Professional Programming in Java

Session: 13

Advanced Concurrency and Parallelism

Objectives

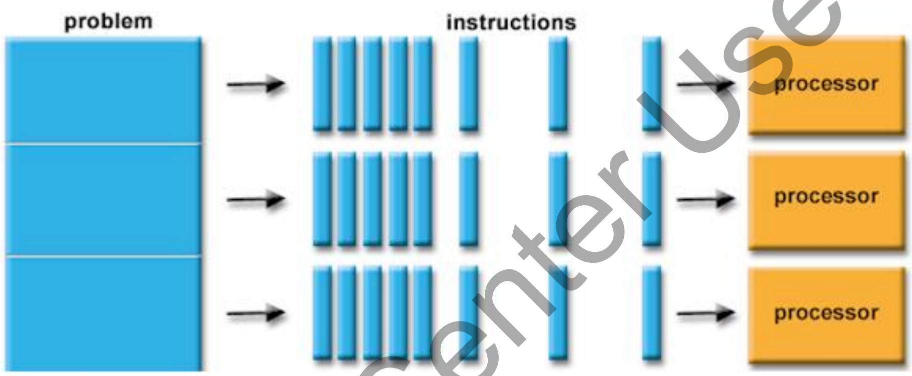
- Explain the enhancements of `java.util.concurrency` package
- Describe atomic operations with the new set of classes of the `java.util.concurrent.atomic` package
- Explain the `StampedLock` class to implement locks
- Explain the new features of `ForkJoinPool`
- Define parallel streams
- Describe parallel sorting of arrays
- Identify recursive actions of the fork/join framework

Introduction [1-2]

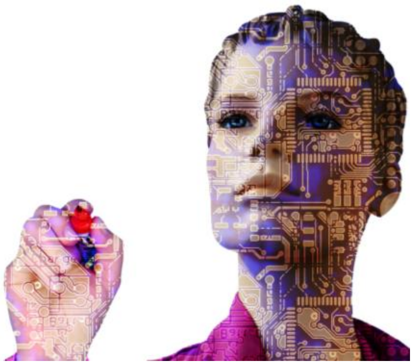
- Similar to tasks that run in parallel in real world, parallelization refers to the process of taking a serial code that runs on a single CPU and spreading the work across multiple CPUs.

Introduction [2-2]

- An important enhancement in Java programming language is parallelization.



- Parallelization is used to make applications run efficiently.
- Challenges faced by parallelism are addressed through work stealing strategy.
- The Fork-Join framework in Java meets the work stealing requirements through recursive job partitioning.



New Enhancements in the java.util.concurrent Package

- Many new enhancements have been made to the `java.util.concurrency` package

Classes

- `CompletableFuture`
- `CountedCompletor`
- `ConcurrentHashMap.KeySetView`

Interface

- `CompletableFuture.AsynchronousCompletionTask`
- `CompletionStage<T>`

Exception

- `CompletionException`

CompletableFuture Class [1-2]

- The class implements the `CompletionStage` and the `Future` interface to simplify asynchronous operations.
- An existing `Future` interface represents the result of an asynchronous computation.
- The `get()` method of the `Future` interface returns the result of the computation.
- The methods of the `CompletableFuture` class run asynchronously without stopping the program execution.

CompletableFuture Class [2-2]

Methods of the `CompletableFuture` Class

Method	Description
`supplyAsync()`	Accepts a `Supplier` object that contains code to be executed asynchronously
`thenApply()`	Returns a new `CompletableFuture` object that is executed with the result of the completed stage, provided the current stage completes normally
`join()`	Returns the result when the current asynchronous computation completes, or throws an exception of type `CompletionException`
`thenAccept()`	Accepts a `Consumer` object
`whenComplete()`	Uses `BiConsumer` as an argument
`getNow()`	Sets the value passed to it as the result if the calling completion stage is not completed

CountedCompletor Class [1-8]

- The class extends `ForkJoinTask` to complete an action performed when triggered, provided there are no pending actions.

The tryComplete() method checks if the pending count is nonzero, and if so, decrements the count.

Or, the tryComplete() method invokes the onCompletion(CountedCompleter) method and attempts to complete the task, and if successful, marks this task as complete.

