Loops and Recursion

Introduction to Programming and Computational Problem Solving: Accelerated Pace

CSE 11

Lecture 7

Announcements

- Assignment 3 is due Apr 23, 11:59 PM
  - Upgrade beginning Apr 26, 12:01 AM
- Assignment 4 will be released Apr 23
  - Due Apr 30, 11:59 PM

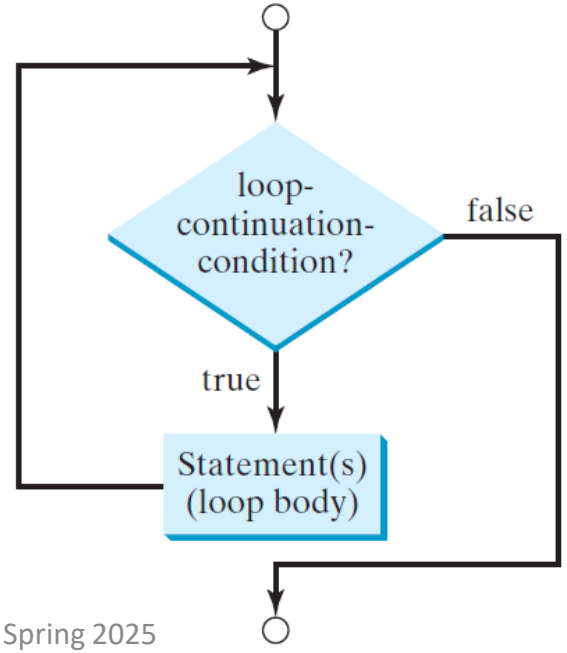
Loops and recursion

- `while` loops
- `do-while` loops
- `for` loops
- Recursion is a technique that leads to elegant solutions to problems that are difficult to program using simple loops
  - A recursive method is one that invokes itself directly or indirectly

`while` loops

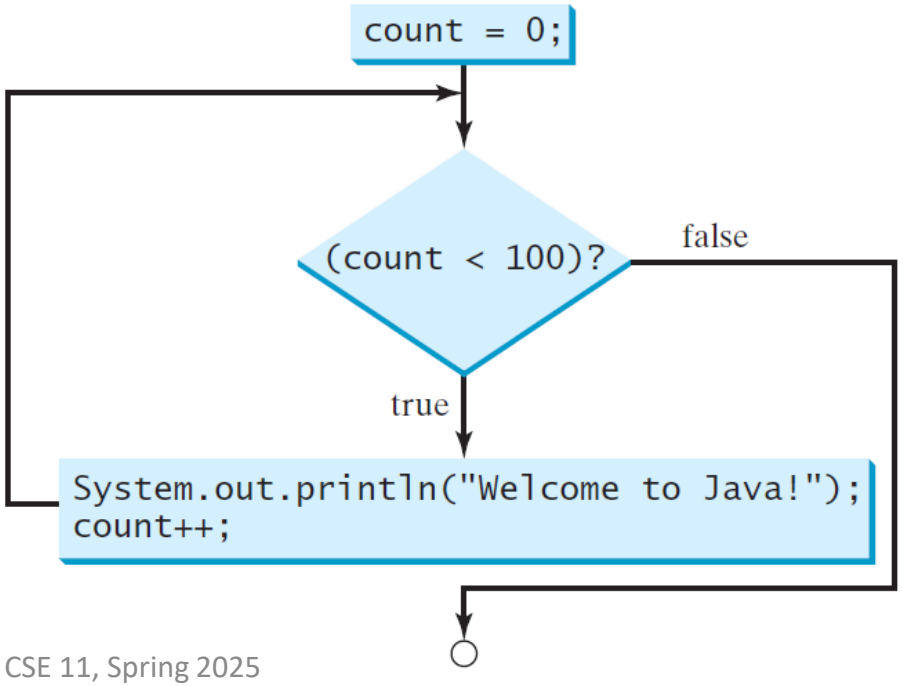
- Executes statements repeatedly while the condition is true

```
while (loop-continuation-condition) {
  // loop-body
  Statement(s);
}
```



while loops

```
int count = 0;
while (count < 100) {
  System.out.println("Welcome to Java");
  count++;
}
```



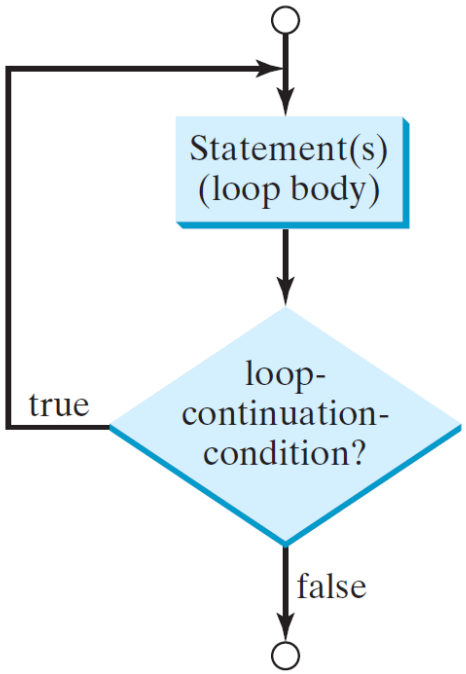
Ending a loop with a sentinel value

- Often the number of times a loop is executed is not predetermined
- You may use an input value to signify the end of the loop
- Such a value is known as a *sentinel value*
- For example, a program reads and calculates the sum of an unspecified number of integers. The input 0 signifies the end of the input.

do-while loops

- Execute the loop body first, then checks the loop continuation condition

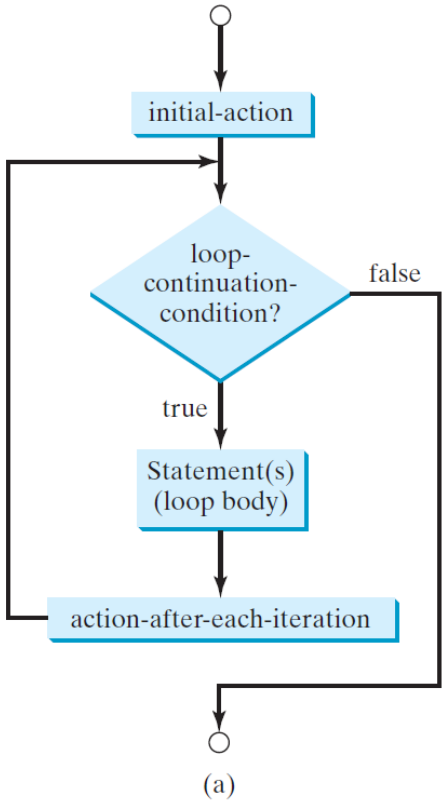
```
do {
  // Loop body
  Statement(s);
} while (loop-continuation-condition);
```



for loops

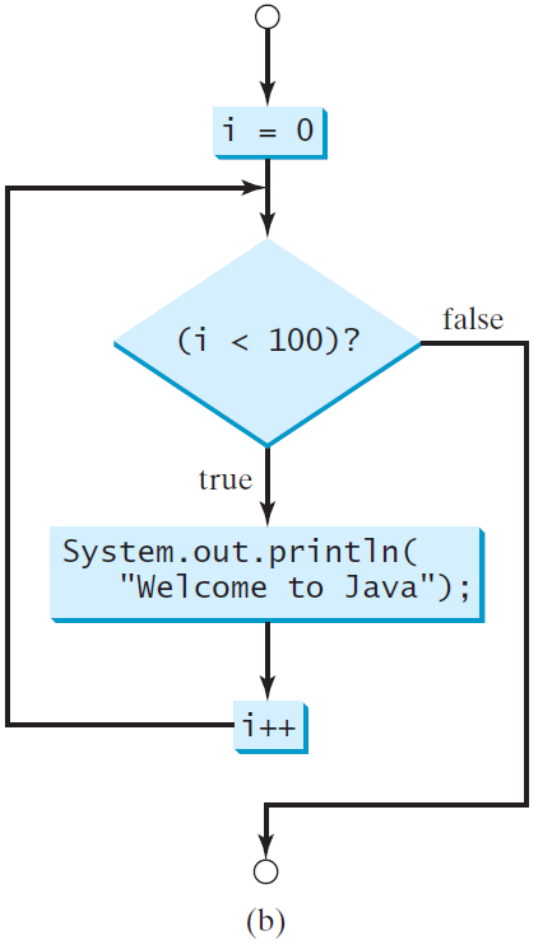
- A concise syntax for writing loops

```
for (initial-action; loop-continuation-condition;
   action-after-each-iteration) {
    // loop body
    Statement(s);
}
```



for loops

```
int i;
for (i = 0; i < 100; i++) {
  System.out.println(
     "Welcome to Java!");
}
```



