

# Java Programming

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Online Course

```
1 class Lecture5 {  
2  
3     "Arrays and More Data Structures"  
4  
5 }
```

# Arrays

An array stores a large collection of data of **same** type.

```
1 ...  
2     // Assume that the size is known.  
3     T[] A = new T[size];  
4     // A is a reference point to T-type array.  
5 ...
```

- Note that **T** could be any type.
- The variable *size* must be a nonnegative integer for the capacity of arrays.
- We now proceed to look into Line 3 in two stages.

## Stage 1: Creation

- First we focus on the RHS of Line 3.
- By invoking the **new** operator followed by **T** and **[ ]** surrounding an integer as its size, **one array is allocated in the heap**.<sup>1</sup>
- Note that the size **cannot** be changed after allocation.<sup>2</sup>
- In the end, one memory address associated with that array is returned and should be cached.

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<sup>1</sup>Recall about the simplified memory model.

<sup>2</sup>What if the array is full?! Stay tuned.

## Stage 2: Reference

- We declare one reference of **T**[ ], say A, for the array.
- I strongly emphasize that **A is not the array**.
- To understand the type correctly, one should read the type **from right to left**.
- For example, A is a reference to an array (represented by [ ]) whose elements are of **T** type.

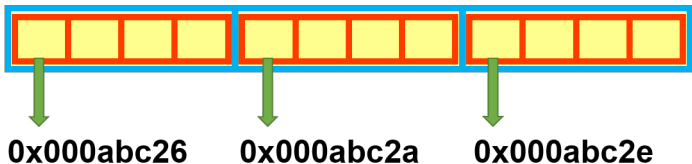
# Zero-Based Array Indexing

- Every array starts from **0**, but not 1.
- For example, the first element is **A[0]**, the second A[1], the third A[2], and so on.
- Note that the last index of one array is *size* − 1.
  - An **ArrayIndexOutOfBoundsException** is thrown out if the index exceeds *size* − 1.
- This convention is common among the mainstream languages! (Why?)

# Memory Allocation of Arrays

- An array is **allocated contiguously** in the memory.
- Indeed, we can treat the whole memory as an array.
- For example,

```
1 ...  
2     int[] A = new int[3];  
3 ...
```



## Zero-Based Array Indexing (Concluded)

- To fetch the second element, jump to the address stored by A and shift by 1 unit size of `int`, denoted by `A[1]`.
- Now you could explain why the first element is denoted by `A[0]`.
- Array index clearly acts as the `offset` from the beginning of arrays!



# Array Initialization

- Every array is implicitly initialized once the array is created.
- Default values are listed below:
  - 0 for all numeric types;
  - `\u0000` for `char` type;
  - `false` for `boolean` type;
  - `null` for all reference types.<sup>3</sup>
- An array can also be created by **enumerating** all elements without using the `new` operator, for example,

```
1 ...  
2     int[] A = {10, 20, 30}; // Syntax sugar.  
3 ...
```

---

<sup>3</sup>We will visit the keyword `null` in the chapter of OOP.

# Processing Arrays

We often use **for** loops to process array elements.

- Arrays have an attribute called *length*, which is the array capacity.
  - For example, *A.length*.
- So it is natural to use a **for** loop to manipulate arrays.

# Examples

```
1 ...  
2     // Create an integer array of size 5.  
3     int[] A = new int[5];  
4  
5     // Generate 5 random integers ranging from 0 to 99.  
6     for (int i = 0; i < A.length; ++i) {  
7         A[i] = (int) (Math.random() * 100);  
8     }  
9  
10    // Display all elements of A: O(n).  
11    for (int i = 0; i < A.length; ++i) {  
12        System.out.printf("%d ", A[i]);  
13    }  
14    System.out.println();  
15 ...
```

```
1 ...  
2 // Find maximum and minimum of A: O(n).  
3 int max = A[0];  
4 int min = A[0];  
5 for (int i = 1; i < A.length; ++i) {  
6     if (max < A[i]) max = A[i];  
7     if (min > A[i]) min = A[i];  
8 }  
9 ...
```

- How about the locations of extreme values?
- Can you find the 2nd max of A?
- Can you keep the first  $k$  max of A?

```
1 ...  
2     // Sum of A: O(n).  
3     int sum = 0;  
4     for (int i = 0; i < A.length; ++i) {  
5         sum += A[i];  
6     }  
7 ...
```

- Calculate the mean of A.
- Calculate the variance of A.
- Calculate the standard deviation of A.

