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Enhancing Java Streams API with PowerList Computation

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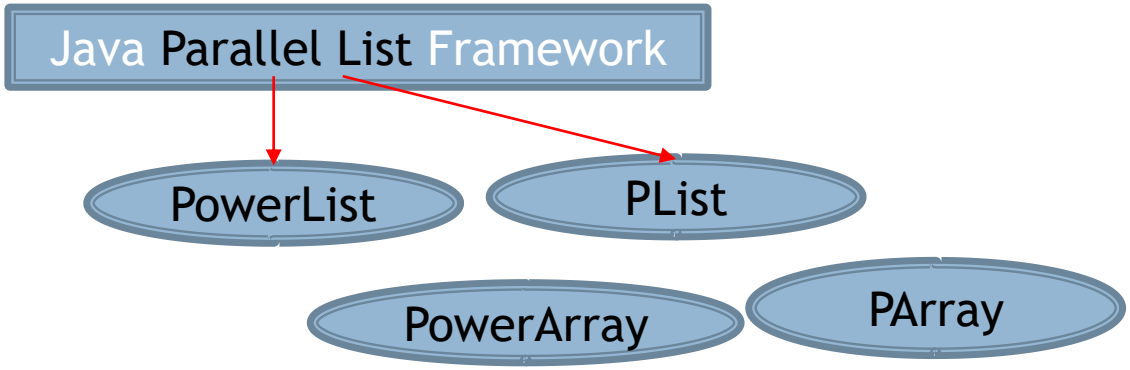
Summary

- JPLF framework
- Motivation and Goals
- Java Streams
- Powerlist and PList Theories
- Adapting Java Streams for PowerList functions
- Polynomial value computation
- Conclusions

JPLF framework for parallel programming

- **JPLF**
  [V. Niculescu, F. Loulergue, D. Bufnea, and A. Sterca. "A Java Framework for High Level Parallel Programming using Powerlists," in Parallel and Distributed Computing, Applications and Technologies (PDCAT). IEEE, Taipei, Taiwan. 2017, pp. 255-262.]
  - Java framework for parallel programming
    - including High Performance Computing
  - start from a formal base -- *PowerList theory* – in order to assure correctness
  - allow efficient executions on both shared memory and distributed memory systems

divide-and-conquer skeleton



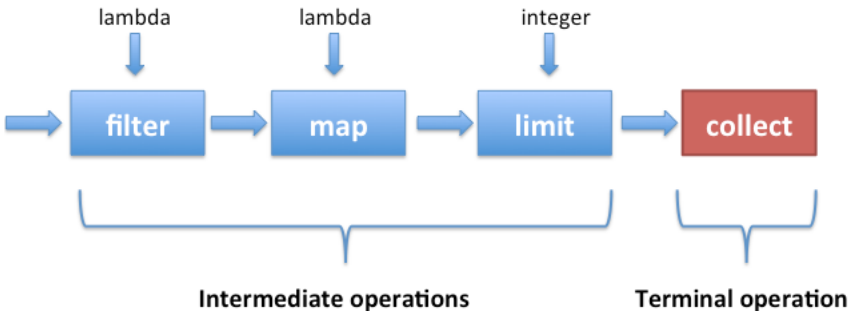
Motivation and Goals

- Goals
  - The purpose of this work is to investigate if the computations defined based on ***PowerList and PList*** theories could be specified using the ***Java Streams*** infrastructure, and to which extent.

- ***Java Stream API is very popular nowadays, and so if some powerful parallel programming skeletons could be adopted to be executed inside this API, then they will be easily popularized while the expressiveness of the Java Stream API increases.***

Java streams

- A Java stream is a sequence of objects.
- Usually it has a data source and a destination where they are transmitted.
- A stream is not a repository, but it operates on a data source such as an array or a collection.
- More formally, we may consider the streams as being monads, which is a structure that represents computations defined as sequences of steps.
- In Java Stream API there are many already implemented operations that could be sent to a stream, the most common being *map, filter, reduce, collect*.
- ***Parallel computation is possible for parallel streams.***



Powerlist Theory

Powerlist Theory was introduced by J. Misra in 1994.

