Big data: architectures and data analytics

RDD-based programming

Basic Actions

Basic RDD actions

- The Spark's actions can
  - Return the content of the RDD and "store" it in a local Java variable of the Driver program
    - **Pay attention to the size of the returned value**
  - Store the content of an RDD in an output file
- The basic actions returning (Java) objects to the Driver are
  - collect(), count(), countByValue(), take(), top(), takeSample(), reduce(), fold(), aggregate(), foreach()

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Syntax

- In the following, the following syntax is used
  - T = Type of the objects of the RDD on which the transformation is applied
  - The RDD on which the action is applied in referred as "input" RDD

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Collect action

Collect action

- Goal
  - The collect action returns a local Java list of objects containing the same objects of the considered RDD
  - **Pay attention to the size of the RDD**
  - **Large RDD cannot be memorized in a local variable of the Driver**
- Method
  - The collect action is based on the **List<T> collect()** method of the **JavaRDD<T>** class

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Collect action: Example 1

- Create an RDD of integers containing the values {1, 2, 3, 3}
- Retrieve the values of the created RDD and store them in a local Java list that is instantiated in the Driver

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Collect action: Example 1

```
// Create an RDD of integers. Load the values 1, 2, 3, 3 in this RDD
List<Integer> inputList = Arrays.asList(1, 2, 3, 3);
JavaRDD<Integer> inputRDD = sc.parallelize(inputList);

// Retrieve the elements of the inputRDD and store them in
// a local Java list
List<Integer> retrievedValues = inputRDD.collect();
```

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Collect action: Example 1

```
// Create an RDD of integers. Load the values 1, 2, 3, 3 in this RDD
List<Integer> inputList = Arrays.asList(1, 2, 3, 3);
JavaRDD<Integer> inputRDD = sc.parallelize(inputList);

// Retrieve the elements of the inputRDD and store them in
// a local Java list
List<Integer> retrievedValues = inputRDD.collect();
```

inputRDD is distributed across the nodes of the cluster.
It can be large and it is stored in the local disks of the nodes if it is needed

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Collect action: Example 1

```
// Create an RDD of integers. Load the values 1, 2, 3, 3 in this RDD
List<Integer> inputList = Arrays.asList(1, 2, 3, 3);
JavaRDD<Integer> inputRDD = sc.parallelize(inputList);

// Retrieve the elements of the inputRDD and store them in
// a local Java list
List<Integer> retrievedValues = inputRDD.collect();
```

retrievedValues is a local Java variable.
It can only be stored in the main memory of the process/task associated with the Driver.
Pay attention to the size of the list.
Use the collect() action if and only if you are sure that the list is small.
Otherwise, store the content of the RDD in a file by using the saveAsTextFile method

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Count action

Count action

- Goal
  - Count the number of elements of an RDD
- Method
  - The count action is based on the **long count()** method of the **JavaRDD<T>** class

Count action: Example 1

- Consider the textual files "document1.txt" and "document2.txt"
- Print the name of the file with more lines

Count action: Example 1

```
// Read the content of the two input textual files
JavaRDD<String> inputRDD1 = sc.textFile("document1.txt");
JavaRDD<String> inputRDD2 = sc.textFile("document2.txt");

// Count the number of lines of the two files = number of elements
// of the two RDDs
long numLinesDoc1 = inputRDD1.count();
long numLinesDoc2 = inputRDD2.count();

if (numLinesDoc1> numLinesDoc2) {
	System.out.println ("document1.txt");
}
else {
	if (numLinesDoc2> numLinesDoc1)
		System.out.println ("document2.txt");
	else
		System.out.println("Same number of lines");
}
```


CountByValue action

CountByValue action

- Goal
  - The countByValue action returns a local Java Map object containing the information about the number of times each element occurs in the RDD
- Method
  - The countByValue action is based on the **java.util.Map<T, java.lang.Long> countByValue()** method of the **JavaRDD<T>** class

CountByValue action: Example 1

- Create an RDD from a textual file containing the first names of a list of users
  - Each line contain one name
- Compute the number of occurrences of each name and "store" this information in a local variable of the Driver

