Loops and Recursion

Introduction to Programming and Computational Problem Solving - 2

CSE 8B

Lecture 7

Announcements

- Assignment 3 is due Apr 26, 11:59 PM
  - Upgrade beginning Apr 29, 12:01 AM
- Assignment 4 will be released Apr 26
  - Due May 3, 11:59 PM
- Educational research study
  - Apr 28, weekly survey

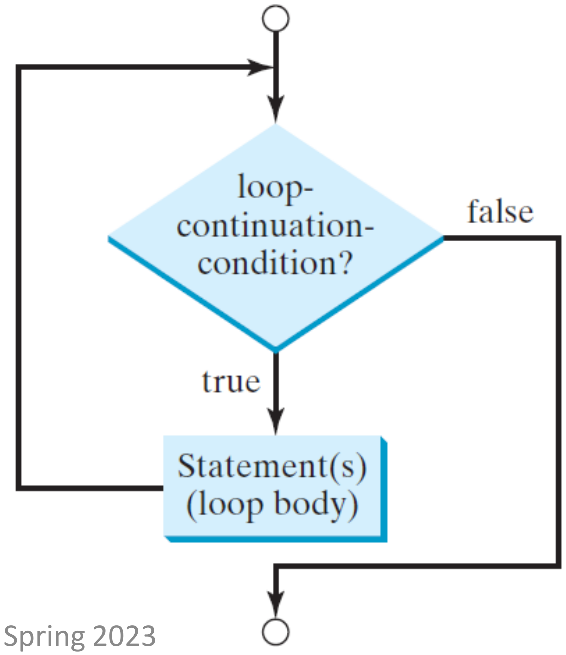
Loops and recursion

- `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

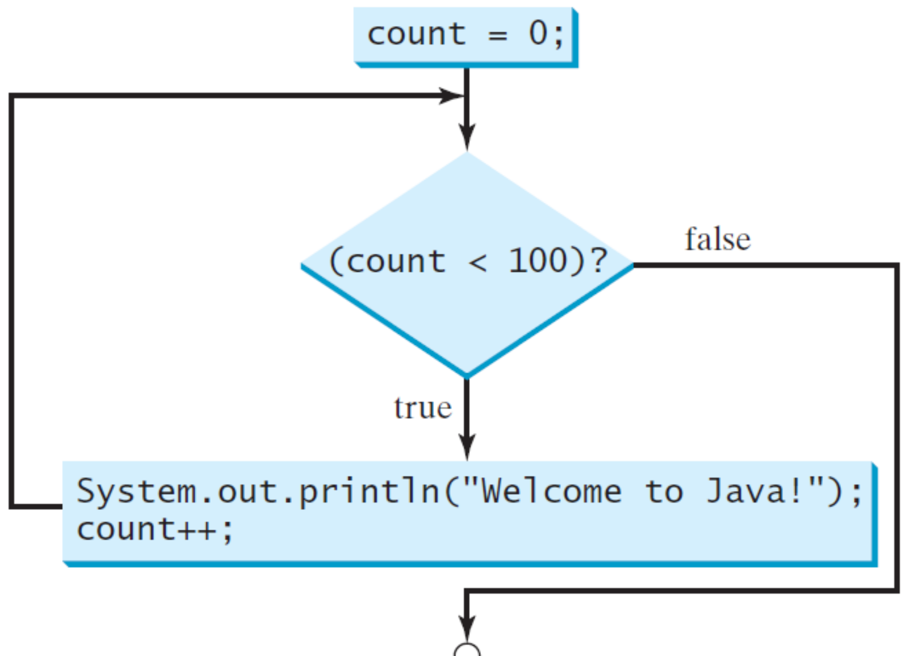
- Executes statements repeatedly while the condition is true

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



`while` loops

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



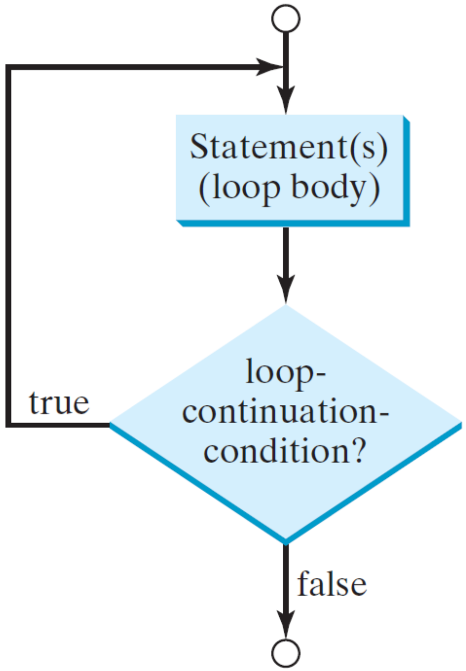
Ending a loop with a sentinel value

- 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

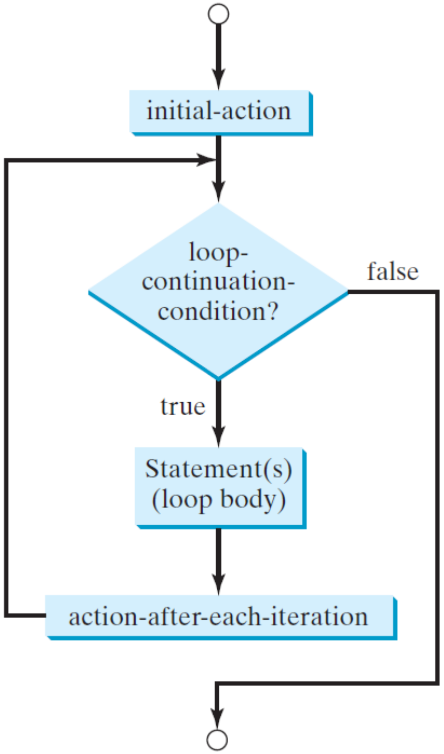
```
do {
  // Loop body
  Statement(s);
} while (loop-continuation-condition);
```



