CSE 1322
Module 4 – Part 2

Recursion

Factorial

$$6! = 6 * 5 * 4 * 3 * 2 * 1$$

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Factorial

$$75! = ?$$

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Factorial

$$75! = 75 * 74!$$

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Factorial

$$75! = 75 * 74!$$

Defined in terms of itself

Factorial

$$75! = 75 * 74!$$

$$74! = 74 * 73!$$

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Factorial

$$75! = 75 * 74!$$

$$74! = 74 * 73!$$

$$73! = 73 * 72!$$

Factorial

$$75! = 75 * 74!$$
$$74! = 74 * 73!$$
$$73! = 73 * 72!$$
$$\dots$$
$$2! = 2 * 1!$$
$$1! = 1 + 0!$$
$$0! = 1$$

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Factorial

In general…

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

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Recursion

- When a method calls itself
  - Easy to identify
  - Going to create “clones” of the function
  - Usually, the clone has a smaller problem to work
- Requirements
  - Must have the recursive call
  - Must have a terminating condition (Base case)
  - Must make progress towards terminating.

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Recursion

- A recursive method works like this:
  - If it is asked the simplest problem, it directly solves it. This is called the base condition/base case.
  - If it is asked a more complex question, it breaks that question into a slightly simpler problem and makes a recursive call to solve the simpler problem.
- Eventually, you get to the simplest problem, and when you plug in the answer from each layer, you can solve the next layer.

Recursion – Technique Design

1. Determine the base case, i.e. the stopping point for the recursion. It should normally be the simplest case.
2. What is the case that is just one step above it? Can it be generalized enough to fit?

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Recursion – Technique Design

- The base case will contain some form of resolution to the method/recursion call.
- This will be usually in the form of a return statement, either by itself (return a void type) or by returning some value.
- We can also resolve a function by naturally reaching the end of the function without encountering any further recursive calls.
  - In Java, the function will just return void by default.

Factorial Example

- A recursive declaration of the factorial method is arrived at by observing the following relationship:

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

- What is the simplest case / terminating state?

$$0! = 1 \text{ or } 1! = 1$$

Factorial Example

- Let’s start by defining the method:

```
public static int factorial(int number){

}
```

Factorial Example – Base Case

- As shown previously, we have to ways to handle the base case:

```
if(number == 0){
    return 1;
}
```

- Or

```
if(number == 1){
    return 1;
}
```

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Factorial Example

Remember:

$$75! = 75 * 74!$$
$$74! = 74 * 73!$$
$$73! = 73 * 72!$$
$$\ldots$$
$$2! = 2 * 1!$$
$$1! = 1 + 0!$$
$$0! = 1$$

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Factorial Example

- When designing the recursive method process and recursive call, always have in mind that we are going to stack up the function stack.
- We can either “work” while we stack up, or “work” when we stack down.
- Or both!

Factorial Example

0! = 1 <- Base Case

1! = 1 + 0!

2! = 2 + 1!

…

73! = 73 * 72!

74! = 74 * 73!

75! = 75 * 74!

Factorial Example – Recursive Call

- We are going to use this expression to calculate the factorial:

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

- This is how it will look like in our method:

```
return number * factorial(number - 1);
```

Factorial Example

```java
public class FactorialExample {
    public static int factorial(int number){
        if(number == 0){
            return 1;
        }
        return number * factorial(number - 1);
    }

    public static void main(String[] args) {
        System.out.println(factorial(5));
    }
}
```

Week-8/Recursion/FactorialExample.java

Factorial Example

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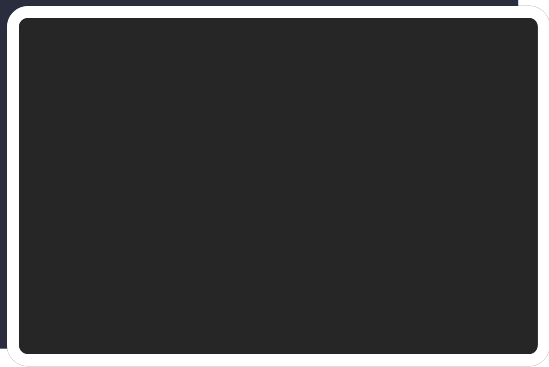

main()
1. Call factorial(5)
2. Print returned value

Week-8/Recursion/FactorialExample.java

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Factorial Example

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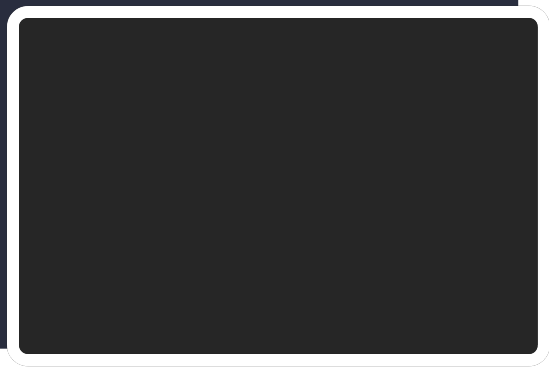

main()
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Week-8/Recursion/FactorialExample.java

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Factorial Example

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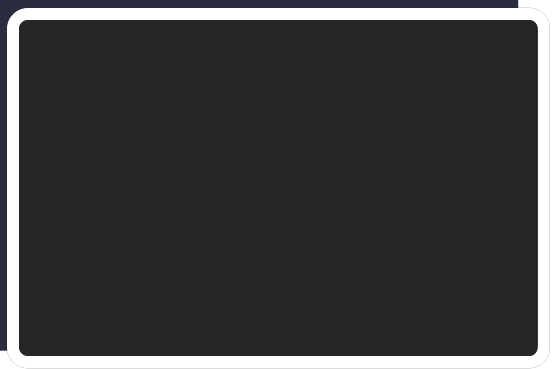

