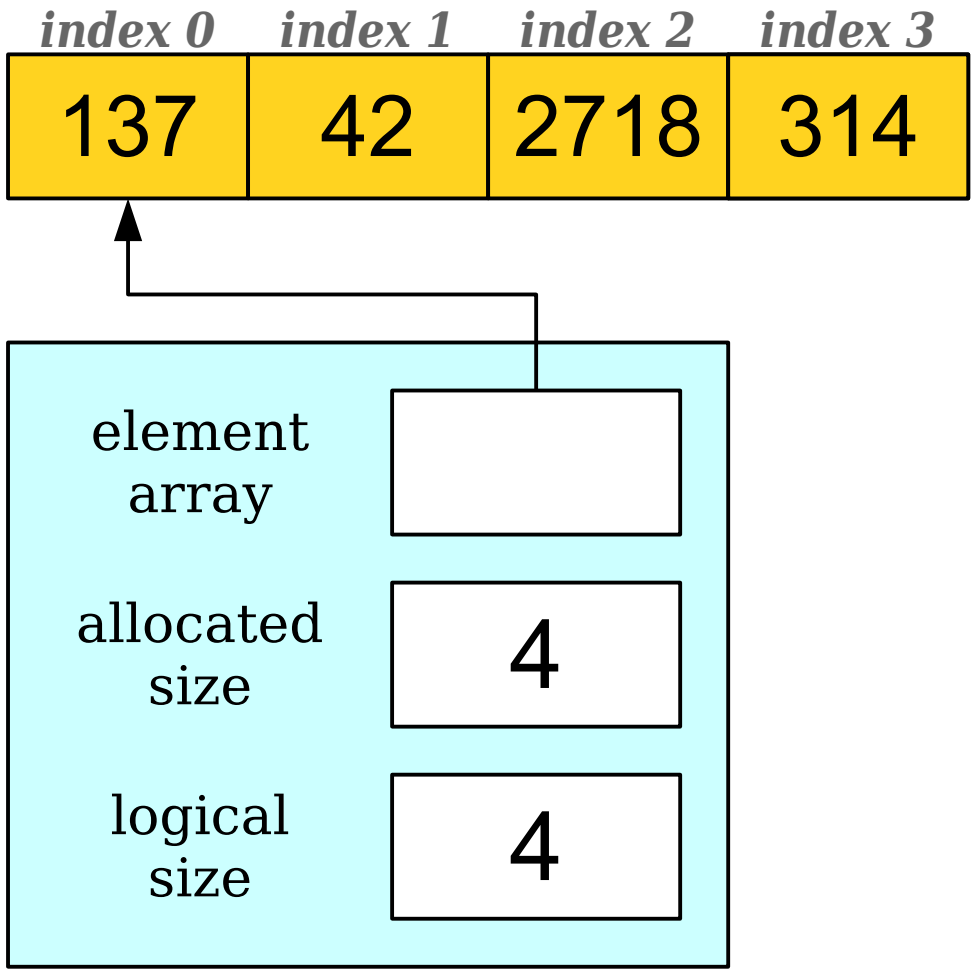


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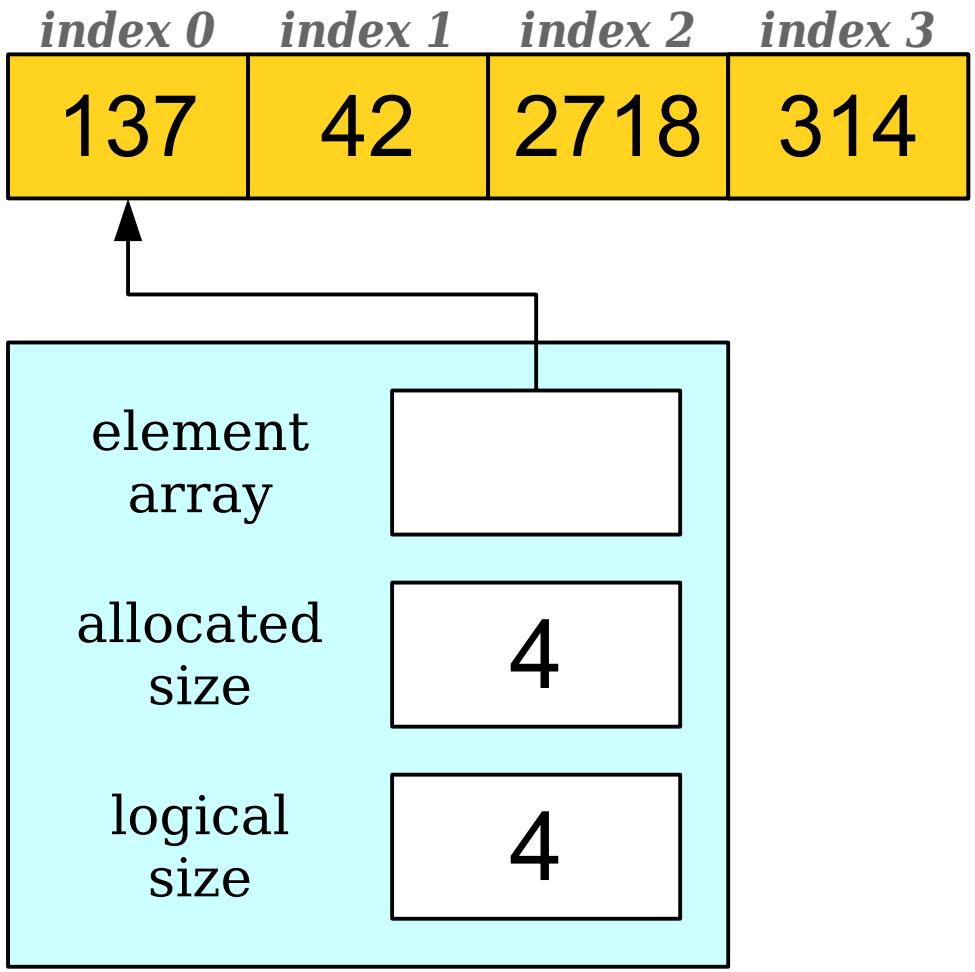