The compute() method performs the main computation and invokes the tryComplete() method.

CountedCompletor Class [2-8]

- The `CountedCompletor` class may override the following methods:

Method	Description
`onCompletion(CountedCompleter)`	To perform some action upon normal completion.
`onExceptionalCompletion(Throwable, CountedCompleter)`	To perform some action when an exception is thrown.

CountedCompletor Class [3-8]

- The `CountedCompleter<Void>` class is declared as `CountedCompleter<Void>` when the class does not generate results.
- The class returns `null` as a value.
- The class must be overridden to yield a value.

CountedCompletor Class [4-8]

- The code demonstrates the implementation of the `CountedCompleter` class.

Code Snippet

```
package com.training.demo.countedcompletor;
import java.util.ArrayList;
import java.util.concurrent.ConcurrentLinkedQueue;
import java.util.concurrent.CountedCompleter;
import java.util.concurrent.ExecutionException;
import java.util.concurrent.ForkJoinPool;

public class CountedCompletorDemo {
    static class NumberComputator extends
    CountedCompleter<Void> {
    final ConcurrentLinkedQueue<String>
    concurrentLinkedQueue;
    final int start;
    final int end;
```

CountedCompletor Class [5-8]

```
NumberComputator(ConcurrentLinkedQueue<String>
concurrentLinkedQueue, int start, int end) {
this(concurrentLinkedQueue, start, end, null);
}
  NumberComputator(ConcurrentLinkedQueue<String>
  concurrentLinkedQueue, int start, int end,
  NumberComputator parent) {
  super(parent);
  this.concurrentLinkedQueue = concurrentLinkedQueue;
  this.start = start;
  this.end = end;
}
  @Override
  public void compute() {
  if (end - start < 5) {
  String s = Thread.currentThread().getName();
  for (int i = start; i < end; i++) {
  concurrentLinkedQueue.add(String.format("Iteration
  number: {%d} performed by thread {%s}", i, s));
```

CountedCompletor Class [6-8]

```
}
propagateCompletion();
} else {
int mid = (end + start) / 2;
NumberComputator subTaskA = new
NumberComputator(concurrentLinkedQueue, start,
mid, this);
NumberComputator subTaskB = new
NumberComputator(concurrentLinkedQueue, mid, end,
this);
setPendingCount(1);
subTaskA.fork();
subTaskB.compute();
}
}
}
public static void main(String[] args) throws
   ExecutionException, InterruptedException {
   ConcurrentLinkedQueue<String> linkedQueue = new
```

CountedCompletor Class [7-8]

```
        ConcurrentLinkedQueue<>();
        NumberComputator numberComputator = new
        ForkJoinPool.commonPool().invoke(numberComputator);
        ArrayList<String> list = new
        ArrayList<>(linkedQueue);
        for (String listItem : list) {
        System.out.println(" " + listItem);
      }
    }
}
```

Following is the output of the code:

Output - CountedCompletorDemo (run)

```
run:
Iteration number: {44} performed by thread {ForkJoinPool.commonPool-worker-2}
Iteration number: {53} performed by thread {ForkJoinPool.commonPool-worker-3}
Iteration number: {97} performed by thread {main}
Iteration number: {54} performed by thread {ForkJoinPool.commonPool-worker-3}
Iteration number: {45} performed by thread {ForkJoinPool.commonPool-worker-2}
Iteration number: {98} performed by thread {main}
Iteration number: {46} performed by thread {ForkJoinPool.commonPool-worker-2}
Iteration number: {99} performed by thread {main}
Iteration number: {55} performed by thread {ForkJoinPool.commonPool-worker-3}
Iteration number: {51} performed by thread {ForkJoinPool.commonPool-worker-3}
Iteration number: {42} performed by thread {ForkJoinPool.commonPool-worker-2}
Iteration number: {95} performed by thread {main}
Iteration number: {43} performed by thread {ForkJoinPool.commonPool-worker-2}
Iteration number: {52} performed by thread {ForkJoinPool.commonPool-worker-3}
Iteration number: {96} performed by thread {main}
Iteration number: {62} performed by thread {ForkJoinPool.commonPool-worker-1}
Iteration number: {38} performed by thread {ForkJoinPool.commonPool-worker-2}
Iteration number: {63} performed by thread {ForkJoinPool.commonPool-worker-1}
Iteration number: {47} performed by thread {ForkJoinPool.commonPool-worker-3}
Iteration number: {39} performed by thread {ForkJoinPool.commonPool-worker-2}
```

