Model of Execution

Lecture Question

Question: In a package named lecture, write an object named ChangeState with a method named setToZero that takes an object of type NumberProtector as a parameter and returns Unit. The setToZero method should change the input such that its _number state variable has a value of 0.

Do not change the NumberProtector class. This class has a private variable _number which means you cannot change its value directly. You are given two methods, both of which have side-effects that change _number, that you can call to accomplish this task

```
package lecture

class NumberProtector(private var _number: Int) {

  // The value of _number is not directly assemble from outside this class. The following two
  // methods must be used to change _number

  /**
    * Decreases _number by 3
    */
  def reduceNumber():Unit = {
    _number -= 3
  }

  /**
    * Increases _number by 1
    * @return the value of number after incrementing it
    */
  def number: Int = {
    this._number += 1
    this._number
  }

}
```

Interpretation v. Compilation

- Interpretation
  - Code is read and executed one statement at a time
- Compilation
  - Entire program is translated into another language
  - The translated code is interpreted

Interpretation

- Python and JavaScript are interpreted languages
- Run-time errors are common
    - Program runs, but crashes when a line with an error is interpreted

This program runs without error

```
class RuntimeErrorExample:

    def __init__(self, initial_state):
        self.state = initial_state

    def add_to_state(self, to_add):
        print("adding to state")
        self.state += to_add


if __name__ == '__main__':
    example_object = RuntimeErrorExample(5)
    example_object.add_to_state(10)
    print(example_object.state)
```

This program crashes with runtime error

```
class RuntimeErrorExample:

    def __init__(self, initial_state):
        self.state = initial_state

    def add_to_state(self, to_add):
        print("adding to state")
        self.state += to_add


if __name__ == '__main__':
    example_object = RuntimeErrorExample(5)
    example_object.add_to_state("ten")
    print(example_object.state)
```

Compilation

- Scala, Java, C, and C++ are compiled languages
- Compiler errors are common
  - Program fails to be converted into the target language
  - Program never runs
  - Can make debugging easier

Compiles and runs without error

```
class CompilerError(var state: Int) {

  def addToState(toAdd: Int): Unit ={
    this.state += toAdd
  }

}

object Main {
  def main(args: Array[String]): Unit = {
    val exampleObject = new CompilerError(5)
    exampleObject.addToState(10)
    println(exampleObject.state)
  }
}
```

Does not compile. Will not run any code

```
class CompilerError(var state: Int) {

  def addToState(toAdd: Int): Unit ={
    this.state += toAdd
  }

}

object Main {
  def main(args: Array[String]): Unit = {
    val exampleObject = new CompilerError(5)
    exampleObject.addToState("ten")
    println(exampleObject.state)
  }
}
```

Compilation

- Compilers produce efficient code
  - While translating, the compiler "fixes" our code whenever it can
  - Compilers are very smart!
- Can even fix some major errors