- PowerLists are homonogeously typed sequences of elements.
- The size of a PowerList is a power of two.
- A ***singleton*** is a PowerList containing a single element - notation [v]
- Two PowerLists of the same size and same type for elements are ***similar***.
- **Two constructors** exist to combine two similar PowerLists:
  - (|) the operator ***tie*** yields a PowerList containing the elements of p followed by elements of q;
  - (#) the operator ***zip*** returns a PowerList containing alternatively the elements of p and q.
- The functions on Powerlists are ***recursive functions*** defined based on a **structural induction**.
  - the **base case** considers the singleton list
  - the **recursive case** may use either (|) or (#) for decomposing/composing

Functions examples

- Map - applies a scalar function f_s to each element of a PowerList

$$\begin{cases} map(f_s, [v]) & = & [f_s(v)] \\ map(f_s, pl_1 \,|\, pl_2) & = & map(f_s, pl_1) \,|\, map(f, pl_2) \end{cases}$$

- Reduce – for an associative operator $\oplus$

$$\begin{cases} red(\oplus, [v]) & = & [v] \\ red(\oplus, pl_1 \,|\, pl_2) & = & red(\oplus, pl_1) \oplus (red(\oplus, pl_2) \end{cases}$$

- Fast Fourier Transform

$$\begin{cases} fft([x]) & = & [x] \\ fft(p \natural q) & = & (F_p + u \times F_q) \,|\, (F_p - u \times F_q) \end{cases}$$

where

- $F_p = fft\ (p)$, $F_q = fft\ (q)$, $u = powers(p)$,
- **+, -** are the correspondent *associative binary operators extended* to PowerLists.
- *powers(p)* is the PowerList $[w^0, w^1, ..., w^{|p-1|}]$

  where |p| denotes the size of p and w denotes the 2nd principal root of 1.

PList

- The PList extension of PowerLists (Kornerup,1997) lifts the restriction of the length being a power of 2.
- PLists are also defined based on *tie* and *zip* operators.
- For PLists, both ***tie* and *zip* are generalized** to take as arguments an **arbitrary number of similar PLists.**
- The map function on PLists can then be defined as:

$$\begin{cases} map(f, [], [a]) & = & [f(a)] \\ map(f, n::l, |_{i\in n}\, p_i) & = & |_{i\in n}\, map(f, l, p_i) \end{cases}$$

where $n::l$ denotes the list with head element n, and with tail l (a list) and $|_{i\in n}\, p_i$ is the generalized *tie* applied on n lists p_i

PowerList functions execution

express ***Divide-and Conquer*** computation

1) ***Descending/splitting*** phase that considers the operations needed to split the list arguments, and additional operations, if they exist.

2) ***Leaf*** phase that considers the operations executed on singletons.

3) ***Ascending/combining*** phase that considers the operations needed to combine the list arguments, and additional operations, if they exist.

Classes of functions

1. splitting ≣ data decomposition

The class of functions for which the splitting phase needs only data decomposition.

Examples: *map, reduce, fft*

- much easier to implement!

2. splitting ≢ data decomposition

The class of functions for which the splitting phase needs also additional computation besides the data decomposition.

Example: $f(p|q) = f(p+q) \mid f(p-q)$

or

"polynomial value function"

Example: polynomial value

- The functions from the second class involve some additional computations on the sublists obtained at each step.

- Example: computing the value of a polynomial in a given point:

$$vp([a], x) = [a]$$
$$vp((p\#q), x) = vp(p, x^2) + (x \cdot vp(q, x^2))$$

where $(x \cdot p)$ means that every element of the list p is multiplied with x
(it could be considered a map function)

Adaptation strategy

- use *Spliterator* for the splitting phase
- use *collect* function for leaf and combining phases

The *collect* template method

collect(Supplier<R> supplier, BiConsumer<R,? super T> accumulator, BiConsumer<R,R> combiner)

- performs a mutable reduction operation on the elements of the calling stream
- **mutable reduction** => the reduced value is a mutable result container, and elements are incorporated by updating the state of the result rather than by replacing the result.
  - ***supplier***:
    - a function that creates a new mutable result container;
    - in a parallel execution, this function may be called multiple times and must return a fresh value each time.
  - ***accumulator***:
    - fold an element into a result container.
  - ***combiner:***
    - accepts two partial result containers and merges them,
    - fold the elements from the second result container into the first result container

Example

```
List<String> list =
    Arrays.asList("Ana", "Lia", "Dan");
String result = list.parallelStream()
  .collect(
   StringBuilder::new, //the supplier
   (response, element) ->
    response.append(" ").append(element),
     //the accumulator
    (response1, response2) ->
     response1.append(",").append(response2.
         toString()))
     // the combiner
  .toString();
```

- the words in a given list are concatenated, including a comma between each pair of two words

- *combiner* function is specific to the parallel execution of the *collect* method:
- if the stream hadn't been parallel, the combiner would not be used and so
  - the comma wouldn't be added

Collector interface

- The function *collect* has also a definition that receives as an argument a *Collector*.
- ***Collector*** is an interface that provides a wrapper for the ***supplier, accumulator, and combiner*** objects.