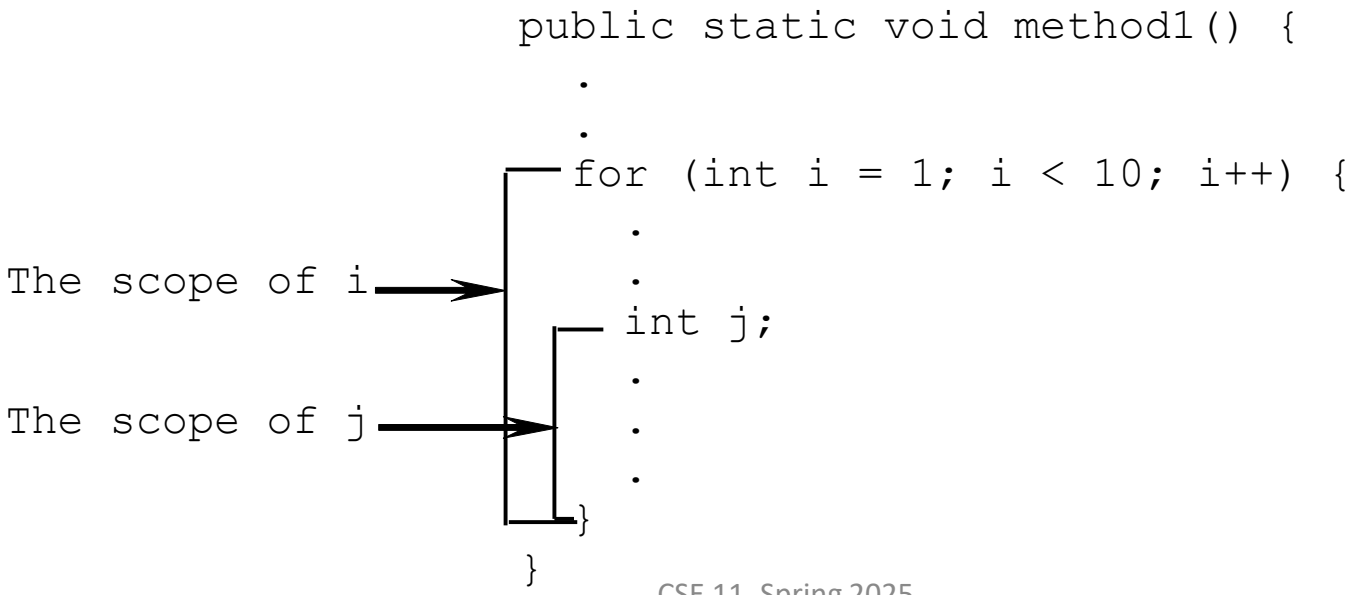
for loops

- The initial-action in a for loop can be a list of zero or more comma-separated expressions
- The action-after-each-iteration in a for loop can be a list of zero or more comma-separated statements
- However, it is best practice (less error prone) **not to use comma-separated** expressions and statements

```
for (int i = 0, j = 0; (i + j < 10); i++, j++) {
  // Do something
}
```

Scope of local variables

- A variable declared in the initial action part of a `for` loop header has its scope in the entire loop
- A variable declared inside a `for` loop body has its scope limited in the loop body from its declaration and to the end of the block that contains the variable

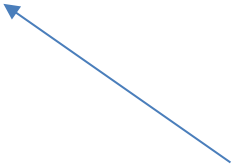


Scope of local variables

```
// Fine with no errors
public static void correctMethod() {
  int x = 1;
  int y = 1;
  // i is declared
  for (int i = 1; i < 10; i++) {
    x += i;
  }
  // i is declared again
  for (int i = 1; i < 10; i++) {
    y += i;
  }
}
```

Scope of local variables

```
// With errors
public static void incorrectMethod() {
  int x = 1; // x is declared
  int y = 1;
  for (int i = 1; i < 10; i++) {
    int x = 0;
    x += i;
  }
}
```



Compile error: duplicate local variable

Loops and floating-point accuracy

- Remember, calculations involving floating-point numbers are approximated because these numbers are not stored with complete accuracy
- As such, **do not use floating-point values for equality checking in a loop control**

```
double sum = 0;
double item = 1;
while (item != 0) { // No guarantee item will be 0
   sum += item;
   item -= 0.1;
}
System.out.println(sum);
```

Infinite loops

- If the loop-continuation-condition in a for loop is omitted, it is implicitly true

```
for ( ; ; ) {
  // Do something
}
```

(a)

Equivalent

```
while (true) {
  // Do something
}
```

(b)

Loops

- The three forms of loop statements, `while`, `do-while`, and `for`, are expressively equivalent
  - You can write a loop in any of these three forms

```
while (loop-continuation-condition) {
  // Loop body
}
```

(a)

Equivalent

```
for ( ; loop-continuation-condition; )
  // Loop body
}
```

(b)

```
for (initial-action;
     loop-continuation-condition;
     action-after-each-iteration) {
  // Loop body;
}
```

(a)

Equivalent

```
initial-action;
while (loop-continuation-condition) {
  // Loop body;
  action-after-each-iteration;
}
```

(b)

Loops

- Use the loop form that is most intuitive and comfortable
  - A `for` loop may be used if the number of repetitions is known
  - A `while` loop may be used if the number of repetitions is not known
  - A `do-while` loop can be used to replace a `while` loop if the loop body must be executed before testing the continuation condition

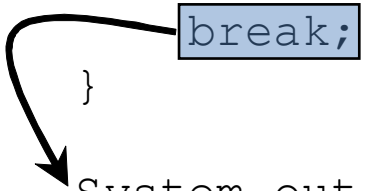
break

- Immediately terminate the loop

```
public class TestBreak {
  public static void main(String[] args) {
    int sum = 0;
    int number = 0;

    while (number < 20) {
      number++;
      sum += number;
      if (sum >= 100)
        break;
    }

    System.out.println("The number is " + number);
    System.out.println("The sum is " + sum);
  }
}
```



continue

- End the current iteration
  - Program control goes to the end of the loop body

```
public class TestContinue {
  public static void main(String[] args) {
    int sum = 0;
    int number = 0;

    while (number < 20) {
      number++;
      if (number == 10 || number == 11)
        continue;
      sum += number;
    }

    System.out.println("The sum is " + sum);
  }
}
```

Nested loops

- Loops can be nested
- For example, nested `for` loops are often used to handle two-dimensional data

```
for (int i = 0; i < numRows; i++) {
  // Handle i-th row
  for (int j = 0; j < numColumns; j++) {
    // Handle j-th column on i-th row
  }
}
```

Recursion

- Recursion is a technique that leads to elegant solutions to problems that are difficult to program using simple loops
- A recursive method is one that invokes itself directly or indirectly

Computing factorials

- Example

  4! = 4 * 3 * 2 * 1 = 24

- Remember, 0! = 1 (and 1! = 1)
- As a (non-recursive) method

```
public static long factorial(int n) {
  long nfactorial = 0 == n ? 1 : n;
  for (int i = n - 1; 1 < i; --i) {
    nfactorial *= i;
  }
  return nfactorial;
}
```

Computing factorials

- Alternatively, think recursively

  0! = 1

  - *Base case* or *stopping condition*

  n! = n * (n – 1)!; n > 0

  - (n – 1)! is a *subproblem* of n! and is a *recursive call*
- Example

  4! = 4 * 3!

  4! = 4 * (3 * 2!)

  4! = 4 * (3 * (2 * 1!))

  4! = 4 * (3 * (2 * (1 * 0!)))