for loops

- A concise syntax for writing loops

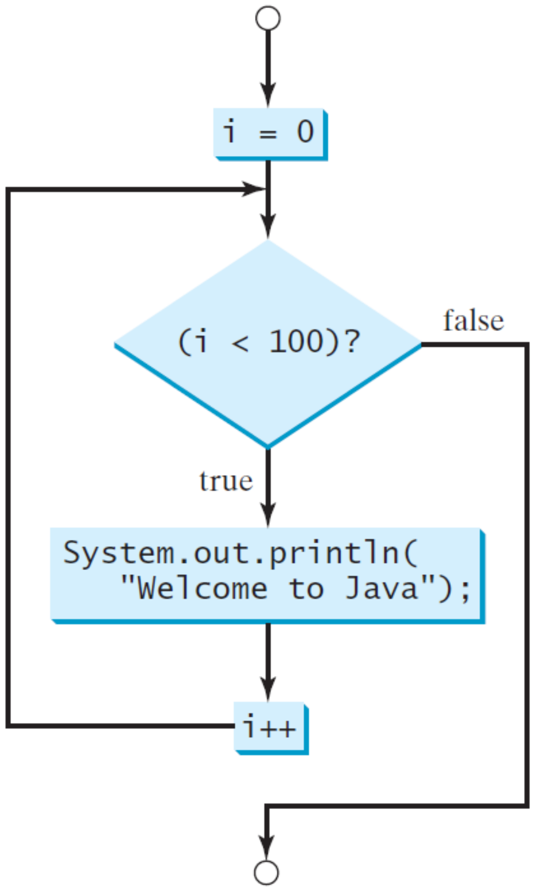
```
for (initial-action; loop-continuation-condition;
   action-after-each-iteration) {
    // loop body
    Statement(s);
}
```



(a)

for loops

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



(b)

`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

```
                    public static void method1() {
                      .
                      .
                      for (int i = 1; i < 10; i++) {
                        .
The scope of i          .
                        int j;
                        .
The scope of j          .
                        .
                      }
                    }
```

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
```

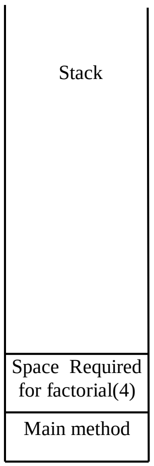
```
factorial(0) = 1
factorial(n) = n * factorial(n - 1)

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)



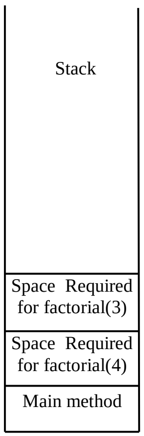
Trace code

factorial(4)

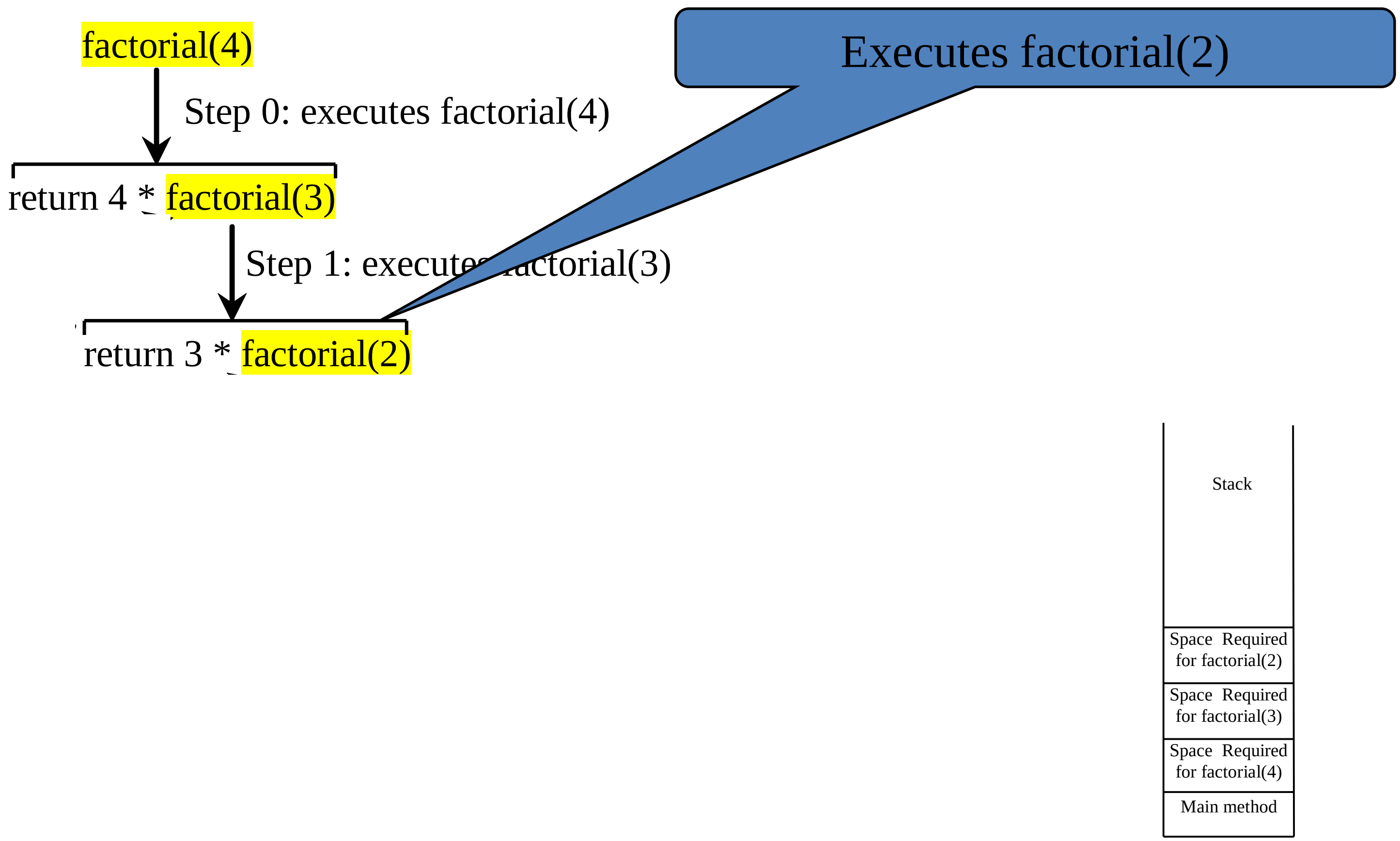
Step 0: executes factorial(4)

return 4 * factorial(3)