ConcurrentHashMap.KeySetView Class [1-3]

- Provides a view of the keys contained in the class
- Implements the Set interface and thus, can access the keys as a Set object
- The Set object and the `ConcurrentHashMap` object have a bi-directional relationship

ConcurrentHashMap.KeySetView Class [2-3]

- The code demonstrates the method to access the keys of a `ConcurrentHashMap` as a `Set`.

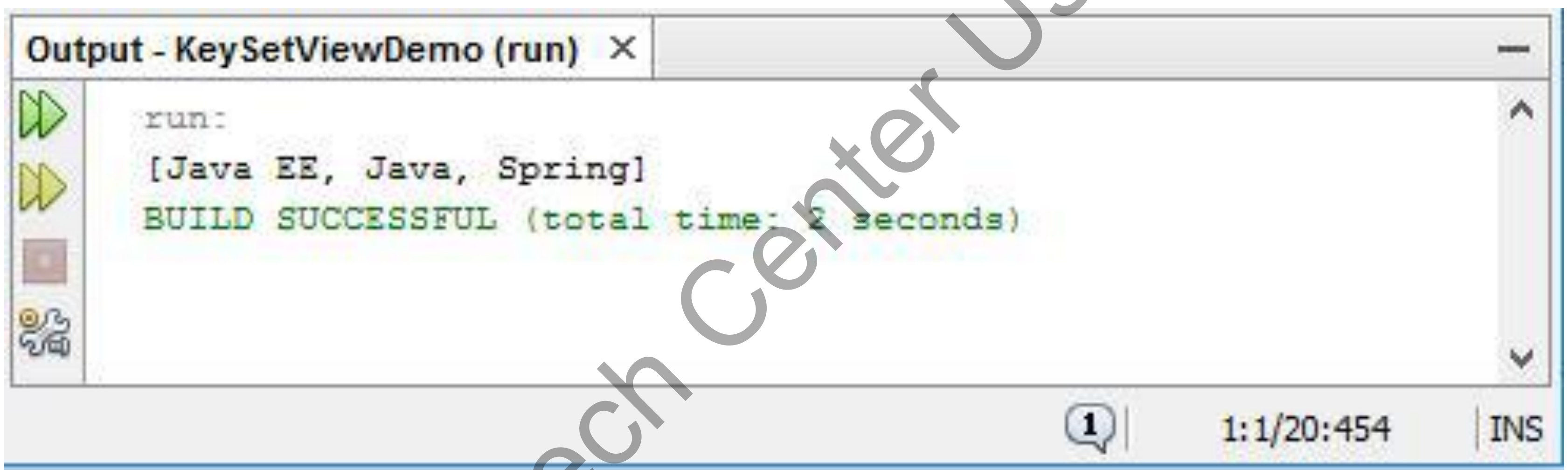
Code Snippet

```
package com.training.demo.kesysetview;
import java.util.Iterator;
import java.util.Map;
import java.util.Set;
import
java.util.concurrent.ConcurrentHashMap;

public class KeySetViewDemo {
      public static void main(String[] args) {
      Map<String,String> map =
           new ConcurrentHashMap<>();
     map.put("Spring", "Spring");
     Set keySet = map.keySet();
     System.out.println(keySet);
   }
}
```

ConcurrentHashMap.KeySetView Class [3-3]

Following is the output of the code:



Atomic Operations and Locks [1-15]

New classes in the `java.util.concurrent.atomic` package

- `LongAccumulator`: Maintains a long running value updated using a supplied function
- `LongAdder`: Maintains an initially zero long sum
- `DoubleAccumulator`: Maintains a double running value updated using a supplied function
- `DoubleAdder`: Maintains an initially zero double sum

Atomic Operations and Locks [2-15]

- The code demonstrates the use of the `LongAdder` and `DoubleAdder` atomic operation classes.

