CS 162
Intro to Computer Science II

Lecture 21

Recursion

3/6/24

Oregon State University

Today's topic(s)

- Recursion

Recursion

- Function that calls itself 1 or more times (directly or indirectly)
- Form of repetition
- Has one or more base case for stopping
- Inductive reasoning: general case must eventually be reduced to a base case

Example: Factorial

- Definition

  n!=n * (n-1) * … * (n-(n-1)) * 1 = n * (n-1)! ; n > 0

  Base case: 0!=1;

$$n! = n * (n-1)!$$

$$(n-1)! = (n-1) * (n-2)!$$

Iterative Factorial

```
int factorial(int n) {
        int fact;
        if(n==0)
            fact=1;
        else
           for(fact=n; n > 1; n--)
              fact = fact*(n-1);
       return fact;
}
```

Computing Factorial Iteratively

factorial(4)

factorial(0) = 1;
factorial(n) = n*(n-1)*...*2*1;

Computing Factorial Iteratively

factorial(4) = 4 * 3

factorial(0) = 1;
factorial(n) = n*(n-1)*...*2*1;

Computing Factorial Iteratively

factorial(4) = 4 * 3

= 12 * 2

```
factorial(0) = 1;
factorial(n) = n*(n-1)*...*2*1;
```

Computing Factorial Iteratively

factorial(4) = 4 * 3
= 12 * 2
= 24 * 1

```
factorial(0) = 1;
factorial(n) = n*(n-1)*...*2*1;
```

Computing Factorial Iteratively

factorial(0) = 1;
factorial(n) = n*(n-1)*…*2*1;

factorial(4) = 4 * 3
= 12 * 2
= 24 * 1
= 24

Recursive Factorial

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

Computing Factorial Recursively

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

factorial(4)

Computing Factorial Recursively

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

factorial(4) = 4 * factorial(3)

Computing Factorial Recursively

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

factorial(4) = 4 * factorial(3)

= 4 * (3 * factorial(2))

Computing Factorial Recursively

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

factorial(4) = 4 * factorial(3)

= 4 * (3 * factorial(2))

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

Computing Factorial Recursively

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

factorial(4) = 4 * factorial(3)

= 4 * (3 * factorial(2))

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

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

Computing Factorial Recursively

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

factorial(4) = 4 * factorial(3)

= 4 * (3 * factorial(2))

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

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

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

Computing Factorial Recursively

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

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

Computing Factorial Recursively

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

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

Computing Factorial Recursively

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

factorial(4) = 4 * factorial(3)

= 4 * (3 * factorial(2))

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

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

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

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

= 4 * (3 * 2)

= 4 * 6

Computing Factorial Recursively

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

factorial(4) = 4 * factorial(3)

= 4 * (3 * factorial(2))

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

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

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

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

= 4 * (3 * 2)

= 4 * 6

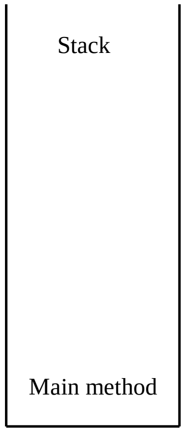
= 24

Recursive Factorial

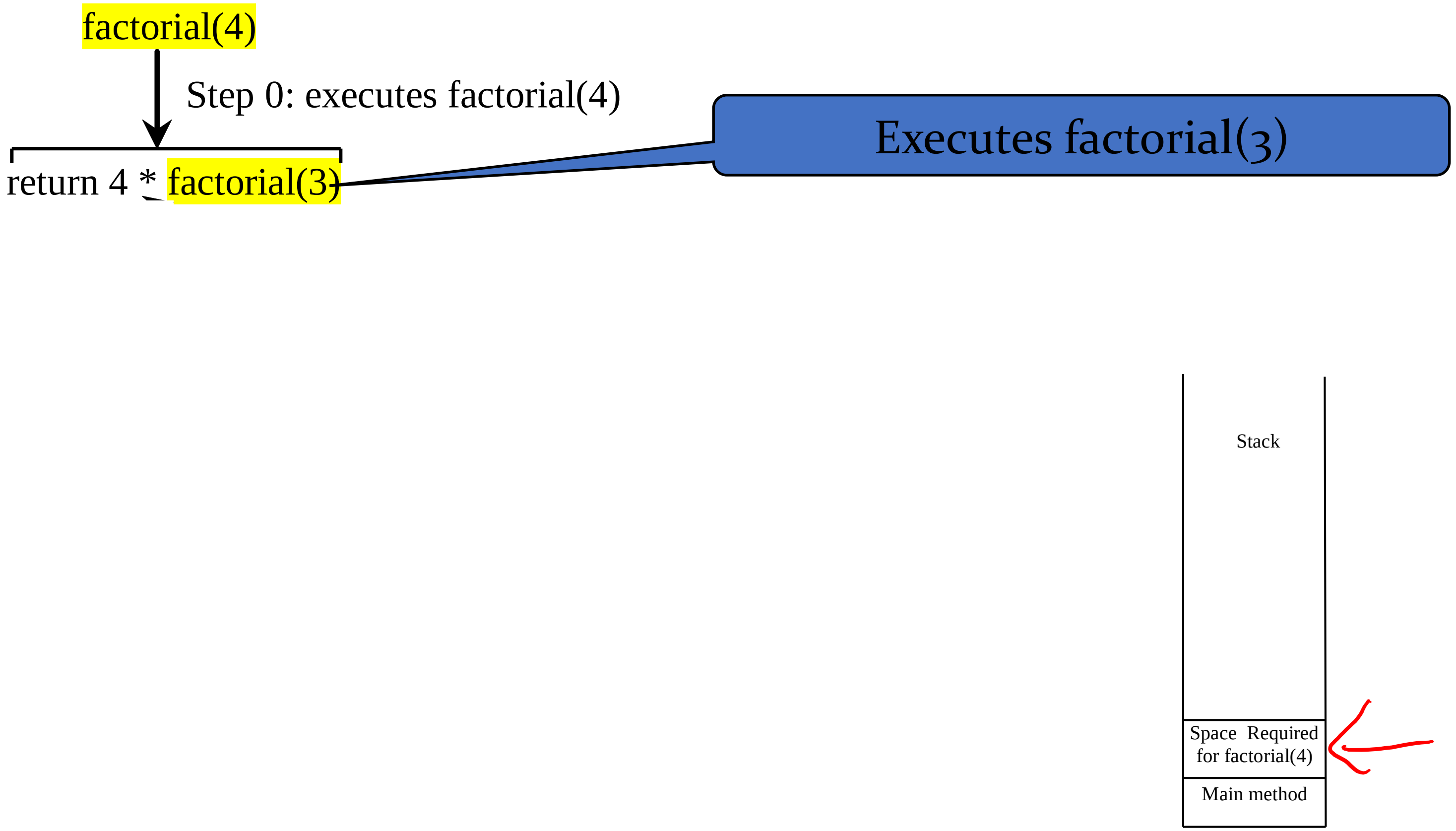
main() ;
fact(4)