# Shuffle Algorithm

```
1 ...  
2     for (int i = 0; i < A.length; ++i) {  
3  
4         // Choose a random integer j.  
5         int j = (int) (Math.random() * A.length);  
6  
7         // Swap A[i] and A[j].  
8         int tmp = A[i];  
9         A[i] = A[j];  
10        A[j] = tmp;  
11  
12    }  
13 ...
```

- However, this naive algorithm is broken!<sup>4</sup>
- How to swap by using XOR (that is,  $\wedge$ )?

<sup>4</sup>See <https://blog.codinghorror.com/the-danger-of-naivete/>.

## Exercise

Write a program to deal the first 5 cards from a deck of 52 shuffled cards.

- As you can see, RNG produces only random numbers.
- How to shuffle nonnumerical objects?
- Simply label 52 cards by  $0, 1, \dots, 51$ .
- Shuffle these numbers!

```

1  ...
2      String[] suits = {"Club", "Diamond", "Heart", "Spade"};
3      String[] ranks = {"3", "4", "5", "6", "7", "8", "9",
4                          "10", "J", "Q", "K", "A", "2"};
5
6      int size = 52;
7      int[] deck = new int[size];
8      for (int i = 0; i < deck.length; i++)
9          deck[i] = i;
10
11     // Shuffle algorithm: correct version.
12     for (int i = 0; i < size - 1; i++) {
13         int j = (int) (Math.random() * (size - i)) + i;
14         int z = deck[i];
15         deck[i] = deck[j];
16         deck[j] = z;
17     }
18
19     for (int i = 0; i < 5; i++) {
20         String suit = suits[deck[i] / 13];
21         String rank = ranks[deck[i] % 13];
22         System.out.printf("%-3s%8s\n", rank, suit);
23     }
24     ...

```



# Sorting Problem

- In computer science, a sorting algorithm is an algorithm that puts elements of a list in a certain **order**.<sup>5</sup>
- For example,

```
1 import java.util.Arrays;
2
3 ...
4     int[] A = {5, 2, 8};
5     Arrays.sort(A); // Becomes 2 5 8.
6
7     String[] B = {"www", "csie", "ntu", "edu", "tw"};
8     Arrays.sort(B); // Result?
9     ...
```

---

<sup>5</sup>What is the natural ordering of things?

## Exercise: Bubble Sort

```
1 ...
2 // Bubble sort:  $O(n^2)$ .
3 boolean swapped;
4 do {
5     swapped = false;
6     for (int i = 0; i < A.length - 1; i++) {
7         if (A[i] > A[i + 1]) {
8             int tmp = A[i];
9             A[i] = A[i + 1];
10            A[i + 1] = tmp;
11            swapped = true;
12        }
13    }
14 } while (swapped);
15 ...
```

- Try to implement the Selection Sort and the Insertion Sort.<sup>6</sup>

<sup>6</sup>See <https://visualgo.net/en/sorting>.

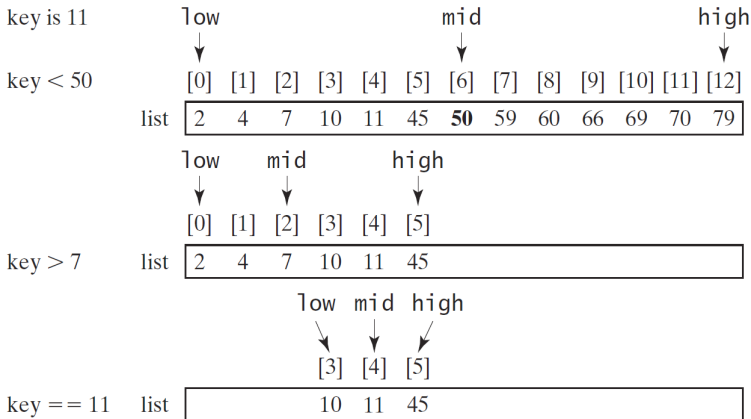
# Searching Problem

- To find the location of a given key, the **linear search** compares the key with all elements sequentially.

```
1  ...
2      // Linear search: O(n).
3      int[] A = {...};
4      int founds = 0;
5      for (int i = 0; i < A.length; i++) {
6          if (A[i] == key) {
7              System.out.printf("%d ", i);
8              founds++;
9          }
10     }
11     System.out.println("\nFounds: " + founds);
12  ...
```

- Could we do better?

