CS6240-Assignment 4

FALL 2020

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GitHub:

https://github.com/2020-F-CS6240/homework-4-mapreduce-rahulpandeycs (MR)

https://github.com/2020-F-CS6240/homework-4-spark-rahulpandeycs (Spark)

PageRank Spark: https://github.com/2020-F-CS6240/homework-4-spark-rahulpandeycs/blob/master/src/main/scala/pageRank/PageRankMain.scala

PageRank MR code: https://github.com/2020-F-CS6240/homework-4-mapreduce-rahulpandeycs/blob/master/src/main/java/pageRank/PageRankFromSyntheticData.java

PageRank in Spark (40 points total):

The graph is of form (page1, page2) which signifies, page1 has outlink to page2. The another table generated on the fly is the pageRank table, which is of form (pageId, pageRank).

PseudoCode:

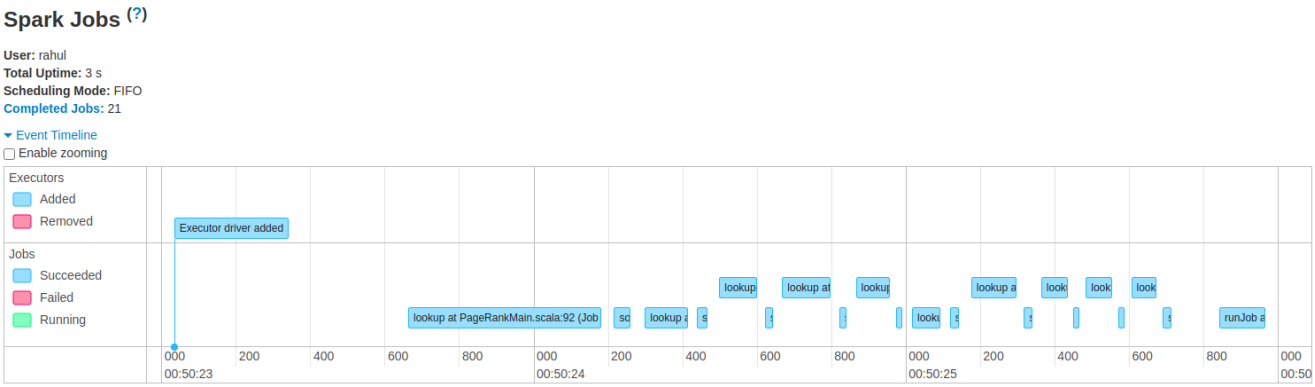
```
SparkPageRank(){

k = first_Argument_via_CommandLine (100)
start = 1

pairV1V2 = new ListBuffer[Row]
pairEdgePageRank = new ListBuffer[Row]

pairEdgePageRank += Row(0, 0.0)

//Creating Graph and RDD on the fly
while (start <= k * k) {

  pairEdgePageRank += Row(start, 1.0 / (k * k)) //Defaulting pageRank for each
page to 1/k*k



  // Fill pairV1V2 with dummy
  if (start % k == 0) { //Creating the Dummy node at the end of each dangling page
    pairV1V2 += Row(start, 0)
  } else {
    pairV1V2 += Row(start, start + 1) //Connecting pages 1->2->3-4 etc.
  }
  start = start + 1
}
```

```
//args(2)
iters = if (args.length > 1) args(1).toInt else 10 //If number of iteration is not
passed default it to 10


//Convert pageRank and V1V2 pair to RDD
pairV1V2RDD = sc.parallelize(pairV1V2) //Converting V1V2 Pair graph to RDD
pairEdgePageRankRDD = sc.parallelize(pairEdgePageRank) //Converting pagerank per
page list to RDD

rddGraph = pairV1V2RDD.map(row => (row(0), List(row(1))))
  .reduceByKey(_++_)
  .cache()  //Cache the graph in the memory


//Converting to RDD(pageId, pageRank)
rddPageRank = pairEdgePageRankRDD.map(row => (row(0), row(1).toString.toDouble))
  .partitionBy(rddGraph.partitioner.get) //using same partition as rddGraph


for (i <- 1 to iters) {
  //Joining RDD's
  temp = rddGraph.join(rddPageRank)

  //Calculating OutLink contribution
  contribs = rddGraph.join(rddPageRank).flatMap {
    case (vertex, (adjNodes, pageRankOfVertex)) => val totalOutLinks =
adjNodes.size

      //Distributing vertex pagerank over its adjacency list
      adjNodes.flatMap(url => List((url, pageRankOfVertex / totalOutLinks),
(vertex, 0.0))) //Pass vertex to keep track of originating vertex, adding 0.0 for
vertex with no inlinks
  }
  contribsMain = contribs.reduceByKey(_+_) //Sum pageRanks

  //Get dangling page mass using the lookup for dummy node
  val danglingMass = contribsMain.lookup(0).head

  rddPageRank = contribsMain.map {  //value is sum of pageRank of all pages adj to
vertex
    case (vertex, value) => if (vertex == 0) {
      (vertex, 0.0)
    } else { // Calculating pagerank
      (vertex, 0.15 * (1.0 / (k * k)) + 0.85 * (value + danglingMass * (1.0 / (k *
k)))) //Distribute dangling pages mass
    }
  }.sortBy(_._1.toString.toInt)
}

//args(2)
logger.info(rddPageRank.toDebugString)
rddPageRank.saveAsTextFile(args(2))  //Save data to local storage
}
```