Collector<T,A,R>

where the type parameters have the following significance:

  - T - the type of input elements;
  - A - the mutable accumulation type;
  - R - the result type.

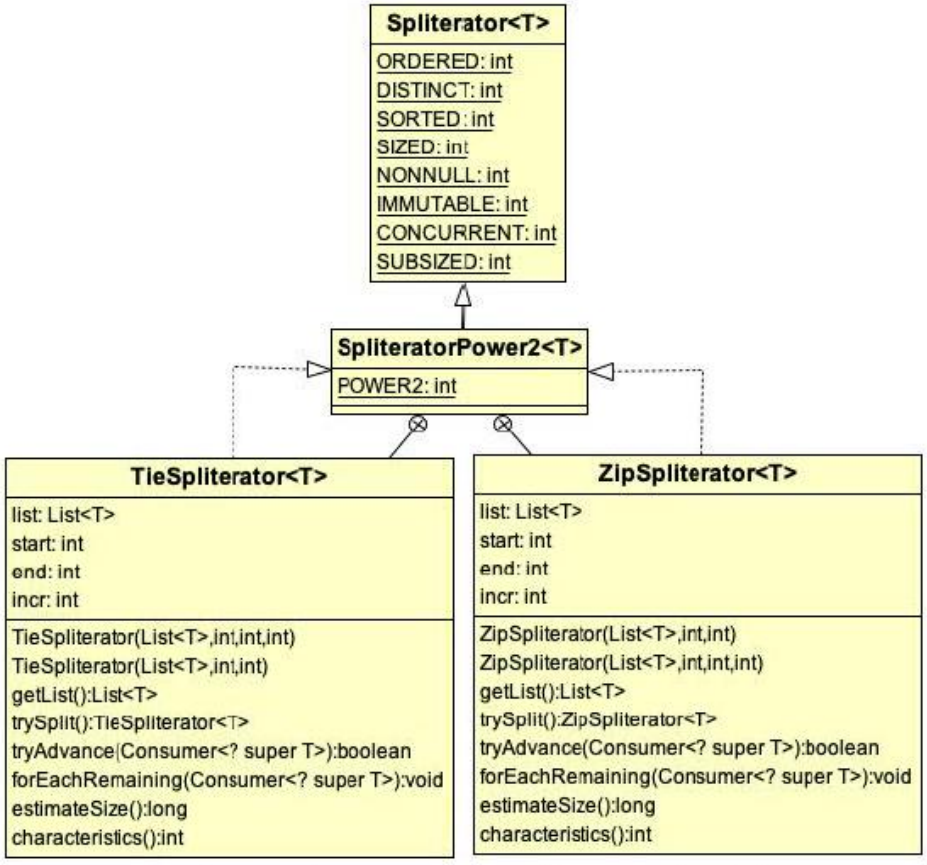
- This variant is more convenient to be used for PowerList functions, because a specific function – *APowerFunction*, could implements the *Collector* interface, and then for its execution we just need to invoke the *collect* function with an ***argument, which is an instance of that class.***

Spliterator

- The parallel computation of the parallel streams is directed by the existence of a special type of iterator – *Spliterator* – and by the usage of the *ForkJoinPool* executor.
- *ForkJoinPool* executor is specialized in the computation of the recursive tasks, and so it is appropriate for the divide-and-conquer computational model.
- The *Spliterator* interface defines several methods, such that
  - *trySplit* operation that partitions off some of its elements as another *Spliterator*
  - by default, the partitioning is performed linearly, in "segments", which is somehow similar to the operator ***tie*** from PowerLists.