  4! = 4 * (3 * (2 * (1 * 1)))

  4! = 4 * (3 * (2 * 1))

  4! = 4 * (3 * 2)

  4! = 4 * 6

  4! = 24

Computing factorials

0! = 1 `factorial(0) = 1`

n! = n * (n – 1)!; n > 0 `factorial(n) = n * factorial(n – 1)`

- As a recursive method

```
public static long factorial(int n) {
  if (0 == n) {
    // Base case
    return 1;
  }
  else {
    // Recursive call
    return n * factorial(n – 1);
  }
}
```

Computing factorials

- Example

$0! = 1$
$n! = n * (n - 1)!;\ n > 0$

$4! = 4 * 3!$
$4! = 4 * (3 * 2!)$
$4! = 4 * (3 * (2 * 1!))$
$4! = 4 * (3 * (2 * (1 * 0!)))$
$4! = 4 * (3 * (2 * (1 * 1)))$
$4! = 4 * (3 * (2 * 1))$
$4! = 4 * (3 * 2)$
$4! = 4 * 6$
$4! = 24$

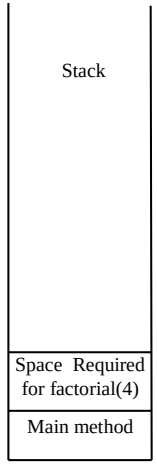
```
factorial(0) = 1
factorial(n) = n * factorial(n - 1)
```

```
factorial(4) = 4 * factorial(3)
factorial(4) = 4 * (3 * factorial(2))
factorial(4) = 4 * (3 * (2 * factorial(1)))
factorial(4) = 4 * (3 * (2 * (1 * factorial(0))))
factorial(4) = 4 * (3 * (2 * (1 * 1)))
factorial(4) = 4 * (3 * (2 * 1))
factorial(4) = 4 * (3 * 2)
factorial(4) = 4 * 6
factorial(4) = 24
```

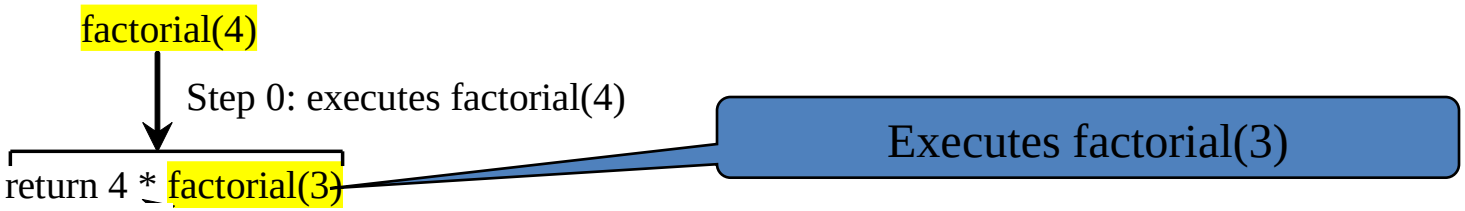
Trace code

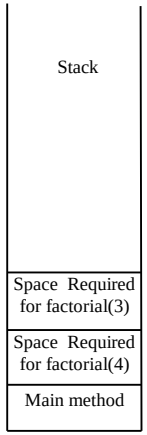
Executes factorial(4)

factorial(4)

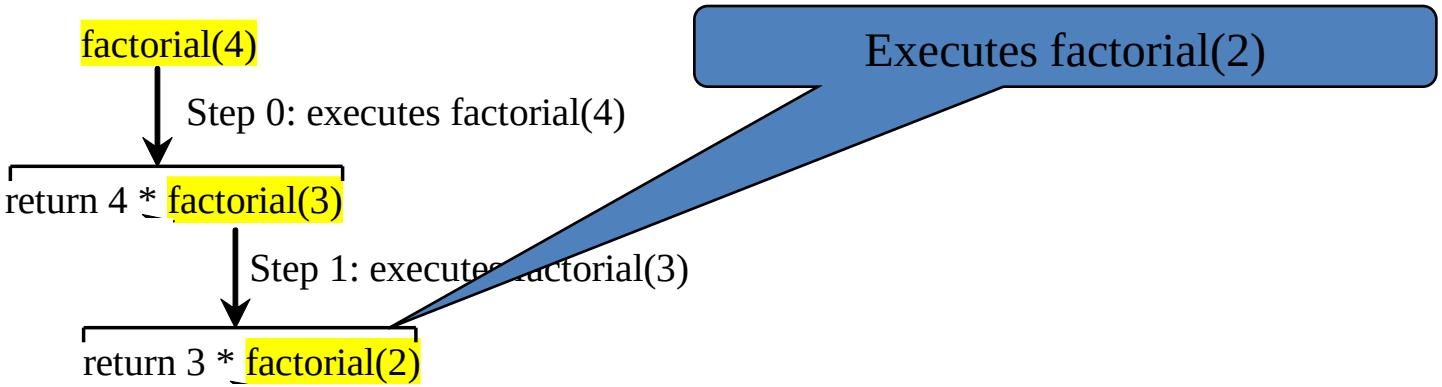


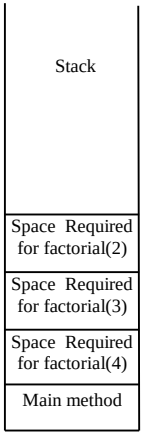
Trace code


factorial(4)
Step 0: executes factorial(4)
return 4 * factorial(3)
Executes factorial(3)

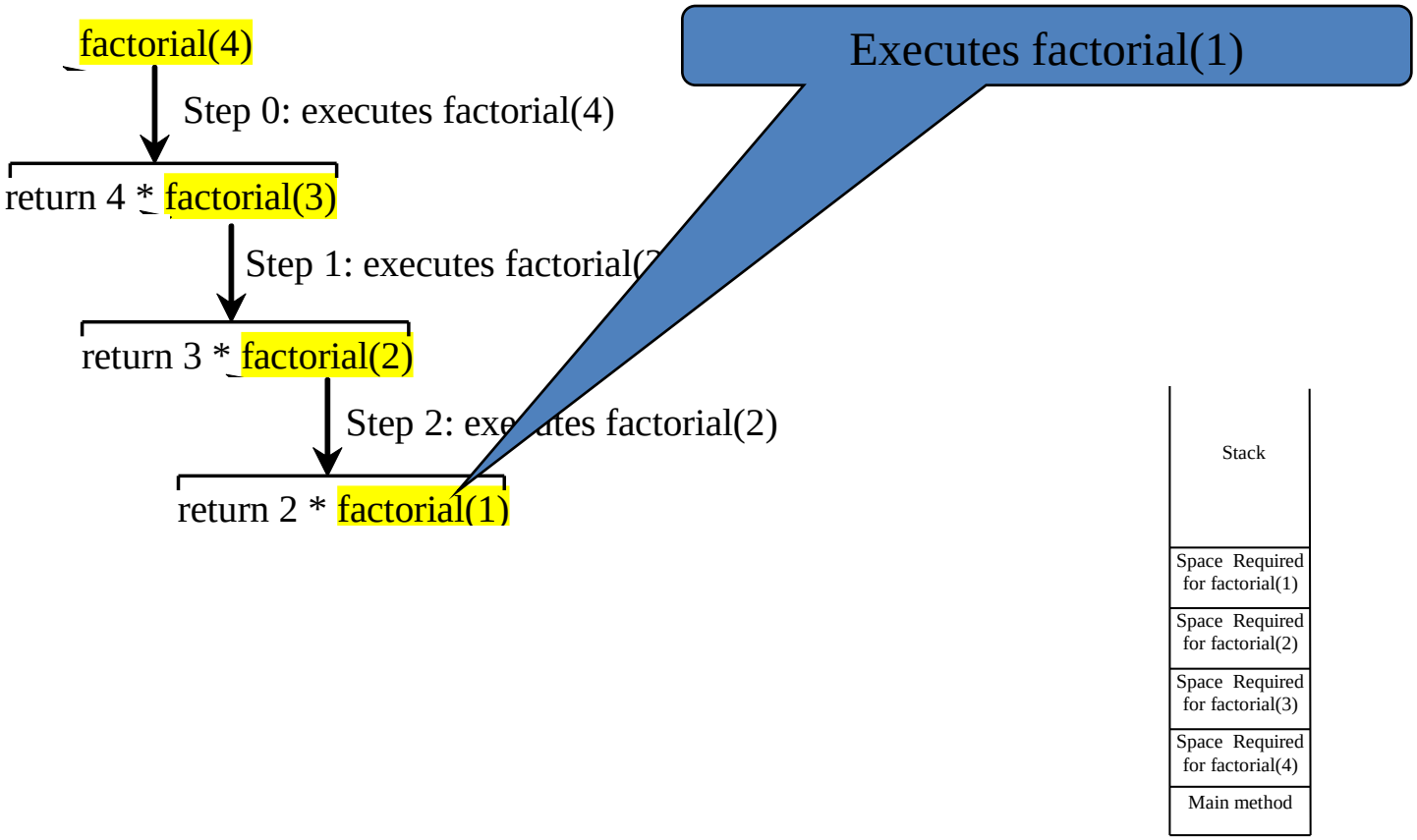

Stack
Space Required for factorial(3)
Space Required for factorial(4)
Main method