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Week-8/Recursion/FactorialExample.java

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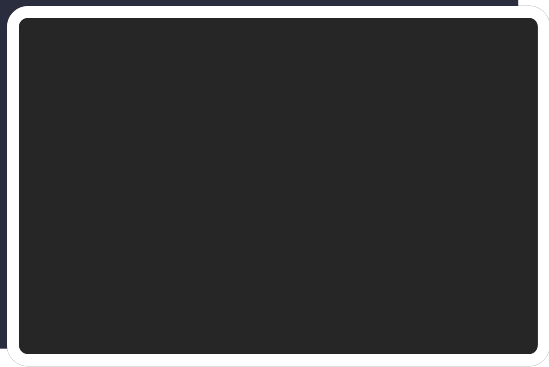

factorial(5)
1. Is 5 == 0?

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Week-8/Recursion/FactorialExample.java

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Factorial Example

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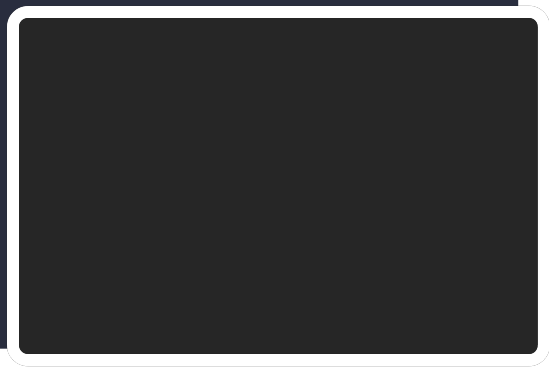

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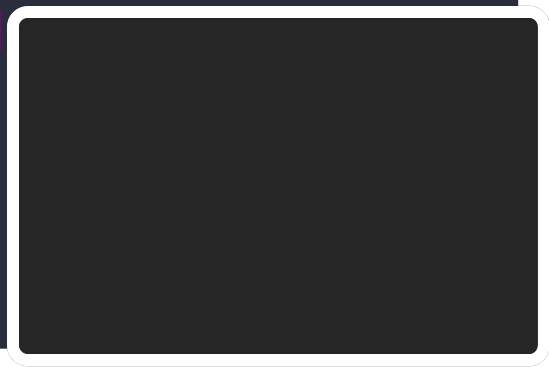

factorial(5)
1. Is 5 == 0?
2. **Return 5 * factorial(4)**

main()
1. **Call factorial(5)**
2. Print returned value

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Factorial Example

```java
public class FactorialExample {
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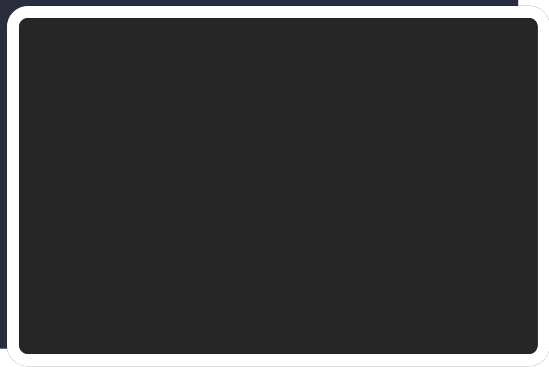

factorial(4)
1. Is 4 == 0?

factorial(5)
1. Is 5 == 0?
2. **Return 5 * factorial(4)**

main()
1. **Call factorial(5)**
2. Print returned value

Week-8/Recursion/FactorialExample.java

Factorial Example

```java
public class FactorialExample {
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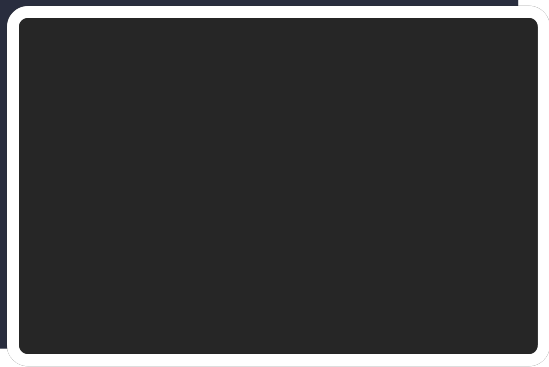

factorial(4)
1. **Is 4 == 0?**

factorial(5)
1. Is 5 == 0?
2. **Return 5 * factorial(4)**

main()
1. **Call factorial(5)**
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Factorial Example

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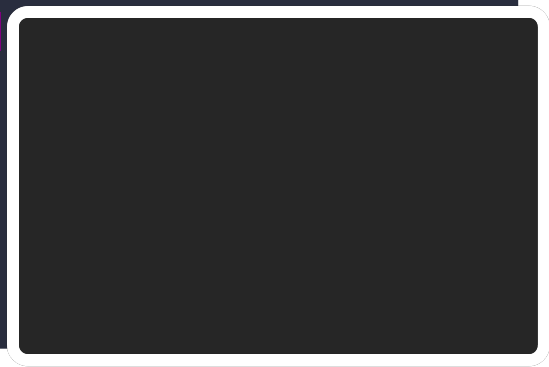

factorial(4)
1. Is 4 == 0?
2. **Return 4 * factorial(3)**

factorial(5)
1. Is 5 == 0?
2. **Return 5 * factorial(4)**

main()
1. **Call factorial(5)**
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Week-8/Recursion/FactorialExample.java