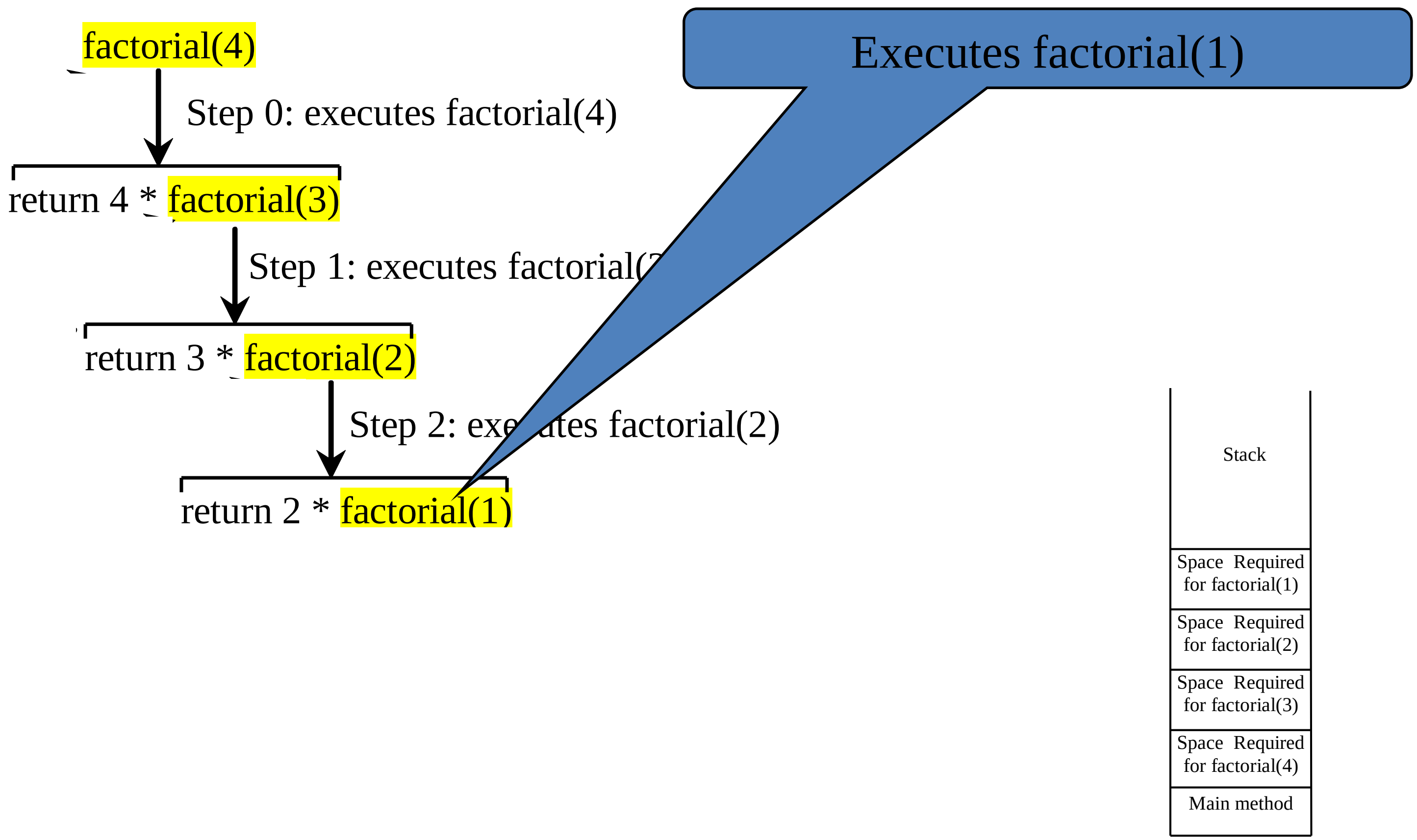
Executes factorial(3)



