Lecture 11

Parallel Data Processing with Streams

SOEN 6441, Summer 2018

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Outline

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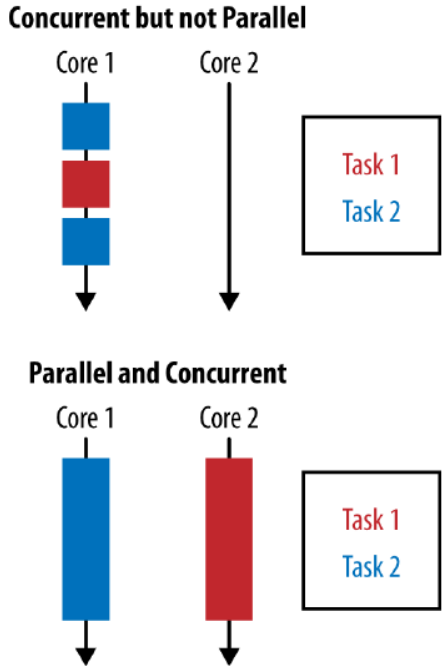
Concurrency vs. Parallelism



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Parallel Streams

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Java 8

```
public static long sequentialSum(long n) {
  return Stream.iterate(1L, i -> i + 1)
               .limit(n)
               .reduce(0L, Long::sum);
}
```

Java 7

```
public static long iterativeSum(long n) {
  long result = 0;
  for (long i = 1L; i <= n; i++) {
    result += i;
  }
  return result;
}
```

Turning a sequential stream into a parallel one

```
public static long parallelSum(long n) {
  return Stream.iterate(1L, i -> i + 1)
               .limit(n)
               .parallel()
               .reduce(0L, Long::sum);
}
```

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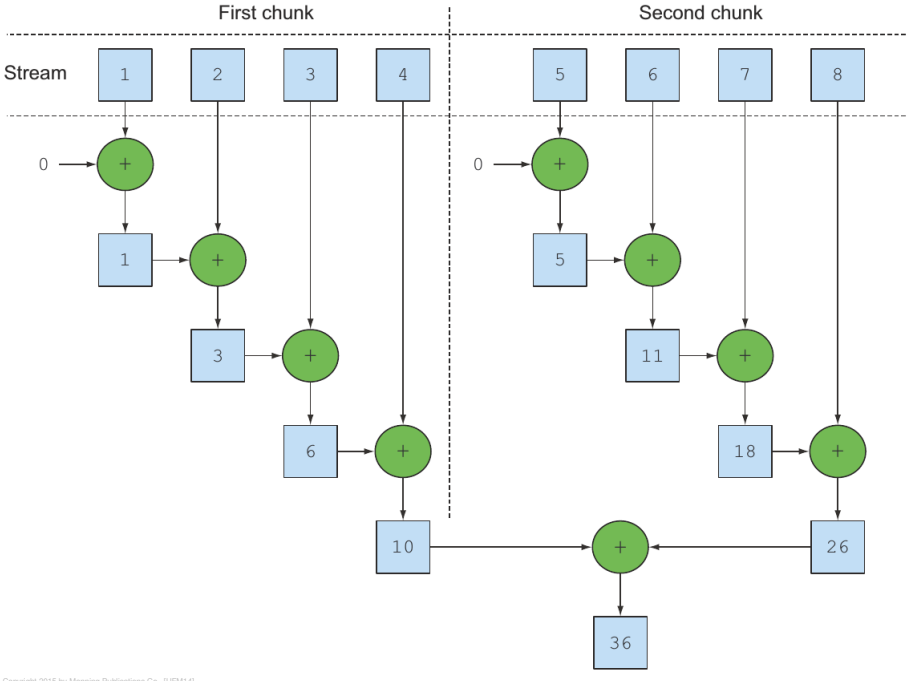
A parallel reduction operation



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The methods `sequential` and `parallel`

```
stream.parallel()
      .filter(...)
      .sequential()
      .map(...)
      .parallel()
      .reduce();
```

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Thread Pools

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`ForkJoinPool`

```
Runtime.getRuntime().availableProcessors()
```

System property `java.util.concurrent.ForkJoinPool.common.parallelism`

```
System.setProperty("java.util.concurrent.ForkJoinPool.common.parallelism",
                   "12");
```