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Factorial Example

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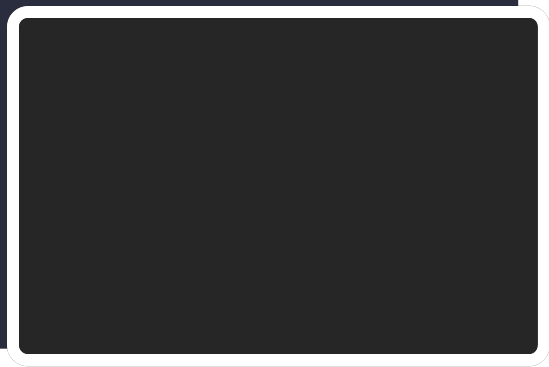

factorial(3)
1. Is 3 == 0?

factorial(4)
1. Is 4 == 0?
2. **Return 4 * factorial(3)**

factorial(5)
1. Is 5 == 0?
2. **Return 5 * factorial(4)**

main()
1. **Call factorial(5)**
2. Print returned value

Week-8/Recursion/FactorialExample.java

Factorial Example

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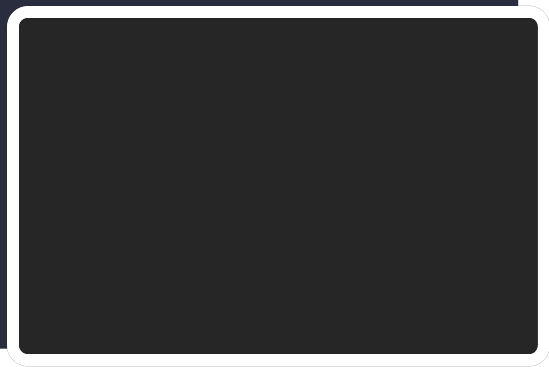

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1. **Is 3 == 0?**

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1. Is 4 == 0?
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factorial(5)
1. Is 5 == 0?
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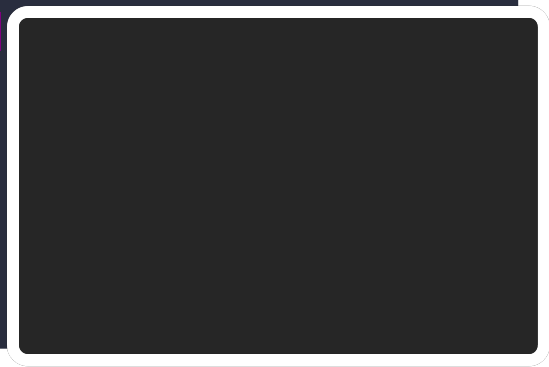

factorial(3)
1. Is 3 == 0?
2. **Return 3 * factorial(2)**

factorial(4)
1. Is 4 == 0?
2. **Return 4 * factorial(3)**

factorial(5)
1. Is 5 == 0?
2. **Return 5 * factorial(4)**

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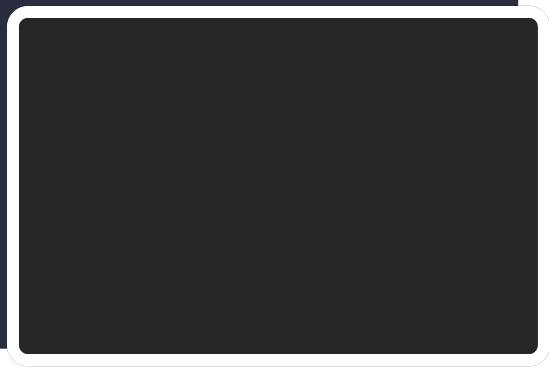

factorial(2)
1. Is 2 == 0?

factorial(3)
1. Is 3 == 0?
2. **Return 3 * factorial(2)**

factorial(4)
1. Is 4 == 0?
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factorial(5)
1. Is 5 == 0?
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main()
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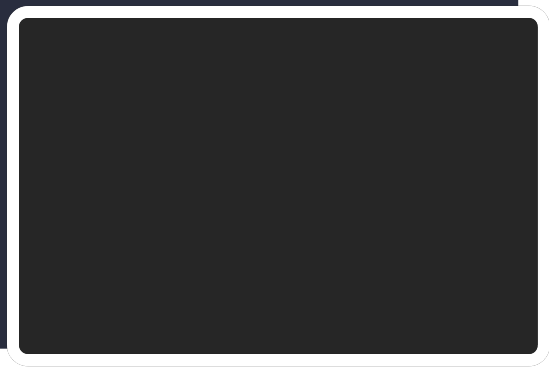

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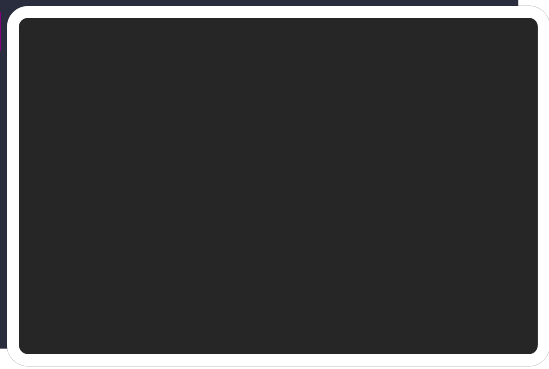

