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# Parallel Two-Phase Construction

Parallel Programming in Scala

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- ▶ has an efficient += method

## Two-Phase Construction

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The *intermediate data structure* is a data structure that:

- ▶ has an efficient combine method –  $O(\log n + \log m)$  or better
- ▶ has an efficient += method
- ▶ can be converted to the resulting data structure in  $O(n/P)$  time

## Example: Array Combiner

Let's implement a combiner for arrays.

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```
class ArrayCombiner[T <: AnyRef: ClassTag](val parallelism: Int) {  
  private var numElems = 0  
  private val buffers = new ArrayBuffer[ArrayBuffer[T]]  
  buffers += new ArrayBuffer[T]
```

## Example: Array Combiner

First, we implement the += method:

```
def +=(x: T) = {  
  buffers.last += x  
  numElems += 1  
  this  
}
```



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  numElems += 1  
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}
```

Amortized  $O(1)$ , low constant factors – as efficient as an array buffer.

## Example: Array Combiner

Next, we implement the combine method:

```
def combine(that: ArrayCombiner[T]) = {  
    buffers += that.buffers  
    numElems += that.numElems  
    this  
}
```

## Example: Array Combiner

Next, we implement the combine method:

```
def combine(that: ArrayCombiner[T]) = {  
    buffers += that.buffers  
    numElems += that.numElems  
    this  
}
```

$O(P)$ , assuming that buffers contains no more than  $O(P)$  nested array buffers.

## Example: Array Combiner

Finally, we implement the result method:

```
def result: Array[T] = {  
  val array = new Array[T](numElems)  
  val step = math.max(1, numElems / parallelism)  
  val starts = (0 until numElems by step) :+ numElems  
  val chunks = starts.zip(starts.tail)  
  val tasks = for ((from, end) <- chunks) yield task {  
    copyTo(array, from, end)  
  }  
  tasks.foreach(_.join())  
  array  
}
```

## Benchmark

Demo – we will test the performance of the aggregate method:

```
xs.par.aggregate(newCombiner)(_ += _, _ combine _).result
```

## Two-Phase Construction for Arrays

Two-phase construction works for in a similar way for other data structures. First, partition the elements, then construct parts of the final data structure in parallel:

1. partition the indices into subintervals
2. initialize the array in parallel

## Two-Phase Construction for Hash Tables

1. partition the hash codes into buckets
2. allocate the table, and map hash codes from different buckets into different regions

## Two-Phase Construction for Search Trees

1. partition the elements into non-overlapping intervals according to their ordering
2. construct search trees in parallel, and link non-overlapping trees



## Two-Phase Construction for Spatial Data Structures

1. spatially partition the elements
2. construct non-overlapping subsets and link them

# Implementing combinators

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# Implementing combiners

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1. Two-phase construction – the combiner uses an intermediate data structure with an efficient combine method to partition the elements. When `result` is called, the final data structure is constructed in parallel from the intermediate data structure.
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# Implementing combiners

How can we implement combiners?

1. Two-phase construction – the combiner uses an intermediate data structure with an efficient `combine` method to partition the elements. When `result` is called, the final data structure is constructed in parallel from the intermediate data structure.
2. An efficient concatenation or union operation – a preferred way when the resulting data structure allows this.
3. Concurrent data structure – different combiners share the same underlying data structure, and rely on *synchronization* to correctly update the data structure when `+=` is called.