LEC 08

CSE 123

Recursion

Questions during Class?
Raise hand or send here

sli.do #cse123

BEFORE WE START

Talk to your neighbors:

What is your favorite season/weather?

Respond on sli.do!

Instructor: Miya Natsuhara

TAs:

Arohan	Shiven	Yuntong	Anya
Sreshta	Vrinda	Amiya	Anisha
Rushil	Gavin	Sahana	Trien
Sean B	Shreya	Anirudh	Neal
Chloe	Jonah	Rohan	Evan
Jenny	Renee	Crystal	Rena
Nate	Chris	Eeshani	
Saachi	Ishita	Prakshi	
Hawa	Kuhu	Aidan	
Maggie	Kavya	Cora	
Sean E	Misha	Nhan	

Music: CSE 123 26sp Lecture Tunes

Lecture Outline: Announcements

- **Announcements**
- Method Calls Review
- Recursion Review
- Recursive Tracing Practice

Announcements

- Quiz 1 Tuesday (May 5)!
  - Topics: `ListNodes`, `LinkedIntList`, Runtime analysis
  - Topics not on Quiz 1: Recursion
  - Practice quizzes and reference sheet for Quiz 1 will be posted soon!
  - Quiz 0 feedback will be released before Quiz 1
- Programming Assignment 1 due in one week (May 6) @ 11:59pm
- Creative Project 1 and Resubmission Cycle 1 grades released today
- Resubmission Period 2 closes this Friday (May 1) @ 11:59pm
  - Available assignments: ***C0***, P0, C1
  - ***Last opportunity to resubmit C0***
- Trien will be giving lecture on Friday!

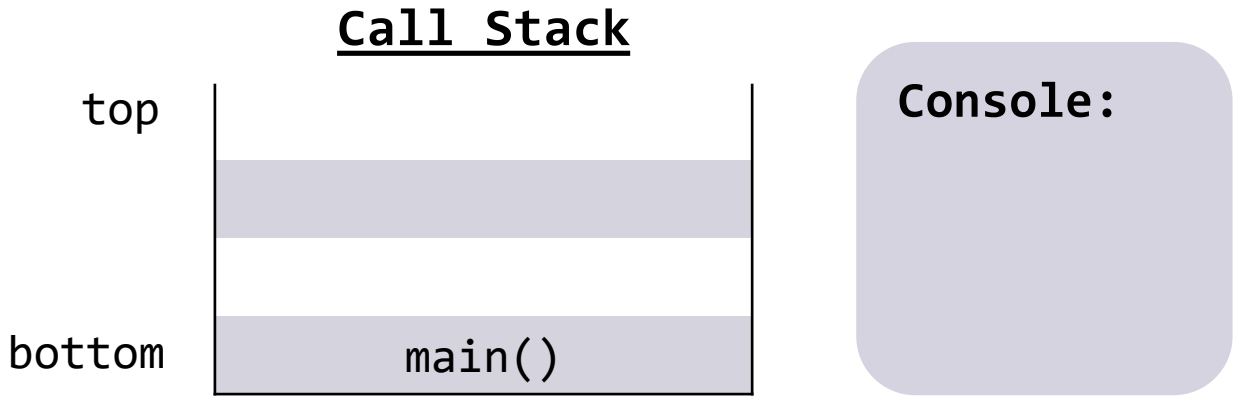
Lecture Outline: Method Calls Review

- Announcements
- **Method Calls Review**
- Recursion Review
- Recursive Tracing Practice

Method Calls

- Regardless how you use them, methods work the same way!
  - Pause execution, finish method, return where you left off
- How does Java keep track of the prior method?
  - Sort of like the "history" of the method calls it has paused… (LIFO)
  - Something called the **Call Stack**

Call Stack: Step 1



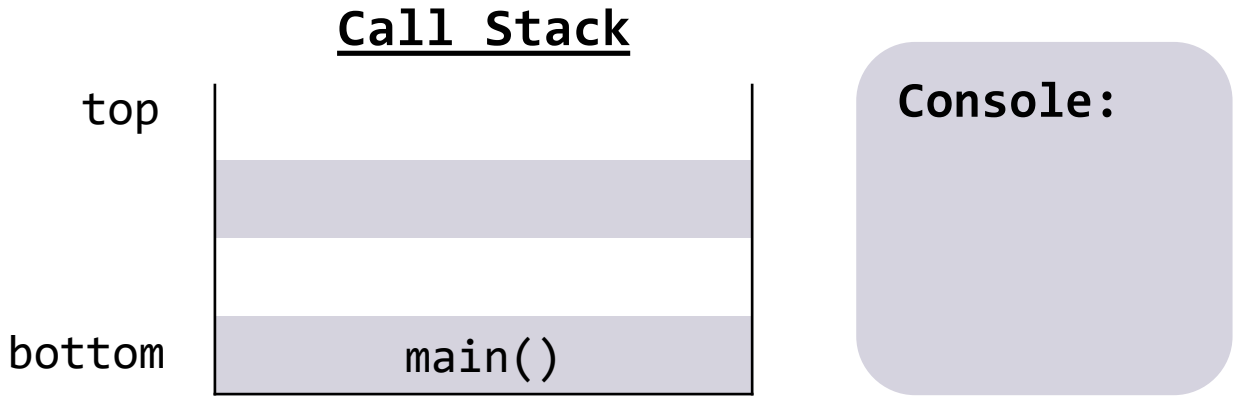

```
public static void main(String[] args) {
    mystery1();
    mystery2();
}

public static void mystery1() {
    System.out.println("One");
}
```

```
public static void mystery2() {
    System.out.println("Two");
    mystery3();
}

public static void mystery3() {
    System.out.println("Three");
}
```