factorial(4)

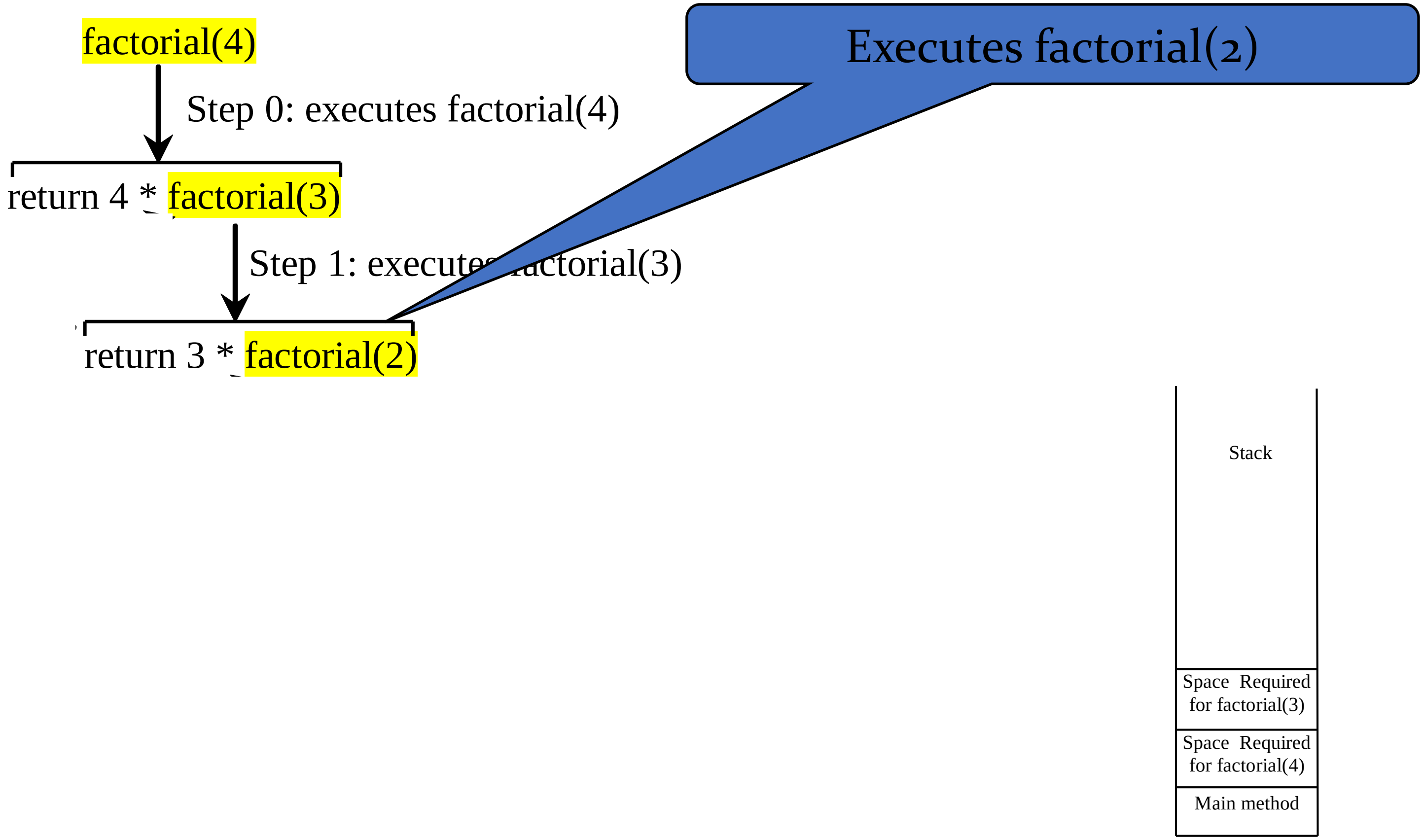
Executes factorial(4)