Measuring Stream Performance

```
public long measureSumPerf(Function<Long, Long> adder, long n) {
  long fastest = Long.MAX_VALUE;
  for (int i = 0; i < 10; i++) {
    long start = System.nanoTime();
    long sum = adder.apply(n);
    long duration = (System.nanoTime() - start) / 1_000_000;
    System.out.println("Result: " + sum);
    if (duration < fastest) fastest = duration;
  }
  return fastest;
}
```

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Some tests

Sequential Sum

```
System.out.println("Sequential sum done in: "
    + measureSumPerf(ParallelStreams::sequentialSum, 10_000_000)
    + " msecs");
```

```
Sequential sum done in: 97 msecs
```

Iterative Sum

```
System.out.println("Iterative sum done in: "
    + measureSumPerf(ParallelStreams::iterativeSum, 10_000_000)
    + " msecs");
```

```
Iterative sum done in: 2 msecs
```

Parallel Sum

```
System.out.println("Parallel sum done in: "
    + measureSumPerf(ParallelStreams::parallelSum, 10_000_000)
    + " msecs" );
```

```
Parallel sum done in: 164 msecs
```

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The problem with `iterate`

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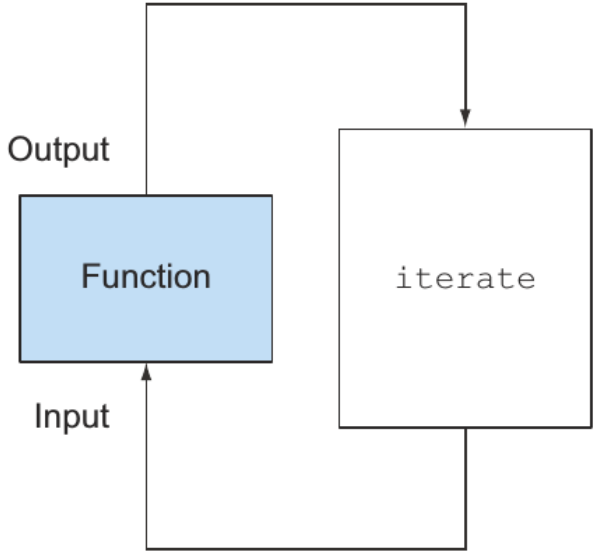

Using more specialized methods

`LongStream.rangeClosed`

- works on primitive `long` – no boxing/unboxing!
- produces ranges of numbers that can be split into chunks

Performance without unboxing

```
public static long rangedSum(long n) {
  return LongStream.rangeClosed(1, n)
                   .reduce(0L, Long::sum);
}

Ranged sum done in: 17 msecs
```

Performance with parallel stream

```
public static long parallelRangedSum(long n) {
  return LongStream.rangeClosed(1, n)
                   .parallel()
                   .reduce(0L, Long::sum);
}

Parallel range sum done in: 1 msecs
```

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Using parallel streams correctly

```
public static long sideEffectSum(long n) {
  Accumulator accumulator = new Accumulator();
  LongStream.rangeClosed(1, n)
            .forEach(accumulator::add);
  return accumulator.total;
}

public class Accumulator {
  public long total = 0;
  public void add(long value) { total += value; }
}
```

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Now with `parallel()`

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```
public static long sideEffectParallelSum(long n) {
  Accumulator accumulator = new Accumulator();
  LongStream.rangeClosed(1, n)
            .parallel()
            .forEach(accumulator::add);
  return accumulator.total;
}

...

System.out.println("SideEffect␣parallel␣sum␣done␣in:␣"
  + measurePerf(ParallelStreams::sideEffectParallelSum, 10_000_000L)
  + "msecs" );
```

Result?