Call Stack: Step 2



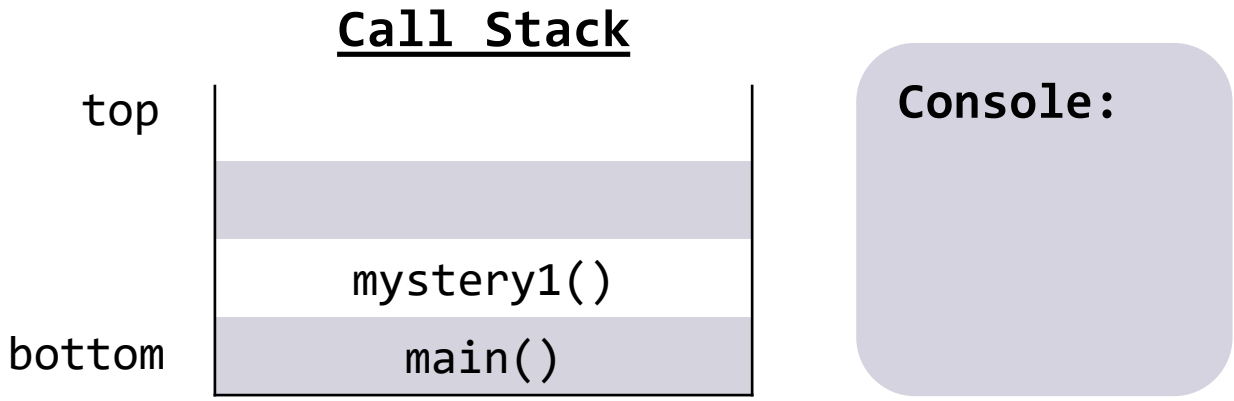

```
public static void main(String[] args) {
    mystery1();
    mystery2();
}

public static void mystery1() {
    System.out.println("One");
}
```

```
public static void mystery2() {
    System.out.println("Two");
    mystery3();
}

public static void mystery3() {
    System.out.println("Three");
}
```

Call Stack: Step 3



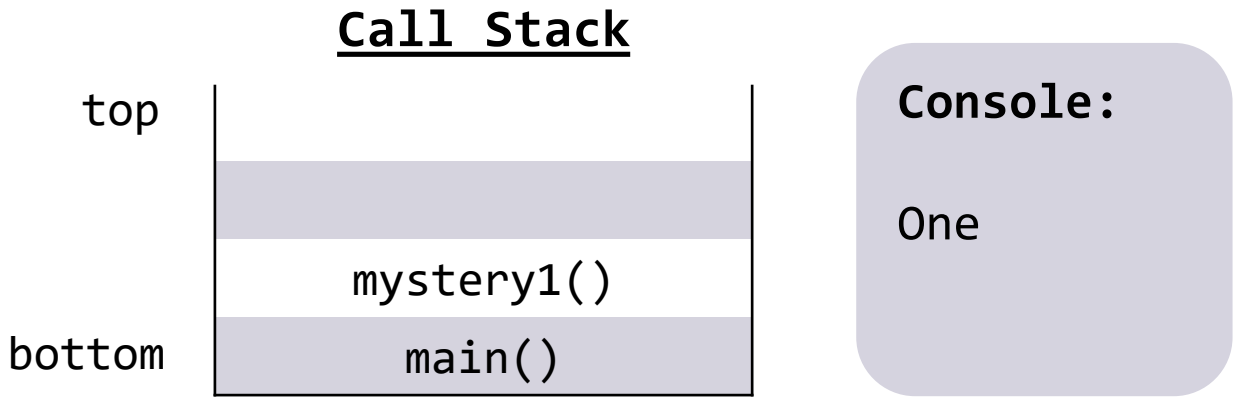

```
public static void main(String[] args) {
    mystery1();
    mystery2();
}

public static void mystery1() {
    System.out.println("One");
}
```

```
public static void mystery2() {
    System.out.println("Two");
    mystery3();
}

public static void mystery3() {
    System.out.println("Three");
}
```

Call Stack: Step 4



Console:

One

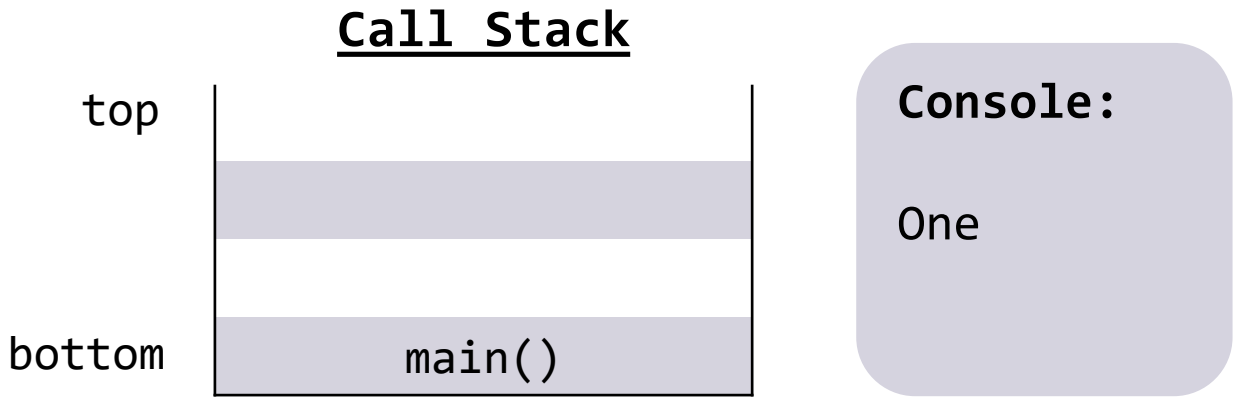
```
public static void main(String[] args) {
    mystery1();
    mystery2();
}

public static void mystery1() {
    System.out.println("One");
}
```

```
public static void mystery2() {
    System.out.println("Two");
    mystery3();
}

public static void mystery3() {
    System.out.println("Three");
}
```

Call Stack: Step 5



Console:

One

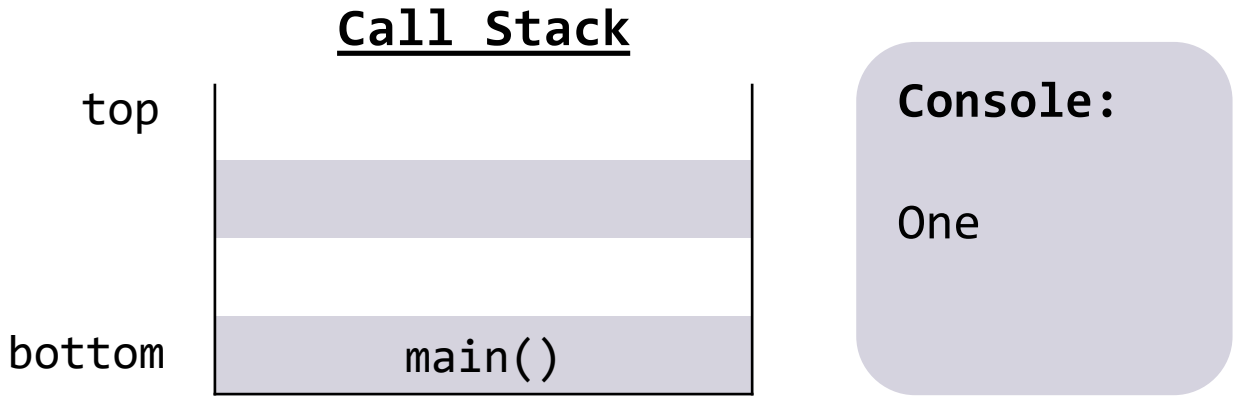
```
public static void main(String[] args) {
    mystery1();
    mystery2();
}

public static void mystery1() {
    System.out.println("One");
}
```

```
public static void mystery2() {
    System.out.println("Two");
    mystery3();
}

public static void mystery3() {
    System.out.println("Three");
}
```

Call Stack: Step 6



Console:

One

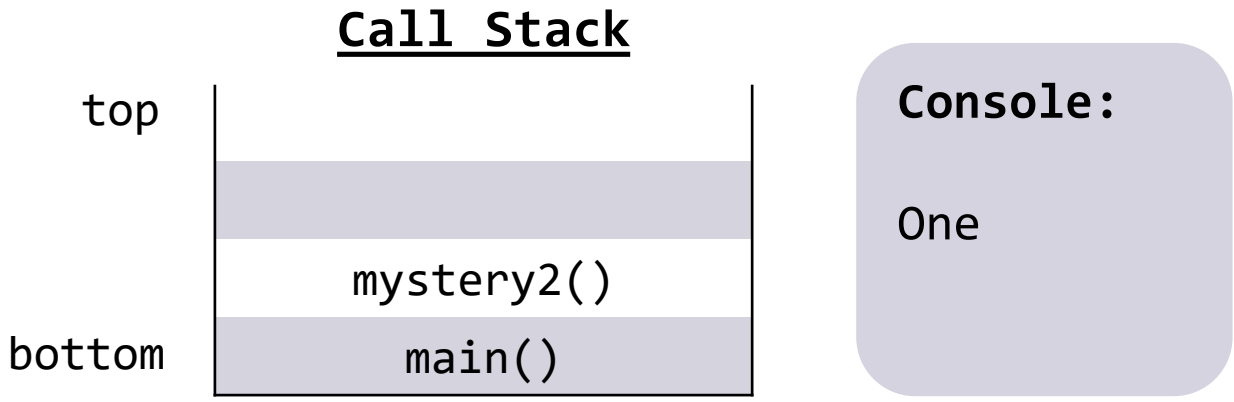
```
public static void main(String[] args) {
    mystery1();
    mystery2();
}

public static void mystery1() {
    System.out.println("One");
}
```

```
public static void mystery2() {
    System.out.println("Two");
    mystery3();
}

public static void mystery3() {
    System.out.println("Three");
}
```

Call Stack: Step 7



Console:

One

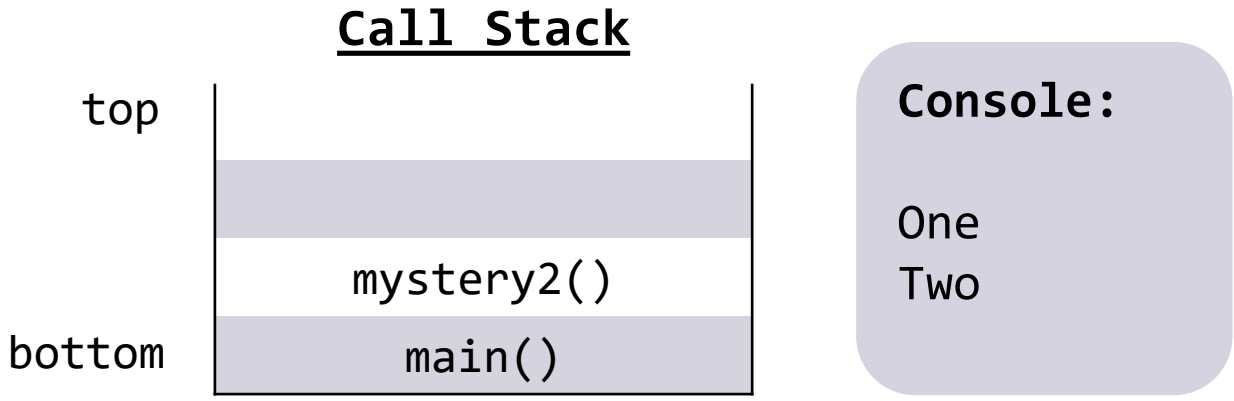
```
public static void main(String[] args) {
    mystery1();
    mystery2();
}

public static void mystery1() {
    System.out.println("One");
}
```

```
public static void mystery2() {
    System.out.println("Two");
    mystery3();
}

public static void mystery3() {
    System.out.println("Three");
}
```

Call Stack: Step 8



Console:

One
Two

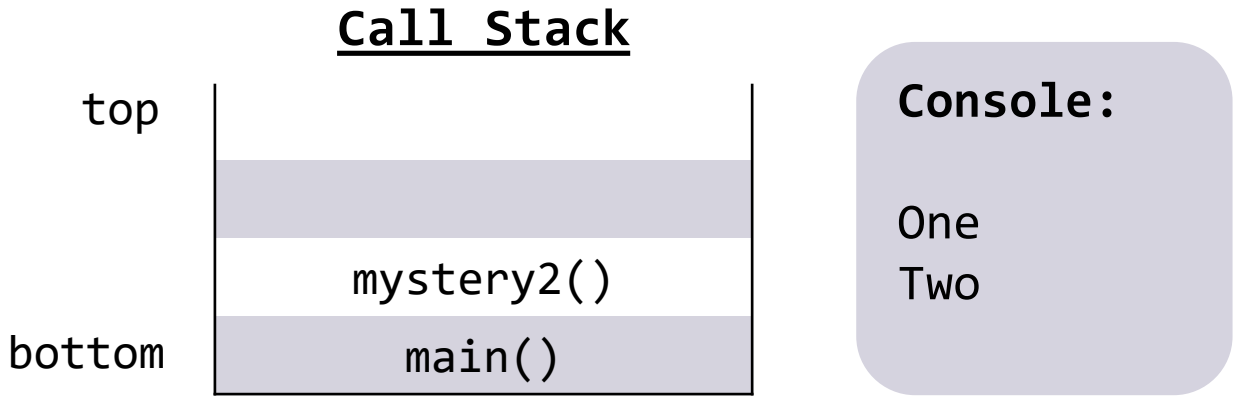
```
public static void main(String[] args) {
    mystery1();
    mystery2();
}

public static void mystery1() {
    System.out.println("One");
}
```

```
public static void mystery2() {
    System.out.println("Two");
    mystery3();
}

public static void mystery3() {
    System.out.println("Three");
}
```