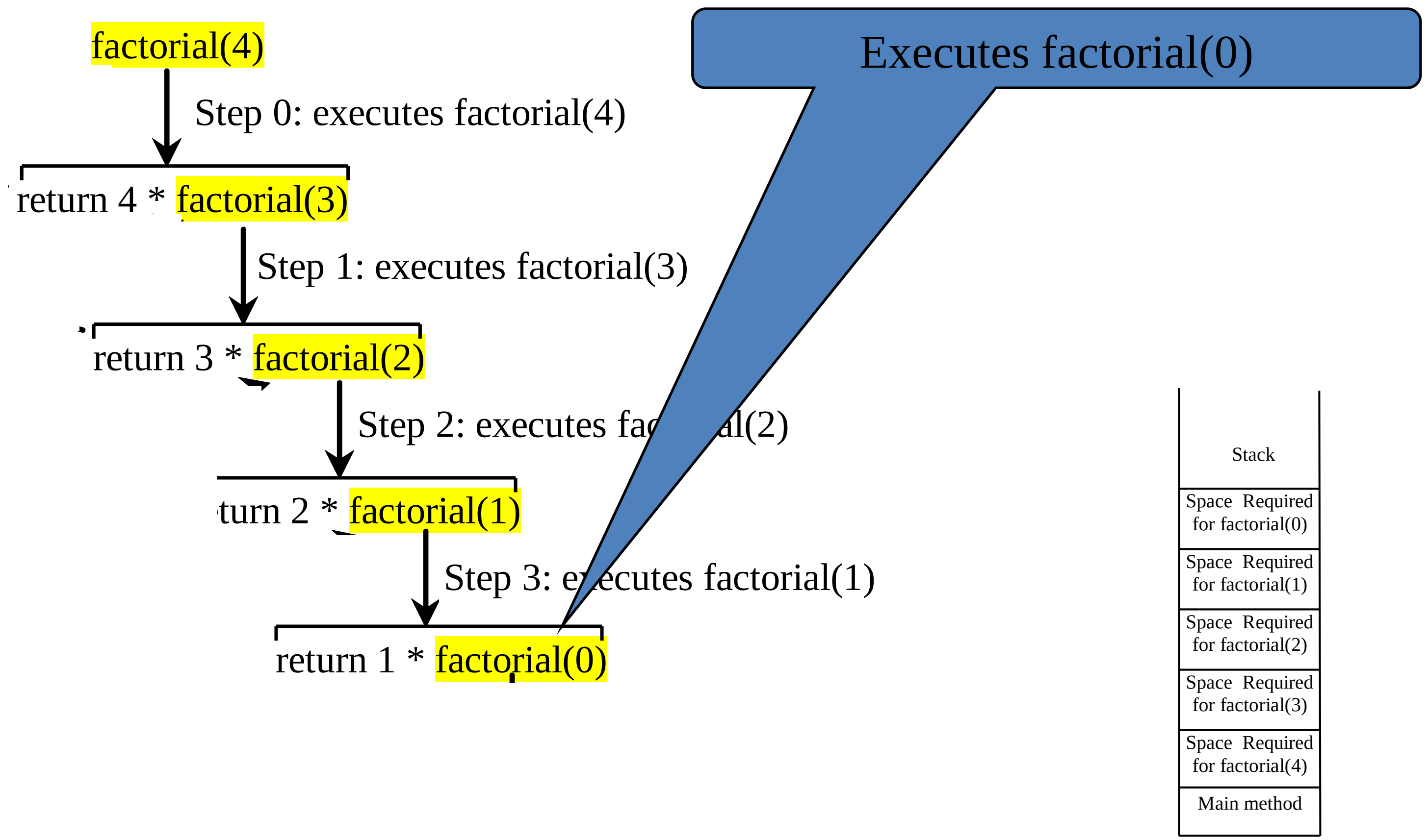
Trace code


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

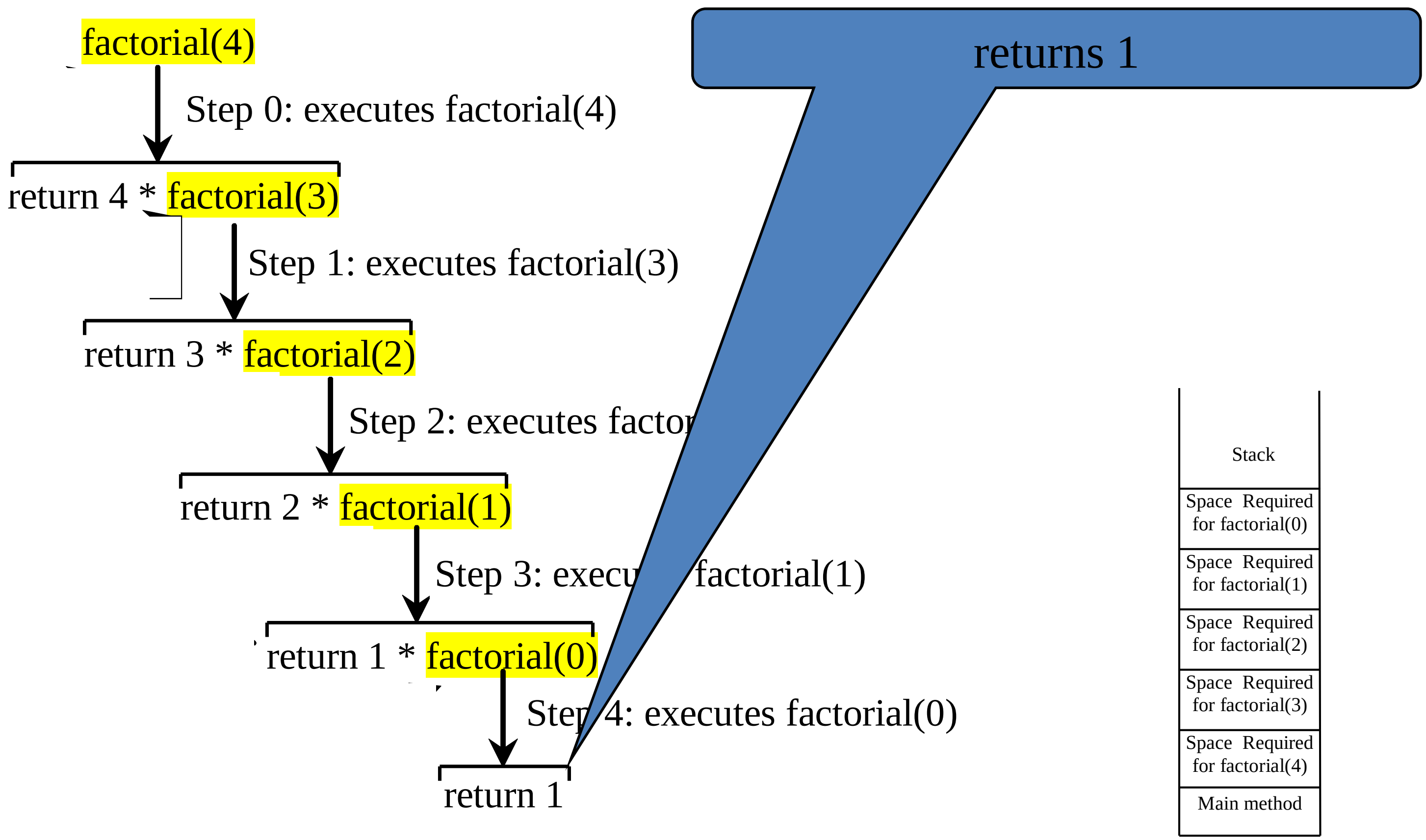

Executes factorial(1)
factorial(4)
Step 0: executes factorial(4)
return 4 * factorial(3)
Step 1: executes factorial(
return 3 * factorial(2)
Step 2: exe
utes factorial(2)
return 2 * factorial(1)
Stack
Space Required for factorial(1)
Space Required for factorial(2)
Space Required for factorial(3)
Space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