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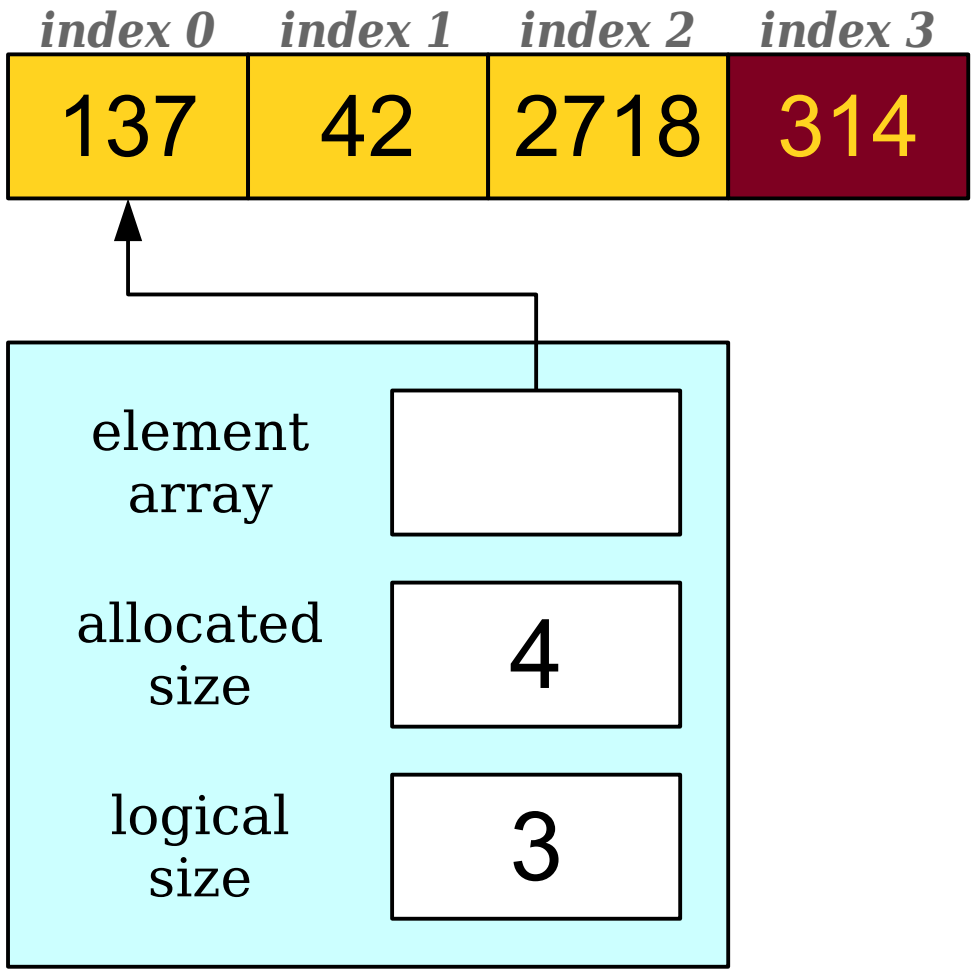


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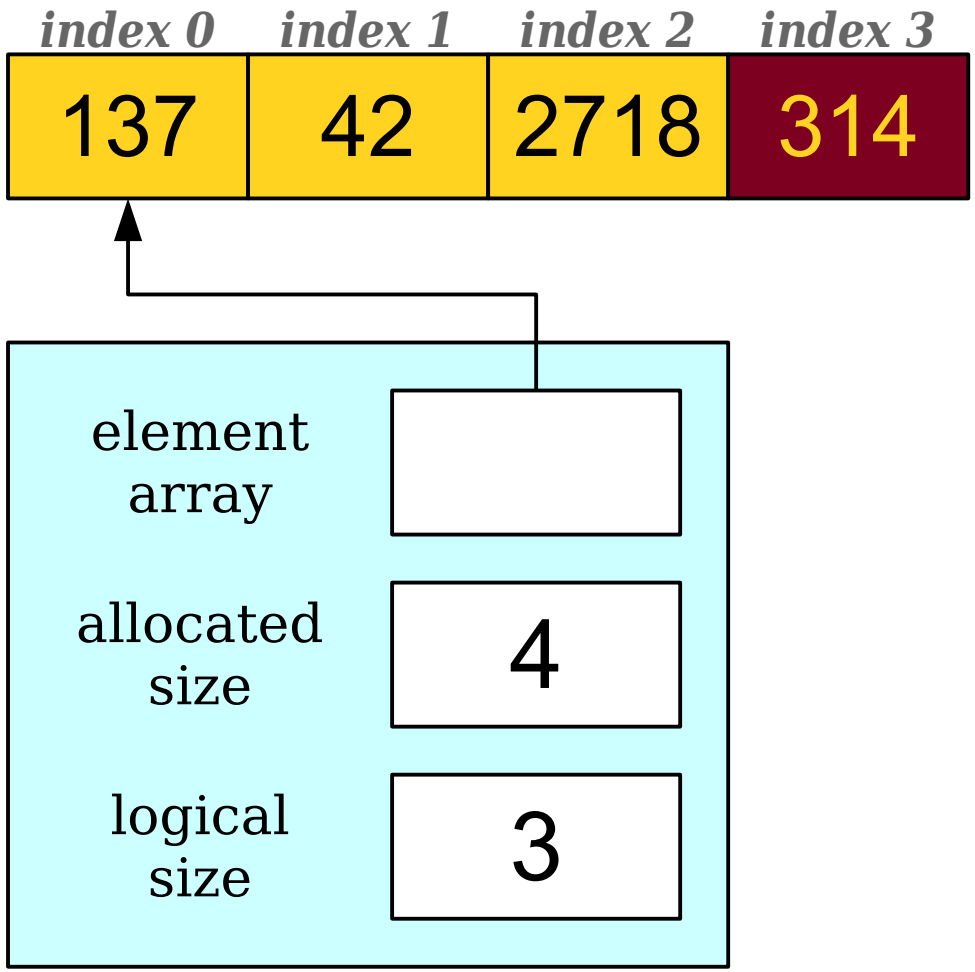