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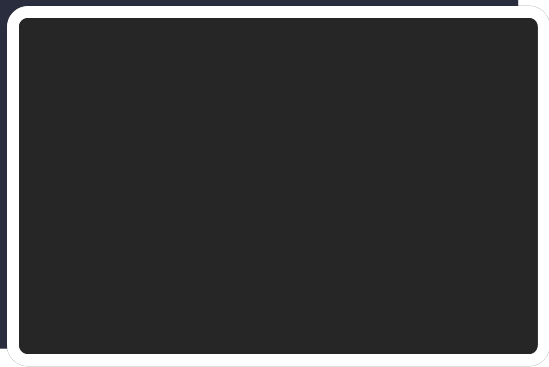

factorial(1)
1. Is 1 == 0?

factorial(2)
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factorial(3)
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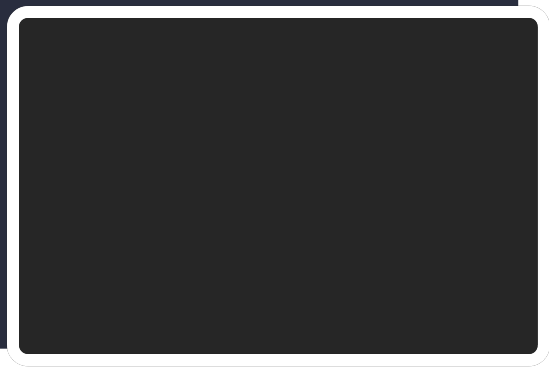

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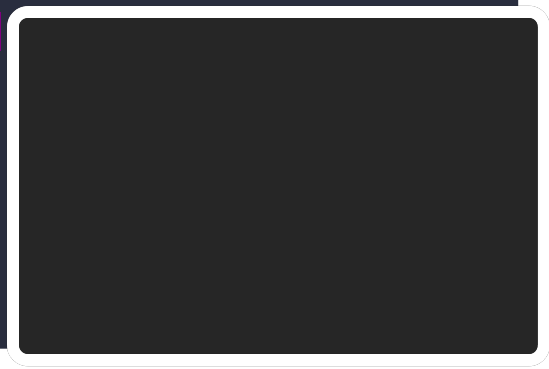

Week-8/Recursion/FactorialExample.java

factorial(1)
1. Is 1 == 0?
2. **Return 1 * factorial(0)**

factorial(2)
1. Is 2 == 0?
2. **Return 2 * factorial(1)**

factorial(3)
1. Is 3 == 0?
2. **Return 3 * factorial(2)**

factorial(4)
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factorial(5)
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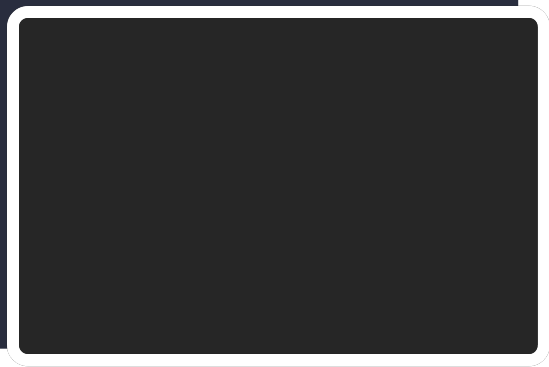

Week-8/Recursion/FactorialExample.java

factorial(0)
1. Is 0 == 0?

factorial(1)
1. Is 1 == 0?
2. **Return 1 * factorial(0)**

factorial(2)
1. Is 2 == 0?
2. **Return 2 * factorial(1)**

factorial(3)
1. Is 3 == 0?
2. **Return 3 * factorial(2)**

factorial(4)
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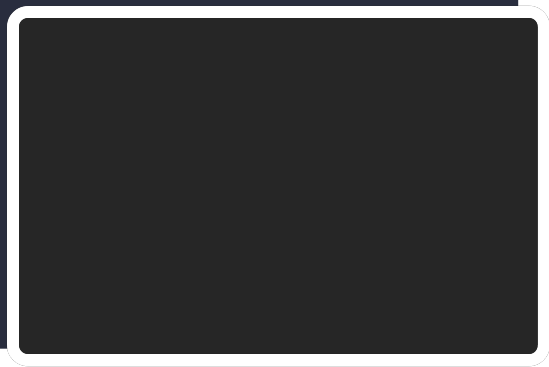

factorial(0)
1. **Is 1 == 0?**

factorial(1)
1. Is 1 == 0?
2. **Return 1 * factorial(0)**

factorial(2)
1. Is 2 == 0?
2. **Return 2 * factorial(1)**

factorial(3)
1. Is 3 == 0?
2. **Return 3 * factorial(2)**

factorial(4)
1. Is 4 == 0?
2. **Return 4 * factorial(3)**

factorial(5)
1. Is 5 == 0?
2. **Return 5 * factorial(4)**

main()
1. **Call factorial(5)**
2. Print returned value

Week-8/Recursion/FactorialExample.java

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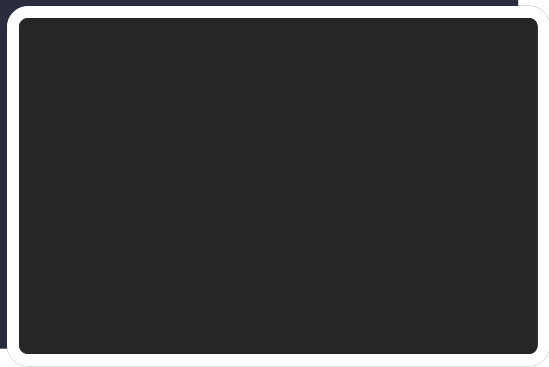
Factorial Example

```java
public class FactorialExample {
    public static int factorial(int number){
        if(number == 0){
            return 1;
        }
        return number * factorial(number - 1);
    }

    public static void main(String[] args) {
        System.out.println(factorial(5));
    }
}
```