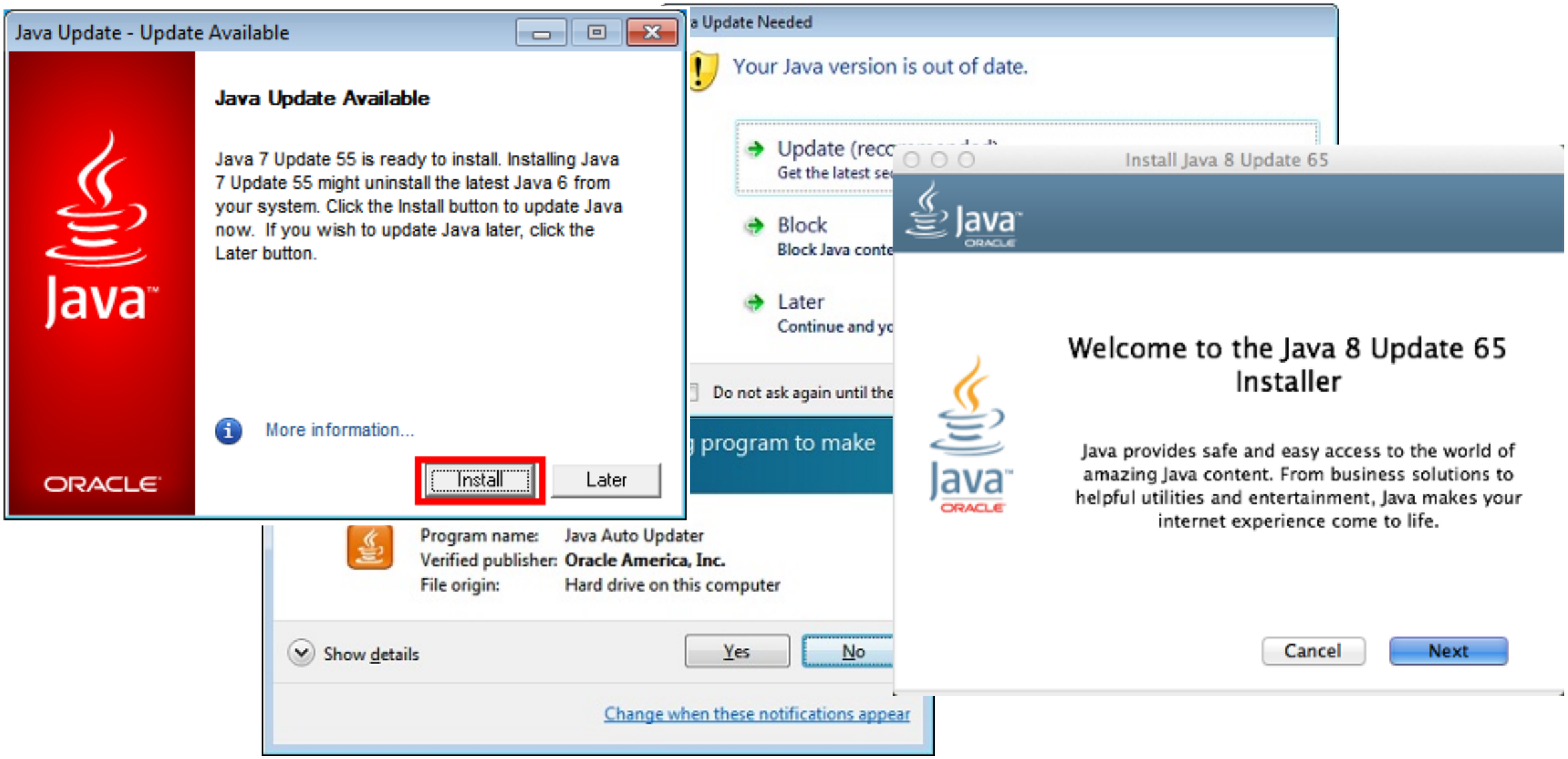
This code runs.. forever, but it doesn't overflow the stack. Thanks compiler!

```
object StackFlow {

  def recursiveFunction(n: Int): Int ={
    recursiveFunction(n)
  }

  def main(args: Array[String]): Unit = {
    recursiveFunction(1)
  }

}
```

***If you are interested in more details about this example, search for Tail Recursion**

Compilation - Scala

- Scala compiles to Java Byte Code
- Executed by the Java Virtual Machine (JVM)
  - Installed on Billions of devices!



More Memory Examples

- Multiple Objects on the heap

- Multiple frames on the stack

More Memory Examples

- Multiple Objects on the heap

```
def main(args: Array[String]): Unit =
{
  val bird: Bird = new Bird()
  var action: String = "Nothing"
  if(bird.inDanger()){
    val action: String = "Panic!"
  }else{
    val action: String = "Check bird"
  }
  println(action)
  val box: Box = new Box(bird, new
Bird())
  if(box.inDanger()){
    action = "Stay in the boat"
  }
  println(action)
}
```

```
class Bird {
  val timesHelpful: Int = 0
  var timesChecked: Int = 0

  def inDanger(): Boolean = {
    timesChecked += 1
    true
  }
}
```

```
class Box(val bird1: Bird, val bird2: Bird) {
  def inDanger(): Boolean = {
    bird1.inDanger() || bird2.inDanger()
  }
}
```

Index	Value
81078	args
81079	name:bird, value:42976
81080	
81081	
81082	
81083	
81084	
81085	

Index	Value
42976	Object of type Bird
42977	-timesHelpful value:0
42978	-timesChecked value:0

```
def main(args: Array[String]): Unit = {
  val bird: Bird = new Bird()
  var action: String = "Nothing"
  if(bird.inDanger()){
    val action: String = "Panic!"
  }else{
    val action: String = "Check bird"
  }
  println(action)
  val box: Box = new Box(bird, new Bird())
  if(box.inDanger()){
    action = "Stay in the boat"
  }
  println(action)
}
```

- Start program with command line args on the stack
- Ask OS for heap space for 1 Bird

```
class Bird {
  val timesHelpful: Int = 0
  var timesChecked: Int = 0

  def inDanger(): Boolean = {
    timesChecked += 1
    true
  }
}
```

```
class Box(val bird1: Bird, val bird2: Bird) {
  def inDanger(): Boolean = {
    bird1.inDanger() || bird2.inDanger()
  }
}
```

Index	Value
81078	args
81079	name:bird, value:42976
81080	name:action, value:"Nothing"
81081	
81082	
81083	
81084	
81085	

