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What is the state of `nums` at the end of `main()`?

```
1  static void shuffle(int[] arr) {
2    int temp = arr[0];
3    arr[0] = arr[2];
4    arr[2] = temp;
5    arr = new int[]{arr[1], arr[2], arr[0]};
6  }
7
8  public static void main(String[] args) {
9    int[] nums = {1, 2, 3};
10   shuffle(nums);
11 }
```

`{1, 2, 3}`	(A)
`{2, 1, 3}`	(B)
`{2, 3, 1}`	(C)
`{3, 2, 1}`	(D)

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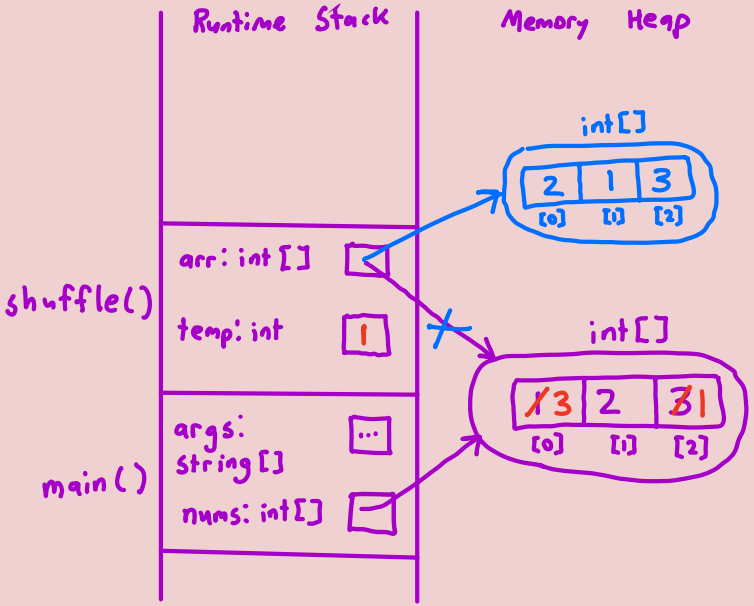
4    arr[2] = temp;
5    arr = new int[]{arr[1], arr[2], arr[0]};
6  }
7
8  public static void main(String[] args) {
9    int[] nums = {1, 2, 3};
10   shuffle(nums);
11 }
```

swap entries a[0] and a[2]

reassign reference



Lecture 3: Specifications and Testing

CS 2110

September 1, 2026

Today's Learning Outcomes

12. Identify the pre-conditions, post-conditions, and side effects of a method and use these to write detailed Javadoc specifications.

14. Write comprehensive unit tests for a method given only its specifications and signature.

16. Explain the process of *test-driven development* and identify its potential benefits.

17. Differentiate between *black-box* and *glass-box* testing and identify scenarios where each is appropriate.

Client and Implementer Roles

Large, long-lasting software systems require coordination between developers.

Different people write different parts of the code, which must later be integrated.

A single developer interacts with a code module (a class, package, or **method**) from one (or both) of two possible perspectives:

1. Client ← Need way to coordinate → 2. Implementer

- caller of module
- needs to know how to use it, but not necessarily how it works (abstraction)
- actually run the code in their application

- author of module
- Knows all "internal details"
- may not ever "run" their code in a real system

Method Specifications

What information does a client need to (properly) use a method in their code?

- method name
- # of arguments
- type of each argument
- order of arguments

} method signature
how does the client call the method?

- interpretation of each argument
- conditions / requirements of inputs

} how do they call it correctly?

- return type
- interpretation of return value

} what will it do?

⋮

Pre-conditions and Post-conditions

Pre-conditions: Properties that must be true when a method is called

Today (for static methods): requirements on parameters

- allowed / disallowed values (valid ranges)
- required state of reference types (e.g., order of array entries)
- relationships between parameters

Post-conditions: Properties that will be true when a method returns **<u>if</u>** the pre-conditions were met.

- interpretation / assertions about <u>return value</u>
- <u>side effects</u>: modifications to the program state
  - state of shared objects
  - print output

Specifying Pre-conditions

/** ... */ for multiline Javadoc comments
built-in support to generate specs documentation from these

```
1  /**
2   * Returns `true` if the character in `str` at index `i` is uppercase; otherwise
3   * returns `false`. Requires that 0 ≤ i < str.length() .
4   */
5  static boolean uppercaseAt(String str, int i) { ... }
```

Predicate clauses

↑ ; must be valid index into str

Use "Requires..." clauses to specify pre-conditions.

* In CS2110, we'll add an implicit (unwritten) non-null pre-condition to all reference type parameters, unless otherwise specified

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What should a method do if its pre-conditions are not met by its client?

"undefined behavior"

- Try to meet the post-conditions anyway (A)
- Return an obviously wrong value to "get back" at the client ? (B)
- Throw an exception to report the issue to the client (C)
- Crash the program (D)

Handling Pre-condition Violations

When the client violates a method's pre-conditions, it does not offer any guarantees about its behavior. **Any** behavior satisfies its specifications!

Easiest Approach: Ignore pre-condition violations

- write the code to work under the assumption of pre-conditions with no extra checks

"Best" Approach: Defensive programming

- Turn pre-condition violations into runtime errors with Java assert statements
- actively check pre-conditions, helpful for debugging

Coding Demo: Defensive Programming

* Remember to enable assertions!
  they're ignored by default
  instructions in IntelliJ guide

(Bad) Pre-condition Violation Handling

Do something special without including it in the specs

Throwing a "more appropriate" exception