Trace code

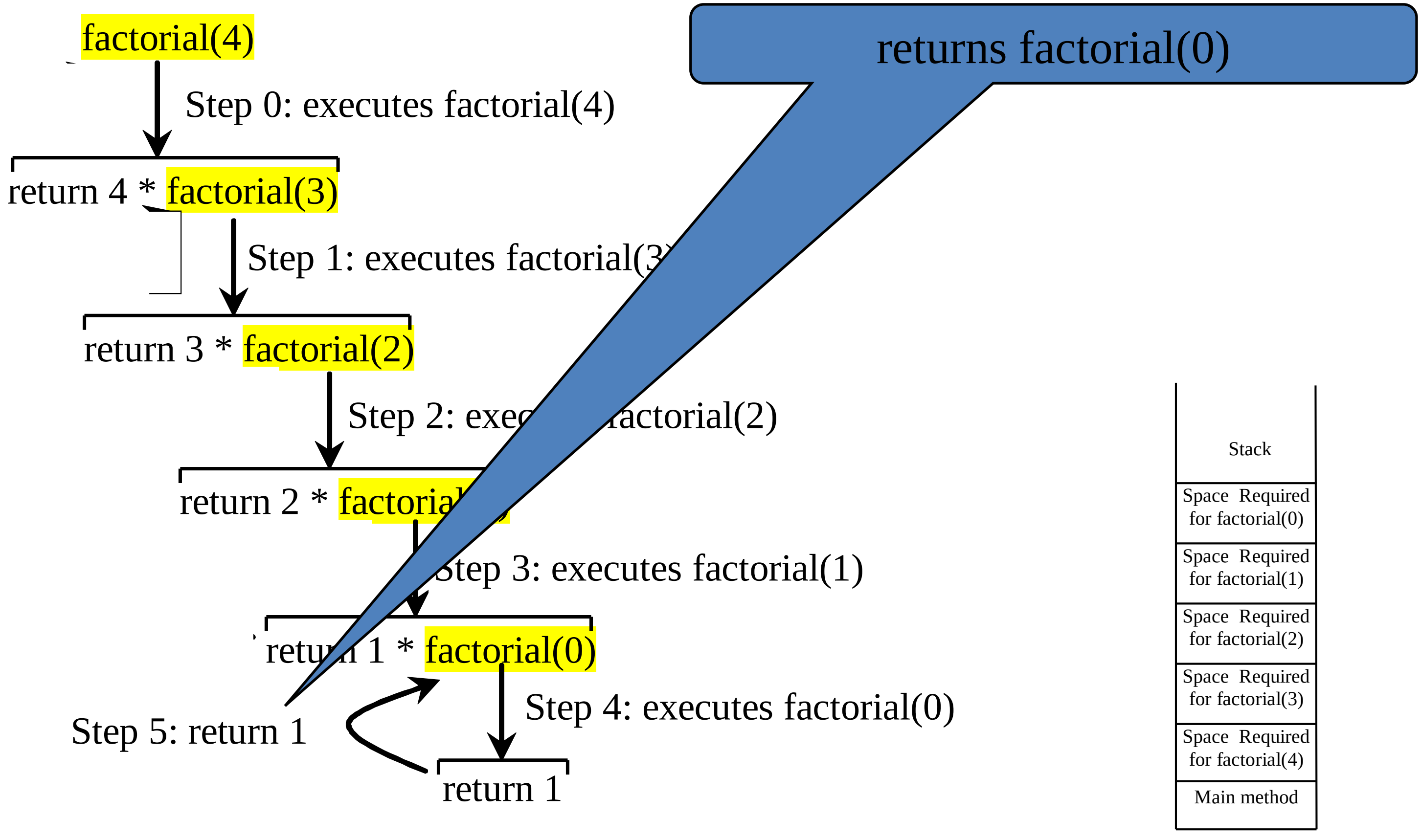


factorial(4)
Step 0: executes factorial(4)
return 4 * factorial(3)
Step 1: executes factorial(3)
return 3 * factorial(2)
Step 2: executes factorial(2)
return 2 * factorial(1)
Step 3: executes factorial(1)
return 1 * factorial(0)
Executes factorial(0)
Stack
Space Required for factorial(0)
Space Required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

Trace code

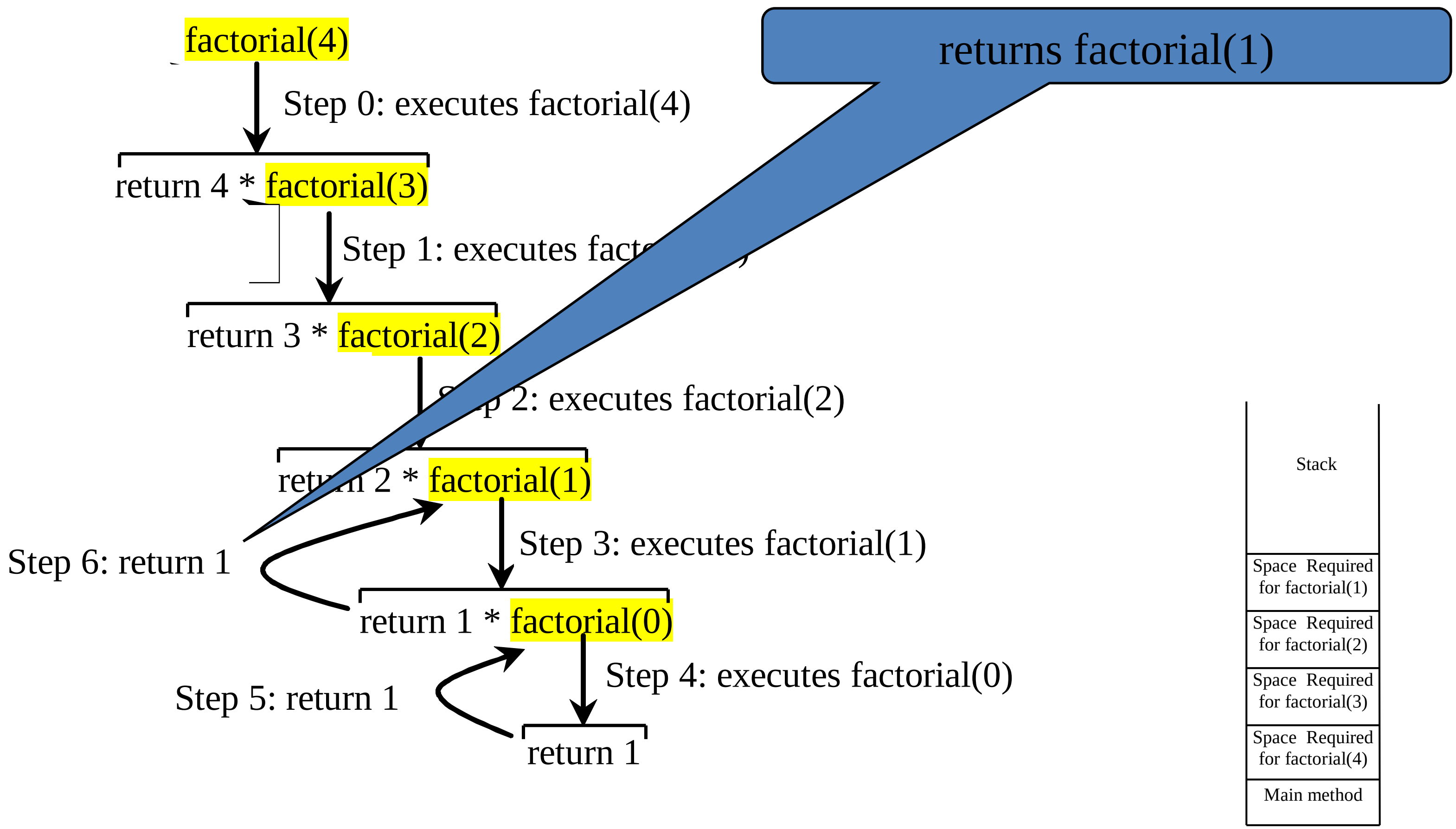

factorial(4)
Step 0: executes factorial(4)
return 4 * factorial(3)
Step 1: executes factorial(3)
return 3 * factorial(2)
Step 2: executes factor
return 2 * factorial(1)
Step 3: execu
factorial(1)
return 1 * factorial(0)
Step 4: executes factorial(0)
return 1
returns 1
Stack
Space Required for factorial(0)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