Index	Value
42976	Object of type Bird
42977	-timesHelpful value:0
42978	-timesChecked value:0

```
def main(args: Array[String]): Unit = {
  val bird: Bird = new Bird()
  var action: String = "Nothing"
  if(bird.inDanger()){
    val action: String = "Panic!"
  }else{
    val action: String = "Check bird"
  }
  println(action)
  val box: Box = new Box(bird, new Bird())
  if(box.inDanger()){
    action = "Stay in the boat"
  }
  println(action)
}
```

```
class Bird {
  val timesHelpful: Int = 0
  var timesChecked: Int = 0

  def inDanger(): Boolean = {
    timesChecked += 1
    true
  }
}
```

```
class Box(val bird1: Bird, val bird2: Bird) {
  def inDanger(): Boolean = {
    bird1.inDanger() || bird2.inDanger()
  }
}
```

- Declare variable action
- Add to stack

Index	Value
81078	args
81079	name:bird, value:42976
81080	name:action, value:"Nothing"
81081	<new stack frame>
81082	
81083	
81084	
81085	

Index	Value
42976	Object of type Bird
42977	-timesHelpful value:0
42978	-timesChecked value:0

```
def main(args: Array[String]): Unit = {
  val bird: Bird = new Bird()
  var action: String = "Nothing"
  if(bird.inDanger()){
    val action: String = "Panic!"
  }else{
    val action: String = "Check bird"
  }
  println(action)
  val box: Box = new Box(bird, new Bird())
  if(box.inDanger()){
    action = "Stay in the boat"
  }
  println(action)
}
```

```
class Bird {
  val timesHelpful: Int = 0
  var timesChecked: Int = 0

  def inDanger(): Boolean = {
    timesChecked += 1
    true
  }
}
```

```
class Box(val bird1: Bird, val bird2: Bird) {
  def inDanger(): Boolean = {
    bird1.inDanger() || bird2.inDanger()
  }
}
```

- Call method
- Create new stack frame
- increment timesChecked

Index	Value
81078	args
81079	name:bird, value:42976
81080	name:action, value:"Nothing"
81081	<if block>
81082	name:action, value:"Panic!"
81083	
81084	
81085	

Index	Value
42976	Object of type Bird
42977	-timesHelpful value:0
42978	-timesChecked value:1

```
def main(args: Array[String]): Unit = {
  val bird: Bird = new Bird()
  var action: String = "Nothing"
  if(bird.inDanger()){
    val action: String = "Panic!"
  }else{
    val action: String = "Check bird"
  }
  println(action)
  val box: Box = new Box(bird, new Bird())
  if(box.inDanger()){
    action = "Stay in the boat"
  }
  println(action)
}
```

```
class Bird {
  val timesHelpful: Int = 0
  var timesChecked: Int = 0

  def inDanger(): Boolean = {
    timesChecked += 1
    true
  }
}
```

```
class Box(val bird1: Bird, val bird2: Bird) {
  def inDanger(): Boolean = {
    bird1.inDanger() || bird2.inDanger()
  }
}
```

- Destroy stack frame
- Enter if block
- Declare value action

Index	Value
81078	args
81079	name:bird, value:42976
81080	name:action, value:"Nothing"
81081	
81082	
81083	
81084	
81085	

Index	Value
42976	Object of type Bird
42977	-timesHelpful value:0
42978	-timesChecked value:1

```
def main(args: Array[String]): Unit = {
  val bird: Bird = new Bird()
  var action: String = "Nothing"
  if(bird.inDanger()){
    val action: String = "Panic!"
  }else{
    val action: String = "Check bird"
  }
  println(action)
  val box: Box = new Box(bird, new Bird())
  if(box.inDanger()){
    action = "Stay in the boat"
  }
  println(action)
}
```

```
class Bird {
  val timesHelpful: Int = 0
  var timesChecked: Int = 0

  def inDanger(): Boolean = {
    timesChecked += 1
    true
  }
}
```

```
class Box(val bird1: Bird, val bird2: Bird) {
  def inDanger(): Boolean = {
    bird1.inDanger() || bird2.inDanger()
  }
}
```

- End of if block
- Destroy block and action

Index	Value
81078	args
81079	name:bird, value:42976
81080	name:action, value:"Nothing"
81081	
81082	
81083	
81084	
81085	

Index	Value
42976	Object of type Bird
42977	-timesHelpful value:0
42978	-timesChecked value:1

```
def main(args: Array[String]): Unit = {
  val bird: Bird = new Bird()
  var action: String = "Nothing"
  if(bird.inDanger()){
    val action: String = "Panic!"
  }else{
    val action: String = "Check bird"
  }
  println(action)
  val box: Box = new Box(bird, new Bird())
  if(box.inDanger()){
    action = "Stay in the boat"
  }
  println(action)
}
```