Trace code

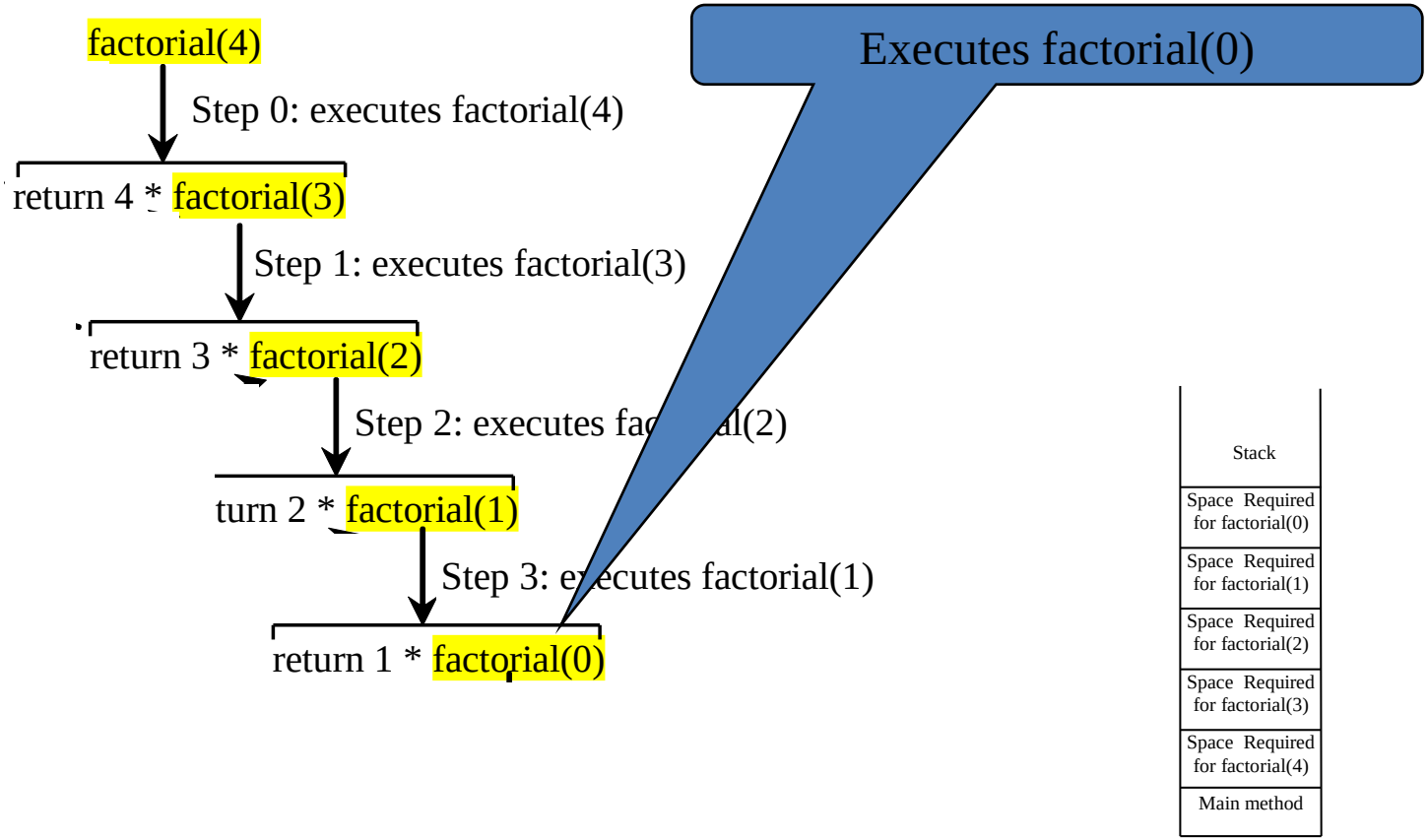

factorial(4)
Step 0: executes factorial(4)
return 4 * factorial(3)
Step 1: executes factorial(3)
return 3 * factorial(2)
Executes factorial(2)


Stack
Space Required for factorial(2)
Space Required for factorial(3)
Space Required for factorial(4)
Main method

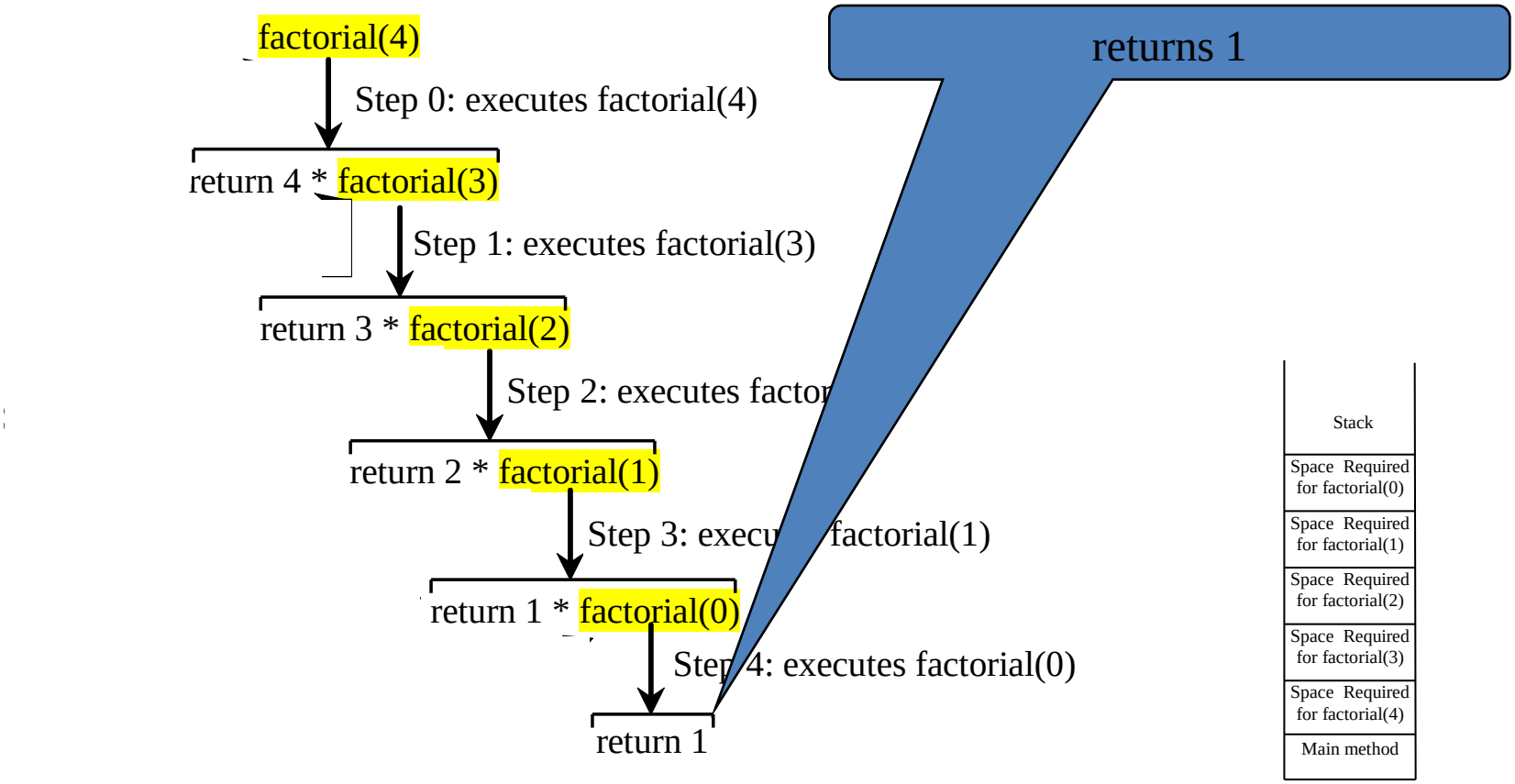
Trace code


factorial(4)
Step 0: executes factorial(4)
return 4 * factorial(3)
Step 1: executes factorial(3)
return 3 * factorial(2)
Step 2: executes factorial(2)
return 2 * factorial(1)
Executes factorial(1)
Stack
Space Required for factorial(1)
Space Required for factorial(2)
Space Required for factorial(3)
Space Required for factorial(4)
Main method