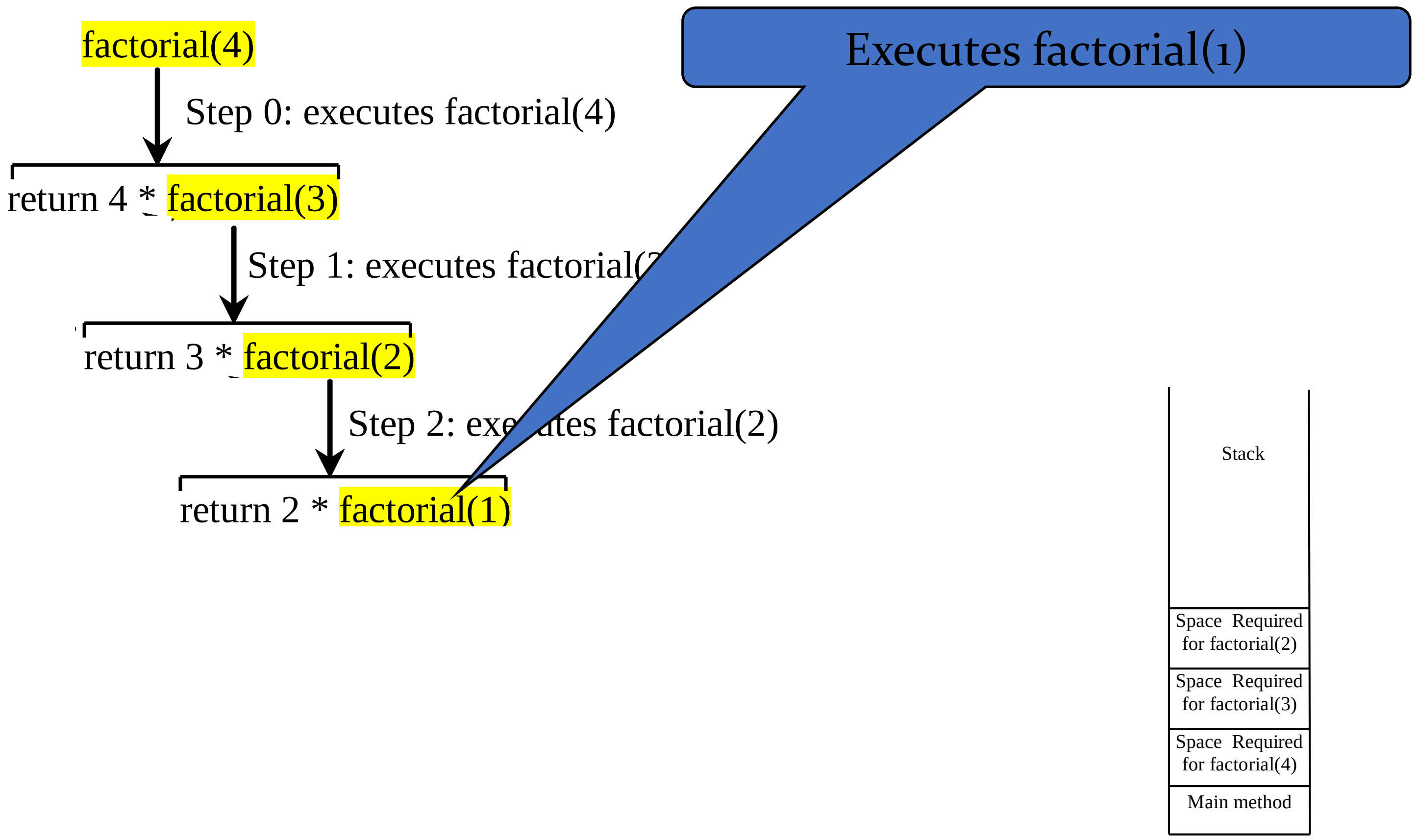
Recursive Factorial



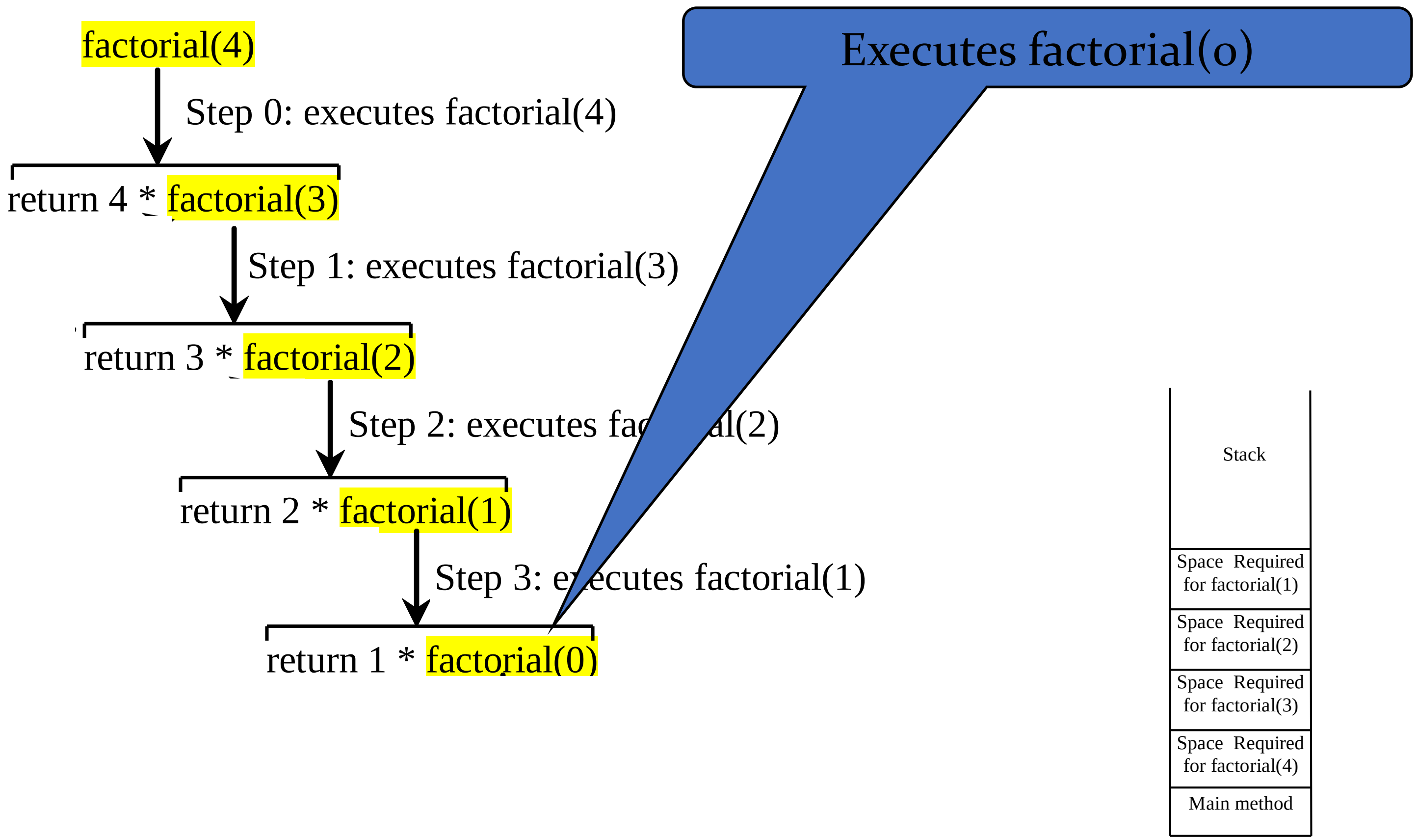
Recursive Factorial



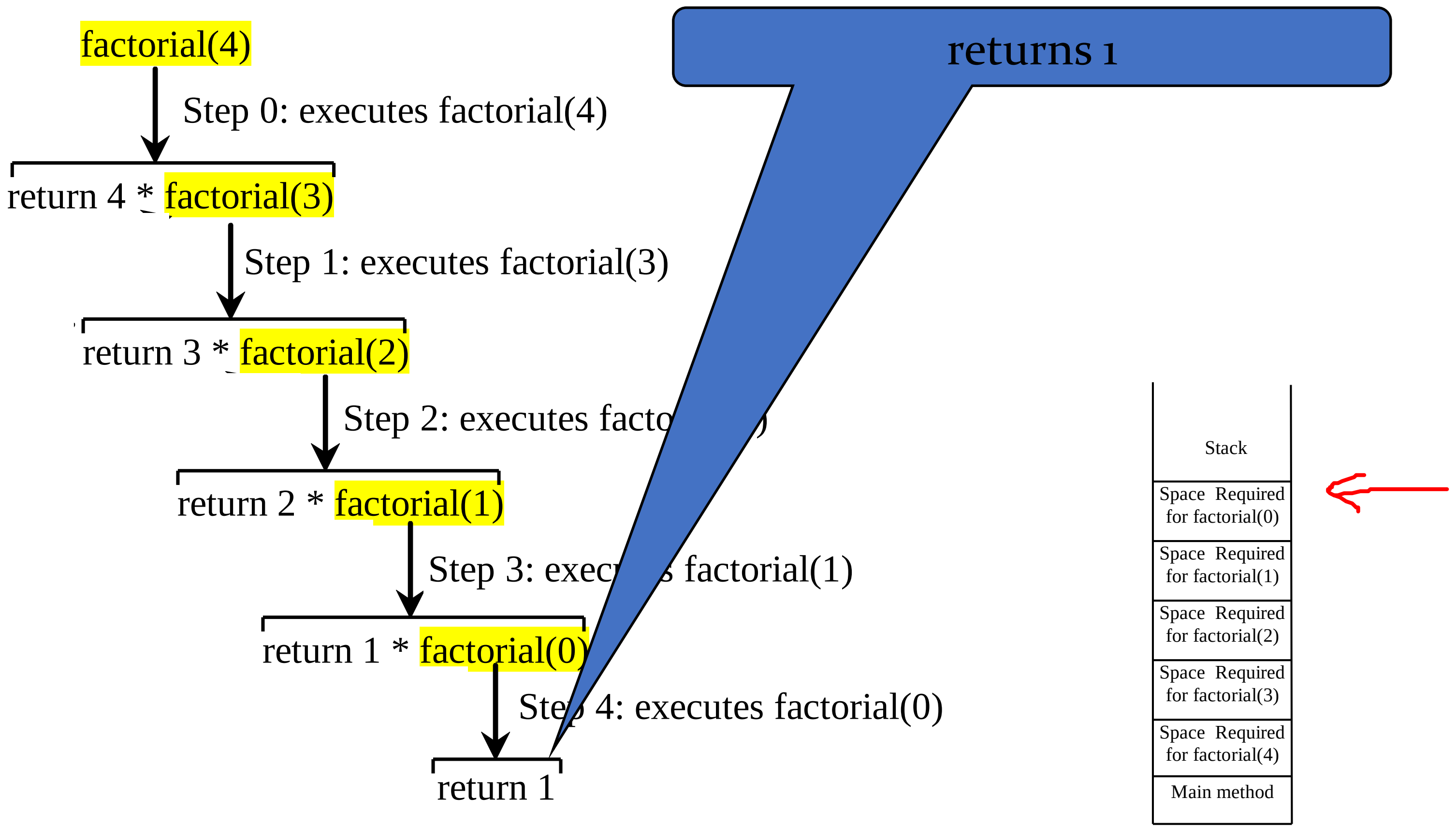
Recursive Factorial



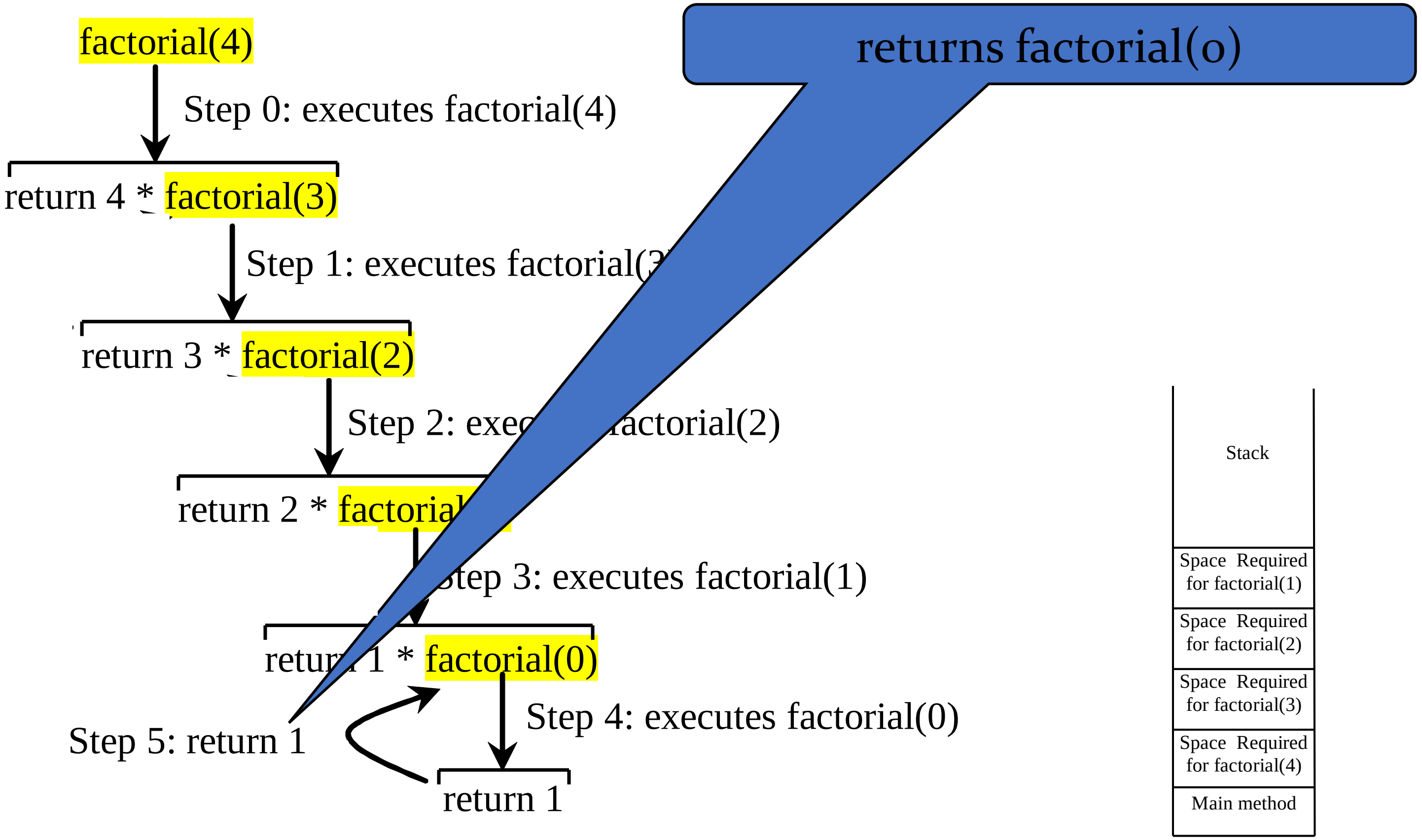
Recursive Factorial



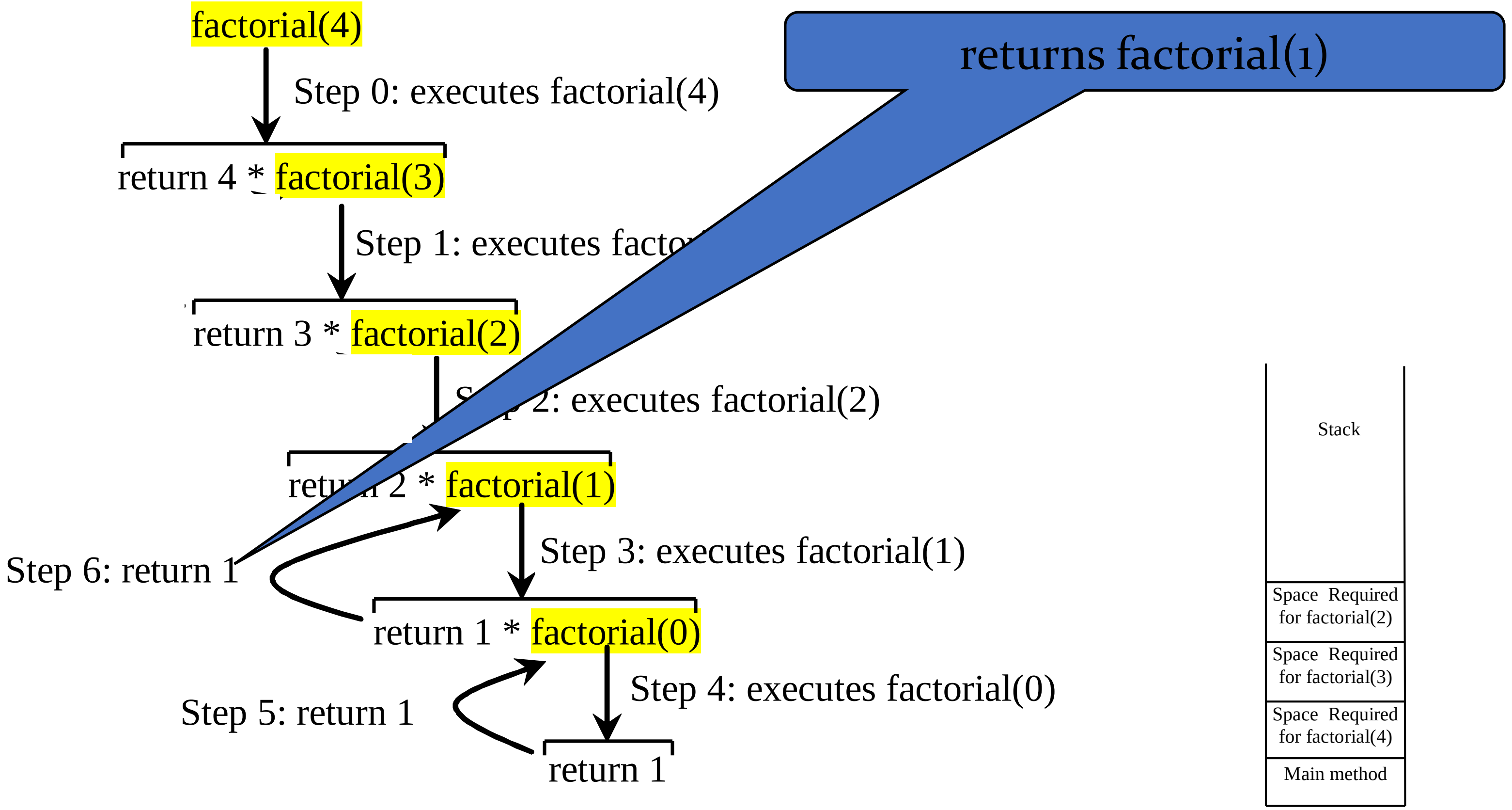
Recursive Factorial



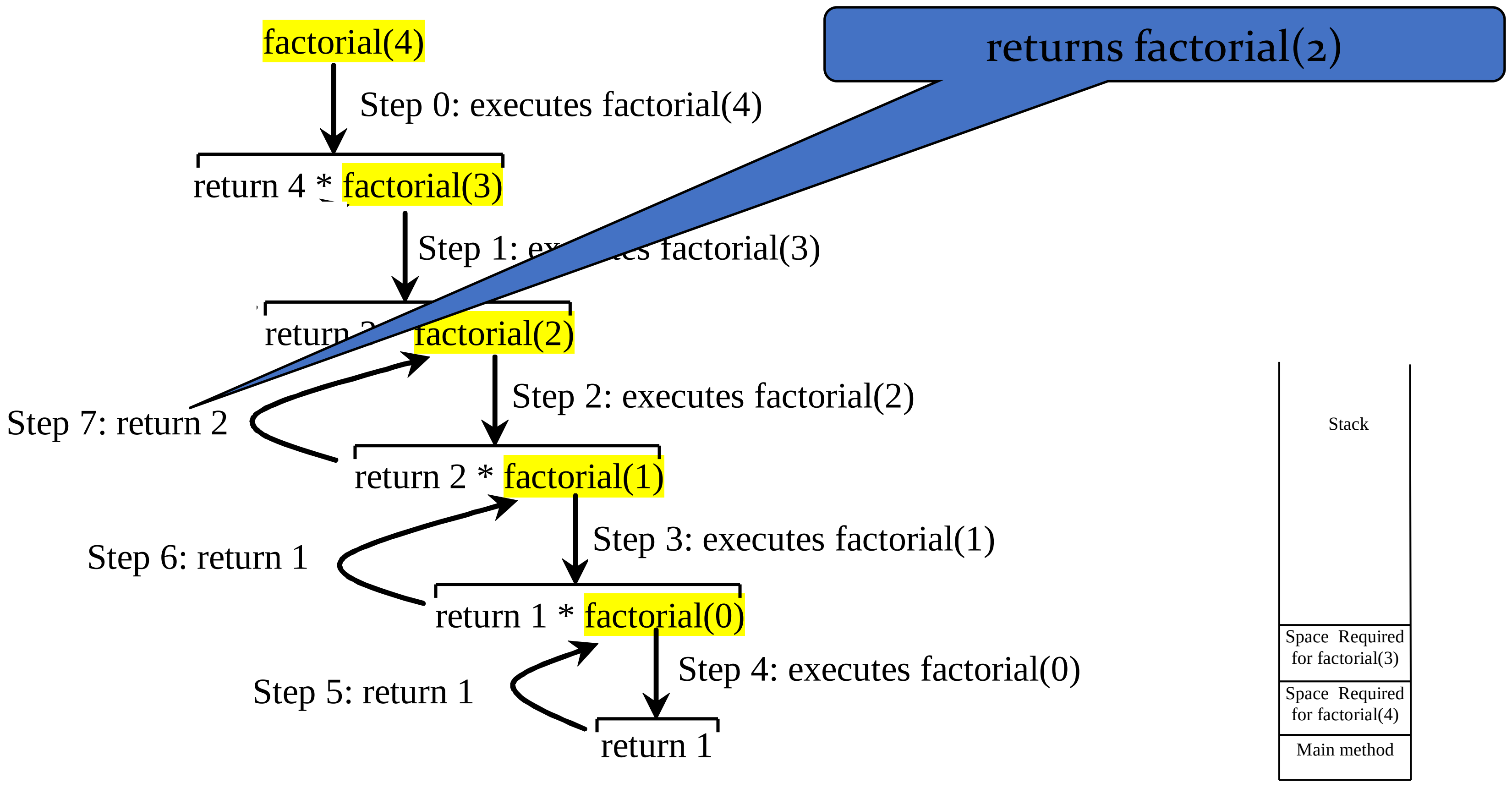
Recursive Factorial



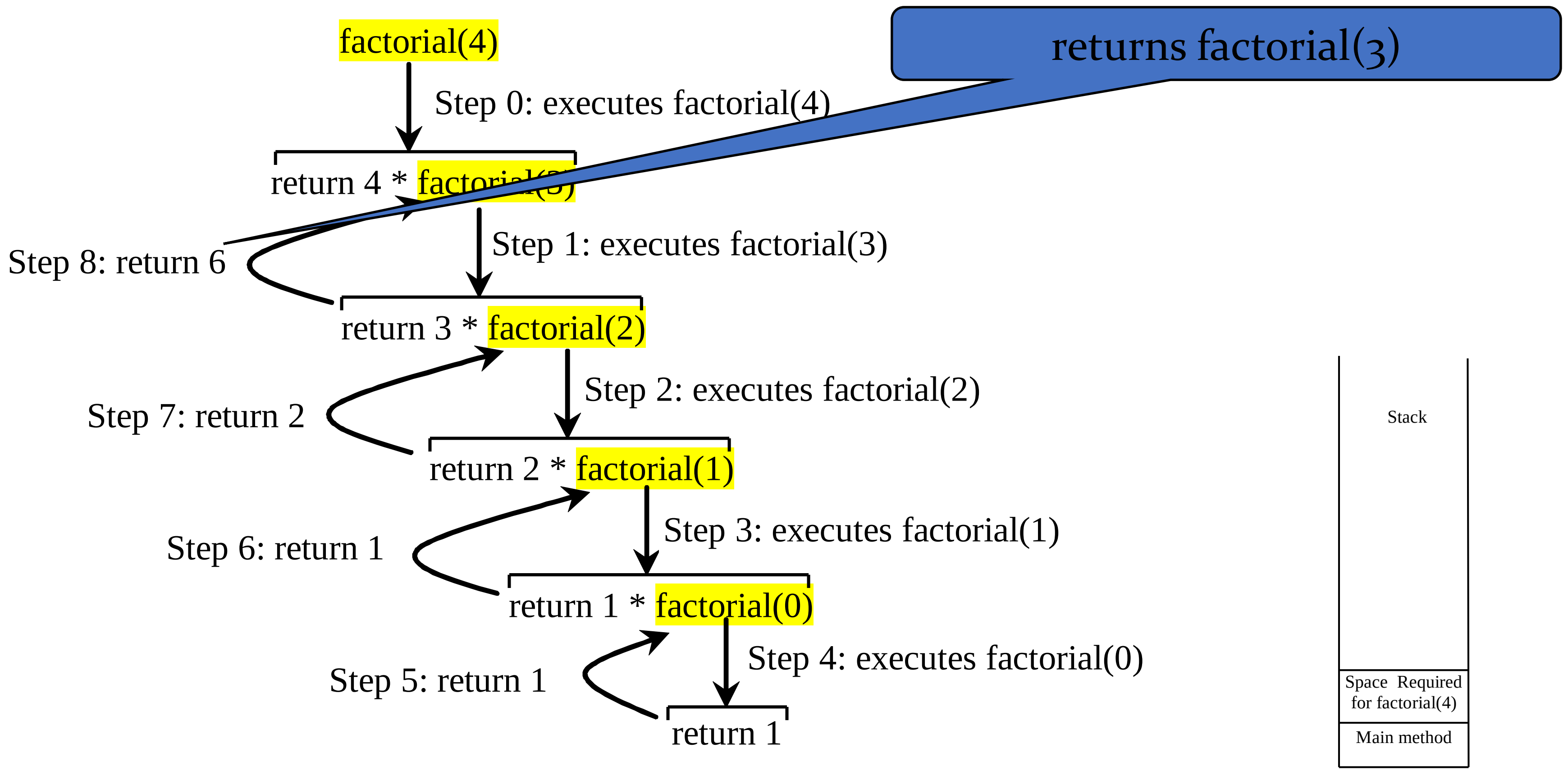
Recursive Factorial



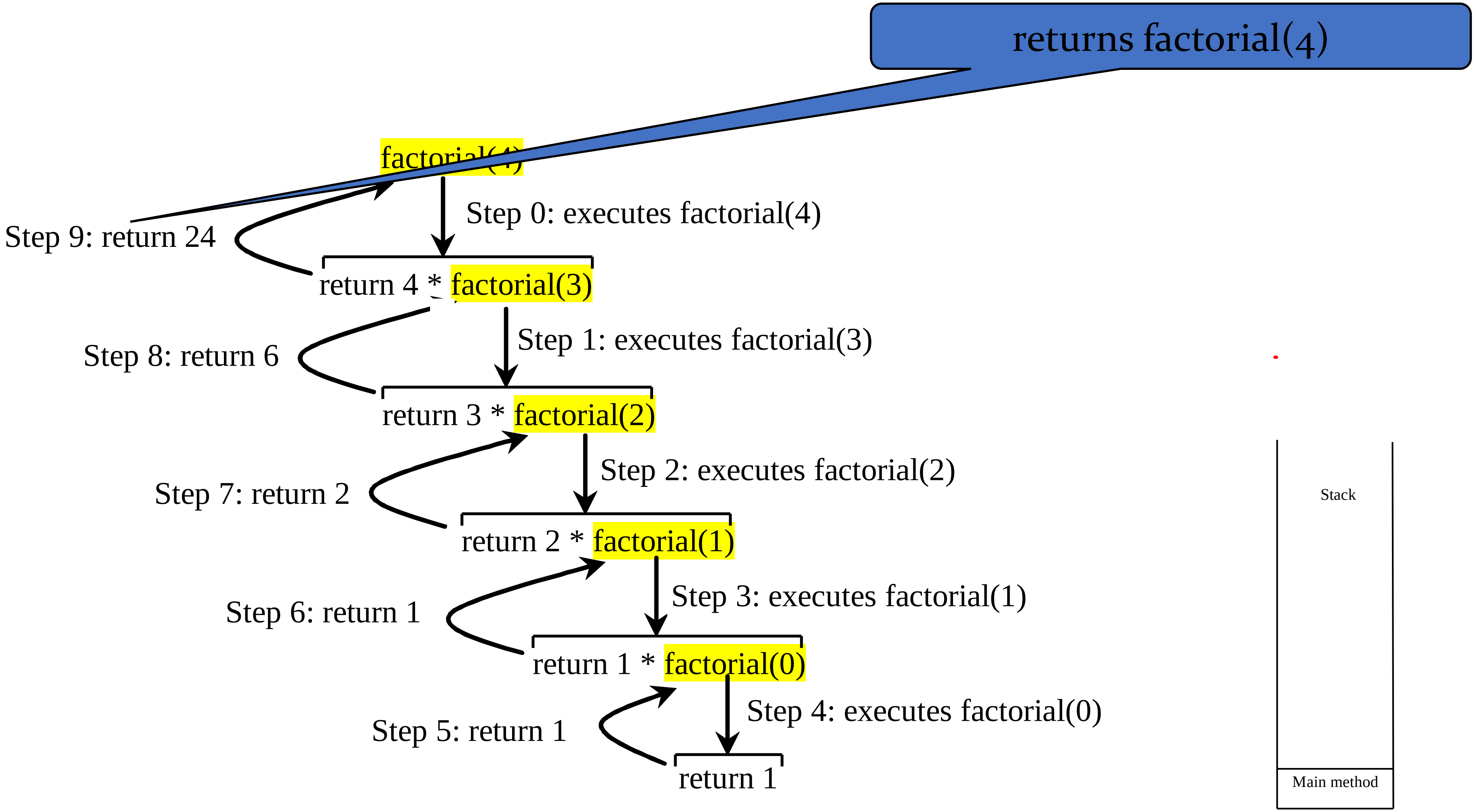
Recursive Factorial



Recursive Factorial



Recursive Factorial



Exercise

- Write your own recursive *int pwr()* function that takes two integers as arguments and returns the integer result.
  - Prototype: int pwr(int base, int exp);

pwr(2,10)

$2^{10} = 1024$

Demo…

Pros and Cons of Recursion

- Pros
  - Readable
  - Sometimes easier to conceptualize for problems that have many moving parts

- Cons
  - Efficiency
  - Memory usage