CountByValue action: Example 1

```
// Read the content of the input textual file
JavaRDD<String> namesRDD = sc.textFile("names.txt");

// Compute the number of occurrencies of each name
 java.util.Map<String, java.lang.Long> namesOccurrences =
namesRDD.countByValue();
```


CountByValue action: Example 1

```
// Read the content of the input textual file
JavaRDD<String> namesRDD = sc.textFile("names.txt");

// Compute the number of occurrencies of each name
 java.util.Map<String, java.lang.Long> namesOccurrences =
namesRDD.countByValue();
```

Also in this case, pay attention to the size of the returned map (i.e., the number of names in this case). Use the countByValue() action if and only if you are sure that the returned java.util.Map is small. Otherwise, use an appropriate chain of Spark's transformations and write the final result in a file by using the saveAsTextFile method.

Take action

Take action

- Goal
  - The take(n) action returns a local Java list of objects containing the first n elements of the considered RDD
    - The order of the elements in an RDD is consistent with the order of the elements in the file or collection that has been used to create the RDD
- Method
  - The take action is based on the **List<T> take(int n)** method of the **JavaRDD<T>** class

Take action: Example 1

- Create an RDD of integers containing the values {1, 5, 3, 3, 2}
- Retrieve the first two values of the created RDD and store them in a local Java list that is instantiated in the Driver

Take action: Example 1

```
// Create an RDD of integers. Load the values 1, 5, 3, 3, 2 in this RDD
List<Integer> inputList = Arrays.asList(1, 5, 3, 3, 2);
JavaRDD<Integer> inputRDD = sc.parallelize(inputList);

// Retrieve the first two elements of the inputRDD and store them in
// a local Java list
List<Integer> retrievedValues = inputRDD.take(2);
```

First action

First action

- Goal
  - The first() action returns a local Java object containing the first element of the considered RDD
    - The order of the elements in an RDD is consistent with the order of the elements in the file or collection that has been used to create the RDD
- Method
  - The first action is based on the **T first()** method of the **JavaRDD<T>** class

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First vs Take(1)

- The only difference between first() and take(1) is given by the fact that
  - first() returns a **single element** of type T
    - The returned element is the first element of the RDD
  - take(1) returns a **list** of elements **containing one single element** of type T
    - The only element of the returned list is the first element of the RDD

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Top action

Top action

- Goal
  - The top(n) action returns a local Java list of objects containing the top n (largest) elements of the considered RDD
    - The ordering is the default one of class T (the class of the objects of the RDD)
    - The descending order is used
- Method
  - The top action is based on the **List<T> top(int n)** method of the **JavaRDD<T>** class

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Top action: Example 1

- Create an RDD of integers containing the values {1, 5, 3, 3, 2}
- Retrieve the top-2 greatest values of the created RDD and store them in a local Java list that is instantiated in the Driver

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Top action: Example 1

```
// Create an RDD of integers. Load the values 1, 5, 3, 3,2 in this RDD
List<Integer> inputList = Arrays.asList(1, 5, 3, 3, 2);
JavaRDD<Integer> inputRDD = sc.parallelize(inputList);

// Retrieve the top-2 elements of the inputRDD and store them in
// a local Java list
List<Integer> retrievedValues = inputRDD.top(2);
```

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TakeOrdered action

TakeOrdered action

- Goal
  - The takeOrdered(n, comparator<T>) action returns a local Java list of objects containing the top n (smallest) elements of the considered RDD
    - The ordering is specified by the developer by means of a class implementing the java.util.Comparator<T> interface
- Method
  - The takeOrderedaction is based on the **List<T> takeOrdered (int n, java.util.Comparator<T> comp)** method of the **JavaRDD<T>** class

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TakeSample action

TakeSample action

- Goal
  - The takeSample(withReplacement, n, [seed]) action returns a local Java list of objects containing n random elements of the considered RDD
- Method
  - The takeSampleaction is based on the **List<T> takeSample(boolean withReplacement, int n)** method of the **JavaRDD<T>** class
    - withReplacement specifies if the random sample is with replacement (true) or not (false)