Code Snippet

```
package com.training.demo.atomicoperation;
import java.util.concurrent.atomic.DoubleAdder;
import java.util.concurrent.atomic.LongAdder;
public class AtomicOperationClassDemo {
    private final LongAdder longAdder;
    private final DoubleAdder doubleAdder;

    public AtomicOperationClassDemo(LongAdder
    longAdder, DoubleAdder doubleAdder)
     {
       this.longAdder = longAdder;
       this.doubleAdder = doubleAdder;
     }
```

Atomic Operations and Locks [3-15]

```
public void incrementLong() {
   longAdder.increment();
}
public long getLongCounter() {
  return longAdder.longValue();
}
public void addDouble(int doubleValue) {
  doubleAdder.add(doubleValue);
}
public double getSumAsDouble() {
  return doubleAdder.doubleValue();
}
public static void main(String[] args) {
    AtomicOperationClassDemo
    atomicOperationClassDemo1 = new
    AtomicOperationClassDemo(new LongAdder(), new
    DoubleAdder());
```

Atomic Operations and Locks [4-15]

```
        System.out.println("-----Long Counter-----");
        for (int i = 0; i < 10; i++) {
          atomicOperationClassDemo1.incrementLong();
          System.out.println("Long Counter " +
          atomicOperationClassDemo1.getLongCounter());
        }
        System.out.println("-----Double Sum-----");
        for (int j = 0; j < 10; j++) {
            atomicOperationClassDemo1.addDouble(j);
            System.out.println("Double Sum " +
            atomicOperationClassDemo1.getSumAsDouble());
        }
    }
}
```

Atomic Operations and Locks [5-15]

Following is the output of the code:

Output - AtomicOperationClassDemo (run)

```
run:
-----Long Counter-----
Long Counter 1
Long Counter 2
Long Counter 3
Long Counter 4
Long Counter 5
Long Counter 6
Long Counter 7
Long Counter 8
Long Counter 9
Long Counter 10
-----Double Sum-----
Double Sum 0.0
Double Sum 1.0
Double Sum 3.0
Double Sum 6.0
Double Sum 10.0
Double Sum 15.0
Double Sum 21.0
Double Sum 28.0
Double Sum 36.0
Double Sum 45.0
BUILD SUCCESSFUL (total time: 1 second)
```

Atomic Operations and Locks [6-15]

- The `StampedLock` class of the `java.util.concurrent.locks` package enables to implement locks.
- The class returns a `long` number, also known as stamp, when a lock is granted.
- The stamp is used either to release a lock or to check if the lock is valid.
- The lock supports a new lock mode known as optimistic locking.

Atomic Operations and Locks [7-15]

Implements lock with three modes for read/write access

Writing

- This mode is achieved through the `writeLock()` method.
- The `writeLock()` method returns a stamp to release a lock.
- This mode is supported by timed and untimed versions of `tryWriteLock()` method.
- When a thread is locked in write mode then no read locks can be obtained.

Implements lock with three modes for read/write access

Reading

- This mode is achieved through the `readLock()` method.
- The `readLock()` method returns a stamp to release a lock.
- This mode is supported by timed and untimed versions of `tryReadLock()` method.

Implements lock with three modes for read/write access

Optimistic Reading

- This mode is achieved through the `tryOptimisticRead()` and `validate(long)` methods.
- The `tryOptimisticRead()` returns a non-zero stamp only if the lock in not held in the write mode.
- The `validate(long)` returns the value true if the lock has not been acquired by any other thread in the write mode.

Atomic Operations and Locks [10-15]

- Code demonstrates use of the `StampedLock` class in reading, writing, and optimistic reading mode.