## Alternative: Binary Search (Revisited)



```

1  ...
2      int idx = -1; // Why?
3      int high = A.length - 1, low = 0, mid;
4      while (high > low && idx < 0) {
5          mid = low + (high - low) / 2; // Why?
6          if (A[mid] < key)
7              low = mid + 1;
8          else if (A[mid] > key)
9              high = mid - 1;
10         else
11             idx = mid;
12     }
13
14     if (idx > -1)
15         System.out.printf("%d: %d\n", key, idx);
16     else
17         System.out.printf("%d: not found\n", key);
18     ...

```

- However, the binary search works only when the data is sorted!

## Discussions

- If the data is immutable, sort the data once for all and then do binary search.
- What if the data may be changed all the time?

Scenario / Operation	Insert	Search
Immutable unsorted array	N/A	$O(n)$
Immutable sorted array	N/A	$O(\log n)$
Mutable unsorted array	$O(1)^*$	$O(n)$
Mutable sorted array	$O(n)$	$O(\log n)$

\*: insert by attaching behind the array.

- Note that big- $O$  is additive by simply keeping the most dominant term.
- For example,  $O(n) + O(\log n) = O(n)$ .

## Short Introduction to Data Structures

- A data structure is a particular way of **organizing** data in a program so that it can perform **efficiently**.<sup>7</sup>
- **The choice among data structures depends on applications.**
- As an alternative to arrays, **linked lists**<sup>8</sup> are used to store data in the way different from arrays.
- You may see plenty of data structures in the future.<sup>9</sup>
  - For example, priority queues, trees, graphs, tables.
- You could also find many questions about data structures on LeetCode.<sup>10</sup>

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<sup>7</sup>See <http://bigocheatsheet.com/>.

<sup>8</sup>See [https://en.wikipedia.org/wiki/Linked\\_list](https://en.wikipedia.org/wiki/Linked_list).

<sup>9</sup>See [https://en.wikipedia.org/wiki/Java\\_collections\\_framework](https://en.wikipedia.org/wiki/Java_collections_framework).

<sup>10</sup>See <https://leetcode.com/>.

## Special Issue: **for**-each Loops

- A **for**-each loop is designed to **iterate** over a collection of objects, such as arrays and other data structures, in strictly sequential fashion, from start to finish.

```
1 ...  
2     T[] A = { ... };  
3     for (T element: A) {  
4         // Loop body.  
5     }  
6 ...
```



# Example

```
1 ...  
2     int s = 0;  
3     for (int i = 0; i < A.length; ++i) {  
4         s += A[i];  
5     }  
6 ...
```

```
1 ...  
2     int s = 0;  
3     for (int item: A) {  
4         s += item;  
5     }  
6 ...
```

- Short and sweet!
- You may consider using the for-each loop when you **iterate over all elements** and **the order of iteration is irrelevant**.

# Exercise

```
1 ...  
2     String[] letters = {"A", "B", "C", "D", "E"};  
3  
4     for (String letter: letters) {  
5         System.out.printf("%s ", letter);  
6     }  
7     System.out.println();  
8 ...
```

## Special Issue: Cloning Arrays

- In practice, one might duplicate an array for some purpose.
- For example,

```
1 ...  
2     int x = 1;  
3     int y = x; // You can say that y copies the value of x.  
4     x = 2;  
5     System.out.println(y); // Output 1.  
6  
7     int[] A = {10, ...}; // Ignore the rest of elements.  
8     int[] B = A;  
9     A[0] = 100;  
10    System.out.println(B[0]); // Output?  
11 ...
```

- This is called the **shallow copy**.
- As you can see, the result differs from our expectation.  
(Why?)

- To clone an array, you should create a new array and use loops to copy every element, one by one.

```
1 ...  
2 // Let A be an array to be copied.  
3 int[] B = new int[A.length];  
4 for (int i = 0; i < A.length; ++i) {  
5     B[i] = A[i];  
6 }  
7 ...
```

- This is called the **deep copy**.

## Beyond 1-Dimensional Arrays

- 2D or higher dimensional arrays are widely used in various applications.
  - For example, RGB images are stored as 3D arrays.
- We can create 2D **T**-type arrays simply by adding one more [ ] with its size.
- For example,

```
1 ...  
2     int rows = 4; // Row size.  
3     int cols = 3; // Column size.  
4     T[][] M = new T[rows][cols];  
5 ...
```

	[0]	[1]	[2]	[3]	[4]
[0]	0	0	0	0	0
[1]	0	0	0	0	0
[2]	0	0	0	0	0
[3]	0	0	0	0	0
[4]	0	0	0	0	0

`matrix = new int[5][5];`

(a)

	[0]	[1]	[2]	[3]	[4]
[0]	0	0	0	0	0
[1]	0	0	0	0	0
[2]	0	7	0	0	0
[3]	0	0	0	0	0
[4]	0	0	0	0	0