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TakeSample action

- Method
  - The **List<T> takeSample(boolean withReplacement, int n, long seed)** method of the **JavaRDD<T>** class is used when we want to set the seed

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TakeSample action: Example 1

- Create an RDD of integers containing the values {1, 5, 3, 3, 2}
- Retrieve randomly, without replacement, 2 values from the created RDD and store them in a local Java list that is instantiated in the Driver

TakeSample action: Example 1

```
// Create an RDD of integers. Load the values 1, 5, 3, 3,2 in this RDD
List<Integer> inputList = Arrays.asList(1, 5, 3, 3, 2);
JavaRDD<Integer> inputRDD = sc.parallelize(inputList);

// Retrieve randomly two elements of the inputRDD and store them in
// a local Java list
List<Integer> randomValues= inputRDD.takeSample(true, 2);
```


Reduce action

Reduce action

- Goal
  - Return a single Java object obtained by combining the objects of the RDD by using a user provide "function"
    - The provided "function" must be **associative** and **commutative**
      - otherwise the result is not deterministic
    - The returned object and the ones of the "input" RDD are all instances of the same class (T)

Reduce action

- Method
  - The reduce action is based on the **T reduce(Function2<T, T, T> f)** method of the **JavaRDD<T>** class
  - An object of a class implementing the Function2<T, T, T> interface is passed to the reduce method
    - The **public T call(T element1, T element2)** method of the Function2<T, T, T> interface must be implemented
      - It contains the code that is applied to combine the values of the elements of the RDD

Reduce action: how it woks

- Suppose L contains the list of elements of the "input" RDD
- To compute the final element, the reduce action operates as follows
  1. Apply the user specified "function" on a pair of elements e_1 and e_2 occurring in L and obtain a new element e_{new}
  2. Remove the "original" elements e_1 and e_2 from L and then insert the element e_{new} in L
  3. If L contains only one value then return it as final result of the reduce action. Otherwise, return to step 1

Reduce action: how it woks

- If the "function" is associative and commutative, the computation of the reduce action can be performed in parallel without problems
- Otherwise the result is not deterministic and depends on the order of execution of the function on the elements of the RDD

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Reduce action: Example 1

- Create an RDD of integers containing the values {1, 2, 3, 3}
- Compute the sum of the values occurring in the RDD and "store" the result in a local Java integer variable in the Driver

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Reduce action: Example 1

```
// Define a class implementing the Function2 interface
class SumClass implements Function2<Integer, Integer, Integer> {
	// Implement the call method
	public Integer call(Integer element1, Integer element2) {
		return element1+element2;
	}
}
.....
// Create an RDD of integers. Load the values 1, 2, 3, 3 in this RDD
List<Integer> inputListReduce = Arrays.asList(1, 2, 3, 3);
JavaRDD<Integer> inputRDDReduce = sc.parallelize(inputListReduce);

// Compute the sum of the values;
Integer sum= inputRDDReduce.reduce(new SumClass());
```

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Reduce action: Example 2

- Create an RDD of integers containing the values {1, 2, 3, 3}
- Compute the maximum value occurring in the RDD and "store" the result in a local Java integer variable in the Driver

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Reduce action: Example 2

```
// Define a class implementing the Function2 interface
class MaxClass implements Function2<Integer, Integer, Integer> {
	// Implement the call method
	public Integer call(Integer element1, Integer element2) {
		if (element1>element2)
			return element1;
		else
			return element2;
	}
}
.....
// Create an RDD of integers. Load the values 1, 2, 3, 3 in this RDD
List<Integer> inputListReduce = Arrays.asList(1, 2, 3, 3);
JavaRDD<Integer> inputRDDReduce = sc.parallelize(inputListReduce);

// Compute the maximum value
Integer max = inputRDDReduce.reduce(new MaxClass());
```