- Print the string "Nothing"

```
class Bird {
  val timesHelpful: Int = 0
  var timesChecked: Int = 0

  def inDanger(): Boolean = {
    timesChecked += 1
    true
  }
}
```

```
class Box(val bird1: Bird, val bird2: Bird) {
  def inDanger(): Boolean = {
    bird1.inDanger() || bird2.inDanger()
  }
}
```

Index	Value
81078	args
81079	name:bird, value:42976
81080	name:action, value:"Nothing"
81081	
81082	
81083	
81084	
81085	

```
def main(args: Array[String]): Unit = {
  val bird: Bird = new Bird()
  var action: String = "Nothing"
  if(bird.inDanger()){
    val action: String = "Panic!"
  }else{
    val action: String = "Check bird"
  }
  println(action)
  val box: Box = new Box(bird, new Bird())
  if(box.inDanger()){
    action = "Stay in the boat"
  }
  println(action)
}
```

- Ask OS for heap memory for
  - Another Bird
  - A Box

Index	Value
42976	Object of type Bird
42977	-timesHelpful value:0
42978	-timesChecked value:1

Index	Value
27177	Object of type Bird
27178	-timesHelpful value:0
27179	-timesChecked value:0

Index	Value
59683	Object of type Box
59684	-bird1 value:42976
59685	-bird2 value:27177

```
class Bird {
  val timesHelpful: Int = 0
  var timesChecked: Int = 0

  def inDanger(): Boolean = {
    timesChecked += 1
    true
  }
}
```

```
class Box(val bird1: Bird, val bird2: Bird) {
  def inDanger(): Boolean = {
    bird1.inDanger() || bird2.inDanger()
  }
}
```

Index	Value
81078	args
81079	name:bird, value:42976
81080	name:action, value:"Nothing"
81081	name:box, value:59683
81082	
81083	
81084	
81085	

```
def main(args: Array[String]): Unit = {
  val bird: Bird = new Bird()
  var action: String = "Nothing"
  if(bird.inDanger()){
    val action: String = "Panic!"
  }else{
    val action: String = "Check bird"
  }
  println(action)
  val box: Box = new Box(bird, new Bird())
  if(box.inDanger()){
    action = "Stay in the boat"
  }
  println(action)
}
```

- Store reference to Box in value box
- main method has no direct reference to the second Bird

Index	Value
42976	Object of type Bird
42977	-timesHelpful value:0
42978	-timesChecked value:1

Index	Value
27177	Object of type Bird
27178	-timesHelpful value:0
27179	-timesChecked value:0

Index	Value
59683	Object of type Box
59684	-bird1 value:42976
59685	-bird2 value:27177

```
class Bird {
  val timesHelpful: Int = 0
  var timesChecked: Int = 0

  def inDanger(): Boolean = {
    timesChecked += 1
    true
  }
}
```

```
class Box(val bird1: Bird, val bird2: Bird) {
  def inDanger(): Boolean = {
    bird1.inDanger() || bird2.inDanger()
  }
}
```

Index	Value
81078	args
81079	name:bird, value:42976
81080	name:action, value:"Nothing"
81081	name:box, value:59683
81082	<new stack frame box.inDanger>
81083	<new stack frame bird1.inDanger>
81084	
81085	

```
def main(args: Array[String]): Unit = {
  val bird: Bird = new Bird()
  var action: String = "Nothing"
  if(bird.inDanger()){
    val action: String = "Panic!"
  }else{
    val action: String = "Check bird"
  }
  println(action)
  val box: Box = new Box(bird, new Bird())
  if(box.inDanger()){
    action = "Stay in the boat"
  }
  println(action)
}
```

- Create stack frame for box.inDanger call
- Create stack frame for bird1.inDanger

Index	Value
42976	Object of type Bird
42977	-timesHelpful value:0
42978	-timesChecked value:1

Index	Value
27177	Object of type Bird
27178	-timesHelpful value:0
27179	-timesChecked value:0

Index	Value
59683	Object of type Box
59684	-bird1 value:42976
59685	-bird2 value:27177

```
class Bird {
  val timesHelpful: Int = 0
  var timesChecked: Int = 0

  def inDanger(): Boolean = {
    timesChecked += 1
    true
  }
}
```

```
class Box(val bird1: Bird, val bird2: Bird) {
  def inDanger(): Boolean = {
    bird1.inDanger() || bird2.inDanger()
  }
}
```

Index	Value
81078	args
81079	name:bird, value:42976
81080	name:action, value:"Nothing"
81081	name:box, value:59683
81082	<new stack frame box.inDanger>
81083	<new stack frame bird2.inDanger>
81084	
81085	

```
def main(args: Array[String]): Unit = {
  val bird: Bird = new Bird()
  var action: String = "Nothing"
  if(bird.inDanger()){
    val action: String = "Panic!"
  }else{
    val action: String = "Check bird"
  }
  println(action)
  val box: Box = new Box(bird, new Bird())
  if(box.inDanger()){
    action = "Stay in the boat"
  }
  println(action)
}
```