```
Result: 5959989000692
Result: 7425264100768
Result: 6827235020033
Result: 7192970417739
Result: 6714157975331
Result: 7497810541907
Result: 6435348440385
Result: 6999349840672
Result: 7435914379978
Result: 7715125932481
SideEffect parallel sum done in: 49 msecs
```

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Using parallel streams effectively
Some general guidelines

- Always benchmark the performance
- Avoid boxing – use primitive specializations (`IntStream`, `LongStream`, `DoubleStream`)
- Consider the stream operations – e.g., `limit` and `findFirst` are more expensive on parallel streams
  - use `findAny` unless you must know the first element
  - can turn ordered stream into unordered by calling `unordered`
  - calling `limit` more efficient on unordered parallel stream
- Consider the total computational cost:
  - N items, Q cost of processing/item: total $= N \times Q$
  - parallel streams have better performance for higher values of Q
- Don't use parallel streams for small data sizes

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Decomposition Process

Splitting `ArrayList` more efficient than `LinkedList`

Source	Decomposability
`ArrayList`	Excellent
`LinkedList`	Poor
`IntStream.range`	Excellent
`Stream.iterate`	Poor
`HashSet`	Good
`TreeSet`	Good

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Decomposition Process (II)

Splitting a `SIZED` stream more efficient than a filtered stream (unknown size)

Stream flag	Interpretation
`SIZED`	The size of the stream is known
`DISTINCT`	The elements of the stream are distinct (using `Object.equals()` for objects; == for primitives)
`SORTED`	The elements of the stream are sorted
`ORDERED`	The stream has a meaningful encounter order

Outline

MapReduce: Simplified Data Processing on Large Clusters

Jeffrey Dean and Sanjay Ghemawat

jeff@google.com, sanjay@google.com

Google, Inc.

Programming Model

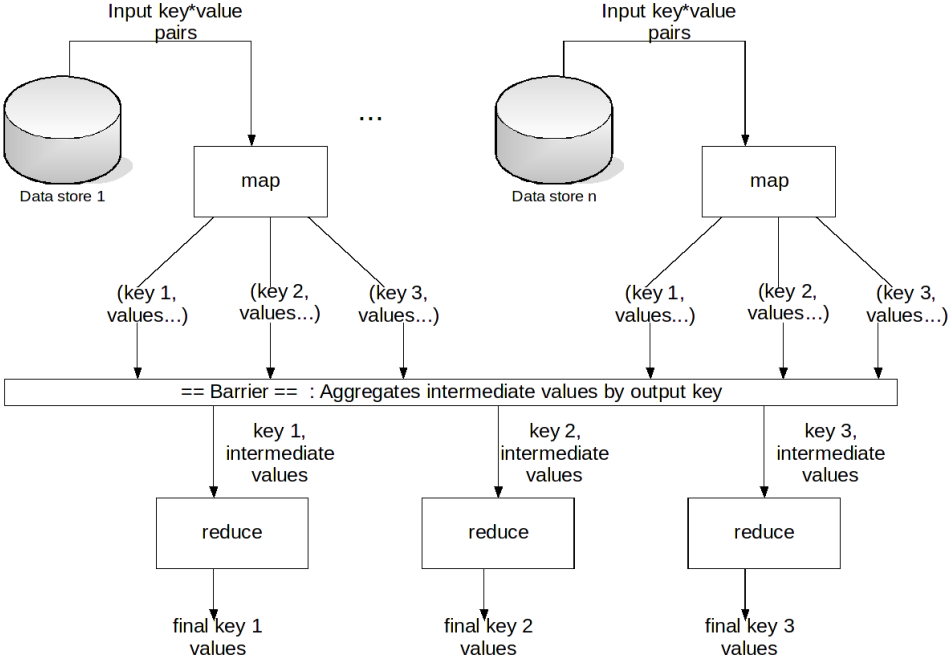
Map