<u>Which of the operations in your program perform an action</u> ?

The operations sortBy, Lookup and saveAsTextFile() triggers an actions. This can be verified using the below screenshot from Spark UI visualization at:

http://localhost:18080/history/local-1604728223014/jobs/



The above result is for total of 10 iteration for k =10. We can see there are 10 lookup() and corresponding sortBy() call. We can see at the end the even around 800 is a write to local storage and is triggered by saveAsTextFile()

<u>Program for 10 iterations for k=100, and output</u>:

Output:

https://github.com/2020-F-CS6240/homework-4-spark-rahulpandeycs/tree/master/localOutputK100

Logs: https://github.com/2020-F-CS6240/homework-4-spark-rahulpandeycs/blob/master/logs/SparkLocal_K100/K100_LocalRun.txt

Show the lineage for RDD Ranks :

After 1 loop iterations:

```
2020-11-07 01:05:41 INFO  root:98 - (4) MapPartitionsRDD[19] at sortBy at
PageRankMain.scala:94 []
 |  ShuffledRDD[18] at sortBy at PageRankMain.scala:94 []
 +-(4) MapPartitionsRDD[15] at sortBy at PageRankMain.scala:94 []
    |  MapPartitionsRDD[14] at map at PageRankMain.scala:88 []
    |  ShuffledRDD[13] at reduceByKey at PageRankMain.scala:83 []
    +-(4) MapPartitionsRDD[12] at flatMap at PageRankMain.scala:78 []
       |  MapPartitionsRDD[11] at join at PageRankMain.scala:78 []
       |  MapPartitionsRDD[10] at join at PageRankMain.scala:78 []
       |  CoGroupedRDD[9] at join at PageRankMain.scala:78 []
       |  ShuffledRDD[3] at reduceByKey at PageRankMain.scala:67 []
       |      CachedPartitions: 4; MemorySize: 820.4 KB; ExternalBlockStoreSize:
0.0 B; DiskSize: 0.0 B
       +-(4) MapPartitionsRDD[2] at map at PageRankMain.scala:66 []
          |  ParallelCollectionRDD[0] at parallelize at PageRankMain.scala:63 []
       |  ShuffledRDD[5] at partitionBy at PageRankMain.scala:71 []
       +-(4) MapPartitionsRDD[4] at map at PageRankMain.scala:70 []
          |  ParallelCollectionRDD[1] at parallelize at PageRankMain.scala:64 []
```