- Destroy stack frame for bird1.inDanger
- Create stack frame for bird2.inDanger

Index	Value
42976	Object of type Bird
42977	-timesHelpful value:0
42978	-timesChecked value:2

Index	Value
27177	Object of type Bird
27178	-timesHelpful value:0
27179	-timesChecked value:0

Index	Value
59683	Object of type Box
59684	-bird1 value:42976
59685	-bird2 value:27177

```
class Bird {
  val timesHelpful: Int = 0
  var timesChecked: Int = 0

  def inDanger(): Boolean = {
    timesChecked += 1
    true
  }
}
```

```
class Box(val bird1: Bird, val bird2: Bird) {
  def inDanger(): Boolean = {
    bird1.inDanger() || bird2.inDanger()
  }
}
```

Index	Value
81078	args
81079	name:bird, value:42976
81080	name:action, value:"Nothing"
81081	name:box, value:59683
81082	<if block>
81083	
81084	
81085	

```
def main(args: Array[String]): Unit = {
  val bird: Bird = new Bird()
  var action: String = "Nothing"
  if(bird.inDanger()){
    val action: String = "Panic!"
  }else{
    val action: String = "Check bird"
  }
  println(action)
  val box: Box = new Box(bird, new Bird())
  if(box.inDanger()){
    action = "Stay in the boat"
  }
  println(action)
}
```

- Destroy stack frame for bird2.inDanger
- Enter if block
- Find action in outer scope

Index	Value
42976	Object of type Bird
42977	-timesHelpful value:0
42978	-timesChecked value:2

Index	Value
27177	Object of type Bird
27178	-timesHelpful value:0
27179	-timesChecked value:1

Index	Value
59683	Object of type Box
59684	-bird1 value:42976
59685	-bird2 value:27177

```
class Bird {
  val timesHelpful: Int = 0
  var timesChecked: Int = 0

  def inDanger(): Boolean = {
    timesChecked += 1
    true
  }
}
```

```
class Box(val bird1: Bird, val bird2: Bird) {
  def inDanger(): Boolean = {
    bird1.inDanger() || bird2.inDanger()
  }
}
```

Index	Value
81078	args
81079	name:bird, value:42976
81080	name:action, value:"Stay in the boat"
81081	name:box, value:59683
81082	<if block>
81083	
81084	
81085	

```
def main(args: Array[String]): Unit = {
  val bird: Bird = new Bird()
  var action: String = "Nothing"
  if(bird.inDanger()){
    val action: String = "Panic!"
  }else{
    val action: String = "Check bird"
  }
  println(action)
  val box: Box = new Box(bird, new Bird())
  if(box.inDanger()){
    action = "Stay in the boat"
  }
  println(action)
}
```

- Destroy stack frame for bird2.inDanger
- Enter if block
- Find action in outer scope

Index	Value
42976	Object of type Bird
42977	-timesHelpful value:0
42978	-timesChecked value:2

Index	Value
27177	Object of type Bird
27178	-timesHelpful value:0
27179	-timesChecked value:1

Index	Value
59683	Object of type Box
59684	-bird1 value:42976
59685	-bird2 value:27177

```
class Bird {
  val timesHelpful: Int = 0
  var timesChecked: Int = 0

  def inDanger(): Boolean = {
    timesChecked += 1
    true
  }
}
```

```
class Box(val bird1: Bird, val bird2: Bird) {
  def inDanger(): Boolean = {
    bird1.inDanger() || bird2.inDanger()
  }
}
```

Index	Value
81078	args
81079	name:bird, value:42976
81080	name:action, value:"Stay in the boat"
81081	name:box, value:59683
81082	
81083	
81084	
81085	

```
def main(args: Array[String]): Unit = {
  val bird: Bird = new Bird()
  var action: String = "Nothing"
  if(bird.inDanger()){
    val action: String = "Panic!"
  }else{
    val action: String = "Check bird"
  }
  println(action)
  val box: Box = new Box(bird, new Bird())
  if(box.inDanger()){
    action = "Stay in the boat"
  }
  println(action)
}
```

- Destroy if block
- print "Stay in the boat"

Index	Value
42976	Object of type Bird
42977	-timesHelpful value:0
42978	-timesChecked value:2

Index	Value
27177	Object of type Bird
27178	-timesHelpful value:0
27179	-timesChecked value:1

Index	Value
59683	Object of type Box
59684	-bird1 value:42976
59685	-bird2 value:27177

```
class Bird {
  val timesHelpful: Int = 0
  var timesChecked: Int = 0

  def inDanger(): Boolean = {
    timesChecked += 1
    true
  }
}
```

```
class Box(val bird1: Bird, val bird2: Bird) {
  def inDanger(): Boolean = {
    bird1.inDanger() || bird2.inDanger()
  }
}
```