Trace code

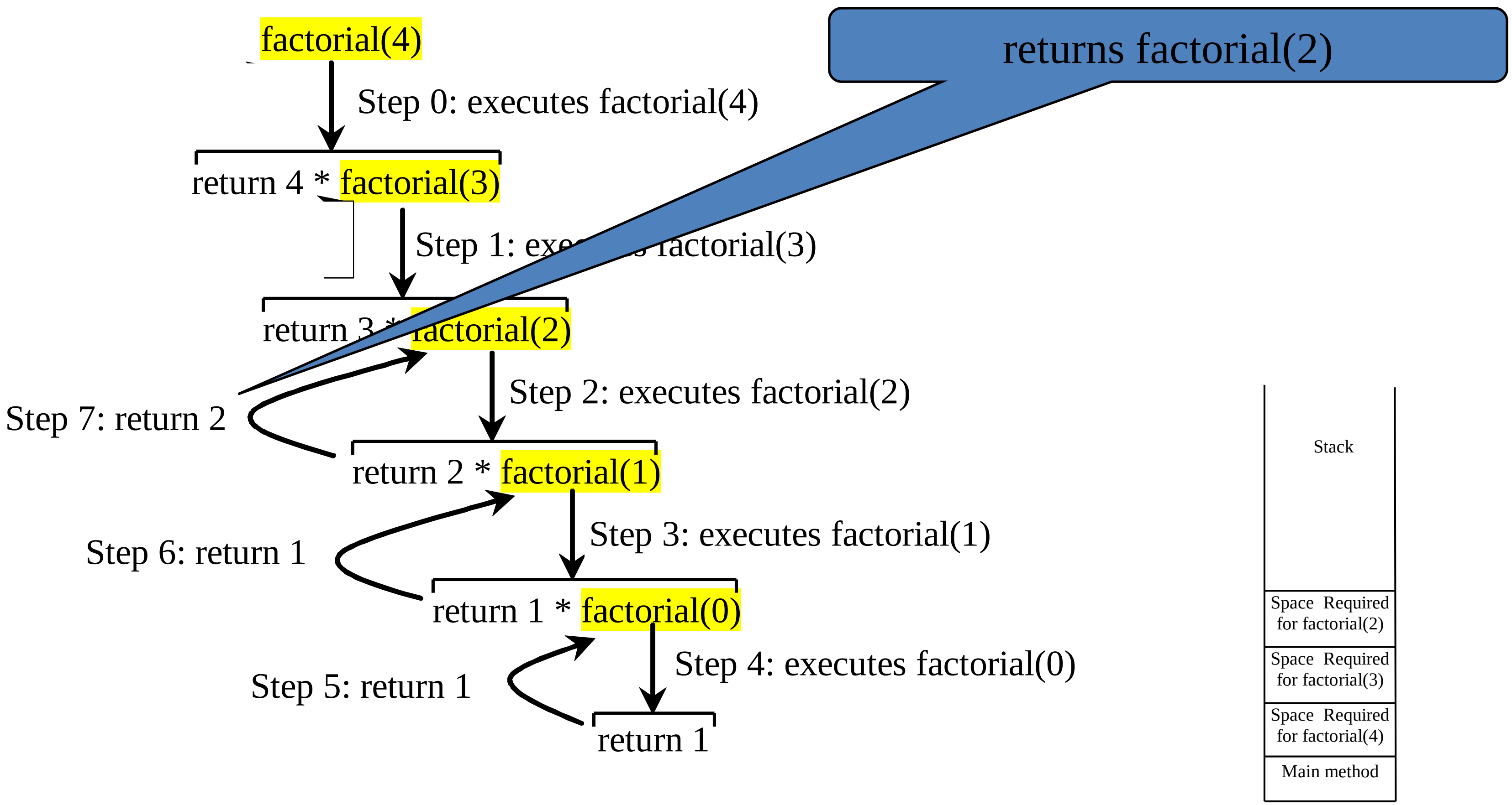


factorial(4)
Step 0: executes factorial(4)
return 4 * factorial(3)
Step 1: executes factorial(3)
return 3 * factorial(2)
Step 2: executes factorial(2)
return 2 * factorial
Step 3: executes factorial(1)
return 1 * factorial(0)
Step 4: executes factorial(0)
Step 5: return 1
return 1
returns factorial(0)
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