Code Snippet

```
package com.training.demo.stampedlock;
import java.util.concurrent.locks.StampedLock;

public class StampedLockDemo {
     private final StampedLock stampedLock = new
     StampedLock();
     private double balance;
     public StampedLockDemo(double balance) {
        this.balance = balance;
        System.out.println("Available balance: "+balance);
     }
     public void deposit(double amount) {
       System.out.println("\nAbout to deposit $:
       "+amount);
       long stamp = stampedLock.writeLock();
       System.out.println("Applied read lock");
```

Atomic Operations and Locks [11-15]

```
try {
   balance += amount;
   System.out.println("Available balance: "+balance);
} finally {
    stampedLock.unlockWrite(stamp);
    System.out.println("Unlocked write lock");
  }
}
public void withdraw(double amount) {
System.out.println("\nAbout to withdraw $: "+amount);
   long stamp = stampedLock.writeLock();
   System.out.println("Applied write lock");
   try {
    balance -= amount;
    System.out.println("Available balance: "+balance);
   } finally {
        stampedLock.unlockWrite(stamp);
        System.out.println("Unlocked write lock");
        }
}
```

Atomic Operations and Locks [12-15]

```
public double checkBalance() {
    System.out.println("\nAbout to check balance");
    long stamp = stampedLock.readLock();
    System.out.println("Applied read lock");
    try {
    System.out.println("Available balance: "+balance);
    return balance;
    } finally {
    stampedLock.unlockRead(stamp);
    System.out.println("Unlocked read lock");
    }
}
  public double checkBalanceOptimisticRead() {
  System.out.println("\nAbout to check balance with
  optimistic read lock");
  long stamp = stampedLock.tryOptimisticRead();
  System.out.println("Applied non-blocking optimistic
  read lock");
  double balance = this.balance;
```

Atomic Operations and Locks [13-15]

```
    if (!stampedLock.validate(stamp)) {
       System.out.println("Stamp have changed. Applying
        full-blown read lock.");
       stamp = stampedLock.readLock();
       try {
          balance = this.balance;
       } finally {
          stampedLock.unlockRead(stamp);
          System.out.println("Unlocked read lock");
    }
    }
    System.out.println("Available balance: "+balance);
    return balance;
    }
```

Atomic Operations and Locks [14-15]

```
    public static void main(String[] args){
     StampedLockDemo stampedLockDemo=new
     StampedLockDemo(4000.00);
     stampedLockDemo.withdraw(1000.00);
     stampedLockDemo.deposit(5000.00);
     stampedLockDemo.checkBalance();
     stampedLockDemo.checkBalanceOptimisticRead();
     }
}
```

Atomic Operations and Locks [15-15]

Following is the output of the code:

Output - StampedLockDemo (run)

```
run:
Available balance: 4000.0

About to withdraw $: 1000.0
Applied write lock
Available balance: 3000.0
Unlocked write lock

About to deposit $: 5000.0
Applied read lock
Available balance: 8000.0
Unlocked write lock

About to check balance
Applied read lock
Available balance: 8000.0
Unlocked read lock

About to check balance with optimistic read lock
Applied non-blocking optimistic read lock
Available balance: 8000.0
BUILD SUCCESSFUL (total time: 1 second)
```

More Features of the Fork-Join Framework

- The framework has included many new features such as:

New ForkJoinPool Features	Stream Parallelization
Array Sorting Parallelism	Recursive Action

New ForkJoinPool Features

- Enables the use of a common thread
- Helps the application to reduce resource usage
- Methods included in the `ForkJoinPool` class are:

`commonPool()`: A static method that returns a common thread pool.

`getCommonPoolParallelism()`: A new method that returns the targeted parallelism level of the common thread pool.

Stream Parallelization [1-2]

- The code demonstrates the use of parallel stream to iterate through the elements of an `ArrayList`.

Code Snippet

```
package com.training.demo.parallelstream;
import java.util.ArrayList;
import java.util.List;
import java.util.stream.Stream;

public class ParallelStreamDemo {
    public static void main(String[] args) {
        List<String> items = new ArrayList<String>();
        items.add("one");
        items.add("two");
        items.add("three");
        items.add("four");
        Stream parallelStream = items.parallelStream();
        parallelStream.forEach(System.out::println);
    }
}
```

Stream Parallelization [2-2]

Following is the output of the code:

Output - ParallelStreamDemo (run)

```
run:
three
four
two
one
BUILD SUCCESSFUL (total time: 1 second)
```

Arrays Sort Parallelism [1-2]

- The code demonstrates how to sort arrays in parallel.