Call Stack: Step 9



Console:

One
Two

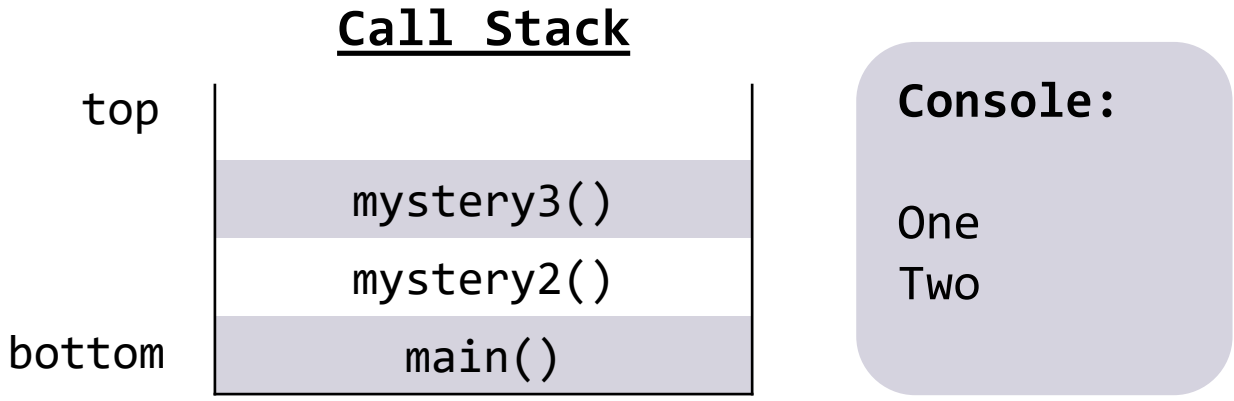
```
public static void main(String[] args) {
    mystery1();
    mystery2();
}

public static void mystery1() {
    System.out.println("One");
}
```

```
public static void mystery2() {
    System.out.println("Two");
    mystery3();
}

public static void mystery3() {
    System.out.println("Three");
}
```

Call Stack: Step 10



Console:

One
Two

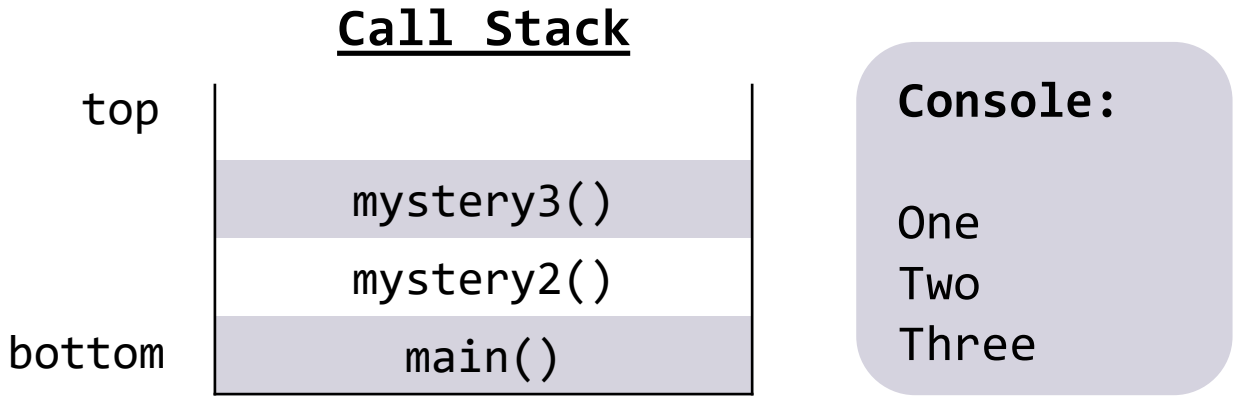
```
public static void main(String[] args) {
    mystery1();
    mystery2();
}

public static void mystery1() {
    System.out.println("One");
}
```

```
public static void mystery2() {
    System.out.println("Two");
    mystery3();
}

public static void mystery3() {
    System.out.println("Three");
}
```

Call Stack: Step 11



Console:

One
Two
Three

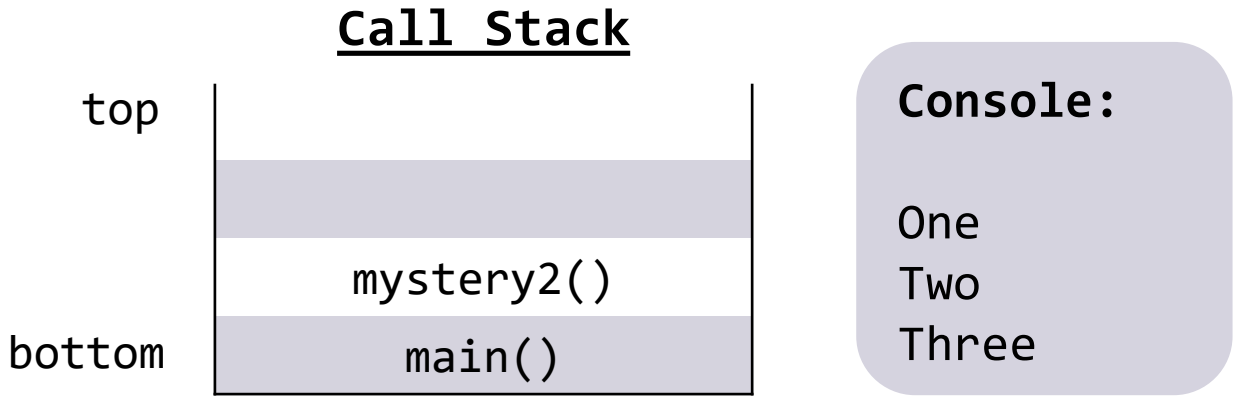
```
public static void main(String[] args) {
    mystery1();
    mystery2();
}

public static void mystery1() {
    System.out.println("One");
}
```

```
public static void mystery2() {
    System.out.println("Two");
    mystery3();
}

public static void mystery3() {
    System.out.println("Three");
}
```

Call Stack: Step 12



Console:

One
Two
Three

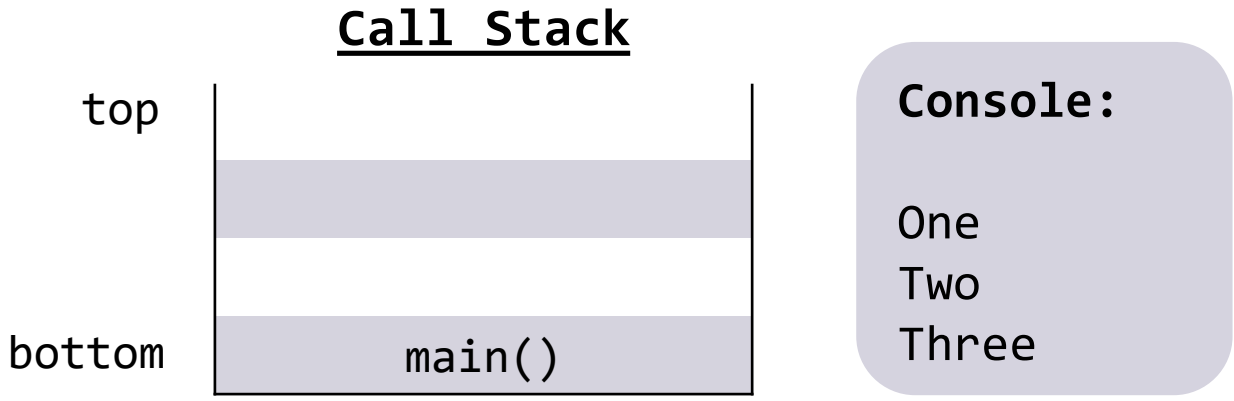
```
public static void main(String[] args) {
    mystery1();
    mystery2();
}

public static void mystery1() {
    System.out.println("One");
}
```

```
public static void mystery2() {
    System.out.println("Two");
    mystery3();
}

public static void mystery3() {
    System.out.println("Three");
}
```

Call Stack: Step 13



Console:

One
Two
Three

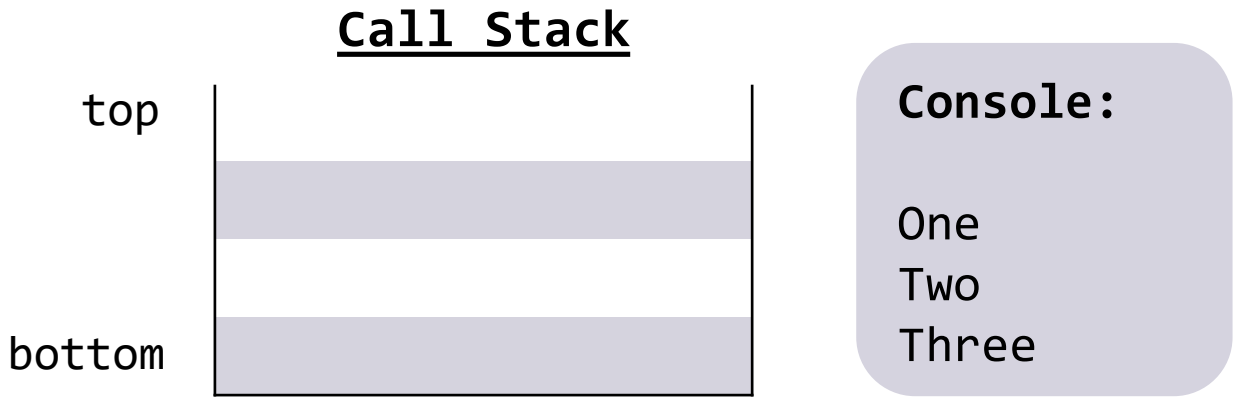
```
public static void main(String[] args) {
    mystery1();
    mystery2();
}

public static void mystery1() {
    System.out.println("One");
}
```

```
public static void mystery2() {
    System.out.println("Two");
    mystery3();
}

public static void mystery3() {
    System.out.println("Three");
}
```