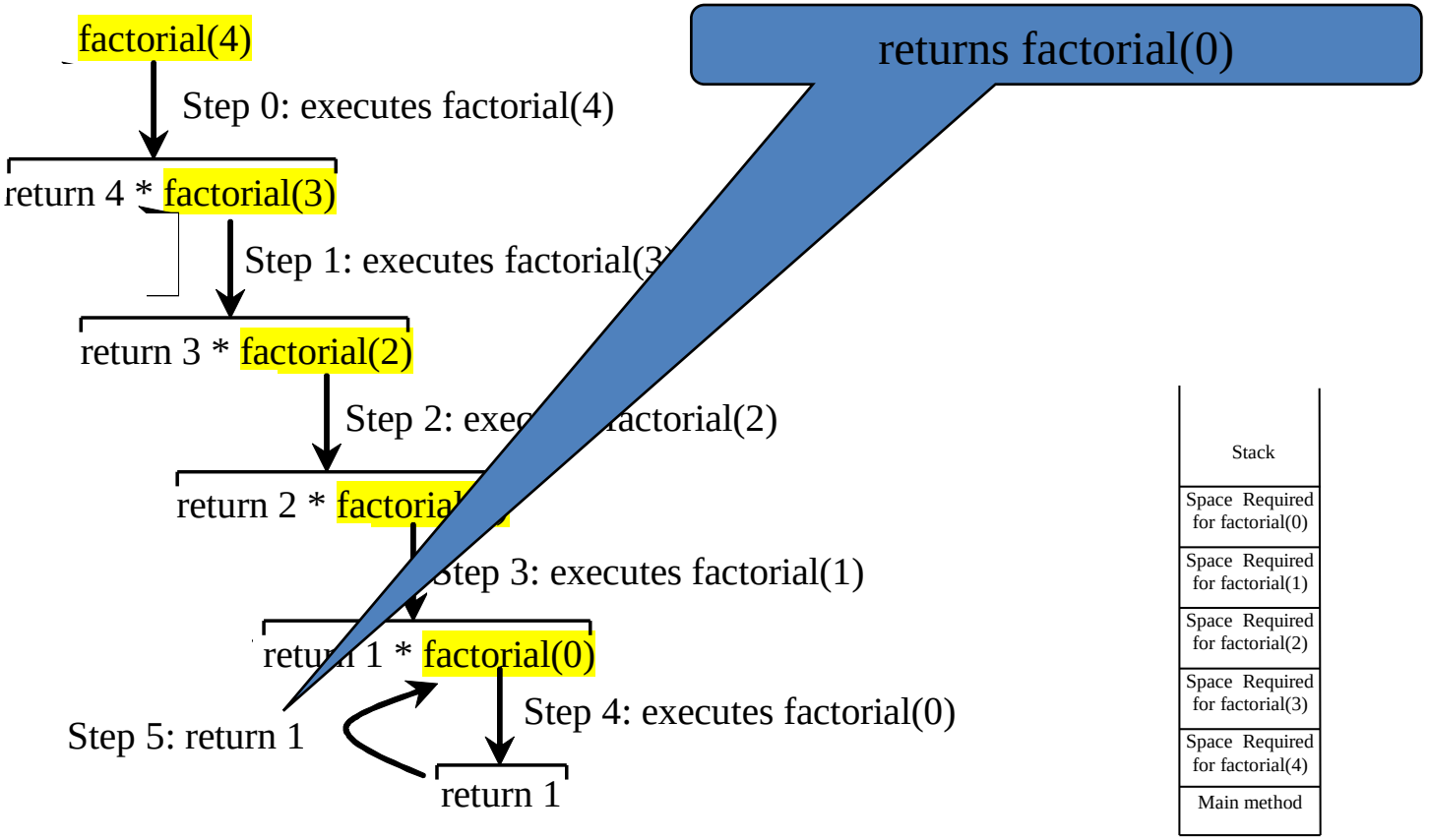
Trace code


factorial(4)
Step 0: executes factorial(4)
return 4 * factorial(3)
Step 1: executes factorial(3)
return 3 * factorial(2)
Step 2: executes fac al(2)
turn 2 * factorial(1)
Step 3: e ecutes factorial(1)
return 1 * factorial(0)
Executes factorial(0)
Stack
Space Required for factorial(0)
Space Required for factorial(1)
Space Required for factorial(2)
Space Required for factorial(3)
Space Required for factorial(4)
Main method

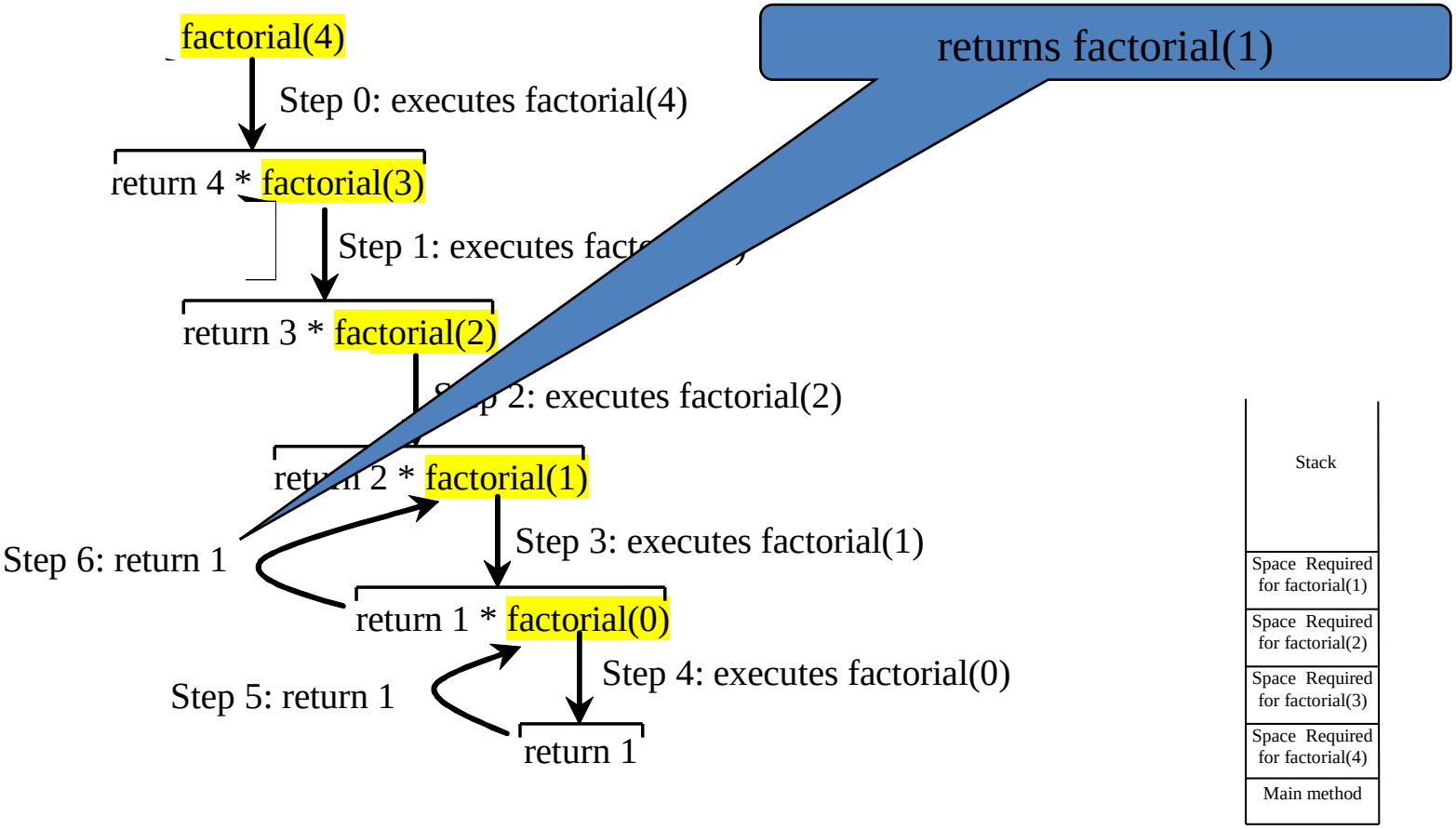
Trace code


factorial(4)
Step 0: executes factorial(4)
return 4 * factorial(3)
Step 1: executes factorial(3)
return 3 * factorial(2)
Step 2: executes factor
return 2 * factorial(1)
Step 3: execu factorial(1)
return 1 * factorial(0)
Step 4: executes factorial(0)
return 1
returns 1
Stack
Space Required for factorial(0)
Space Required for factorial(1)
Space Required for factorial(2)
Space Required for factorial(3)
Space Required for factorial(4)
Main method

