arrays

mental model of an array

mental model of an array

- elements live in equally-sized boxes all right next to each other
  - 
  - the array itself lives "in memory"

arrays

arrays (1/2)

- an **array** is a fixed-size sequence of elements, all of the same type
  - "an array of 4372 `double`'s"
  - "an array of 1 `int`'s"
  - "an array of 64 `Student`'s"

arrays (2/2)

- we will often write an array using curly braces
  - `{ 7, 7, 9 }` is an array containing `7`, `7`, and `9`
  - optionally, you can include a comma after the last element
    - `{ 7, 7, 9, }`
- **even though sets from math also use curly braces, Java arrays have nothing to do with sets; in a set, all elements must be unique**

array operations

creating an array (1/2)

- you can create an array by specifying its **length** (the number of elements); if you do, the array is **zero-initialized** (all elements are initially set to zero)
  - `int[] array = new int[8]; // { 0, 0, 0, 0, 0, 0, 0, 0 }`
  - `boolean[] array = new boolean[2]; // { false, false }`
  - `String[] array = new String[3]; // { null, null, null }`

creating an array (2/2)

- you can also create an array by specifying its elements; if you do, the array's length is the number of elements you specified
  - `int[] array = { 7, 7, 9 };`
  - `boolean[] array = { true };`
  - `String[] array = { "hello", "world" };`

getting an array's length

- after creating an array, you can get (but not set) its length

```
int[] array = { 7, 7, 9 };
System.out.println(array.length); // 3
```

```
int[] array = new int[8];
System.out.println(array.length); // 8
```

```
Error: cannot assign a value to final variable length

array.length = 42;
```

getting the value of an element of an array

- you can **get** the value of an element of an array using the square brackets and the index of the element
  - this is also called "accessing the array"

```
int[] array = { 3, 4, 5 };
int foo = array[0]; // 3
```

```
int[] array = { 3, 4, 5 };
int foo = array[42];

java.lang.ArrayIndexOutOfBoundsException: 42
```

setting the value of an element of an array

- you can **set** the value of an element of an array using the square brackets and the index of the element

```
int[] array = { 7, 7, 9 };
array[1] = 8;
// { 7, 8, 9 }
```

```
int[] array = { 7, 7, 9 };
array[-1] = 1000;

java.lang.ArrayIndexOutOfBoundsException: -1
```

printing the elements of an array

- **in Java, you don't simply call** `System.out.println(array)`
  - **instead, you call** `System.out.println(Arrays.toString(array));`
    - **note: this prints with square brackets instead of curly brackets**
      - 🤷

runtime of array operations

runtime of array operations

- arrays are fast!
  - ⏱ creating an array takes $\mathcal{O}(n)$ time, where n is the length of the array
  - ⏱ getting the value of the i-th element of an array takes $\mathcal{O}(1)$ time
  - ⏱ setting the value of the i-th element of an array takes $\mathcal{O}(1)$ time

accessing an array "under the hood"

- how Java does `array[4]`, step-by-step:
  - start at the head (0-th element) of the array
    🟦⬛⬛⬛⬛⬛⬛⬛
  - move over 4 slots (using an $\mathcal{O}(1)$ "add")
    ⬛⬛⬛⬛🟦⬛⬛⬛
  - return the value of the element in that slot
    ⬛⬛⬛⬛🟨⬛⬛⬛
- we can't actually see Java do this (it's too "low level")
  - but we *can* see C do it! (stay tuned 🙂)

iterating over an array

iterating over an array

- a for loop can be used to iterate over an array

```
for (int i = 0; i < array.length; ++i) {
    array[i] = ...;
}
```

array examples

example: creating an array of the first 100 non-negative integers

example: creating an array of the first 100 non-negative integers

```
import java.util.*;

class Main {
    public static void main(String[] arguments) {
        int[] array = new int[100];
        for (int i = 0; i < array.length; ++i) {
            array[i] = i;
        }
        System.out.println(Arrays.toString(array));
    }
}
```

example: array copy

example: array copy

```
import java.util.*;

class Main {
    public static void main(String[] arguments) {
        int[] source = { 3, 4, 5 };

        int[] destination = new int[source.length];
        for (int i = 0; i < source.length; ++i) {
            destination[i] = source[i];
        }

        System.out.println(Arrays.toString(source));
        System.out.println(Arrays.toString(destination));
    }
}
```