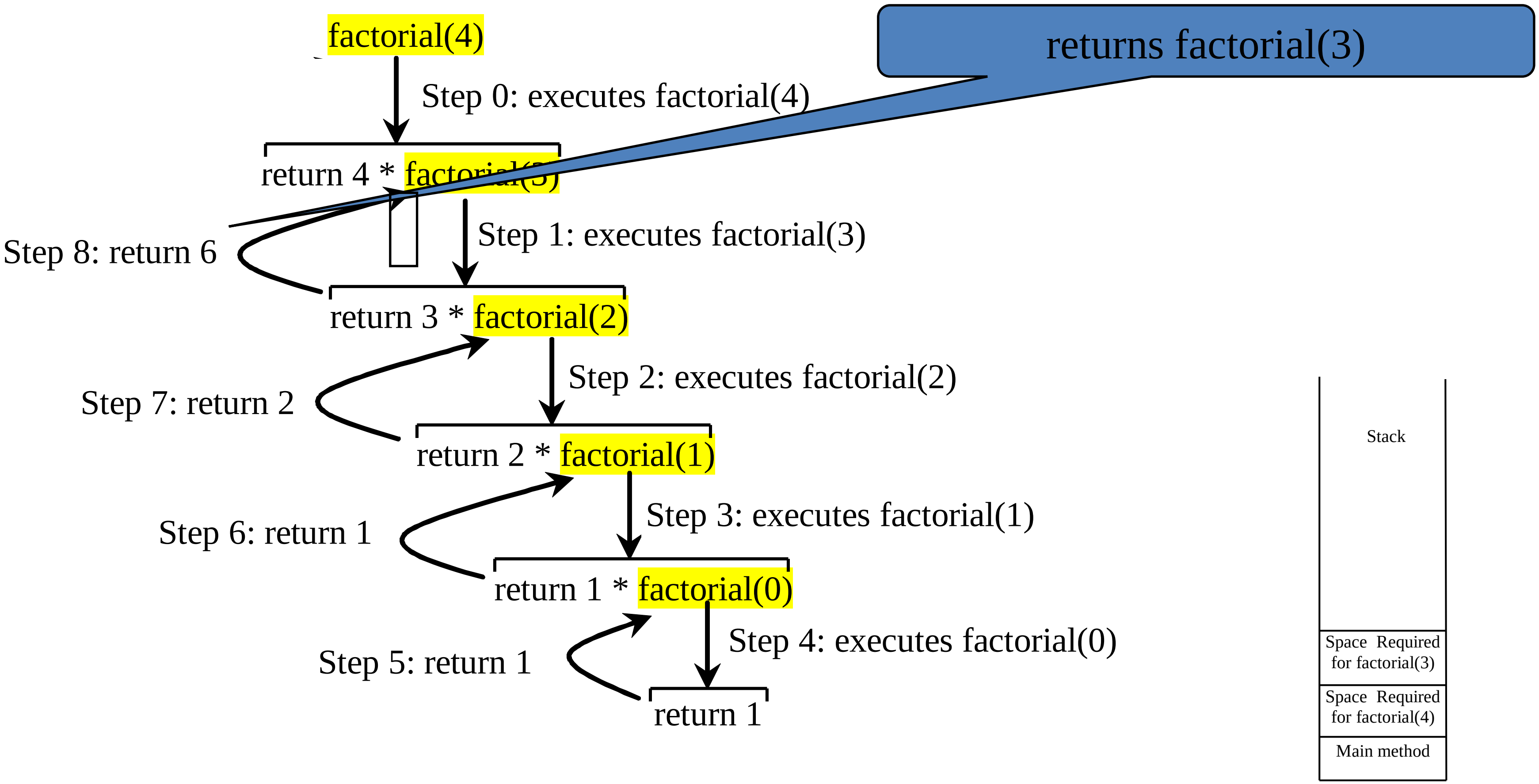
Trace code


factorial(4)
Step 0: executes factorial(4)
return 4 * factorial(3)
Step 1: executes fact
return 3 * factorial(2)
2: executes factorial(2)
ret
n 2 * factorial(1)
Step 6: return 1
Step 3: executes factorial(1)
return 1 * factorial(0)
Step 4: executes factorial(0)
Step 5: return 1
return 1
returns 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