```
map (in_key, in_value) -> list(out_key, intermediate_value)
```

Reduce

```
reduce (out_key, list(intermediate_value)) -> list(out_value)
```

MapReduce Workflow



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Apache Hadoop

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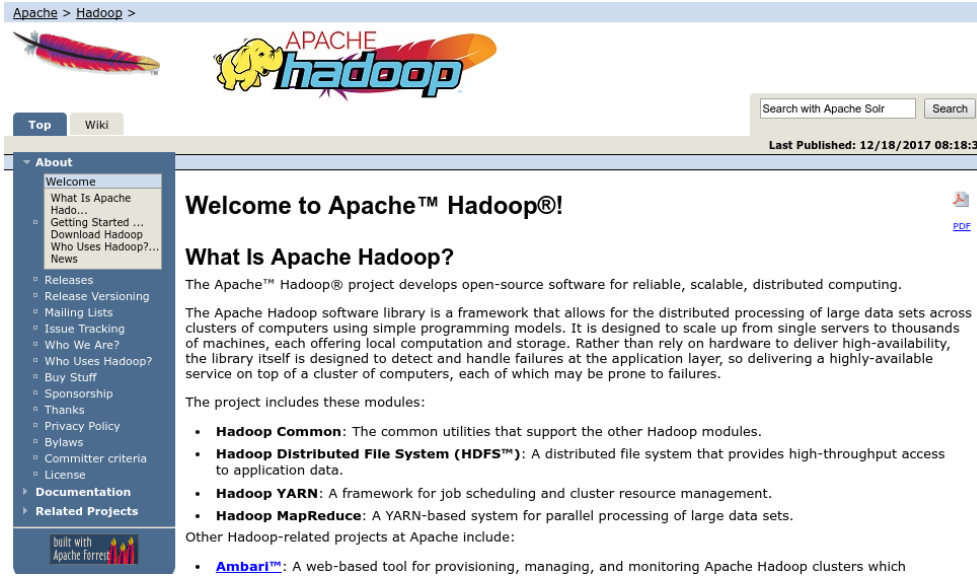

Hadoop Programming Example

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Task: Count words

```
$ bin/hadoop fs -ls /user/joe/wordcount/input/
/user/joe/wordcount/input/file01
/user/joe/wordcount/input/file02

$ bin/hadoop fs -cat /user/joe/wordcount/input/file01
Hello World Bye World

$ bin/hadoop fs -cat /user/joe/wordcount/input/file02
Hello Hadoop Goodbye Hadoop
```

See http://hadoop.apache.org/docs/current/hadoop-mapreduce-client/hadoop-mapreduce-client-core/MapReduceTutorial.html

Map Phase

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`map` function

```
public void map(Object key, Text value, Context context)
            throws IOException, InterruptedException {
  StringTokenizer itr = new StringTokenizer(value.toString());
  while (itr.hasMoreTokens()) {
    word.set(itr.nextToken());
    context.write(word, one);
  }
}
```

Output

First file:

```
< Hello, 1>
< World, 1>
< Bye, 1>
< World, 1>
```

Second file:

```
< Hello, 1>
< Hadoop, 1>
< Goodbye, 1>
< Hadoop, 1>
```

Reduce Phase

`reduce` function

```
public void reduce(Text key, Iterable<IntWritable> values,
                   Context context)
              throws IOException, InterruptedException {
  int sum = 0;
  for (IntWritable val : values) {
    sum += val.get();
  }
  result.set(sum);
  context.write(key, result);
}
```

Output

Final result:

```
< Bye, 1>
< Goodbye, 1>
< Hadoop, 2>
< Hello, 2>
< World, 2>
```

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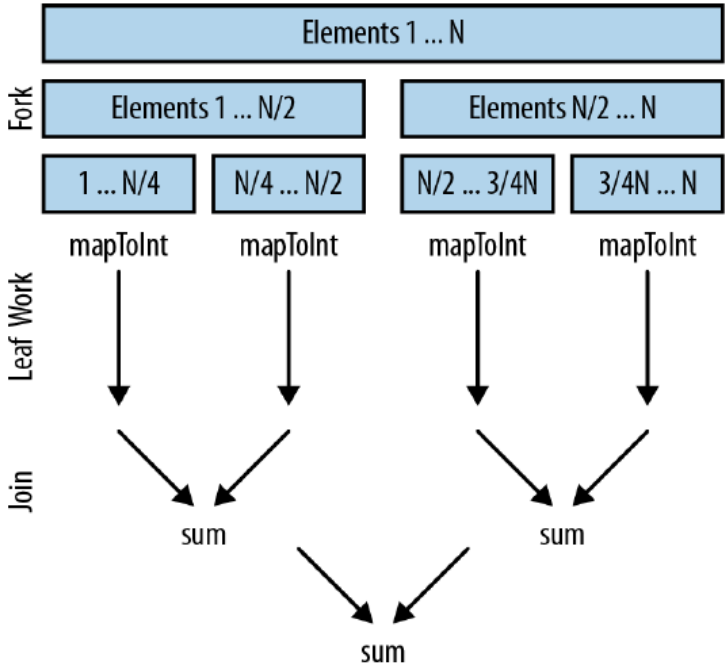
The fork/join framework (Java 7)



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Working with RecursiveTask

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To submit tasks to `ForkJoinPool`
create a subclass of either:

`RecursiveTask<R>` where `R` is type of the result

`RecursiveAction` when no result is returned (e.g., side-effects)

Defining a `RecursiveTask`
Implement the abstract method