Week-8/Recursion/FactorialExample.java

factorial(0)
1. Is 1 == 0?
2. **Return 1**

factorial(1)
1. Is 1 == 0?
2. **Return 1 * factorial(0)**

factorial(2)
1. Is 2 == 0?
2. **Return 2 * factorial(1)**

factorial(3)
1. Is 3 == 0?
2. **Return 3 * factorial(2)**

factorial(4)
1. Is 4 == 0?
2. **Return 4 * factorial(3)**

factorial(5)
1. Is 5 == 0?
2. **Return 5 * factorial(4)**

main()
1. **Call factorial(5)**
2. Print returned value

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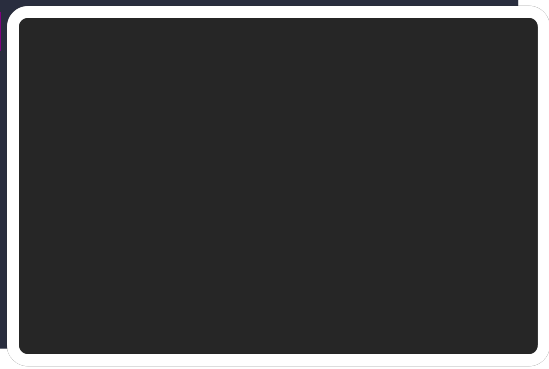
Factorial Example

```java
public class FactorialExample {
    public static int factorial(int number){
        if(number == 0){
            return 1;
        }
        return number * factorial(number - 1);
    }

    public static void main(String[] args) {
        System.out.println(factorial(5));
    }
}
```



Week-8/Recursion/FactorialExample.java

factorial(1)
1. Is 1 == 0?
2. **Return 1 * ~~factorial(0)~~ 1**

factorial(2)
1. Is 2 == 0?
2. **Return 2 * factorial(1)**

factorial(3)
1. Is 3 == 0?
2. **Return 3 * factorial(2)**

factorial(4)
1. Is 4 == 0?
2. **Return 4 * factorial(3)**

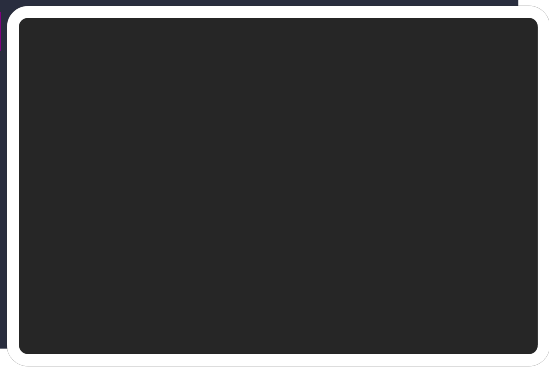
factorial(5)
1. Is 5 == 0?
2. **Return 5 * factorial(4)**

main()
1. **Call factorial(5)**
2. Print returned value

Factorial Example

```java
public class FactorialExample {
    public static int factorial(int number){
        if(number == 0){
            return 1;
        }
        return number * factorial(number - 1);
    }

    public static void main(String[] args) {
        System.out.println(factorial(5));
    }
}
```



Week-8/Recursion/FactorialExample.java

factorial(1)
1. Is 1 == 0?
2. **Return 1 * 1**

factorial(2)
1. Is 2 == 0?
2. **Return 2 * factorial(1)**

factorial(3)
1. Is 3 == 0?
2. **Return 3 * factorial(2)**

factorial(4)
1. Is 4 == 0?
2. **Return 4 * factorial(3)**

factorial(5)
1. Is 5 == 0?
2. **Return 5 * factorial(4)**

main()
1. **Call factorial(5)**
2. Print returned value

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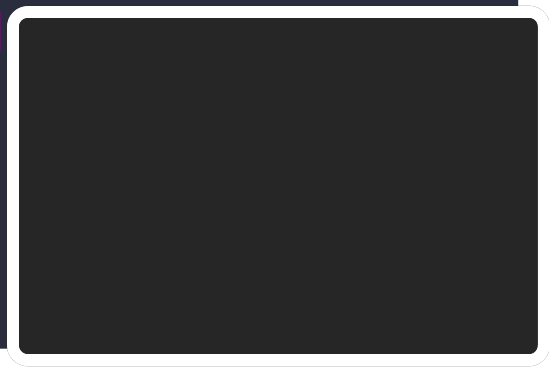
Factorial Example

```java
public class FactorialExample {
    public static int factorial(int number){
        if(number == 0){
            return 1;
        }
        return number * factorial(number - 1);
    }

    public static void main(String[] args) {
        System.out.println(factorial(5));
    }
}
```



factorial(1)
1. Is 1 == 0?
2. **Return 1**

factorial(2)
1. Is 2 == 0?
2. **Return 2 * factorial(1)**

factorial(3)
1. Is 3 == 0?
2. **Return 3 * factorial(2)**

factorial(4)
1. Is 4 == 0?
2. **Return 4 * factorial(3)**

factorial(5)
1. Is 5 == 0?
2. **Return 5 * factorial(4)**

main()
1. **Call factorial(5)**
2. Print returned value

Week-8/Recursion/FactorialExample.java

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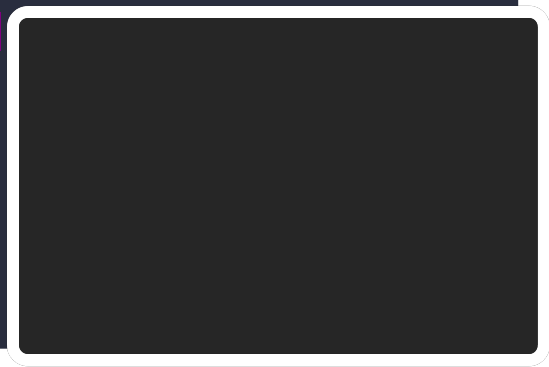
Factorial Example

```java
public class FactorialExample {
    public static int factorial(int number){
        if(number == 0){
            return 1;
        }
        return number * factorial(number - 1);
    }

    public static void main(String[] args) {
        System.out.println(factorial(5));
    }
}
```