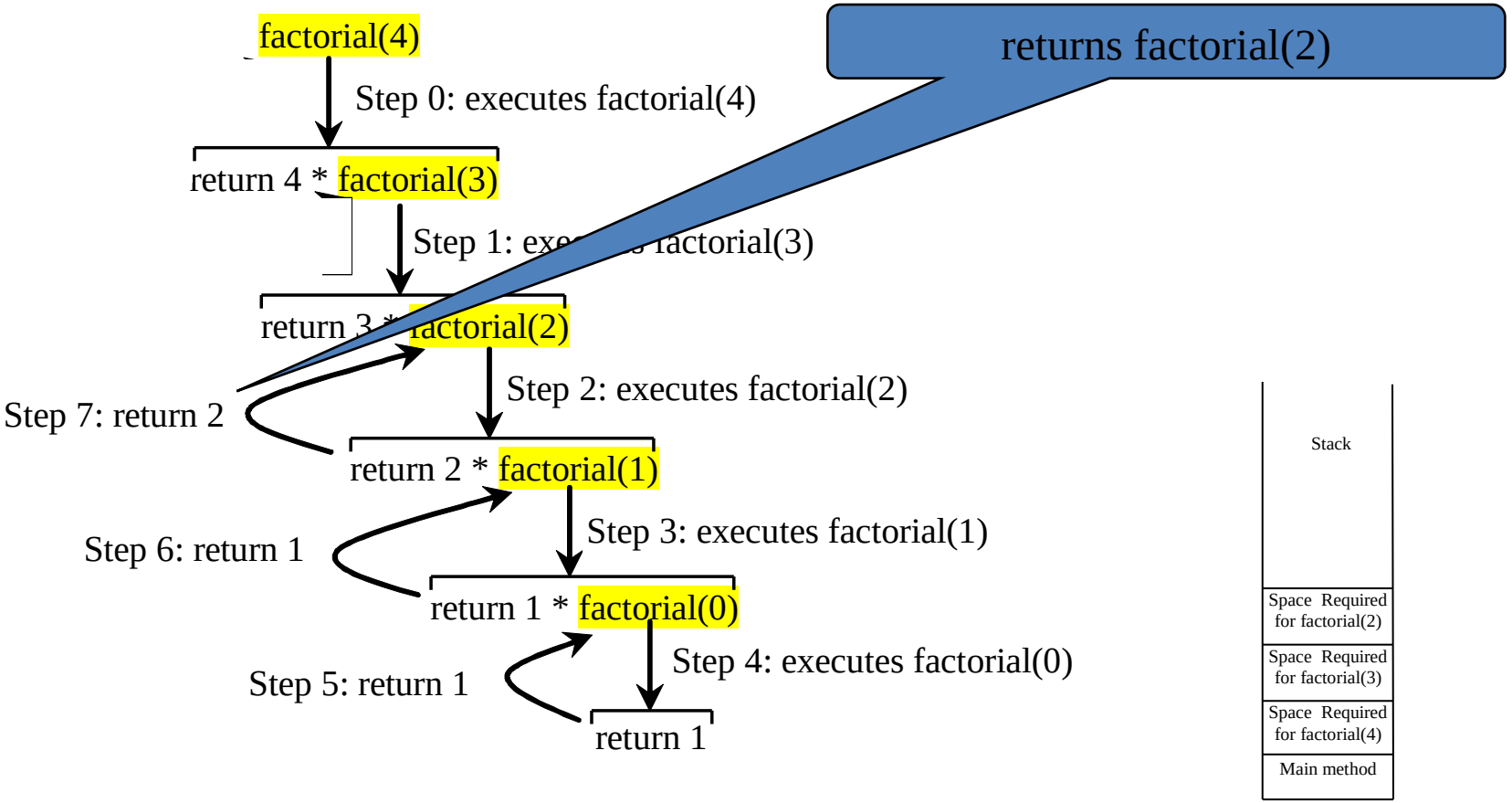
Trace code


factorial(4)
Step 0: executes factorial(4)
return 4 * factorial(3)
Step 1: executes factorial(3)
return 3 * factorial(2)
Step 2: executes factorial(2)
return 2 * factorial(1)
Step 3: executes factorial(1)
return 1 * factorial(0)
Step 4: executes factorial(0)
return 1
Step 5: return 1
returns factorial(0)
Stack
Space Required for factorial(0)
Space Required for factorial(1)
Space Required for factorial(2)
Space Required for factorial(3)
Space Required for factorial(4)
Main method

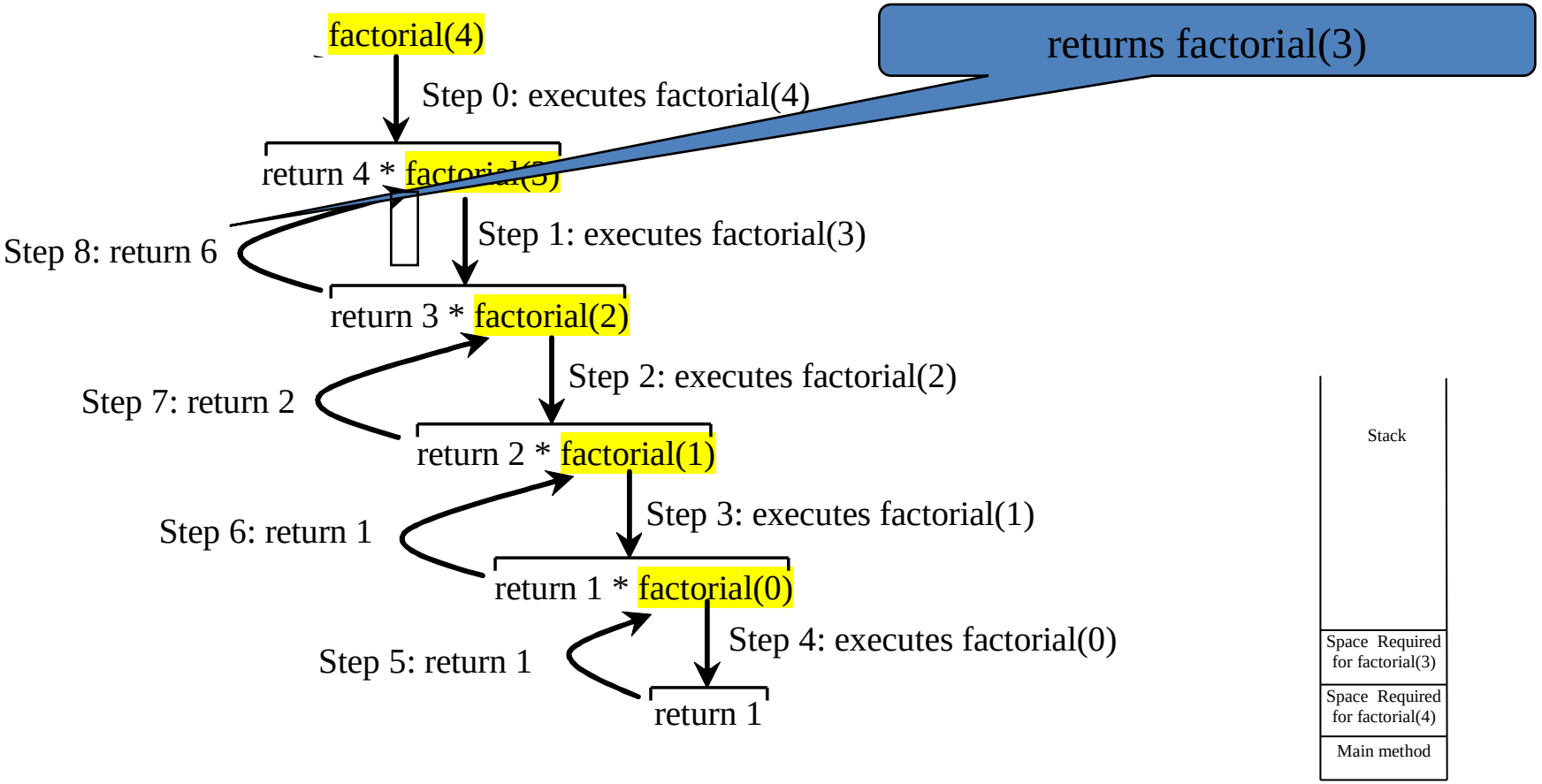
Trace code


factorial(4)
returns factorial(1)
Step 0: executes factorial(4)
return 4 * factorial(3)
Step 1: executes facto
return 3 * factorial(2)
Step 2: executes factorial(2)
return 2 * factorial(1)
Step 6: return 1
Step 3: executes factorial(1)
return 1 * factorial(0)
Step 5: return 1
Step 4: executes factorial(0)
return 1
Stack
Space Required for factorial(1)
Space Required for factorial(2)
Space Required for factorial(3)
Space Required for factorial(4)
Main method