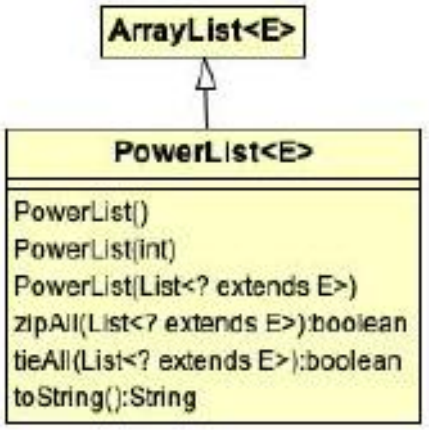
Spliterator specializations

- In order to control the partitioning, new implementations for the *Spliterator* interface are provided
  - *TieSpliterator* and
  - *ZipSpliterator*
  - *trySplit*
    defined correspondingly



Tie and Zip constructors

=> we need to provide operations for the ***tie and zip constructor operators***



- This could be achieved by defining a class *PowerList* that extends any *RandomAccess* collection (e.g. *ArrayList*)
- the class provides the methods:
  - *tieAll*
  - *zipAll*
- ***zip*** operation:
  - when executing the *collect* function, the stream is decomposed using *ZipSpliterator* instance, and then recomposed based on the function *zipAll* of the class *PowerList*.
- ***tie*** operation: similar

General approach

- Define a class that implements *Collector* -> ACollector
- Provide definition for the three methods: *supplier, accumulator, combiner*
- Create the needed specialized *Spliterator* -> aSpliterator
- Define the stream based on this aSpliterator
- Call the *collect* method using an instance of the ACollector

⇒ this works very easy for the functions that belongs to the first class,

⇒ZipSpliterator or TieSpliterator can be used

But

⇒for the functions belonging to the second class, additional adjustments needed:

⇒define new specialization of the Spliterator

⇒connect the splitting phase with the other phases

Example: computing the value of a polynomial in a point

very simple parallel PowerList definition, but involves some operations at the splitting phase

```
class PolynomialValue implements
Collector< Double, PolynomialValue,
                        PolynomialValue>
{
     private double x;       // the given point
     private double val = 0; // the result
     private int x_degree = 1;

// contructors

@Override
public Supplier<PolynomialValue> supplier
() {
    return () -> {
            return new PolynomialValue(this);
            };
}
```

```
@Override
public
BiConsumer<PolynomialValue, Double> accumulator()
{
return (pv1, d) -> {
pv1.val =
   pv1.val*Math.pow(pv1.x,pv1.x_degree) + d;
              };
}
@Override
public
BinaryOperator<PolynomialValue> combiner () {
 return (pv1, pv2) -> {
     pv1.x_degree/=2;
     pv1.val =  pv1.val*
               Math.pow(this.x, pv1.x_degree)
                        +pv2.val;
     return pv1;
     };
}
```

Specialization of ZipSpliterator

```
class PZipSpliterator
   extends SpliteratorPower2.ZipSpliterator<Double
       > {
  protected int x_degree=1; //local attribute
  public PZipSpliterator(
     List<Double> list, int start, int end, int
         incr, int x_degree) {
    super(list,start,end, incr);
    this.x_degree = x_degree;
  }
  public PZipSpliterator trySplit() {
    int lo = start;
    int step = incr;
    if (start + step <= end) {
      x_degree*=2; // !!!!! updating the exponent
      synchronized(PolynomialValue.this)
      {
        if (PolynomialValue.this.x_degree < x_degree
            )
        PolynomialValue.this.x_degree = x_degree;
      }
      incr *= 2;
      start += step;
      return PolynomialValue.this.new
        PZipSpliterator(list, lo, end-step, incr,
            x_degree);
    }
    else // too small to split
    return null;
  }
```

- This could be solved by defining a specialisation of *ZipSpliterator*, defined as an inner class inside the class *PolynomialValue*.
- In this way, all the instances of the inner class will have access to he instance of the outer class – *PolynomialValue.this*.

Connecting the computation phases

- The supplier provides a new instance of *PolynomialValue*,
  - but it should be one created as a copy of the ***initial*** *PolynomialValue* ***instance***, which also has to be
  - the one through which the ***initial spliterator was created***.
- The reason for this is the need for
  - connection between the different phases of the computation
    - splitting,
    - leaf(basic case),
    - combining.