Index	Value
81078	
81079	
81080	
81081	
81082	
81083	
81084	
81085	

Index	Value
42976	
42977	
42978	

Index	Value
27177	
27178	
27179	

Index	Value
59683	
59684	
59685	

```
def main(args: Array[String]): Unit = {
  val bird: Bird = new Bird()
  var action: String = "Nothing"
  if(bird.inDanger()){
    val action: String = "Panic!"
  }else{
    val action: String = "Check bird"
  }
  println(action)
  val box: Box = new Box(bird, new Bird())
  if(box.inDanger()){
    action = "Stay in the boat"
  }
  println(action)
}
```

```
class Bird {
  val timesHelpful: Int = 0
  var timesChecked: Int = 0

  def inDanger(): Boolean = {
    timesChecked += 1
    true
  }
}
```

```
class Box(val bird1: Bird, val bird2: Bird) {
  def inDanger(): Boolean = {
    bird1.inDanger() || bird2.inDanger()
  }
}
```

- Program ends
- Free all memory

More Memory Examples

- Multiple frames on the stack

```
def computeGeometricSum(n: Int): Int ={
  if(n>0) {
    var result: Int = computeGeometricSum(n - 1)
    result += n
    result
  }else{
    0
  }
}

def main(args: Array[String]): Unit = {
  val result: Int = computeGeometricSum(3)
  println(result)
}
```

Recursive Example

```
def computeGeometricSum(n: Int): Int ={
  if(n>0) {
    var result: Int = computeGeometricSum(n - 1)
    result += n
    result
  }else{
    0
  }
}

def main(args: Array[String]): Unit = {
  val result: Int = computeGeometricSum(3)
  println(result)
}
```

- Call function
- Create new stack frame

Index	Value
96437	args
96438	<new stack frame>
96439	name:n, value:3
96440	
96441	
96442	
96443	
96444	
96445	
96446	
96447	
96448	
96449	
96450	<Used by another program>
96451	<Used by another program>

Recursive Example

```
def computeGeometricSum(n: Int): Int ={
  if(n>0) {
    var result: Int = computeGeometricSum(n - 1)
    result += n
    result
  }else{
    0
  }
}

def main(args: Array[String]): Unit = {
  val result: Int = computeGeometricSum(3)
  println(result)
}
```

- Enter if block
- Call function again
- Create new stack frame

Index	Value
96437	args
96438	<new stack frame>
96439	name:n, value:3
96440	<if block>
96441	<new stack frame>
96442	name:n, value:2
96443	
96444	
96445	
96446	
96447	
96448	
96449	
96450	<Used by another program>
96451	<Used by another program>

Recursive Example

```
def computeGeometricSum(n: Int): Int ={
  if(n>0) {
    var result: Int = computeGeometricSum(n - 1)
    result += n
    result
  }else{
    0
  }
}

def main(args: Array[String]): Unit = {
  val result: Int = computeGeometricSum(3)
  println(result)
}
```

- In next function call, conditional true
- New if block
- New stack frame

Index	Value
96437	args
96438	<new stack frame>
96439	name:n, value:3
96440	<if block>
96441	<new stack frame>
96442	name:n, value:2
96443	<if block>
96444	<new stack frame>
96445	name:n, value:1
96446	
96447	
96448	
96449	
96450	<Used by another program>
96451	<Used by another program>

Recursive Example

```
def computeGeometricSum(n: Int): Int ={
  if(n>0) {
    var result: Int = computeGeometricSum(n - 1)
    result += n
    result
  }else{
    0
  }
}

def main(args: Array[String]): Unit = {
  val result: Int = computeGeometricSum(3)
  println(result)
}
```

- Repeat, repeat
- Many variables named n on the stack
- Each is in different frame so it's ok

Index	Value
96437	args
96438	<new stack frame>
96439	name:n, value:3
96440	<if block>
96441	<new stack frame>
96442	name:n, value:2
96443	<if block>
96444	<new stack frame>
96445	name:n, value:1
96446	<if block>
96447	<new stack frame>
96448	name:n, value:0
96449	
96450	<Used by another program>
96451	<Used by another program>

Recursive Example

```
def computeGeometricSum(n: Int): Int ={
  if(n>0) {
    var result: Int = computeGeometricSum(n - 1)
    result += n
    result
  }else{
    0
  }
}

def main(args: Array[String]): Unit = {
  val result: Int = computeGeometricSum(3)
  println(result)
}
```