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```

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.
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    return 0;
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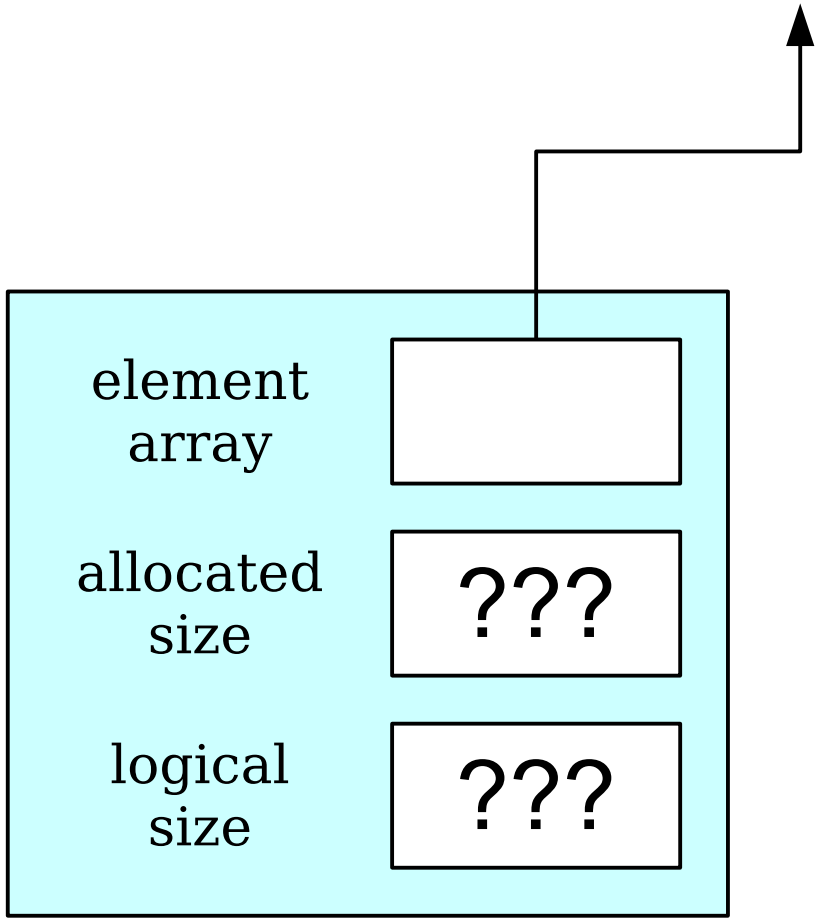


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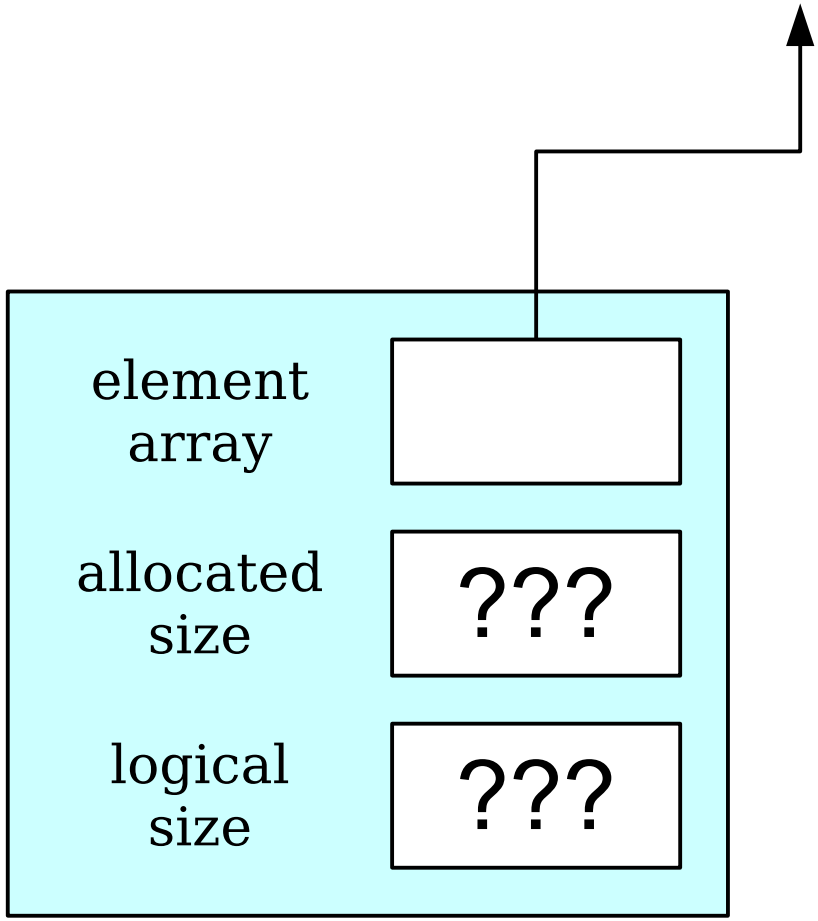


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OurStack::OurStack() {
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```

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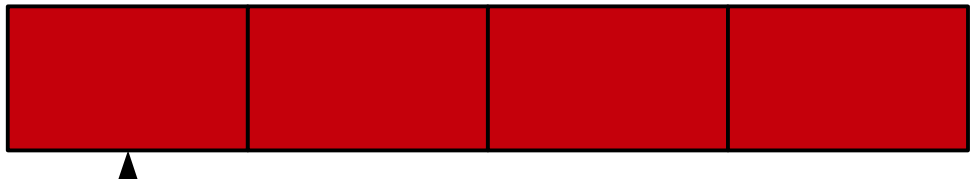