```
protected abstract R compute();
```

Implementing `compute` (Pseudocode)

```
if (task is small enough or no longer divisible) {
  compute task sequentially
} else {
  split task in two subtasks
  call this method recursively, possibly further splitting each subtask
  wait for the completion of all subtasks
  combine the results of each subtask
}
```

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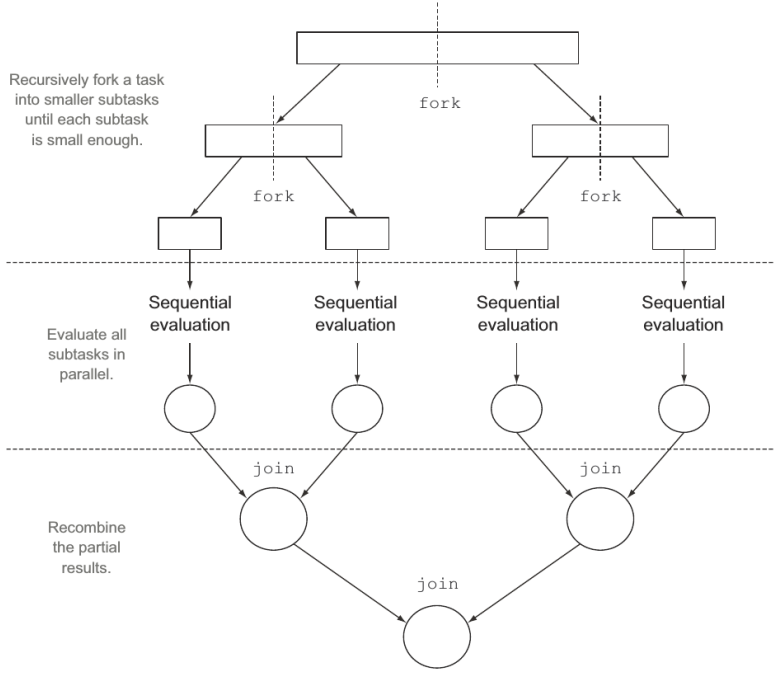
The fork/join process



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Parallel sum using fork/join framework

```
public class ForkJoinSumCalculator
       extends java.util.concurrent.RecursiveTask<Long> {

  private final long[] numbers;
  private final int start;
  private final int end;

  public static final long THRESHOLD = 10_000;

  public ForkJoinSumCalculator(long[] numbers) {
    this(numbers, 0, numbers.length);
  }

  private ForkJoinSumCalculator(long[] numbers, int start, int end) {
    this.numbers = numbers;
    this.start = start;
    this.end = end;
  }

  ...
}
```

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Parallel sum using fork/join framework: `compute`

```
@Override
protected Long compute() {
  int length = end - start;
  if (length <= THRESHOLD) {
    return computeSequentially();
  }
  ForkJoinSumCalculator leftTask =
    new ForkJoinSumCalculator(numbers, start, start + length/2);
  leftTask.fork();
  ForkJoinSumCalculator rightTask =
    new ForkJoinSumCalculator(numbers, start + length/2, end);
  Long rightResult = rightTask.compute();
  Long leftResult = leftTask.join();
  return leftResult + rightResult;
}