☠️ **example:** bad very bad broken array copy

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```
import java.util.*;

class Main {
    public static void main(String[] arguments) {
        int[] source = { 3, 4, 5 };

        int[] destination = source;

        source[0] = 7;
        System.out.println(Arrays.toString(source));
        System.out.println(Arrays.toString(destination));
    }
}
```

example: circular array

example: circular array

```
import java.util.*;

class Main {
    public static void main(String[] arguments) {
        int[] array = new int[5];
        int indexToWriteIntoNext = 0;
        while (true) {
            array[indexToWriteIntoNext] = getIntFromUser();
            indexToWriteIntoNext = (indexToWriteIntoNext + 1) % array.length;
            System.out.println(Arrays.toString(array));
        }
    }

    static int getIntFromUser() {
        Scanner scanner = new Scanner(System.in);
        while (!scanner.hasNextInt()) { scanner.nextLine(); }
        return scanner.nextInt();
    }
}
```

example: finding the index (and value) of an array's maximum element

example: finding the index (and value) of an array's maximum element

```
import java.util.*;

class Main {
    public static void main(String[] arguments) {
        double[] array = { 1.0, 3.0, -42.0, 1000.0, 99.0 };

        int indexOfMaximumElement = -1;
        double valueOfMaximumElement = Double.NEGATIVE_INFINITY;
        for (int i = 0; i < array.length; ++i) {
            if (array[i] > valueOfMaximumElement) {
                indexOfMaximumElement = i;
                valueOfMaximumElement = array[i];
            }
        }

        System.out.println("array[" + indexOfMaximumElement + "] = " + valueOfMaximumElement);
    }
}
```

multi-dimensional arrays

multi-dimensional arrays

multi-dimensional arrays (arrays of arrays of ...)

- multi-dimensional arrays are sometimes really handy

```
int[][] array = { { 3, 4 }, { 5, 6 }, { 7, 8 } };
System.out.println(Arrays.deepToString(array));
// [[3, 4], [5, 6], [7, 8]]
System.out.println(array[0][1]); // 4
```

```
int[][][] array = new int[2][3][4];
array[0][0][0] = 42;
System.out.println(Arrays.deepToString(array));
// [[[42, 0, 0, 0], [0, 0, 0, 0], [0, 0, 0, 0]], [[0, 0, 0, 0],
[0, 0, 0, 0], [0, 0, 0, 0]]]
```

swap

Python swap

Python swap

```
a = 0
b = 1

a, b = b, a # Python swap

# a is now 1
# b is now 0
```

☠ BAD VERY BAD BROKEN swap

☠ BAD VERY BAD BROKEN swap

```
int a = 0;
int b = 1;

{ // BAD VERY BAD BROKEN swap
    a = b; // a <- 1
    b = a; // b <- 1
}
```

swap

swap

```
int a = 0;
int b = 1;

{ // swap
    int tmp = a; // tmp <- 0
    a = b; // a <- 1
    b = tmp; // b <- 0
}
```

array algorithms that use swaps

reversing an array

out-of-place reverse

- we can reverse an array **out-of-place** using an additional array

```
static int[] outOfPlaceReverse(int[] array) {
    int[] result = new int[array.length];
    for (int i = 0; i < array.length; ++i) {
        int j = (array.length - 1) - i;
        result[i] = array[j];
    }
    return result;
}
```

in-place reverse

- we can reverse an array **in-place** using "swaps" (no additional array)

```
static void inPlaceReverse(int[] array) {
    for (int i = 0; i < array.length / 2; ++i) {
        int j = (array.length - 1) - i;
        int tmp = array[i];
        array[i] = array[j];
        array[j] = tmp;
    }
}
```

bubble sort

bubble sort

- **bubble sort** is a simple in-place sorting algorithm that uses swaps