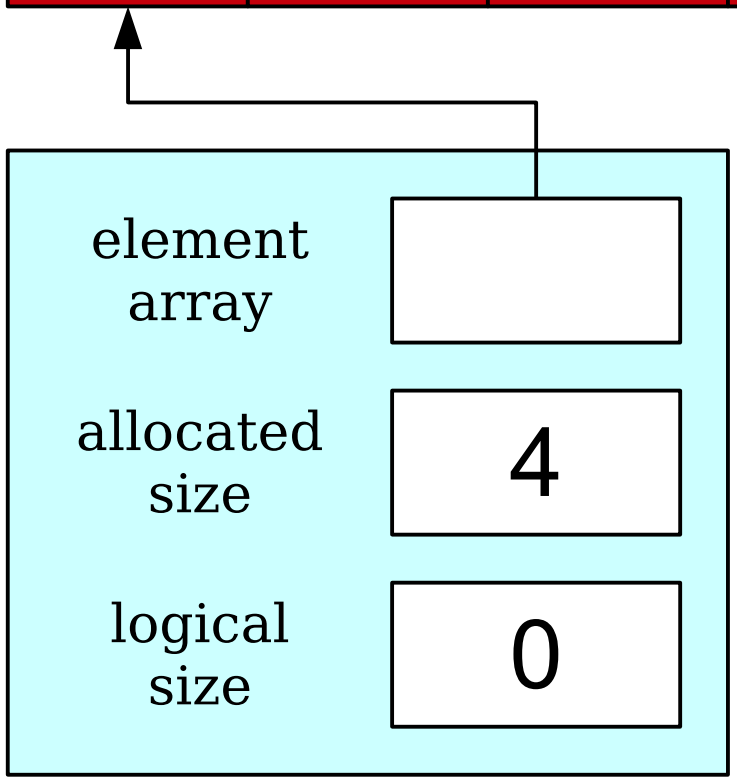


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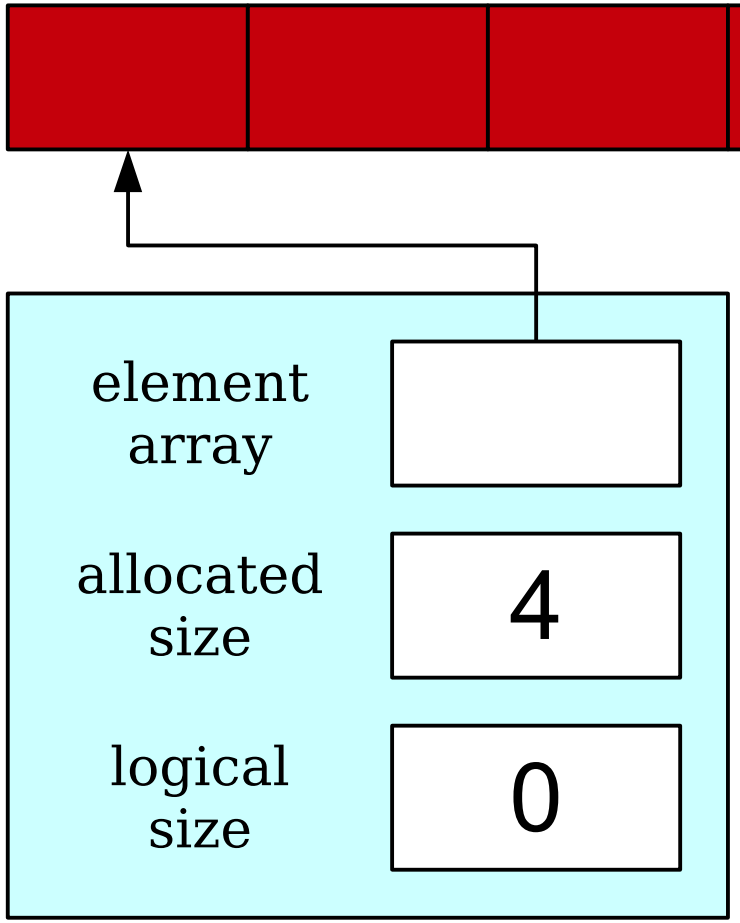


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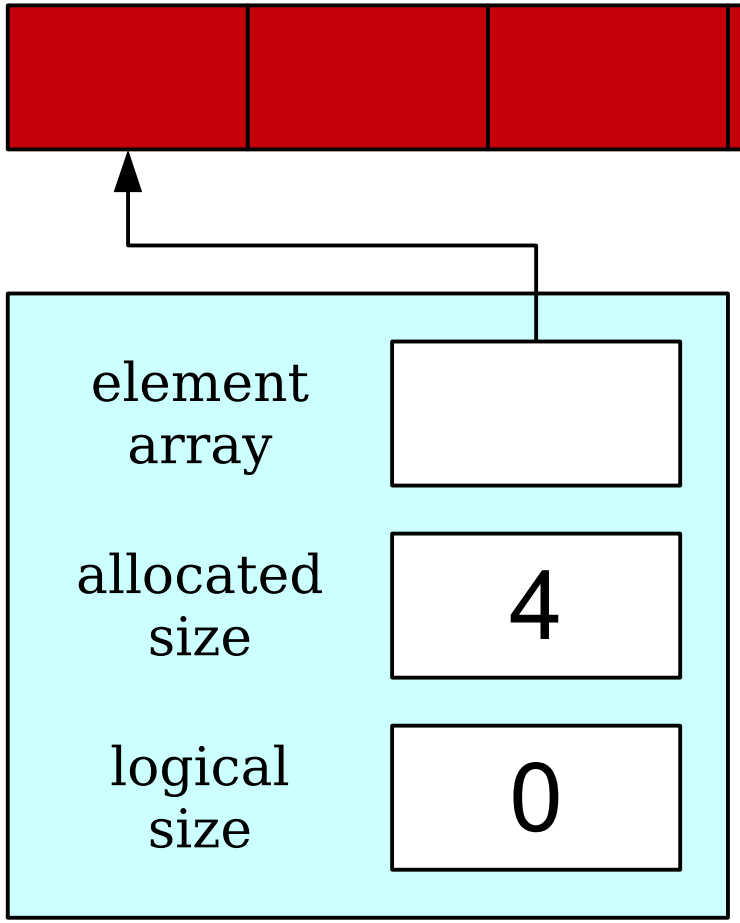