- Conditional finally false
- return 0

Index	Value
96437	args
96438	<new stack frame>
96439	name:n, value:3
96440	<if block>
96441	<new stack frame>
96442	name:n, value:2
96443	<if block>
96444	<new stack frame>
96445	name:n, value:1
96446	<if block>
96447	<new stack frame>
96448	name:n, value:0
96449	
96450	<Used by another program>
96451	<Used by another program>

Recursive Example

```
def computeGeometricSum(n: Int): Int ={
  if(n>0) {
    var result: Int = computeGeometricSum(n - 1)
    result += n
    result
  }else{
    0
  }
}

def main(args: Array[String]): Unit = {
  val result: Int = computeGeometricSum(3)
  println(result)
}
```

- Assign return value to result

Index	Value
96437	args
96438	<new stack frame>
96439	name:n, value:3
96440	<if block>
96441	<new stack frame>
96442	name:n, value:2
96443	<if block>
96444	<new stack frame>
96445	name:n, value:1
96446	<if block>
96447	name:result, value:0
96448	
96449	
96450	<Used by another program>
96451	<Used by another program>

Recursive Example

```
def computeGeometricSum(n: Int): Int ={
  if(n>0) {
    var result: Int = computeGeometricSum(n - 1)
    result += n
    result
  }else{
    0
  }
}

def main(args: Array[String]): Unit = {
  val result: Int = computeGeometricSum(3)
  println(result)
}
```

- Add value of the n in this stack frame to result
- result is the last expression and is returned

Index	Value
96437	args
96438	<new stack frame>
96439	name:n, value:3
96440	<if block>
96441	<new stack frame>
96442	name:n, value:2
96443	<if block>
96444	<new stack frame>
96445	name:n, value:1
96446	<if block>
96447	name:result, value:1
96448	
96449	
96450	<Used by another program>
96451	<Used by another program>

Recursive Example

```
def computeGeometricSum(n: Int): Int ={
  if(n>0) {
    var result: Int = computeGeometricSum(n - 1)
    result += n
    result
  }else{
    0
  }
}

def main(args: Array[String]): Unit = {
  val result: Int = computeGeometricSum(3)
  println(result)
}
```

- Return to function call from previous frame
- Store return value in result

Index	Value
96437	args
96438	<new stack frame>
96439	name:n, value:3
96440	<if block>
96441	<new stack frame>
96442	name:n, value:2
96443	<if block>
96444	name:result, value:1
96445	
96446	
96447	
96448	
96449	
96450	<Used by another program>
96451	<Used by another program>

Recursive Example

```
def computeGeometricSum(n: Int): Int ={
  if(n>0) {
    var result: Int = computeGeometricSum(n - 1)
    result += n
    result
  }else{
    0
  }
}

def main(args: Array[String]): Unit = {
  val result: Int = computeGeometricSum(3)
  println(result)
}
```

- Add value of n from this frame..
- Repeat

Index	Value
96437	args
96438	<new stack frame>
96439	name:n, value:3
96440	<if block>
96441	<new stack frame>
96442	name:n, value:2
96443	<if block>
96444	name:result, value:3
96445	
96446	
96447	
96448	
96449	
96450	<Used by another program>
96451	<Used by another program>

Recursive Example

```
def computeGeometricSum(n: Int): Int ={
  if(n>0) {
    var result: Int = computeGeometricSum(n - 1)
    result += n
    result
  }else{
    0
  }
}

def main(args: Array[String]): Unit = {
  val result: Int = computeGeometricSum(3)
  println(result)
}
```

- Add value of n from this frame..
- Repeat

Index	Value
96437	args
96438	<new stack frame>
96439	name:n, value:3
96440	<if block>
96441	name:result, value:3
96442	
96443	
96444	
96445	
96446	
96447	
96448	
96449	
96450	<Used by another program>
96451	<Used by another program>

Recursive Example

```
def computeGeometricSum(n: Int): Int ={
  if(n>0) {
    var result: Int = computeGeometricSum(n - 1)
    result += n
    result
  }else{
    0
  }
}

def main(args: Array[String]): Unit = {
  val result: Int = computeGeometricSum(3)
  println(result)
}
```

- And repeat..
- Imagine if the original input were 1000
  - This is why we use computers

Index	Value
96437	args
96438	<new stack frame>
96439	name:n, value:3
96440	<if block>
96441	name:result, value:6
96442	
96443	
96444	
96445	
96446	
96447	
96448	
96449	
96450	<Used by another program>
96451	<Used by another program>

Recursive Example

```
def computeGeometricSum(n: Int): Int ={
  if(n>0) {
    var result: Int = computeGeometricSum(n - 1)
    result += n
    result
  }else{
    0
  }
}

def main(args: Array[String]): Unit = {
  val result: Int = computeGeometricSum(3)
  println(result)
}
```