    - Each call to the function makes a new function stack frame (see previous slides)

Today's topic(s)

- Templates
- Standard Template Library (STL)
- Linked List

Templates

- How would you write a function to swap two ints?

```
void swap (int& a, int& b){
        int temp = a;
        a = b;
        b = temp;
}
```

- What if we also want to swap two floats?

```
void swap (float& a, float& b){
        float temp = a;
        a = b;
        b = temp;
}
```

- Two doubles? Two chars? Two strings? Two Animal objects?...

Function Templates

- Useful when have a general algorithm which doesn’t change even if types change
- **Algorithm Abstraction**: expressing algorithms in a very general way so that we can ignore incidental detail and concentrate on the substantive part of the algorithm
- Classic example: swap
  - We can create a template function which can take any type

```
template <class T>
void swap (T& a, T& b){
        T temp = a;
        a = b;
        b = temp;
}
```

Function Templates

- `template <class T>`
  - Referred to as template prefix
  - Tells the compiler that the definition that follows is a template
  - T is a type parameter
- To call this function template, we can explicitly specify our template parameter using angle brackets:
  - `swap<int>(i, j); // where i and j are ints`
  - `swap<float>(x,y); // where x and y are floats`
  - `swap<Animal>(a1, a2); //where a1 and a2 are Animals`
- Since swap() takes parameters of the template type T, we don't need to explicitly specify the template type, i.e. these also work:
  - `swap(i, j); // where i and j are ints`
  - `swap(x,y); // where x and y are floats`
  - `swap(a1, a2); //where a1 and a2 are Animals`

Function Templates

- We can write function templates that include any number of template parameters, e.g:

```
template <class T, class U>
void print_two_things(T first, U second){
    cout << first << second << endl;
}
```