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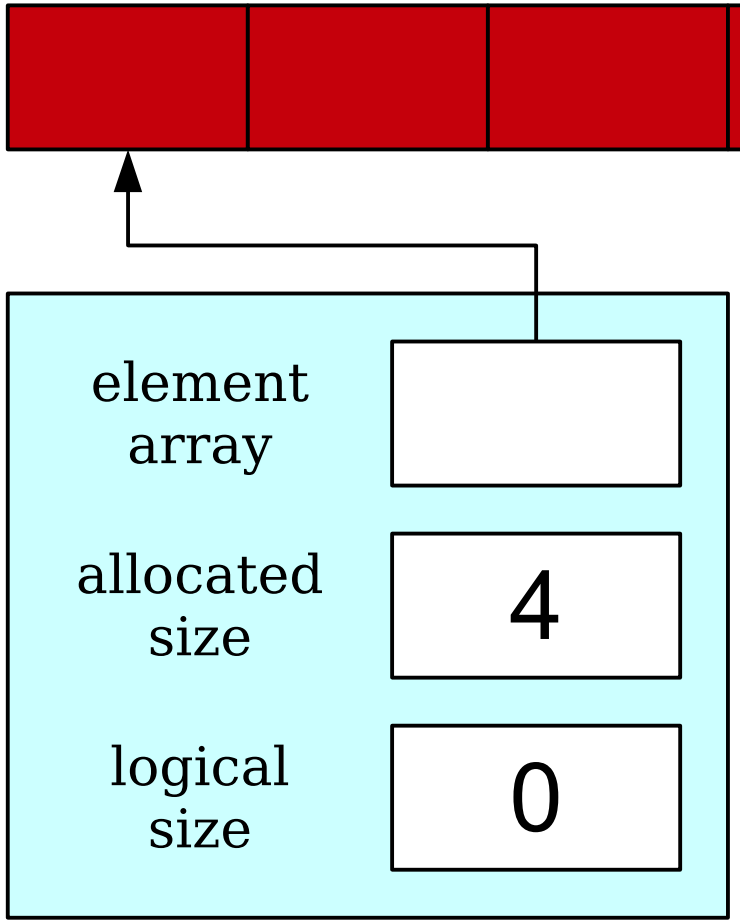


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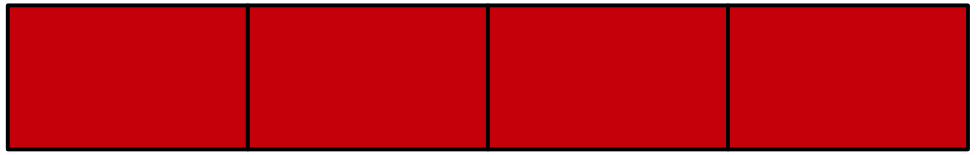

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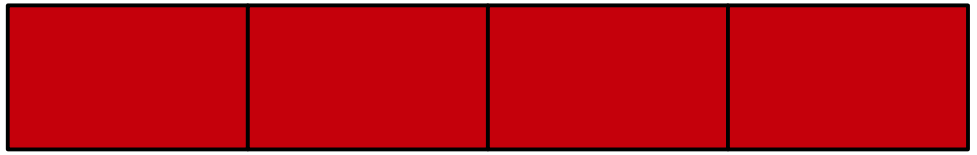

I am adrift, alone, condemned to forever wander meaninglessly.

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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***();

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Cradle to Grave, Take III

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int main() {
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Cradle to Grave, Take III

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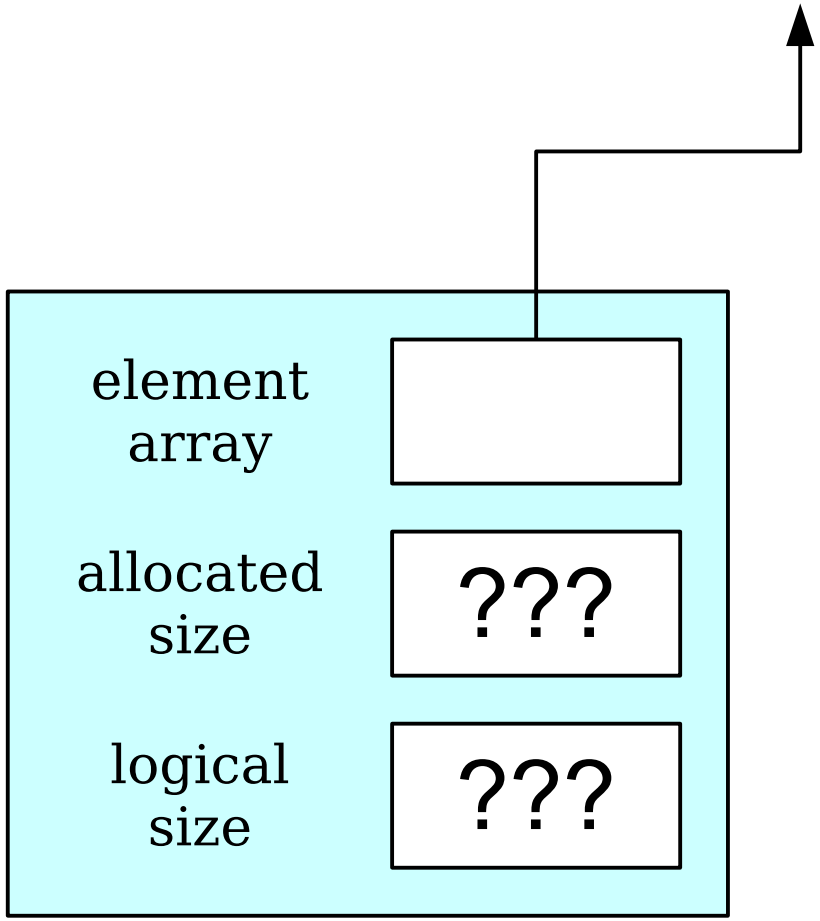
Cradle to Grave, Take III