private long computeSequentially() {
  long sum = 0;
  for (int i = start; i < end; i++) {
    sum += numbers[i];
  }
}
```

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Calling the `ForkJoinSumCalculator`

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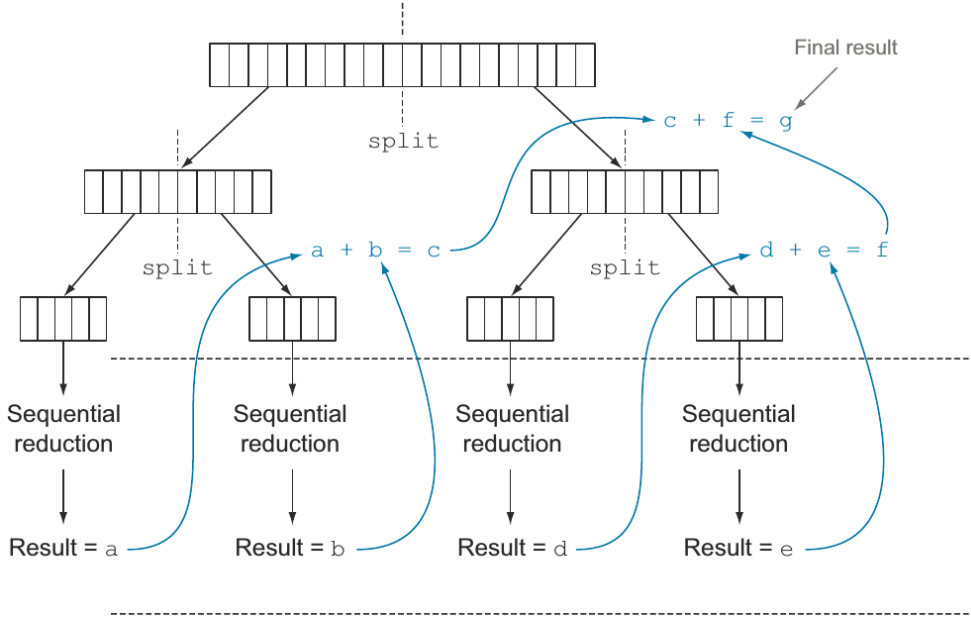
```
public static long forkJoinSum(long n) {
  long[] numbers = LongStream.rangeClosed(1, n).toArray();
  ForkJoinTask<Long> task = new ForkJoinSumCalculator(numbers);
  return new ForkJoinPool().invoke(task);
}

...

System.out.println("ForkJoin sum done in: "
  + measureSumPerf(ForkJoinSumCalculator::forkJoinSum, 10_000_000)
  + " msecs" );
```

```
ForkJoin sum done in: 41 msecs
```

Running the `ForkJoinSumCalculator`



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Best practices for using the fork/join framework

- Invoking `join` blocks the caller: only call it after both subtasks have started
- Do not call `invoke` from within a `RecursiveTask`:
  - call `compute` or `fork` directly
  - only use `invoke` from sequential code to start the fork/join process
- Do not call `fork` twice (creating three threads):
  - re-use current thread for either *left* or *right* subtask
- Measure the performance
  - Be aware of “warm-up” runs and compiler optimizations
- Make `ForkJoinPool` a Singleton in your application

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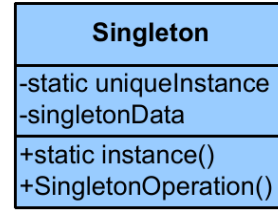
Singleton

Type: Creational

What it is:
Ensure a class only has one instance and provide a global point of access to it.



Work stealing

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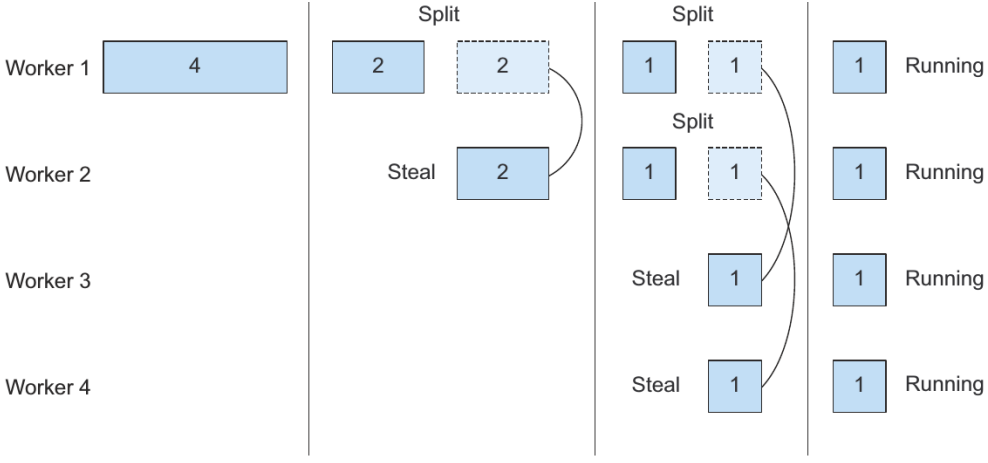

Outline

Spliterator