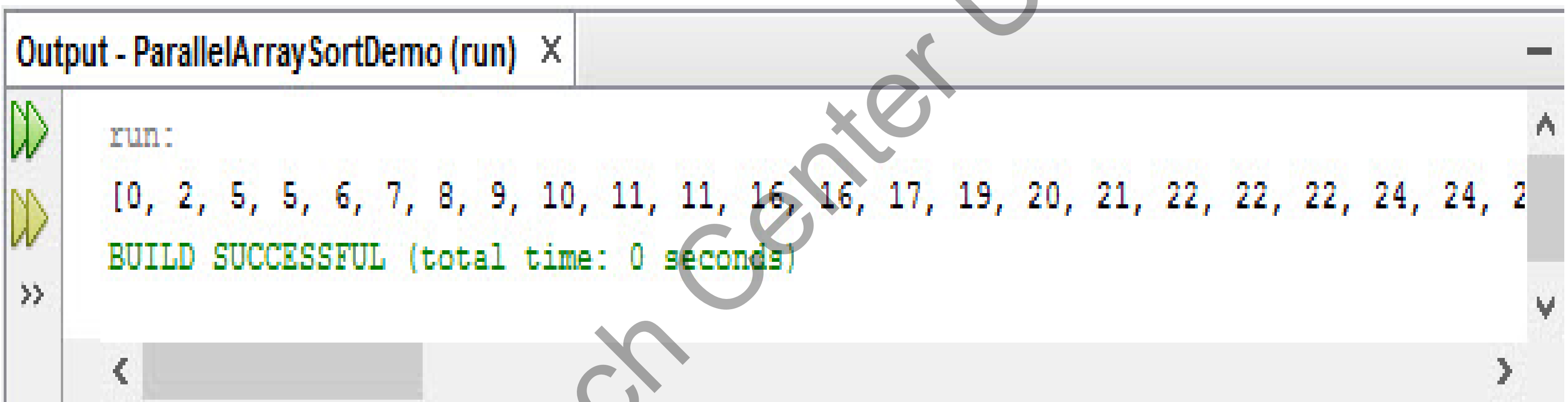
Code Snippet

```
package com.training.demo.parallelarraysort;
import java.util.Arrays;

public class ParallelArraySortDemo {
   public static void main(String[] args) {
      int[] intArray = new int[100];
      for(int i = 0; i < intArray.length; i++) {
      intArray[i] = (int)(Math.random() * 100);
      }
      Arrays.parallelSort(intArray);
      System.out.println(Arrays.toString(intArray));
   }
}
```

Arrays Sort Parallelism [2-2]

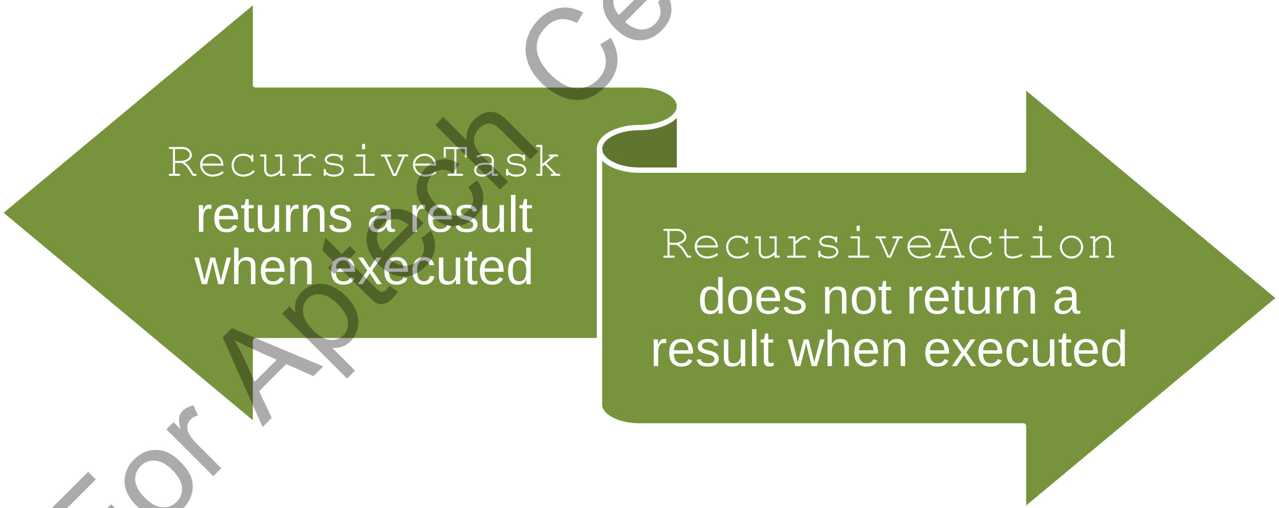
Following is the output of the code:



Recursive Action [1-5]

- The Fork-Join framework extends `AbstractExecutorService` class to override the `ForkJoinTask` processes.