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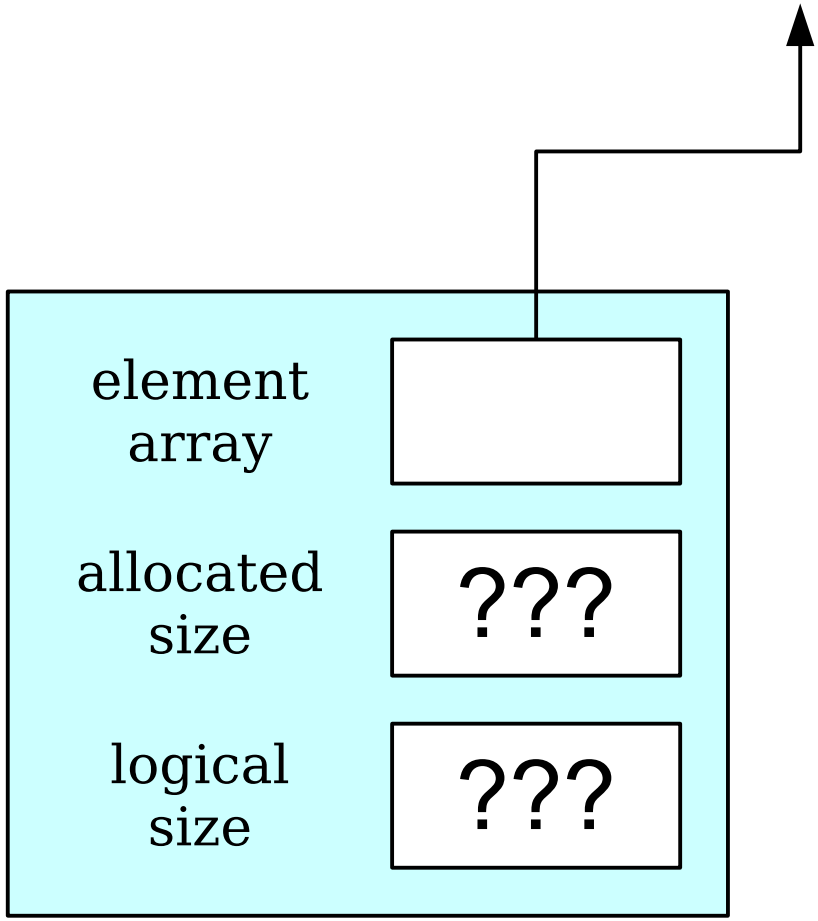
Cradle to Grave, Take III