factorial(2)
1. Is 2 == 0?
2. **Return 2 * ~~factorial(1)~~ 1**

factorial(3)
1. Is 3 == 0?
2. **Return 3 * factorial(2)**

factorial(4)
1. Is 4 == 0?
2. **Return 4 * factorial(3)**

factorial(5)
1. Is 5 == 0?
2. **Return 5 * factorial(4)**

main()
1. **Call factorial(5)**
2. Print returned value

Week-8/Recursion/FactorialExample.java

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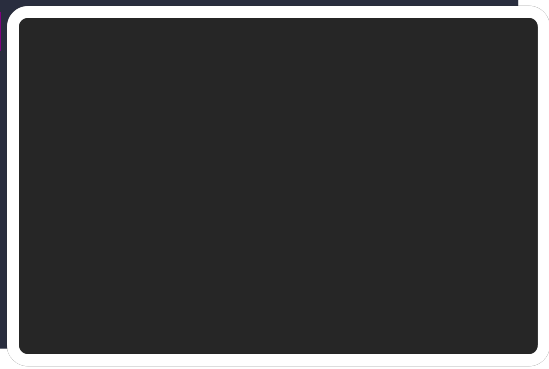
Factorial Example

```java
public class FactorialExample {
    public static int factorial(int number){
        if(number == 0){
            return 1;
        }
        return number * factorial(number - 1);
    }

    public static void main(String[] args) {
        System.out.println(factorial(5));
    }
}
```



factorial(2)
1. Is 2 == 0?
2. **Return 2 * 1**

factorial(3)
1. Is 3 == 0?
2. **Return 3 * factorial(2)**

factorial(4)
1. Is 4 == 0?
2. **Return 4 * factorial(3)**

factorial(5)
1. Is 5 == 0?
2. **Return 5 * factorial(4)**

main()
1. **Call factorial(5)**
2. Print returned value

Week-8/Recursion/FactorialExample.java

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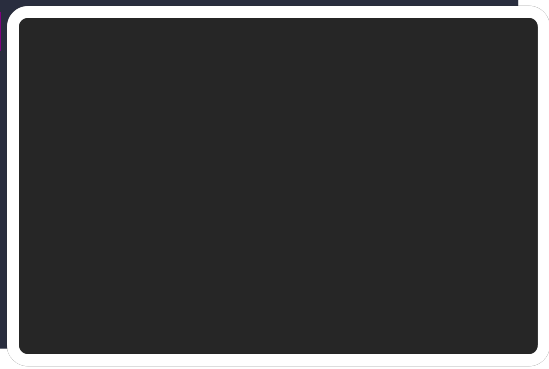
Factorial Example

```java
public class FactorialExample {
    public static int factorial(int number){
        if(number == 0){
            return 1;
        }
        return number * factorial(number - 1);
    }

    public static void main(String[] args) {
        System.out.println(factorial(5));
    }
}
```



factorial(2)
1. Is 2 == 0?
2. **Return 2**

factorial(3)
1. Is 3 == 0?
2. **Return 3 * factorial(2)**

factorial(4)
1. Is 4 == 0?
2. **Return 4 * factorial(3)**

factorial(5)
1. Is 5 == 0?
2. **Return 5 * factorial(4)**

main()
1. **Call factorial(5)**
2. Print returned value

Week-8/Recursion/FactorialExample.java

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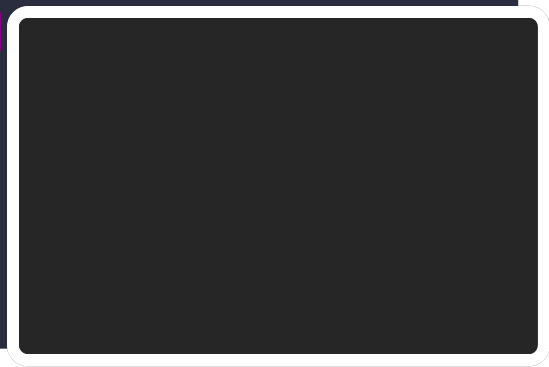
Factorial Example

```java
public class FactorialExample {
    public static int factorial(int number){
        if(number == 0){
            return 1;
        }
        return number * factorial(number - 1);
    }

    public static void main(String[] args) {
        System.out.println(factorial(5));
    }
}
```



factorial(3)
1. Is 3 == 0?
2. **Return 3 * ~~factorial(2)~~ 2**

factorial(4)
1. Is 4 == 0?
2. **Return 4 * factorial(3)**

factorial(5)
1. Is 5 == 0?
2. **Return 5 * factorial(4)**

main()
1. **Call factorial(5)**
2. Print returned value

Week-8/Recursion/FactorialExample.java

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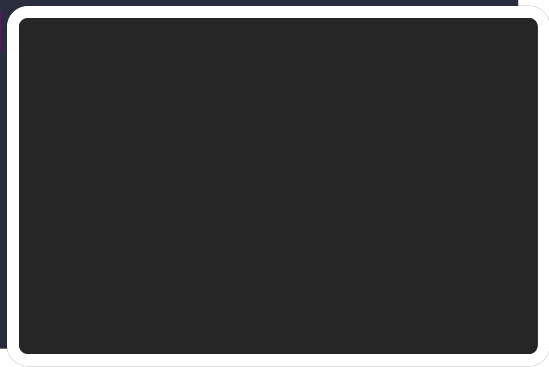
Factorial Example

```java
public class FactorialExample {
    public static int factorial(int number){
        if(number == 0){
            return 1;
        }
        return number * factorial(number - 1);
    }

    public static void main(String[] args) {
        System.out.println(factorial(5));
    }
}
```