Call Stack: Step 14



Console:

One
Two
Three

```
public static void main(String[] args) {
    mystery1();
    mystery2();
}

public static void mystery1() {
    System.out.println("One");
}
```

```
public static void mystery2() {
    System.out.println("Two");
    mystery3();
}

public static void mystery3() {
    System.out.println("Three");
}
```

Lecture Outline: Recursion Review

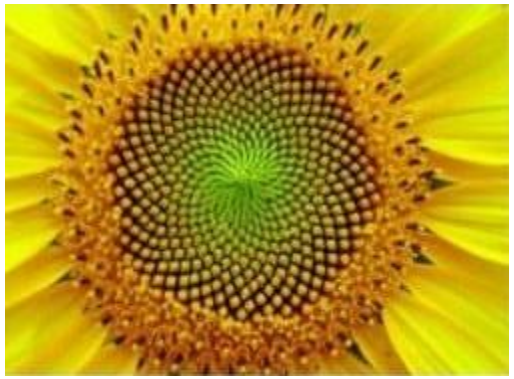
- Announcements
- Method Calls Review
- **Recursion Review**
- Recursive Tracing Practice

Recursion (1)

"The repeated application of a recursive procedure or definition"

- Oxford Languages

- Real-world definition: defining a problem in terms of itself
  - Case in point: above definition
  - Further natural examples:




Recursion (2)

"The repeated application of a recursive procedure or definition"

- Oxford Languages

- Real-world definition: defining a problem in terms of itself
  - Case in point: above definition
  - Further natural examples:

Recursion (3)

"The repeated application of a recursive procedure or definition"

- Oxford Languages

- Real-world definition: defining a problem in terms of itself
  - Case in point: above definition

- Computer science definition: when a method calls itself
  - "Alternative" to iteration (can combine for powerful results)

Recursion (4)

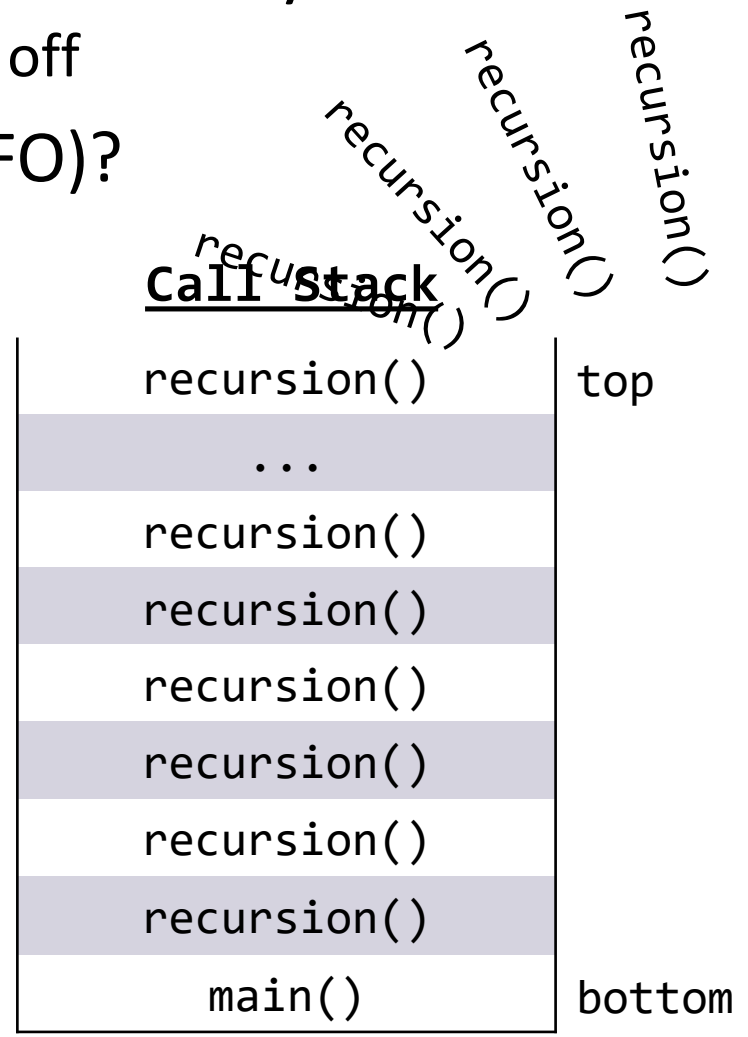
"The repeated application of a recursive procedure or definition"

- Oxford Languages

- Why do we care?
  - It's a fundamental Computer Science topic
  - Some things are easier to describe with recursion than with loops
  - There are some problems that lend themselves more easily to a recursive solution than an iterative (loop-y) solution
    - Though all problems that can be solved with recursion can be solved with loops, and vice versa

Method Calls

- Regardless how you use them, methods work the same way!
  - Pause execution, finish method, return where you left off
- How does Java keep track of the prior method (LIFO)?
  - Something called the **Call Stack**



🤔 Wouldn't that just lead to an infinite loop?

```
public static void recursion() {
    System.out.println("Woah");
    recursion();
}
```

StackOverflowException!