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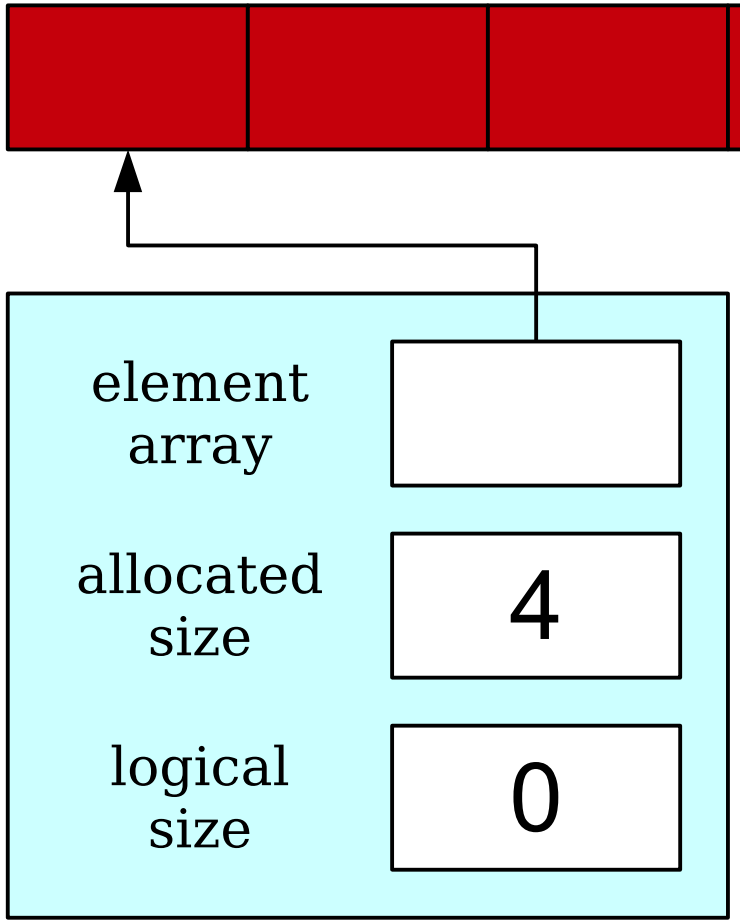
```

Cradle to Grave, Take III

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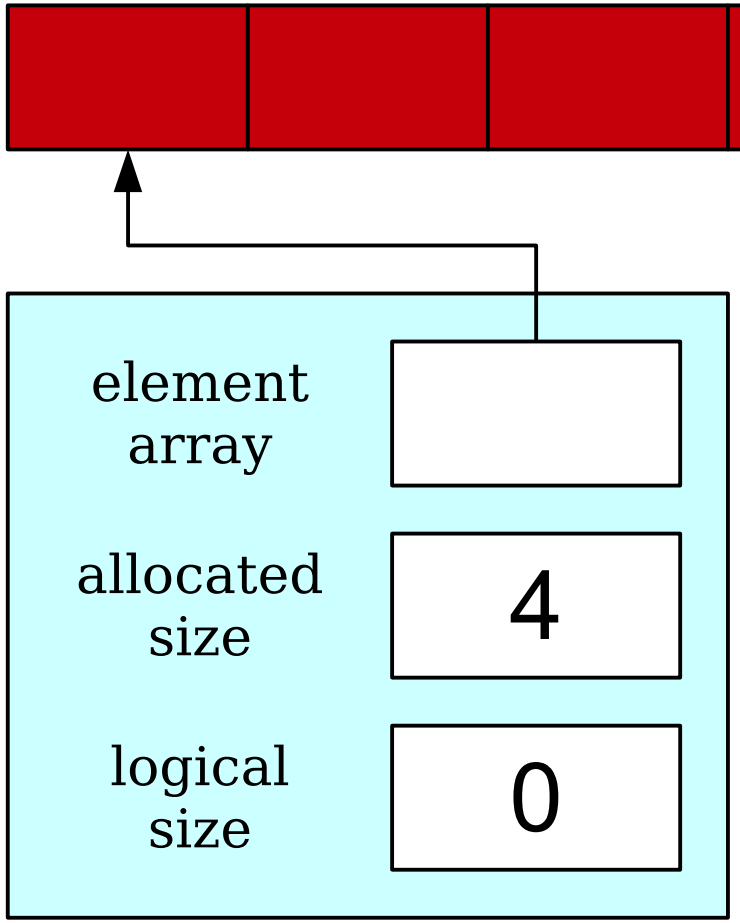


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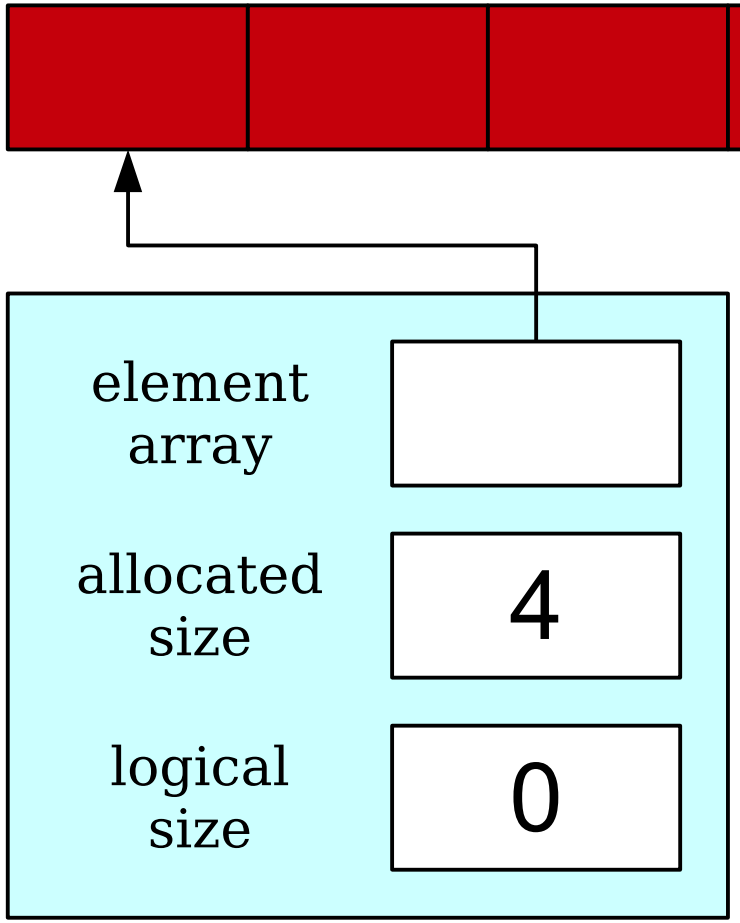


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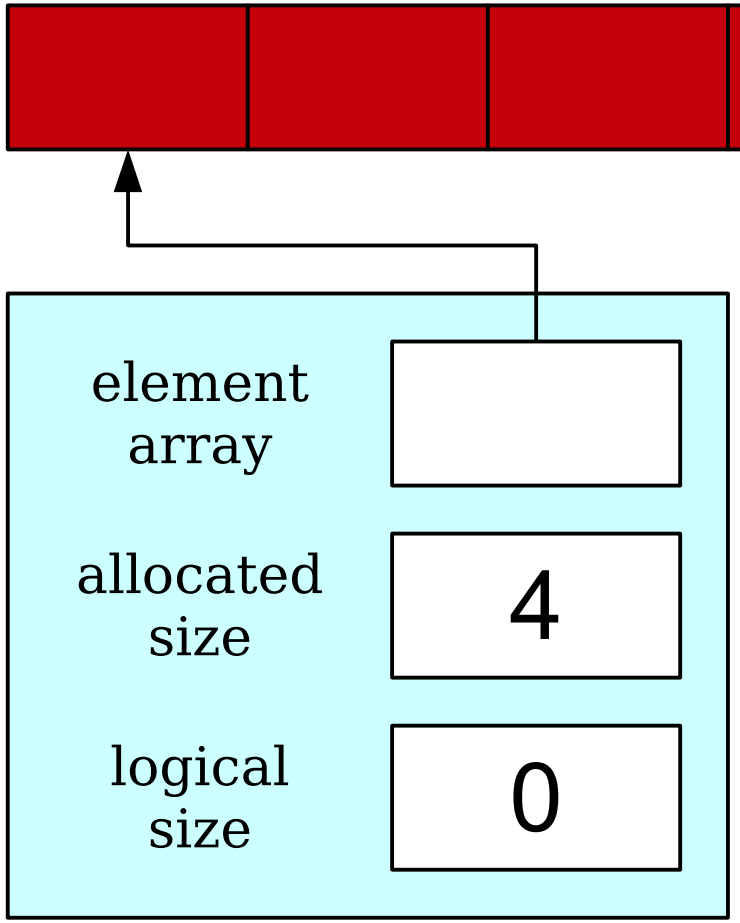


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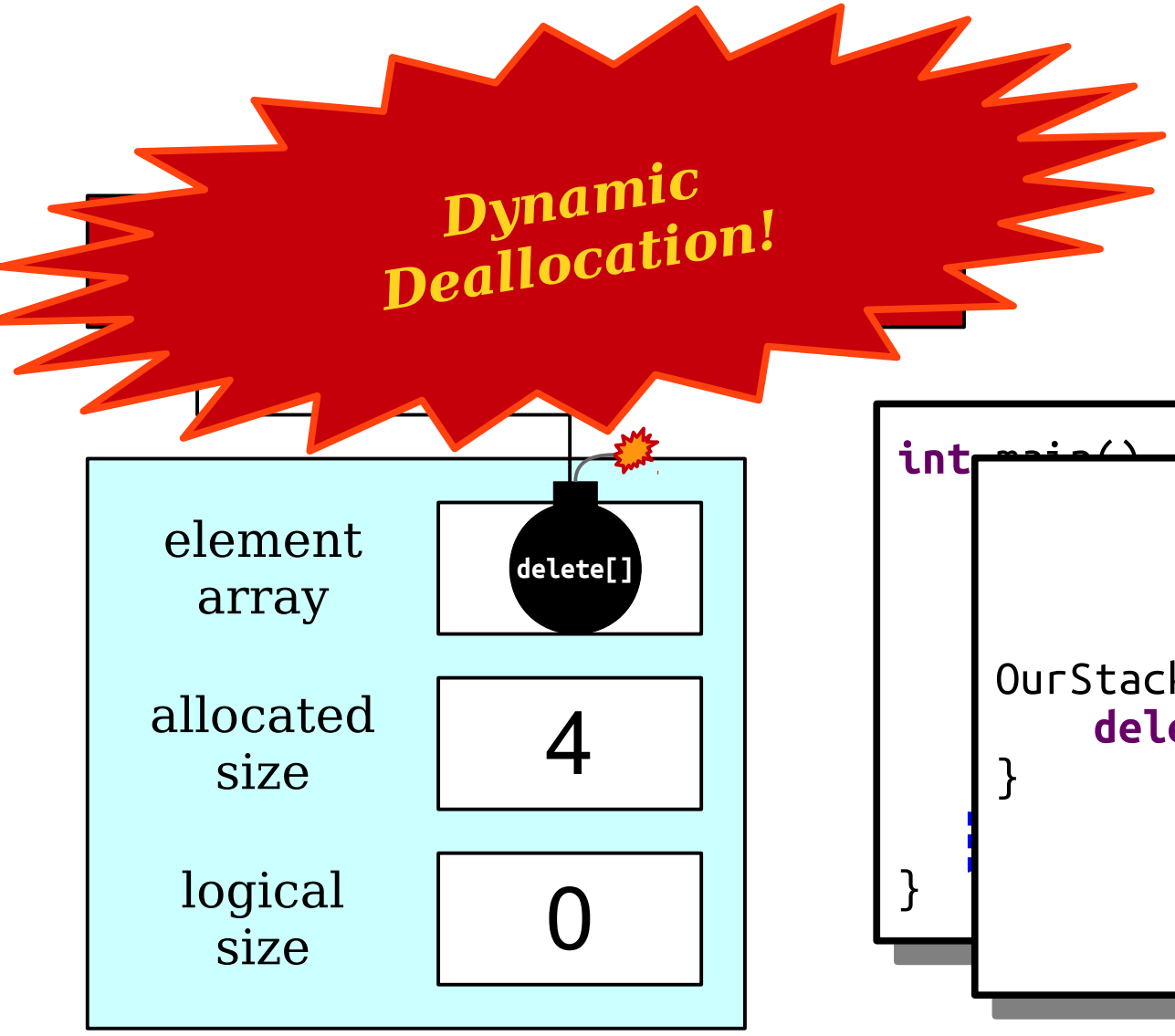
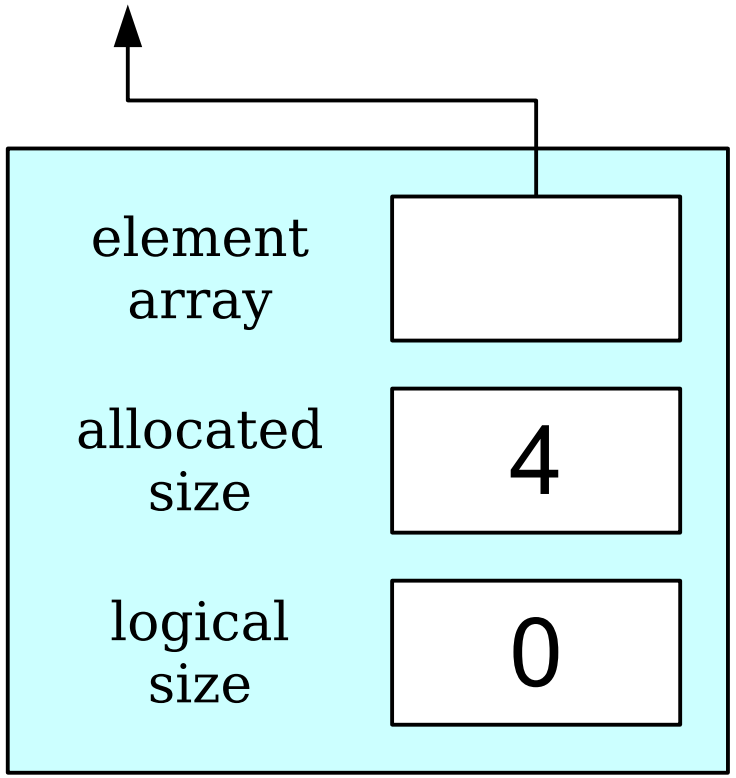



```
int main() {

    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;
}
```

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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

- ***Read Chapter 11.1 – 11.3.***
  - There's some nice descriptions in there of pointers, how they work, and what you can do with them.
- ***Start Assignment 5.***
  - Take some time to work on the Combine algorithm. It's a good way to brush up on the big-O and sorting topics from last week.

Next Time

- ***Making Stack Grow!***
  - Different approaches to `Stack` growth.
  - Analysis of these approaches.
  - The reality: *everything is a tradeoff!*