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Reduce action: Example 2

- The same problem can be solved more easily by using the top action

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Solution based on the Top action

```
// Create an RDD of integers. Load the values 1, 2, 3, 3 in this RDD
List<Integer> inputListReduce = Arrays.asList(1, 2, 3, 3);
JavaRDD<Integer> inputRDDReduce = sc.parallelize(inputListReduce);

// Compute the maximum value
List<Integer> top1 = inputRDDReduce.top(1);
Integer max = top1.get(0);
```

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Fold action

Fold action

- Goal
  - Return a single Java object obtained by combining the objects of the RDD by using a user provide "function"
    - The provided "function" must be **associative** and **commutative**
      - Otherwise the result is not deterministic
  - An initial "zero" value is also specified

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Fold action

- Method
  - The fold action is based on the **T fold(T zeroValue, Function2<T, T, T> f)** method of the **JavaRDD<T>** class
  - The "zero" value of type T is passed
  - And an object of a class implementing the Function2<T, T, T> interface is passed to the fold method
    - The **public T call(T element1, T element2)** method of the Function2<T, T, T> interface must be implemented
      - It contains the code that is applied to combine the values of the elements of the RDD

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Fold vs Reduce

- Fold vs Reduce
  - Fold is characterized by the "zero" value
    - This is the only difference with respect to the reduce() action

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Aggregate action

Aggregate action

- Goal
  - Return a single Java object obtained by combining the objects of the RDD and an initial "zero" value by using two user provide "functions"
    - The provided "functions" must be **associative** and **commutative**
      - otherwise the result is not deterministic
    - The **returned object** and the **ones of the "input" RDD** can be instances of **different classes**
      - This is the main difference with respect to fold( ) and reduce ()

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Aggregate action

- Method
  - The aggregate action is based on the **U aggregate(U zeroValue, Function2<U,T,U> seqOp, Function2<U,U,U> combOp)** method of the **JavaRDD<T>** class
  - The "input" RDD contains objects of type T while the returned object is of type U
    - We need one "function" for merging an element of type T with an element of type U to return a new element of type U
      - It is used to merge the elements of the input RDD and the zero value
    - We need one "function" for merging two elements of type U to return a new element of type U
      - It is used to merge two elements of type U obtained as partial results generated by two different partitions

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Aggregate action

- The first "function" is based on a class implementing the Function2<U, T, U> interface
  - The **public U call(U element1, T element2)** method of the Function2<U, T, U> interface must be implemented
    - It contains the code that is applied to combine the zero value, and the intermediate values, with the elements of the RDD
- The second "function" is based on a class implementing the Function2<U, U, U> interface
  - The **public U call(U element1, U element2)** method of the Function2<U, U, U> interface must be implemented
    - It contains the code that is applied to combine two elements of type U returned as partial results by two different partitions

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Aggregate action: how it woks

- Suppose that L contains the list of elements of the "input" RDD and this RDD is split in a set of partitions, i.e., a set of lists $\{L_1, .., L_n\}$
- The aggregate action computes a partial result in each partition and then combines/merges the results.
- It operates as follows
  1. Aggregate the partial results in each partition, obtaining a set of partial results (of type U) $P = \{p_1, .., p_n\}$
  2. Apply the second user specified "function" on a pair of elements p_1 and p_2 in P and obtain a new element p_{new}
  3. Remove the "original" elements p_1 and p_2 from P and then insert the element p_{new} in P
  4. If P contains only one value then return it as final result of the aggregate action. Otherwise, return to step 2

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Aggregate action: how it woks

- Suppose that
  - L_i is the list of elements on the i-th partition of the "input" RDD
  - And **zeroValue** is the initial zero value
- To compute the partial result over the elements in L_i the aggregate action operates as follows
  1. Set **accumulator** to **zeroValue** (accumulator=zeroValue)
  2. Apply the first user specified "function" on **accumulator** and an elements e_j in L_i and update **accumulator** with the value returned by the function
  3. Remove the "original" elements e_j from L_i
  4. If L_i is empty return **accumulator** as (final) partial result of the current partition. Otherwise, return to step 2