After 2 loop iterations:

```
2020-11-07 01:07:00 INFO  root:98 - (4) MapPartitionsRDD[33] at sortBy at
PageRankMain.scala:94 []
 |  ShuffledRDD[32] at sortBy at PageRankMain.scala:94 []
 +-(4) MapPartitionsRDD[29] at sortBy at PageRankMain.scala:94 []
    |  MapPartitionsRDD[28] at map at PageRankMain.scala:88 []
    |  ShuffledRDD[27] at reduceByKey at PageRankMain.scala:83 []
    +-(4) MapPartitionsRDD[26] at flatMap at PageRankMain.scala:78 []
       |  MapPartitionsRDD[25] at join at PageRankMain.scala:78 []
       |  MapPartitionsRDD[24] at join at PageRankMain.scala:78 []
       |  CoGroupedRDD[23] at join at PageRankMain.scala:78 []
       |  ShuffledRDD[3] at reduceByKey at PageRankMain.scala:67 []
       |      CachedPartitions: 4; MemorySize: 820.4 KB; ExternalBlockStoreSize:
0.0 B; DiskSize: 0.0 B
       +-(4) MapPartitionsRDD[2] at map at PageRankMain.scala:66 []
          |  ParallelCollectionRDD[0] at parallelize at PageRankMain.scala:63 []
       +-(4) MapPartitionsRDD[19] at sortBy at PageRankMain.scala:94 []
          |  ShuffledRDD[18] at sortBy at PageRankMain.scala:94 []
          +-(4) MapPartitionsRDD[15] at sortBy at PageRankMain.scala:94 []
             |  MapPartitionsRDD[14] at map at PageRankMain.scala:88 []
             |  ShuffledRDD[13] at reduceByKey at PageRankMain.scala:83 []
             +-(4) MapPartitionsRDD[12] at flatMap at PageRankMain.scala:78 []
                |  MapPartitionsRDD[11] at join at PageRankMain.scala:78 []
                |  MapPartitionsRDD[10] at join at PageRankMain.scala:78 []
                |  CoGroupedRDD[9] at join at PageRankMain.scala:78 []
                |  ShuffledRDD[3] at reduceByKey at PageRankMain.scala:67 []
                |      CachedPartitions: 4; MemorySize: 820.4 KB;
ExternalBlockStoreSize: 0.0 B; DiskSize: 0.0 B
```

```
               +-(4) MapPartitionsRDD[2] at map at PageRankMain.scala:66 []
                  |  ParallelCollectionRDD[0] at parallelize at
PageRankMain.scala:63 []
               |  ShuffledRDD[5] at partitionBy at PageRankMain.scala:71 []
               +-(4) MapPartitionsRDD[4] at map at PageRankMain.scala:70 []
                  |  ParallelCollectionRDD[1] at parallelize at
PageRankMain.scala:64 []
```