Method Calls: Avoiding Infinite Recursion

- Regardless how you use them, methods work the same way!
  - Pause execution, finish method, return where you left off
- How does Java keep track of the prior method (LIFO)?
  - Something called the **Call Stack**

 Wouldn't that just lead to an infinite loop?

- Yes! We get something called a **StackOverflowException**

- How do we avoid infinite recursion?

Recursive Methods

- 2 components of every recursive method:

- Recursive case
  - Decompose problem into subproblem
  - Make the actual recursive call
  - Combine results meaningfully
- Base case
  - Simplest version of the problem
  - No subproblems to break into
  - Return known answer

Recursive Methods: Decomposition

- 2 components of every recursive method:

- Recursive case
  - Decompose problem into subproblem
  - Make the actual recursive call
  - Combine results meaningfully
- Base case
  - Simplest version of the problem
  - No subproblems to break into
  - Return known answer

If decomposing moves you closer to the base, no infinite recursion!

Math Examples

n! or factorial(n) = product of all positive integers <= n

- Two ways of viewing this idea:

- $n! = n * (n-1) * (n-2) * \cdots * 2 * 1$
  - Iterative approach - loop through all values and multiply together

- $n! = n * (n-1)!$
  - Recursive approach – decompose into subproblem and combine
  - What would our base case / simplest input (n) be?

Math Examples: Hitting the Base Case

n! / factorial(n) = product of all positive integers <= n

- Reminder, recursive approach: $n! = n * (n - 1)!$
  - Let's trace through with a simple example

$4! = 4 * 3!$

$3! = 3 * 2!$

$2! = 2 * 1!$

$1! = 1 * 0!$

$0! = 1$

Math Examples: Popping off callstack 1

n! / factorial(n) = product of all positive integers <= n

- Reminder, recursive approach: $n! = n * (n-1)!$
  - Let's trace through with a simple example

$4! = 4 * 3!$

$3! = 3 * 2!$

$2! = 2 * 1!$

$1! = 1 * 0!$

$0! = 1$

Math Examples: Popping off callstack 2

n! / factorial(n) = product of all positive integers <= n

- Reminder, recursive approach: $n! = n * (n-1)!$
  - Let's trace through with a simple example

$4! = 4 * 3!$

$3! = 3 * 2!$

$2! = 2 * 1!$

$1! = 1 * 1$

Math Examples: Popping off callstack 3

n! / factorial(n) = product of all positive integers <= n

- Reminder, recursive approach: $n! = n * (n-1)!$
  - Let's trace through with a simple example

$4! = 4 * 3!$

$3! = 3 * 2!$

$2! = 2 * 1!$

$1! = 1$

Math Examples: Popping off callstack 4

n! / factorial(n) = product of all positive integers <= n

- Reminder, recursive approach: $n! = n * (n - 1)!$
  - Let's trace through with a simple example

$4! = 4 * 3!$

$3! = 3 * 2!$

$2! = 2 * 1$

Math Examples: Popping off callstack 5

n! / factorial(n) = product of all positive integers <= n

- Reminder, recursive approach: $n! = n * (n - 1)!$
  - Let's trace through with a simple example

$4! = 4 * 3!$

$3! = 3 * 2!$

$2! = 2$

Math Examples: Popping off callstack 6

n! / factorial(n) = product of all positive integers <= n

- Reminder, recursive approach: $n! = n * (n-1)!$
  - Let's trace through with a simple example

$4! = 4 * 3!$

$3! = 3 * 2$

Math Examples: Popping off callstack 7

n! / factorial(n) = product of all positive integers <= n

- Reminder, recursive approach: $n! = n * (n - 1)!$
  - Let's trace through with a simple example

$4! = 4 * 3!$

$3! = 6$

Math Examples: Popping off callstack 8

n! / factorial(n) = product of all positive integers <= n

- Reminder, recursive approach: $n! = n * (n - 1)!$
  - Let's trace through with a simple example

$4! = 4 * 6$

Math Examples: Popping off callstack 9

n! / factorial(n) = product of all positive integers <= n

- Reminder, recursive approach: $n! = n * (n - 1)!$
  - Let's trace through with a simple example

$4! = 24$

Lecture Outline: Recursive Tracing Practice

- Announcements
- Method Calls Review
- Recursion Review
- **Recursive Tracing Practice**