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Aggregate action: Example 1

- Create an RDD of integers containing the values {1, 2, 3, 3}
- Compute both the sum of the values occurring in the input RDD and the number of elements of the input RDD and finally "store" in a local Java variable of the Driver the average computed over the values of the input RDD

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Aggregate action: Example 1

```
// Define a class to store two integers: sum and numElements
class AvgCount implements Serializable {
    public int sum;
    public int numElements;

    public AvgCount(int sum, int numElements){
        this.sum = sum;
        this.numElements = numElements;
    }

    public double avg() {
        return total / (double) num;
    }
}
```

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Aggregate action: Example 1

```
// Define a first class implementing the Function2 interface
// This class contains the call method that is used to combine
// the elements of the input RDD with the zero value and the
// intermediate values of type AvgCount
class AggregateInputElements implements Function2<AvgCount,
Integer, AvgCount> {
    public AvgCount call(AvgCount a, Integer x) {
        a.sum = a. sum + x;
        a.numElements = a.numElements + 1;

        return a;
    }
};
```

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Aggregate action: Example 1

```
// Define a first class implementing the Function2 interface
// This class contains the call method that is used to combine
```

This method (function) combines and object of type AvgCount with an Integer and returns an object of type AvgCount

```
class AggregateInputElements implements Function2<AvgCount,
Integer, AvgCount> {
    public AvgCount call(AvgCount a, Integer x) {
        a.sum = a. sum + x;
        a.numElements = a.numElements + 1;

        return a;
    }
};
```

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Aggregate action: Example 1

```
// Define a second class implementing the Function2 interface
// This class contains the call method that is used to combine
// two elements of type AvgCount returned as partial results
// by two different partitions
class AggregateIntermediateResults implements Function2<AvgCount,
AvgCount, AvgCount> {
    public AvgCount call(AvgCount a, AvgCount b) {
        a.sum = a. sum + b.sum;
        a.numElements = a.numElements + b.numElements;

        return a;
    }
};
```

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Aggregate action: Example 1

```
// Define a second class implementing the Function2 interface
// This class contains the call method that is used to combine
```

This method (function) combines two objects of type AvgCount and returns an object of type AvgCount

```
class AggregateIntermediateResults implements Function2<AvgCount,
AvgCount, AvgCount> {
    public AvgCount call(AvgCount a, AvgCount b) {
        a.sum = a. sum + b.sum;
        a.numElements = a.numElements + b.numElements;

        return a;
    }
};
```

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Aggregate action: Example 1

```
.....
// Create an RDD of integers. Load the values 1, 2, 3, 3 in this RDD
List<Integer> inputListAggr = Arrays.asList(1, 2, 3, 3);
JavaRDD<Integer> inputRDDAggr = sc.parallelize(inputListAggr);

// Compute sum and number of elements of inputRDDAggr
Integer sum= inputRDDAggr.
AvgCount zeroValue = new AvgCount(0, 0);
AvgCount result = inputRDDAggr.aggregate(zeroValue,
new AggregateInputElements(), new AggregateIntermediateResults());

// Compute the average value
double avg = result.avg();
```

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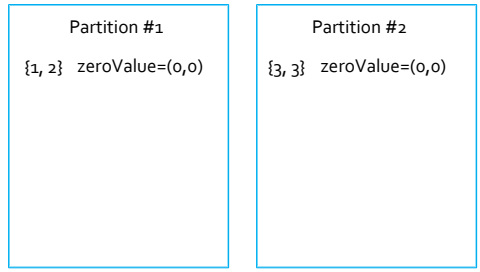
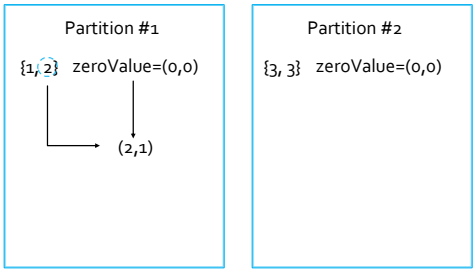
Aggregate action: Simulation