Usage example

```
List<Double> list_int = //...the coeffients list
PolynomialValue pv = new PolynomialValue(x);
PolynomialValue.PZipSpliterator sp_it =
   pv.new PZipSpliterator
      (list_int,0,list_int.size()-1,1);
if (sp_it.hasCharacteristics(
         SpliteratorPower2.POWER2)) {
   System.out.println(" characteristic POWER");
   Stream<Double> myStream =
      StreamSupport.stream(sp_it, true);
   PolynomialValue valp =
      myStream.collect(pv);
   }
```

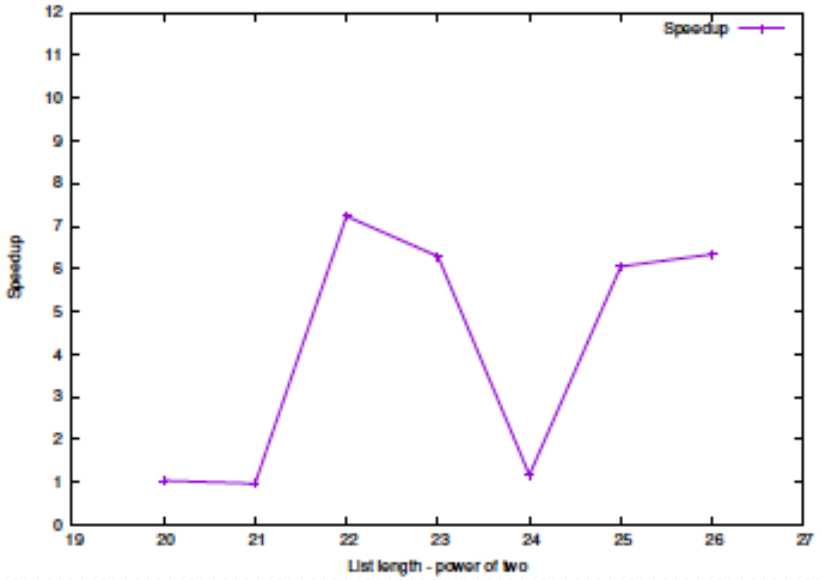
define the spliterator

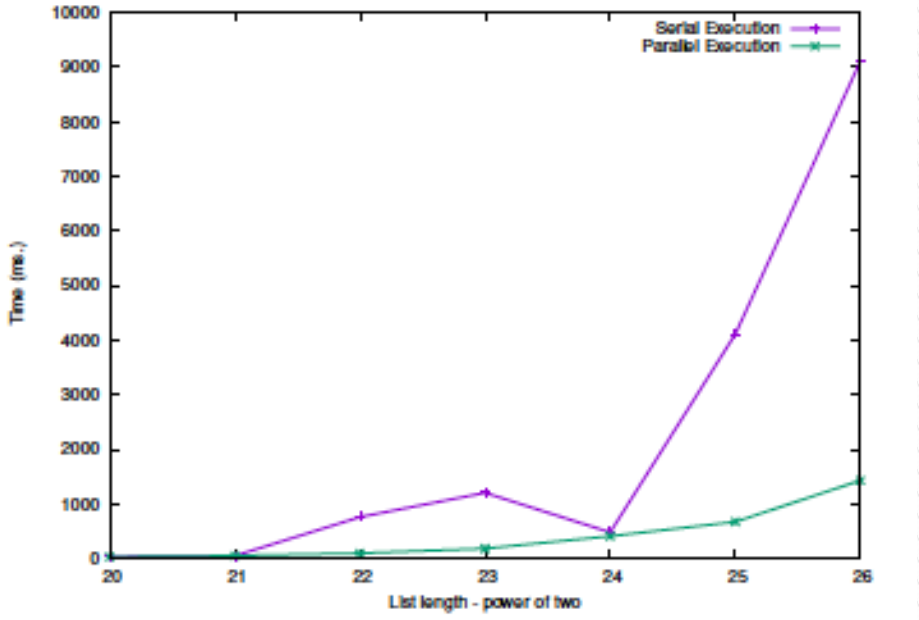
verify the power of 2 length

create the stream

compute the polynomial value

Performance Analysis - Polynomial value





Speedup

Time

Conclusions (1)

- The adaptation of Java Streams uses:
  - the *collect* function as a *template method* for defining the divide-and-conquer PowerList skeletons.
  - specializations of the *Spliterator*
- The PowerList functions are defined as classes implementing the *Collector* interface, and so it wraps the three arguments used in the collect function.
- The analysed examples emphasise the fact that for a large majority of PowerList functions, the definition inside Java Stream API could be done very easy based on the proposed adaptation.

Conclusions (2)

- The performance obtained for the parallel execution of these functions proved to be very good.

- The advantage of Powerlists over general lists is that they provide two different views over the underlying data, simplifying the design of the algorithms on Powerlists.

- Extension to PLists (so multiway divide-and-conquer) needs an extension of the definition of the Spliterator such that *trySplit* method to be able to return a ***set*** of *Spliterator*s that all together cover all the elements of the source.

Thank you!

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