factorial(3)
1. Is 3 == 0?
2. **Return 3 * 2**

factorial(4)
1. Is 4 == 0?
2. **Return 4 * factorial(3)**

factorial(5)
1. Is 5 == 0?
2. **Return 5 * factorial(4)**

main()
1. **Call factorial(5)**
2. Print returned value

Week-8/Recursion/FactorialExample.java

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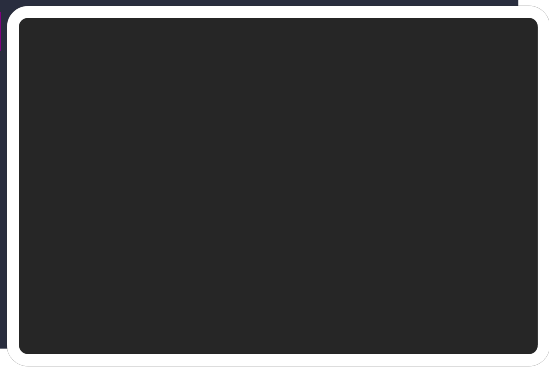
Factorial Example

```java
public class FactorialExample {
    public static int factorial(int number){
        if(number == 0){
            return 1;
        }
        return number * factorial(number - 1);
    }

    public static void main(String[] args) {
        System.out.println(factorial(5));
    }
}
```



factorial(3)
1. Is 3 == 0?
2. **Return 6**

factorial(4)
1. Is 4 == 0?
2. **Return 4 * factorial(3)**

factorial(5)
1. Is 5 == 0?
2. **Return 5 * factorial(4)**

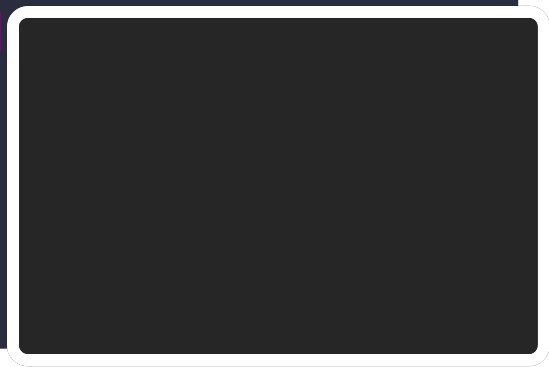
main()
1. **Call factorial(5)**
2. Print returned value

Week-8/Recursion/FactorialExample.java

Factorial Example

```java
public class FactorialExample {
    public static int factorial(int number){
        if(number == 0){
            return 1;
        }
        return number * factorial(number - 1);
    }

    public static void main(String[] args) {
        System.out.println(factorial(5));
    }
}
```



factorial(4)
1. Is 4 == 0?
2. **Return 4 * ~~factorial(3)~~ 6**

factorial(5)
1. Is 5 == 0?
2. **Return 5 * factorial(4)**

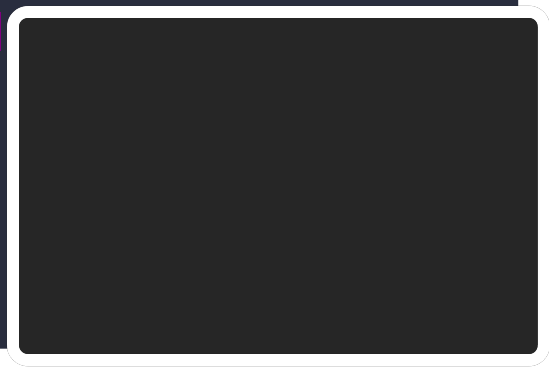
main()
1. **Call factorial(5)**
2. Print returned value

Week-8/Recursion/FactorialExample.java

Factorial Example

```java
public class FactorialExample {
    public static int factorial(int number){
        if(number == 0){
            return 1;
        }
        return number * factorial(number - 1);
    }

    public static void main(String[] args) {
        System.out.println(factorial(5));
    }
}
```



factorial(4)
1. Is 4 == 0?
2. **Return 4 * 6**

factorial(5)
1. Is 5 == 0?
2. **Return 5 * factorial(4)**

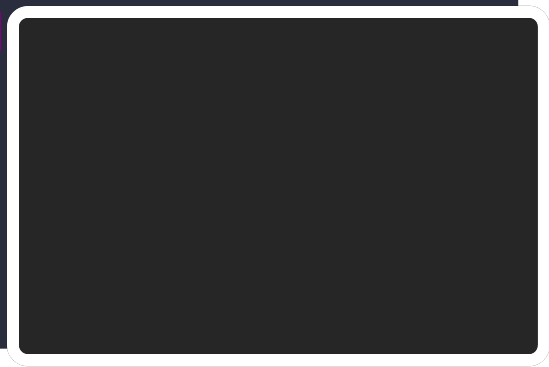
main()
1. **Call factorial(5)**
2. Print returned value