- Value result in main method gets the last return value

Index	Value
96437	args
96438	name:result, value:6
96439	
96440	
96441	
96442	
96443	
96444	
96445	
96446	
96447	
96448	
96449	
96450	<Used by another program>
96451	<Used by another program>

Recursive Example

```
def computeGeometricSum(n: Int): Int ={
  if(n>0) {
    var result: Int = computeGeometricSum(n - 1)
    result += n
    result
  }else{
    0
  }
}

def main(args: Array[String]): Unit = {
  val result: Int = computeGeometricSum(3)
  println(result)
}
```

- print 6

Index	Value
96437	args
96438	name:result, value:6
96439	
96440	
96441	
96442	
96443	
96444	
96445	
96446	
96447	
96448	
96449	
96450	<Used by another program>
96451	<Used by another program>

Recursive Example

```
def computeGeometricSum(n: Int): Int ={
  if(n>0) {
    var result: Int = computeGeometricSum(n - 1)
    result += n
    result
  }else{
    0
  }
}

def main(args: Array[String]): Unit = {
  val result: Int = computeGeometricSum(3)
  println(result)
}
```

- Free memory

Index	Value
96437	
96438	
96439	
96440	
96441	
96442	
96443	
96444	
96445	
96446	
96447	
96448	
96449	
96450	<Used by another program>
96451	<Used by another program>

More Memory Examples

- We were close to the end of the stack on that example
- What if this were our code?

```
def computeGeometricSum(n: Int): Int ={
  var result: Int = computeGeometricSum(n - 1)
  result += n
  result
}

def main(args: Array[String]): Unit = {
  val result: Int = computeGeometricSum(3)
  println(result)
}
```

Recursive Example

```
def computeGeometricSum(n: Int): Int ={
  var result: Int = computeGeometricSum(n - 1)
  result += n
  result
}

def main(args: Array[String]): Unit = {
  val result: Int = computeGeometricSum(3)
  println(result)
}
```

- At this point the other program was going to return 0 and return back up the stack

Index	Value
96437	args
96438	<new stack frame>
96439	name:n, value:3
96440	<if block>
96441	<new stack frame>
96442	name:n, value:2
96443	<if block>
96444	<new stack frame>
96445	name:n, value:1
96446	<if block>
96447	<new stack frame>
96448	name:n, value:0
96449	
96450	<Used by another program>
96451	<Used by another program>

Recursive Example

```
def computeGeometricSum(n: Int): Int ={
  var result: Int = computeGeometricSum(n - 1)
  result += n
  result
}

def main(args: Array[String]): Unit = {
  val result: Int = computeGeometricSum(3)
  println(result)
}
```

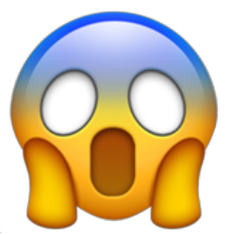
- This program keeps adding frames to the stack

Index	Value
96437	args
96438	<new stack frame>
96439	name:n, value:3
96440	<new stack frame>
96441	name:n, value:2
96442	<new stack frame>
96443	name:n, value:1
96444	<new stack frame>
96445	name:n, value:0
96446	<new stack frame>
96447	name:n, value:-1
96448	<new stack frame>
96449	name:n, value:-2
96450	<Used by another program>
96451	<Used by another program>

Recursive Example

```
def computeGeometricSum(n: Int): Int ={
  var result: Int = computeGeometricSum(n - 1)
  result += n
  result
}

def main(args: Array[String]): Unit = {
  val result: Int = computeGeometricSum(3)
  println(result)
}
```

- STACK OVERFLOW
- Program crashes



Index	Value
96437	args
96438	<new stack frame>
96439	name:n, value:3
96440	<new stack frame>
96441	name:n, value:2
96442	<new stack frame>
96443	name:n, value:1
96444	<new stack frame>
96445	name:n, value:0
96446	<new stack frame>
96447	name:n, value:-1
96448	<new stack frame>
96449	name:n, value:-2
96450	<new stack frame> <Used by another program>
96451	name:n, value:-3 <Used by another program>

Lecture Question

Question: In a package named lecture, write an object named ChangeState with a method named setToZero that takes an object of type NumberProtector as a parameter and returns Unit. The setToZero method should change the input such that its _number state variable has a value of 0.

Do not change the NumberProtector class. This class has a private variable _number which means you cannot change its value directly. You are given two methods, both of which have side-effects that change _number, that you can call to accomplish this task

```
package lecture

class NumberProtector(private var _number: Int) {

  // The value of _number is not directly assemble from outside this class. The following two
  // methods must be used to change _number

  /**
    * Decreases _number by 3
    */
  def reduceNumber():Unit = {
    _number -= 3
  }

  /**
    * Increases _number by 1
    * @return the value of number after incrementing it
    */
  def number: Int = {
    this._number += 1
    this._number
  }

}
```