```
import java.util.*;
class Main {
    public static void main(String[] arguments) {
        int[] array = { 2, 4, 1, 6, 0, 3, 5 };

        boolean arrayIsSorted;

        do {
            arrayIsSorted = true;
            for (int i = 0; i < array.length - 1; ++i) {
                if (array[i] > array[i + 1]) {
                    arrayIsSorted = false;
                    // swap
                    int tmp = array[i];
                    array[i] = array[i + 1];
                    array[i + 1] = tmp;
                }
            }
        } while (!arrayIsSorted);

        System.out.println(Arrays.toString(array));
    }
}
```

💻 array tutorial

💻 array tutorial

(this time with a wiki page)

💻 array tutorial

```
// 🟢 ([5, 4, 7, 0, 0, 7], 7) -> 2
// 🟢 ([5, 4, 7, 0, 0, 7], 3) -> -1
static int findFirstIndexOf(int[] array, int value);
```

```
// 🟦 ([1, 3, 3, 2, 3, 4], 3) -> [1, 2, 4]
static int[] removeAllOccurences(int[] array, int value);
```

```
// ♦️ [[1, 3], [2, 4, 5], [0, 5]] -> [0, 1, 2, 3, 4, 5, 5]
static int[] mergeArrayOfSortedArrays(int[][] arrays);
```

attempt to live-code the solutions while half-asleep 🙂 👍

☕ the art of coding things in the right order

compile and run early, compile and run often

why implement Rule 22 first? why not just skip straight to the general case?

well, let us imagine...

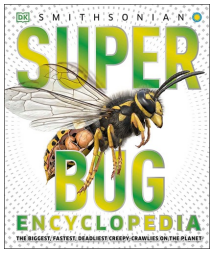
let's imagine...

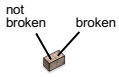
- ...you decide to develop n different things at once...
  - ...and then, finally, you compile and run...
    - ...aaaaand you have a bug! 🦠
- so...what is the cause of the bug? what code is broken? 🤔
  - well...i guess it could be any of the n things you just wrote!
- **and while $\mathcal{O}(n)$ possible sources of bugs might seem bad...**

...the reality is

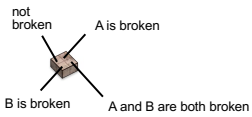
✨ **so much worse** ✨ !

because broken code likes to interact with other broken code, to make ✨ **super bugs** ✨ !

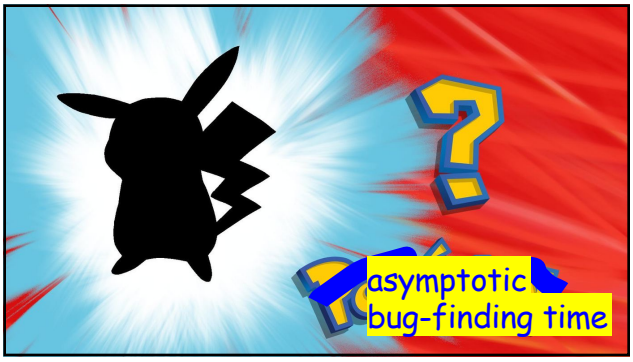


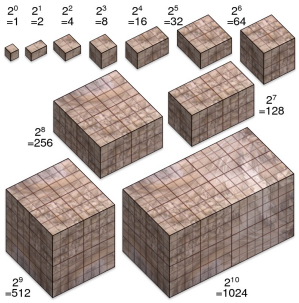


developing one thing at a time



developing two things at a time





$\mathcal{O}(2^n)$

gl;hf 🙂 👍

big lesson

- implement code one thing at a time
- compile and run and test after implementing every single thing
- this is a learned skill!

- how i would actually implement the automata homework
  - make the array
  - print the array as an array
  - print the array as a string
  - update the array once using Rule 22 and print the result
  - wrap the printing and update in a for loop
  - implement code to handle all rules and test it on Rule 22
  - test it on the other rules

this is a learned skill!

in summary