```
public interface Spliterator<T> {
  boolean tryAdvance(Consumer<? super T> action);
  Spliterator<T> trySplit();
  long estimateSize();
  int characteristics();
}
```

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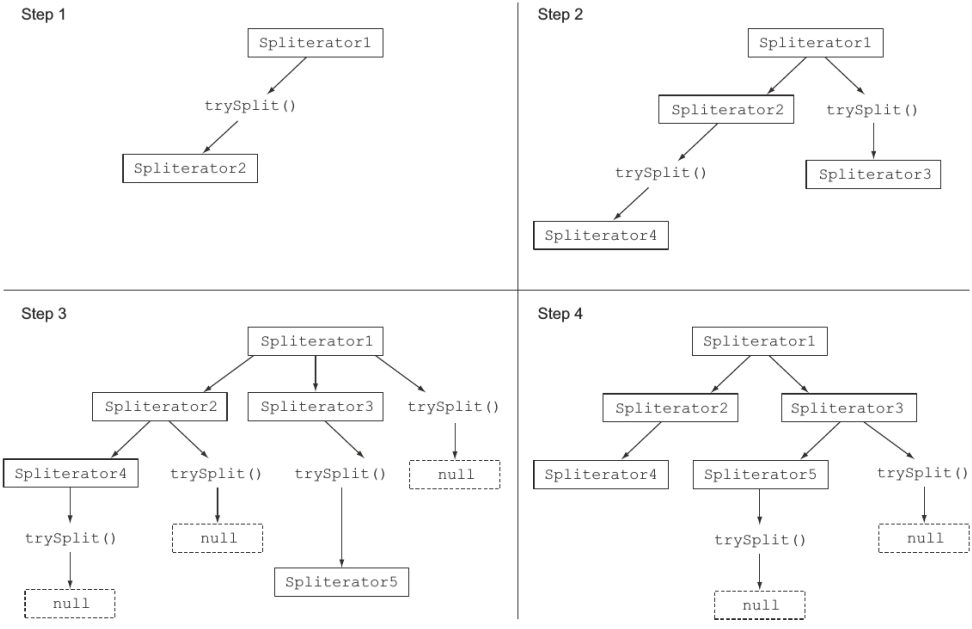
The splitting process



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`Spliterator`'s characteristics

Characteristic	Meaning
`ORDERED`	Elements have a defined order (for example, a `List`), so the `Spliterator` enforces this order when traversing and partitioning them.
`DISTINCT`	For each pair of traversed elements `x` and `y`, `x.equals(y)` returns `false`.
`SORTED`	The traversed elements follow a predefined sort order.
`SIZED`	This `Spliterator` has been created from a source with a known size (for example, a `Set`), so the value returned by `estimatedSize()` is precise.
`NONNULL`	It's guaranteed that the traversed elements won't be `null`.
`IMMUTABLE`	The source of this `Spliterator` can't be modified. This implies that no elements can be added, removed, or modified during their traversal.
`CONCURRENT`	The source of this `Spliterator` may be safely concurrently modified by other threads without any synchronization.
`SUBSIZED`	Both this `Spliterator` and all further `Spliterators` resulting from its split are `SIZED`.

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Summary

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Streams

- Internal iteration allows you to process a stream in parallel without the need to explicitly use and coordinate different threads in your code
- However, always measure your performance and be aware what influences parallel behavior
- Parallel stream execution of an operation on a set of data can provide a significant performance boost on multi-core processors
- From a performance point of view, using the right data structure is very important (e.g., use primitive streams whenever possible)
- Internally, parallel streams make use of Java 7's fork/join framework
- The fork/join framework lets you recursively split a parallelizable task into smaller tasks, execute them on different threads, and then combine the results of each subtask in order to produce the overall result
- Spliterators define how a parallel stream can split the data it traverses

Outline

Reading Material

Required

- [UFM14, Chapter 7] (Parallel Data Processing)

Supplemental

- [War14, Chapter 6] (Data Parallelism)
- [GHJV95] (Singleton Design Pattern)

Further Reading

- [DG04] (MapReduce)
- Apache Hadoop, http://hadoop.apache.org/

References

[DG04] Jeffrey Dean and Sanjay Ghemawat.
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