```java
/** Returns `true` if the character in `str` at index `i` is uppercase, otherwise
 *  returns `false`. Requires that `0 <= i < str.length()`. */
static boolean uppercaseAt(String str, int i) {
  if (i < 0 || i >= str.length()) {
    throw new IllegalArgumentException("`i` must be between 0 and `str.length()-1`.");
  }
  return Character.isUpperCase(str.charAt(i));
}
```

"Correcting" the inputs

```java
static boolean uppercaseAt(String str, int i) {
  return Character.isUpperCase(Math.clamp(i, 0, str.length() - 1));
}
```

Unit Testing

Unit tests check whether a method/class *conforms to its specifications*.

not that method works correctly, does what its code says

* we write tests looking at specs, not source code

Many unit tests follow the same basic structure:

1. Set up inputs (arguments) to method "WHEN..."
2. Call method we're testing
3. Compare output to hard-coded expected output "THEN..."
   or check for expected side effects

Writing many separate unit tests for each method/class allows us to more easily diagnose issues as we code.

Coding Demo: JUnit

Good Unit Test Suites

Soundness: Unit tests should all pass for any implementation that meets the specs

** not just your particular implementation

Coverage: There are enough unit tests to "cover" the possible scenarios the module we're testing can encounter

Any small deviation from the specs should cause at least one test to fail.

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Should a good unit test suite include tests that commit pre-condition violations?

Yes	(A)
No !! can't assert anything about undefined behavior	(B)
I'm not sure	(C)

Testing Methods with Side Effects

```
1  /** Zeroes out all entries before and including the first instance of `key` in `arr`
2   *  and returns the index where `key` was found. If `key` is not present in `arr`,
3   *  then all indices of `arr` are zeroed out, and `arr.length` is returned. */
4   static int zeroThrough(int[] arr, int key) { ... }
```

- can't just "assertEquals()" the return value
- instead, "inspect" state of objects using one or more assertions
- later for testing classes: use "accessor" methods

* Need to think of tests beyond "input, output" pairs to ensure good coverage

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Consider the following method specifications:

```
1  /** Returns an index `i` with `0 < i < a.length-1` corresponding to a local
2    * maximum of array `a`, meaning `a[i] > a[i-1]` and `a[i] > a[i+1]`.
3    * Returns 0 if `a` does not  contain a local maximum. */
4  static int findLocalMax(int[] a) { ... }
```

What's wrong with the following JUnit test for this method?

```
1  @Test
2  void testMultipleMaxima() {
3    int[] a = {10, 12, 15, 13, 16, 14, 11};
4    assertEquals(2, findLocalMax(a));
5  }
```

Underspecification

Sometimes, there can be multiple different return values (or side effect behaviors) that all conform to a method's specifications.

In this case, we say that the method is **underspecified**.

Sound unit tests need to pass when run against all of these possible implementations

** Most common source of errors in CS2110 testing. Don't assume your approach is the only way to meet the specs.

Don't "overspecify" your assertions.

Testing with Underspecification

```java
/** Returns an index `i` with `0 < i < a.length-1` corresponding to a local
  * maximum of array `a`, meaning `a[i] > a[i-1]` and `a[i] > a[i+1]`.
  * Returns 0 if `a` does not  contain a local maximum. */
static int findLocalMax(int[] a) { ... }
```

Account for all possibilities

```java
@Test
void testMultipleMaxima() {
  int[] a = {10, 12, 15, 13, 16, 14, 11};
  int i = findLocalMax(a);
  assertTrue(i==2 || i==4);
}
```

Check the post-condition property

```java
@Test
void testMultipleMaxima() {
  int[] a = {10, 12, 15, 13, 16, 14, 11};
  int i = findLocalMax(a);
  assertTrue(a[i] > a[i-1] &&
             a[i] > a[i+1]);
}
```

Test-Driven Development

= Use specs to write unit tests **first**, then use tests to guide development.

Many Benefits:

- focus code on specs
- think about edge cases upfront - often leads to more elegant code (fewer "patches")
- clear progress measure during development
- separation of responsibilities
- test soundness

But coming up with tests can be tricky... It takes some practice.

Black Box vs. Glass Box Testing

Black Box Testing: Tests are written without access to the source code. These tests are based on only specs, not any implementation details.

- naturally happens for test-driven development
- good for ensuring soundness
- good for dividing work after agreeing on specs

Glass Box Testing: Use implementation details to inform test suite.

- good for identifying corner cases of your implementation, achieving line coverage
- still need to ensure soundness