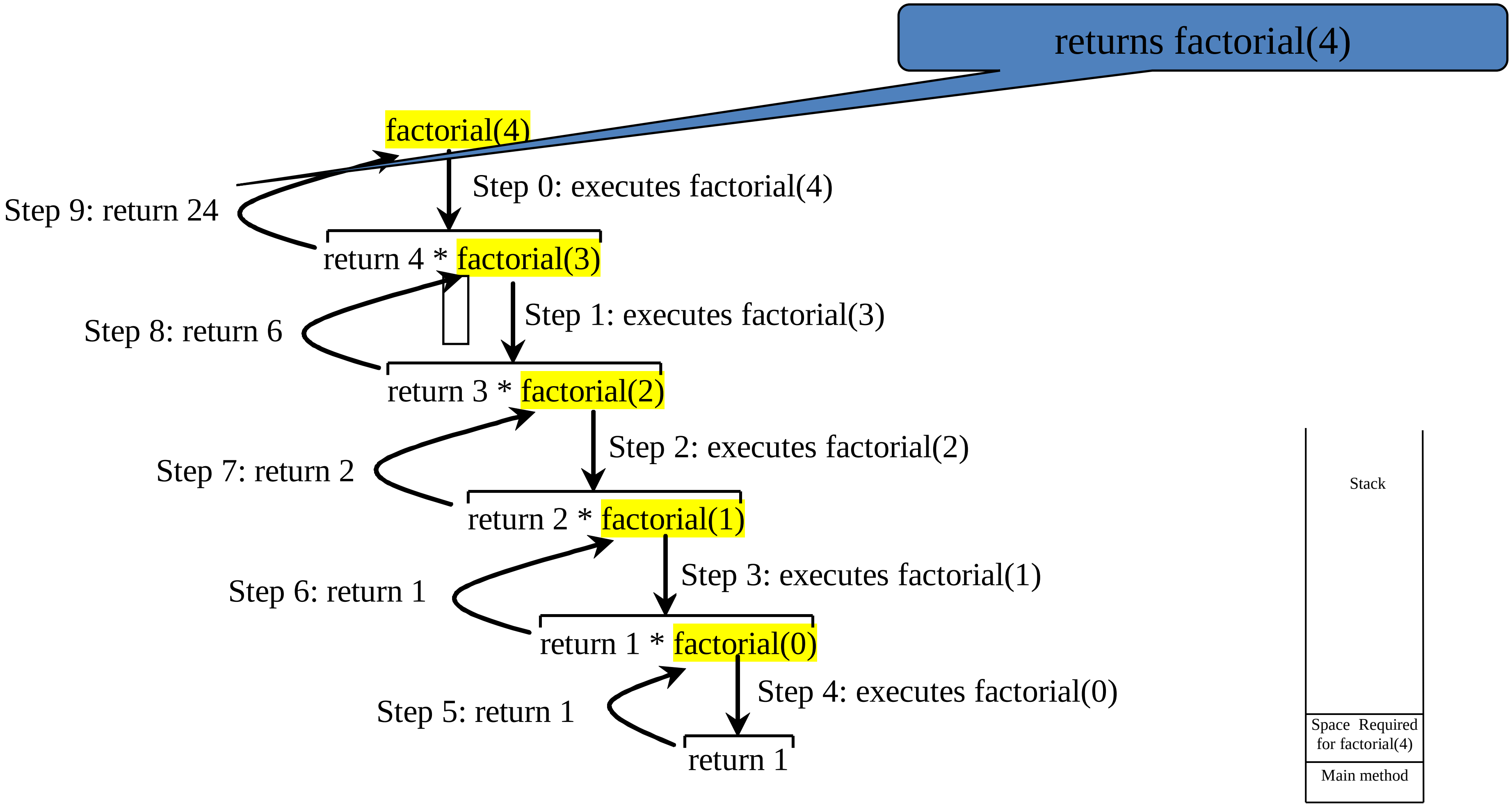
Trace code


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

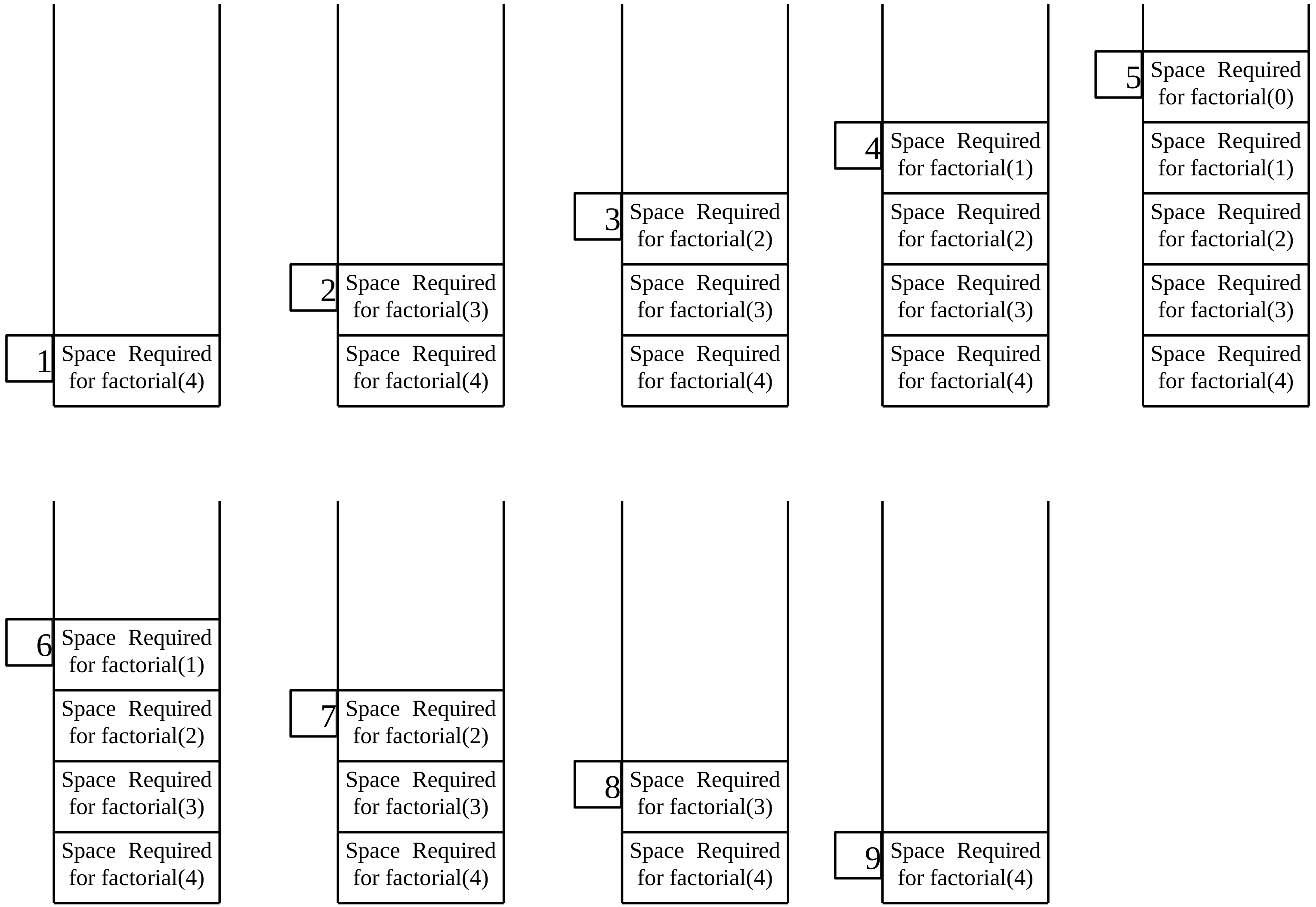
Trace code


returns factorial(3)
factorial(4)
Step 0: executes factorial(4)
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(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);
  }
}
```

Direct recursion

A recursive method is one that invokes itself directly or indirectly

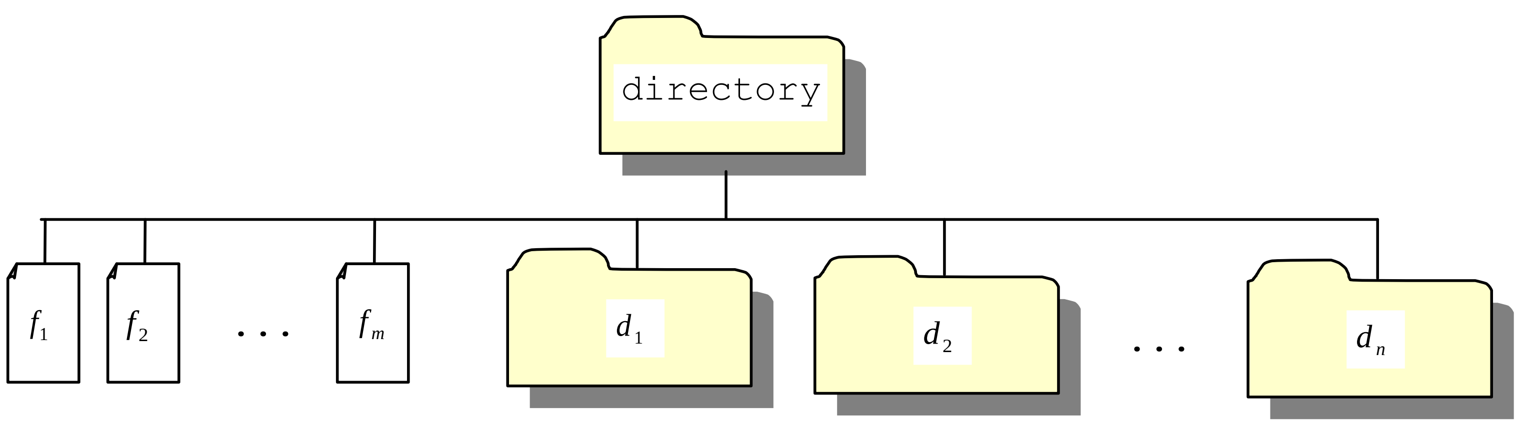
- As a non-recursive method

```
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

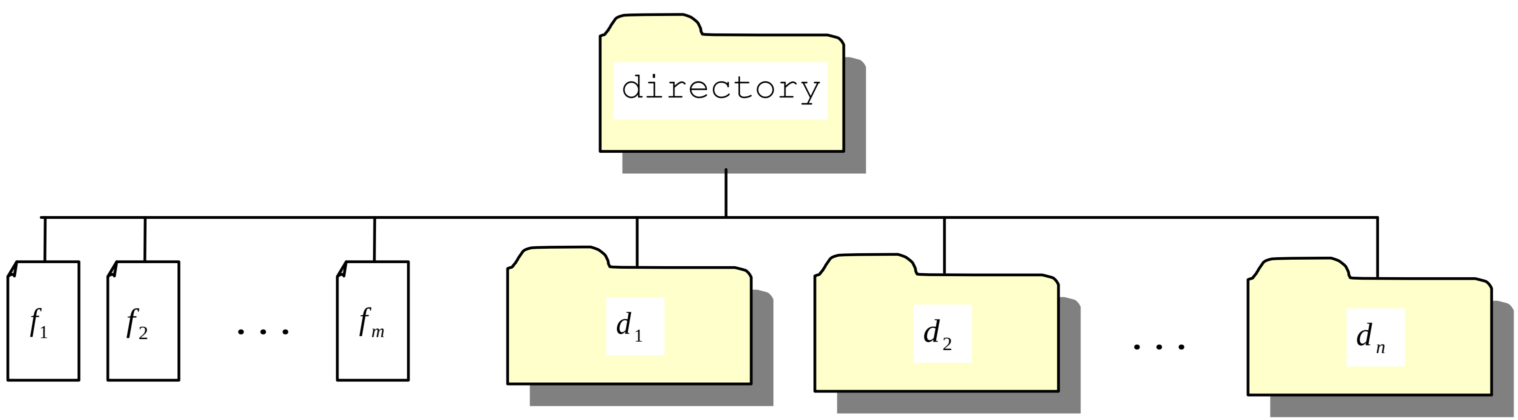
- In practice, recursive methods are used to efficiently solve problems with recursive structures
  - Example problem: find the size of a directory



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