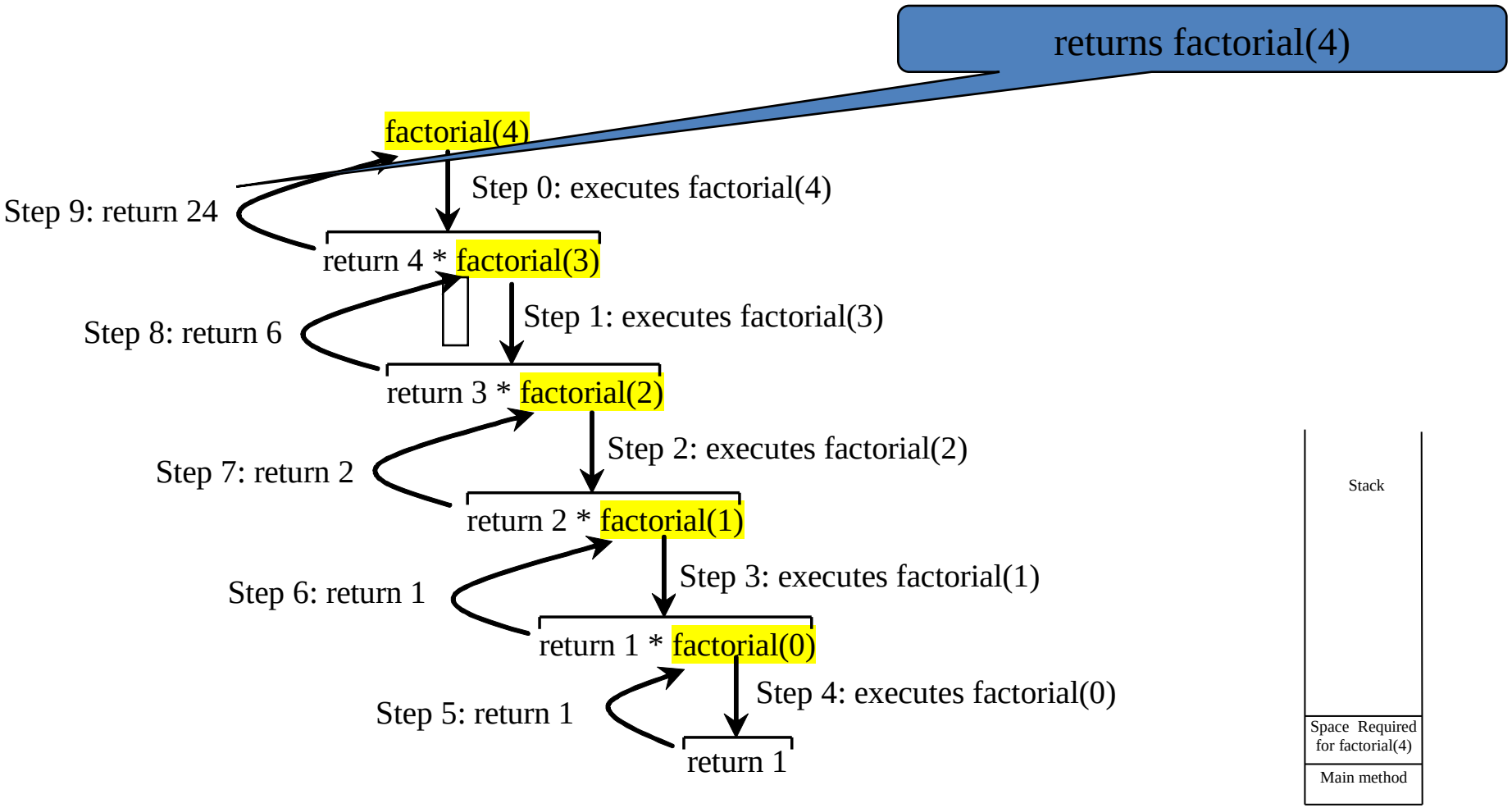
Trace code


factorial(4)
returns factorial(2)
Step 0: executes factorial(4)
return 4 * factorial(3)
Step 1: exe factorial(3)
return 3 * factorial(2)
Step 2: executes factorial(2)
Step 7: return 2
return 2 * factorial(1)
Step 3: executes factorial(1)
Step 6: return 1
return 1 * factorial(0)
Step 4: executes factorial(0)
Step 5: return 1
return 1
Stack
Space Required for factorial(2)
Space Required for factorial(3)
Space Required for factorial(4)
Main method

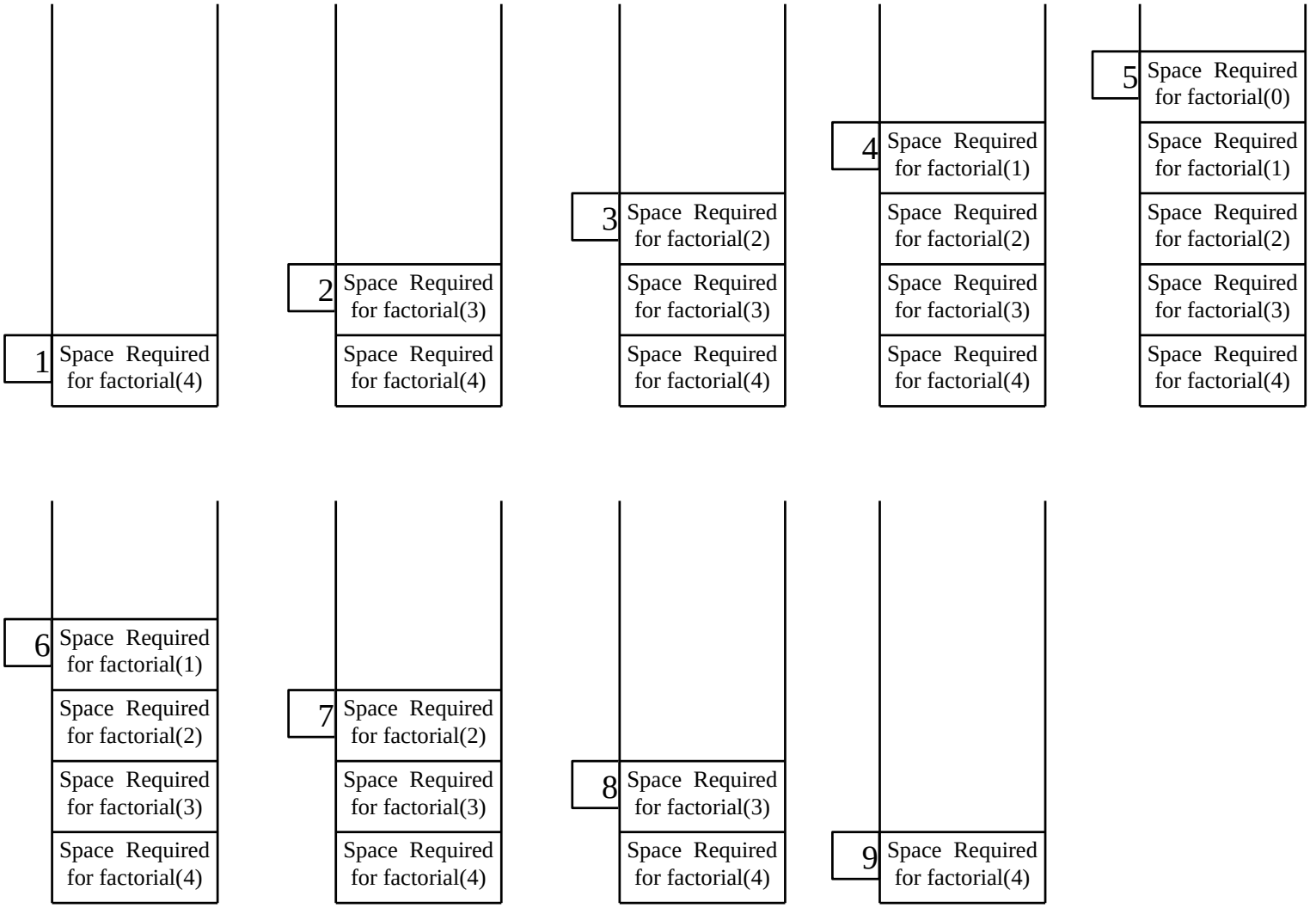
Trace code


factorial(4)
returns factorial(3)
Step 0: executes factorial(4)
return 4 * factorial(3)
Step 8: return 6
Step 1: executes factorial(3)
return 3 * factorial(2)
Step 7: return 2
Step 2: executes factorial(2)
return 2 * factorial(1)
Step 6: return 1
Step 3: executes factorial(1)
return 1 * factorial(0)
Step 5: return 1
Step 4: executes factorial(0)
return 1
Stack
Space Required for factorial(3)
Space Required for factorial(4)
Main method