- inputRDDAggr = {1, 2, 3, 3}
- Suppose it is split in following two partitions
  - {1, 2} and {3, 3}

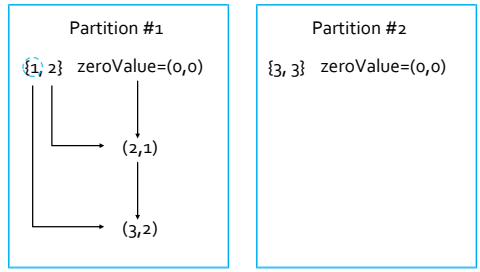
Aggregate action: Simulation



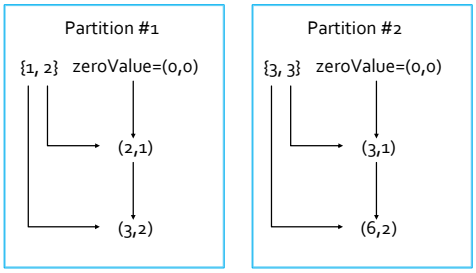
Aggregate action: Simulation



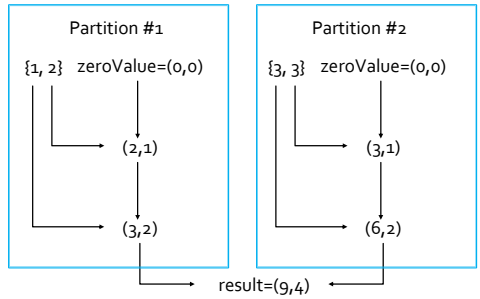
Aggregate action: Simulation



Aggregate action: Simulation



Aggregate action: Simulation



Basic actions: Summary

Basic actions: Summary

- All the examples reported in the following tables are applied on inputRDD that is an RDD of integers containing the following elements (i.e., values)
  - {1, 2, 3, 3}

Basic actions: Summary

Action	Purpose	Example	Result
java.util.List<T> collect()	Return a (Java) List containing all the elements of the RDD on which it is applied. The objects of the RDD and objects of the returned list are objects of the same class.	inputRDD.collect()	{1,2,3,3}
long count()	Return the number of elements of the RDD	inputRDD.count()	4
java.util.Map<T,java.lang.Long> countByValue()	Return a Map object containing the information about the number of times each element occurs in the RDD.	inputRDD. countByValue()	{(1, 1), (2, 1), (3, 2)}

Basic actions: Summary

Action	Purpose	Example	Result
java.util.List<T> take(int n)	Return a (Java) List containing the first num elements of the RDD. The objects of the RDD and objects of the returned list are objects of the same class.	inputRDD.take(2)	{1,2}
T first()	Return the first element of the RDD	first()	{1}
java.util.List<T> top(int n)	Return a (Java) List containing the top num elements of the RDD based on the default sort order/comparator of the objects. The objects of the RDD and objects of the returned list are objects of the same class.	inputRDD.top(2)	{3,3}

Basic actions: Summary

Action	Purpose	Example	Result
java.util.List<T> takeSample(boolean withReplacement, int n, [long seed])	Return a (Java) List containing a random sample of size n of the RDD. The objects of the RDD and objects of the returned list are objects of the same class.	inputRDD. takeSample (false, 1)	Nondeterministic
T reduce(Function2<T, T, T> f)	Return a single Java object obtained by combining the values of the objects of the RDD by using a user provide "function". The provided "function" must be associative and commutative The object returned by the method and the objects of the RDD belong to the same class.	The passed "function" is the sum function	9

Basic actions: Summary

Action	Purpose	Example	Result
T fold(T zeroValue, Function2<T,T,T> f)	Same as reduce but with the provided zero value.	The passed "function" is the sum function and the passed zeroValue is 0	9
<U> U aggregate(U zeroValue, Function2<U,T,U> seqOp, Function2<U,U,U> combOp)	Similar to reduce() but used to return a different type.	Compute a pair of integers where the first one is the sum of the values of the RDD and the second the number of elements	(9, 4)