`matrix[2][1] = 7;`

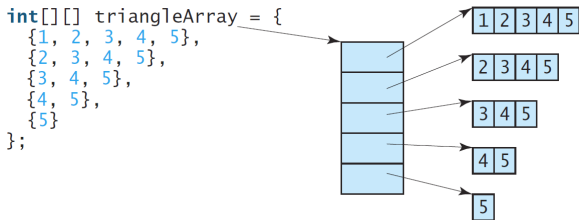
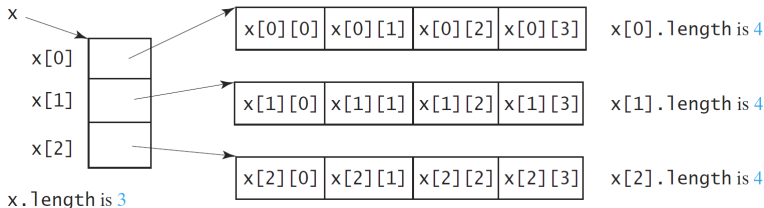
(b)

	[0]	[1]	[2]
[0]	1	2	3
[1]	4	5	6
[2]	7	8	9
[3]	10	11	12

```
int[][] array = {
    {1, 2, 3},
    {4, 5, 6},
    {7, 8, 9},
    {10, 11, 12}
};
```

(c)

## Reality: Memory Allocation for 2D Arrays



## Example: 2D Arrays & Loops<sup>11</sup>

```
1 ...
2     int[][] A = {{10, 20, 30}, {40, 50}, {60}};
3
4     // Conventional for loop.
5     for (int i = 0; i < A.length; i++) {
6         for (int j = 0; j < A[i].length; j++)
7             System.out.printf("%3d", A[i][j]);
8         System.out.println();
9     }
10
11    // For-each loop.
12    for (int[] row: A) {
13        for (int item: row)
14            System.out.printf("%3d", item);
15        System.out.println();
16    }
17 ...
```

<sup>11</sup>Thanks to a lively discussion on January 31, 2016.



## Exercise: Matrix Multiplication

Let  $A_{m \times n}$  and  $B_{n \times q}$  be two matrices for  $m, n, q \in \mathbb{N}$ . Write a program to calculate  $C = A \times B$ .

- Let  $a_{ik}$  and  $b_{kj}$  be elements of  $A$  and  $B$ , respectively.
- For  $k = 1, 2, \dots, n$ , use the formula

$$c_{ij} = \sum_{k=1}^n a_{ik} b_{kj}$$

for  $i = 1, 2, \dots, m$  and for  $j = 1, 2, \dots, q$ .

- It takes  $O(n^3)$  time. (Why?)

## (Native) Array v.s. **ArrayList**

```
1 ...  
2     int[] A = new int[3]; // The size should be preset.  
3     A[0] = 100; A[1] = 200; A[2] = 300;  
4     for (int item: A) System.out.printf("%d ", item);  
5     System.out.println();  
6  
7     ArrayList<Integer> B = new ArrayList<>(); // Size?  
8     B.add(100); B.add(200); B.add(300);  
9     System.out.println(B); // Short and sweet!  
10 ...
```

- Native array is the most fundamental data structure, but not convenient.
  - How to resize the array which is full?
- In practice, you should use **ArrayList**<E>, where E is the type given by users.<sup>12</sup>

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<sup>12</sup>This is called **generics**. Stay tuned in Java Programming 2.

## Case Study: Reversing Array

- Write a program to arrange the array in reverse order.
- Let A be the original array.
- The first try is to create another array with same size and copy each element from A to B, which is a reference to the new array.

```
1 ...  
2     int[] A = {1, 2, 3, 4, 5};  
3     int[] B = new int[A.length];  
4     for (int i = 0; i < A.length; i++) {  
5         B[A.length - 1 - i] = A[i];  
6     }  
7     A = B; // Why?  
8 ...
```

## Another Try

```
1 ...  
2     int[] A = {1, 2, 3, 4, 5};  
3     for (int i = 0; i < A.length / 2; i++) {  
4         int j = A.length - 1 - i;  
5         int tmp = A[i];  
6         A[i] = A[j];  
7         A[j] = tmp;  
8     }  
9 ...
```

Approach	Time Complexity	Space Complexity
First try	$O(n)$	$O(n)$
Second try	$O(n)$	$O(1)$

- The second try is better, both in time<sup>13</sup> and space.
- It is called an **in-place** algorithm.

<sup>13</sup>The second try runs in only half time of the first one, in practice.