Trace code


returns factorial(4)
factorial(4)
Step 0: executes factorial(4)
Step 9: return 24
return 4 * factorial(3)
Step 1: executes factorial(3)
Step 8: return 6
return 3 * factorial(2)
Step 2: executes factorial(2)
Step 7: return 2
return 2 * factorial(1)
Step 3: executes factorial(1)
Step 6: return 1
return 1 * factorial(0)
Step 4: executes factorial(0)
Step 5: return 1
return 1
Stack
Space Required for factorial(4)
Main method

Trace stack


1
Space Required for factorial(4)
2
Space Required for factorial(3)
Space Required for factorial(4)
3
Space Required for factorial(2)
Space Required for factorial(3)
Space Required for factorial(4)
4
Space Required for factorial(1)
Space Required for factorial(2)
Space Required for factorial(3)
Space Required for factorial(4)
5
Space Required for factorial(0)
Space Required for factorial(1)
Space Required for factorial(2)
Space Required for factorial(3)
Space Required for factorial(4)
6
Space Required for factorial(1)
Space Required for factorial(2)
Space Required for factorial(3)
Space Required for factorial(4)
7
Space Required for factorial(2)
Space Required for factorial(3)
Space Required for factorial(4)
8
Space Required for factorial(3)
Space Required for factorial(4)
9
Space Required for factorial(4)

Stack overflow

- Deep recursion may result in stack overflow
- If recursion does not reduce the problem in a manner that allows it to eventually converge into the base case or a base case is not specified, *infinite recursion* can occur
  - Example

```
public static long factorial(int n) {
  // Mistakenly omit base case
  return n * factorial(n – 1);
}
```

    - Results in stack overflow

Computing factorials

- As a recursive method

```
public static long factorial(int n) {
  if (0 == n) {
    // Base case
    return 1;
  }
  else {
    // Recursive call
    return n * factorial(n – 1);
  }
}
```

A recursive method is one that invokes itself directly or indirectly

Direct recursion

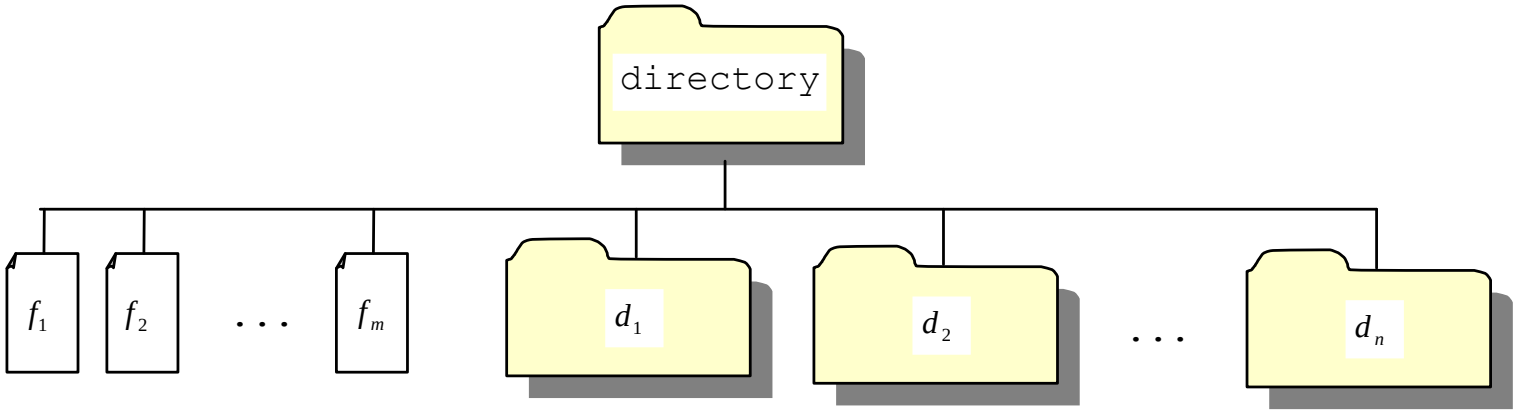
- As a non-recursive method

```
public static long factorial(int n) {
  long nfactorial = 0 == n ? 1 : n;
  for (int i = n - 1; 1 < i; --i) {
    nfactorial *= i;
  }
  return nfactorial;
}
```

Recursive algorithms can be replaced with non-recursive counterparts. However, some problems are inherently recursive, and difficult to solve without using recursion.

Recursion in practice

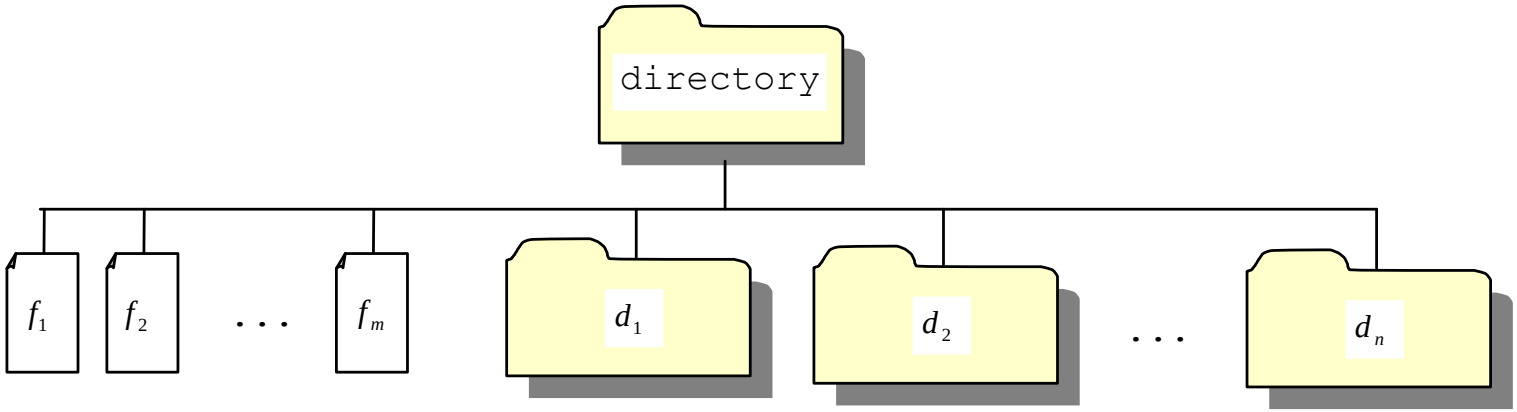
- In practice, recursive methods are used to efficiently solve problems with recursive structures
  - Example problem: find the size of a directory



Finding the directory size

- The size of a directory is the sum of the sizes of all files in the directory
- A directory may contain subdirectories
- Suppose a directory contains files and subdirectories
- The size of the directory can be defined recursively as

$$size(d) = size(f_1) + size(f_2) + \ldots + size(f_m) + size(d_1) + size(d_2) + \ldots + size(d_n)$$



Characteristics of recursion

- All recursive methods have the following characteristics
  - The method is implemented using an if-else (or a switch) statement that leads to **different cases**
  - One or more **base cases** (the simplest case) are used to stop recursion
  - Every recursive call **reduces** the original problem, bringing it increasingly **closer to a base case** until it becomes that case
- In general, to solve a problem using recursion, you break it into subproblems
  - If a subproblem resembles the original problem, you can apply the same approach to solve the subproblem recursively
  - This subproblem is almost the same as the original problem in nature with a smaller size

Recursion vs. iteration

- Recursion is an alternative form of program control
- It is essentially repetition without a loop
- Recursion bears substantial overhead
  - Each time the program calls a method, the system must assign space for all of the method's local variables and parameters
  - This can consume considerable memory and requires extra time to manage the additional space

Recursion vs. iteration

- Recursive algorithms can be replaced with non-recursive counterparts
  - If performance is a concern, then avoid using recursion
  - However, some problems are inherently recursive, and difficult to solve without using recursion
- Use whichever approach can best develop an intuitive solution that naturally mirrors the problem
  - If an iterative solution is obvious, then use it

Next Lecture

- Arrays