- Two new classes have been to implement the `ForkJoinTask` processes:



Recursive Action [2-5]

- The code demonstrates the use of Fork-Join functionality with `RecursiveAction`.

Code Snippet

```
package com.training.demo.recursiveaction;
import java.util.ArrayList;
import java.util.List;
import java.util.concurrent.ForkJoinPool;
import java.util.concurrent.RecursiveAction;

public class RecursiveActionDemo extends RecursiveAction {
   private long assignedWork = 0;
   public RecursiveActionDemo(long assignedWork) {
   this.assignedWork = assignedWork;
   }
   private List<RecursiveActionDemo> createSubtasks() {
   List<RecursiveActionDemo> subtaskList = new
   ArrayList<>();
```

Recursive Action [3-5]

```
    RecursiveActionDemo subtask1 = new
    RecursiveActionDemo(this.assignedWork / 2);
    RecursiveActionDemo subtask2 = new
    RecursiveActionDemo(this.assignedWork / 2);
    subtaskList.add(subtask1);
    subtaskList.add(subtask2);
    return subtaskList;
  }
  @Override
  protected void compute() {
     if (this.assignedWork > 50) {
        System.out.println("Splitting assignedWork : " +
        Thread.currentThread() + " computing: : " +
        this.assignedWork);
        List<RecursiveActionDemo> subtaskList = new
        ArrayList<>();
        subtaskList.addAll(createSubtasks());
        for (RecursiveAction subtask : subtaskList) {
        subtask.fork();
```

Recursive Action [4-5]

```
            }
        } else {
            System.out.println("Main thread " +
            Thread.currentThread() + " computing: : " +
            this.assignedWork);
        }
        }
        public static void main(String[] args) {
              RecursiveActionDemo recursiveActionDemo = new
              RecursiveActionDemo(500);
              final ForkJoinPool forkJoinPool = new
              ForkJoinPool(4);
              forkJoinPool.invoke(recursiveActionDemo);
        }
}
```

Recursive Action [5-5]

Following is the output of the code:

Output - RecursiveAction (run)

```
run:
Splitting assignedWork : Thread[ForkJoinPool-1-worker-1,5,main] computing: : 500
Splitting assignedWork : Thread[ForkJoinPool-1-worker-1,5,main] computing: : 250
Splitting assignedWork : Thread[ForkJoinPool-1-worker-2,5,main] computing: : 250
Splitting assignedWork : Thread[ForkJoinPool-1-worker-1,5,main] computing: : 125
Splitting assignedWork : Thread[ForkJoinPool-1-worker-1,5,main] computing: : 62
Main thread Thread[ForkJoinPool-1-worker-1,5,main] computing: : 31
Main thread Thread[ForkJoinPool-1-worker-1,5,main] computing: : 31
Splitting assignedWork : Thread[ForkJoinPool-1-worker-3,5,main] computing: : 125
BUILD SUCCESSFUL (total time: 1 second)
```

Summary [1-2]

- The `CompletableFuture` class simplifies coordination of asynchronous operations.
- The `CountedCompletor` class represents a completion action performed when triggered, provided there are no remaining pending actions.
- The `LongAccumulator`, `LongAdder`, `DoubleAccumulator`, and `DoubleAdder` classes provide better throughput improvements as compared to Atomic variables.
- The `StampedLock` class implements lock to control read/write access.

Summary [2-2]

- Parallel computation of streams enables working with streams faster without the risk of threading issues.
- The new `parallelSort()` method in the Arrays class allows parallel sorting of array elements.
- `RecursiveTask`, similar to `RecursiveAction` extends `ForkJoinTask` to represent tasks that run within a `ForkJoinPool`.