And we can call it as before:

```
print_two_things<string, int>("number: ", 1);
print_two_things(2.5, 'e');
```

Note:

- The compiler generates a new implementation of the template for each type with which it is used.
  - This means concrete implementations of templates (i.e. int, float) are not created until compile time
- Therefore, we cannot explicitly compile template implementations into object files from .cpp files.
  - In fact, we can’t separate template implementations into separate .cpp files at all
  - Instead, we need to write template implementations either in the same file in which they are used or else in a header (.h) file

Template Classes

- Work the same way as templated functions
- All functions within the class will operate on the provided types
- Scope with `ClassName<T>::functionname()`
- Each function needs the Template prefix

Today's topic(s)

- Template
- Standard Template Library (STL)

Standard Template Library (STL)

- C++ STL can be broken down into:
  - **Containers** – general purpose data structures (templates) for holding things
  - **Iterators** – special classes for traversing containers
  - **Algorithms** – sorting, searching, etc.

- Iterators make it possible to run the algorithm on the containers

- The STL is a great resource:
  - It contains a wide variety of very useful structures and algorithms
  - It is well-implemented, which means the structures and algorithms perform very efficiently
  - In general, it allows us to avoid re-inventing the wheel

Introducing STL Containers

- Predefined templates that can store any type of data
- The appropriate container will be dictated by the application requirements
- Example considerations:
  - Does the data need to be stored?
  - How will the data be accessed?
    - Front to back
    - Randomly?
  - Will additional data ever need to be added or removed?
- Careful planning will allow you to write clean, efficient code

Types of Containers

- Sequential containers (vector, deque, list)
  - Programmer controls the order of the elements
- Associative containers (map, set, multimap, multiset)
  - Position of elements is controlled by container
  - Elements are generally accessed by using a “key”
- Adapters (stack, queue)
  - Use an existing type of container to build other types
    - In this context, we call these “Abstract Data Types”

Examples of C++ Containers

- <array> - stores a constant amount of data in contiguous memory
- <vector> - An array that can be resized
- <list> - Linked list that stores data in non-contiguous memory
- <set> - An ordered collection of items
- <queue> - Stores data & returns it in the order it was received
  - First in, first out
- <stack> - Stores data & returns it in the opposite order that it was received
  - First in, last out

- Generally, it is a good idea to refer to the STL documentation before starting a project