Week-8/Recursion/FactorialExample.java

Factorial Example

```java
public class FactorialExample {
    public static int factorial(int number){
        if(number == 0){
            return 1;
        }
        return number * factorial(number - 1);
    }

    public static void main(String[] args) {
        System.out.println(factorial(5));
    }
}
```



factorial(4)
1. Is 4 == 0?
2. **Return 24**

factorial(5)
1. Is 5 == 0?
2. **Return 5 * factorial(4)**

main()
1. **Call factorial(5)**
2. Print returned value

Week-8/Recursion/FactorialExample.java

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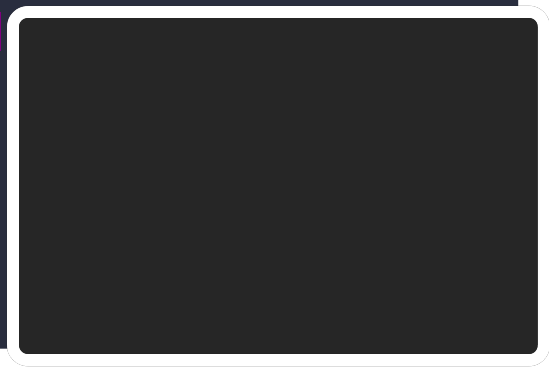
Factorial Example

```java
public class FactorialExample {
    public static int factorial(int number){
        if(number == 0){
            return 1;
        }
        return number * factorial(number - 1);
    }

    public static void main(String[] args) {
        System.out.println(factorial(5));
    }
}
```



factorial(5)
1. Is 5 == 0?
2. **Return 5 * ~~factorial(4)~~ 24**

main()
1. **Call factorial(5)**
2. Print returned value

Week-8/Recursion/FactorialExample.java

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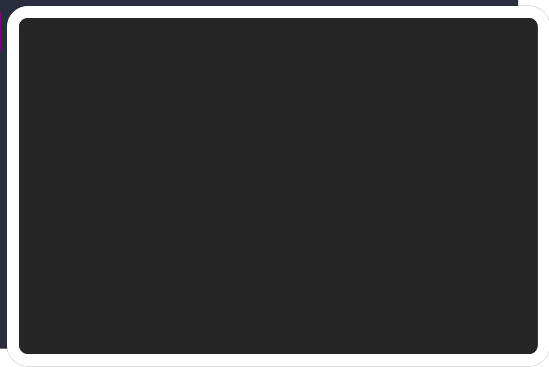
Factorial Example

```java
public class FactorialExample {
    public static int factorial(int number){
        if(number == 0){
            return 1;
        }
        return number * factorial(number - 1);
    }

    public static void main(String[] args) {
        System.out.println(factorial(5));
    }
}
```



factorial(5)
1. Is 5 == 0?
2. **Return 5 * 24**

main()
1. **Call factorial(5)**
2. Print returned value

Week-8/Recursion/FactorialExample.java

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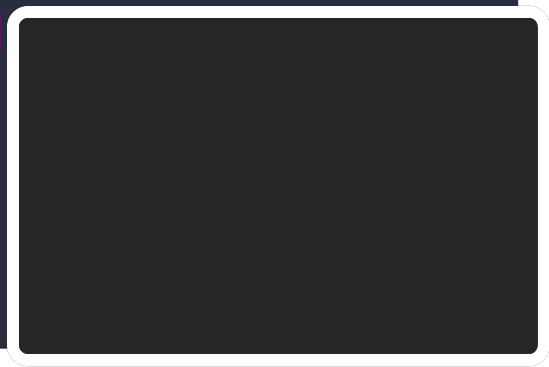
Factorial Example

```java
public class FactorialExample {
    public static int factorial(int number){
        if(number == 0){
            return 1;
        }
        return number * factorial(number - 1);
    }

    public static void main(String[] args) {
        System.out.println(factorial(5));
    }
}
```



factorial(5)
1. Is 5 == 0?
2. **Return 120**

main()
1. **Call factorial(5)**
2. Print returned value

Week-8/Recursion/FactorialExample.java

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Factorial Example

```java
public class FactorialExample {
    public static int factorial(int number){
        if(number == 0){
            return 1;
        }
        return number * factorial(number - 1);
    }

    public static void main(String[] args) {
        System.out.println(factorial(5));
    }
}
```

```
120
```

main()
1. Call factorial(5)
2. **Print returned value**

Week-8/Recursion/FactorialExample.java

Factorial Example

```java
public class FactorialExample {
    public static int factorial(int number){
        if(number == 0){
            return 1;
        }
        return number * factorial(number - 1);
    }

    public static void main(String[] args) {
        System.out.println(factorial(5));
    }
}
```

```
120
```

Week-8/Recursion/FactorialExample.java

Common Programming Error

- If a recursive method does not have a base care or if the recursive call is structured so it does not converge to the base case, the recursion will never terminate.
- Since it does not terminate, this leads to an infinite recursion where the function keeps calling itself indefinitely until the system runs out of memory.
- This error is analogous to the problem of an infinite loop in an iterative (non-recursive) solution.

Stack Overflow

- The problem mentioned before is referred to a Stack Overflow. This occurs when you recurse too many times and run out of memory.
- Often, it is more efficient to perform calculations via iteration (looping), but it can also be easier to express an algorithm via recursion.
- Recursion is especially useful for non-linear situations.

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In-Class problem

- Write a method that calculates exponential function using recursion.
- The method should take in two positive integers: the base and the exponent (in this order).
- The method should return the result of the exponential function.
- Solution will be posted to Github:
  - Week-8/Recursion/ExponentialExample.java

What is the output?

```java
public static void printNumbers(int n){
    if(n > 0){
        System.out.print(n + " ");
        printNumbers(n - 1);
        System.out.print(n + " ");
    }
}

public static void main(String[] args) {
    printNumbers(10);
}
```

Week-8/Recursion/Example.java