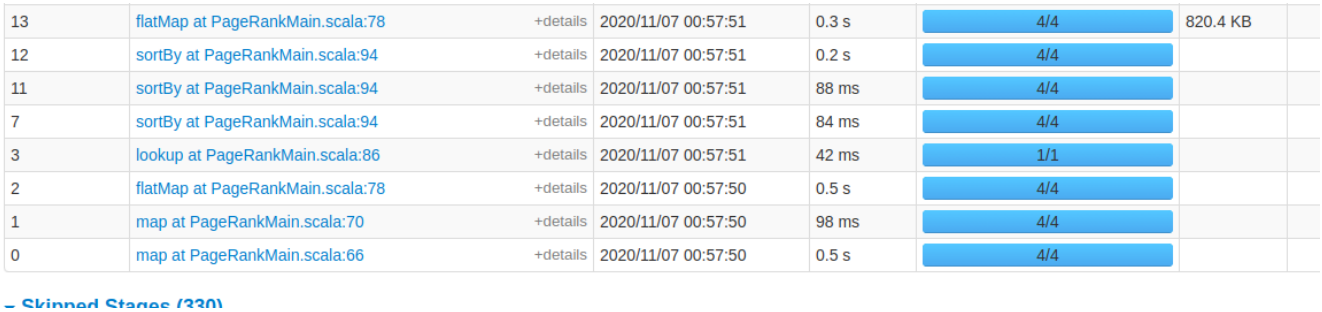
After 3 loop iterations:

```
2020-11-07 01:08:29 INFO  root:98 - (4) MapPartitionsRDD[47] at sortBy at
PageRankMain.scala:94 []
 |  ShuffledRDD[46] at sortBy at PageRankMain.scala:94 []
 +-(4) MapPartitionsRDD[43] at sortBy at PageRankMain.scala:94 []
    |  MapPartitionsRDD[42] at map at PageRankMain.scala:88 []
    |  ShuffledRDD[41] at reduceByKey at PageRankMain.scala:83 []
    +-(4) MapPartitionsRDD[40] at flatMap at PageRankMain.scala:78 []
       |  MapPartitionsRDD[39] at join at PageRankMain.scala:78 []
       |  MapPartitionsRDD[38] at join at PageRankMain.scala:78 []
       |  CoGroupedRDD[37] at join at PageRankMain.scala:78 []
       |  ShuffledRDD[3] at reduceByKey at PageRankMain.scala:67 []
       |      CachedPartitions: 4; MemorySize: 820.4 KB; ExternalBlockStoreSize:
0.0 B; DiskSize: 0.0 B
       +-(4) MapPartitionsRDD[2] at map at PageRankMain.scala:66 []
          |  ParallelCollectionRDD[0] at parallelize at PageRankMain.scala:63 []
       +-(4) MapPartitionsRDD[33] at sortBy at PageRankMain.scala:94 []
          |  ShuffledRDD[32] at sortBy at PageRankMain.scala:94 []
          +-(4) MapPartitionsRDD[29] at sortBy at PageRankMain.scala:94 []
             |  MapPartitionsRDD[28] at map at PageRankMain.scala:88 []
             |  ShuffledRDD[27] at reduceByKey at PageRankMain.scala:83 []
             +-(4) MapPartitionsRDD[26] at flatMap at PageRankMain.scala:78 []
                |  MapPartitionsRDD[25] at join at PageRankMain.scala:78 []
                |  MapPartitionsRDD[24] at join at PageRankMain.scala:78 []
                |  CoGroupedRDD[23] at join at PageRankMain.scala:78 []
                |  ShuffledRDD[3] at reduceByKey at PageRankMain.scala:67 []
                |      CachedPartitions: 4; MemorySize: 820.4 KB;
ExternalBlockStoreSize: 0.0 B; DiskSize: 0.0 B
               +-(4) MapPartitionsRDD[2] at map at PageRankMain.scala:66 []
                  |  ParallelCollectionRDD[0] at parallelize at
PageRankMain.scala:63 []
               +-(4) MapPartitionsRDD[19] at sortBy at PageRankMain.scala:94 []
                  |  ShuffledRDD[18] at sortBy at PageRankMain.scala:94 []
                  +-(4) MapPartitionsRDD[15] at sortBy at PageRankMain.scala:94 []
                     |  MapPartitionsRDD[14] at map at PageRankMain.scala:88 []
                     |  ShuffledRDD[13] at reduceByKey at PageRankMain.scala:83 []
                     +-(4) MapPartitionsRDD[12] at flatMap at
PageRankMain.scala:78 []
                        |  MapPartitionsRDD[11] at join at PageRankMain.scala:78
[]
                        |  MapPartitionsRDD[10] at join at PageRankMain.scala:78
[]
                        |  CoGroupedRDD[9] at join at PageRankMain.scala:78 []
                        |  ShuffledRDD[3] at reduceByKey at PageRankMain.scala:67
[]
```

```
                          |      CachedPartitions: 4; MemorySize: 820.4 KB;
ExternalBlockStoreSize: 0.0 B; DiskSize: 0.0 B
                          +-(4) MapPartitionsRDD[2] at map at PageRankMain.scala:66
[]
                             |  ParallelCollectionRDD[0] at parallelize at
PageRankMain.scala:63 []
                          |  ShuffledRDD[5] at partitionBy at PageRankMain.scala:71
[]
                          +-(4) MapPartitionsRDD[4] at map at PageRankMain.scala:70
[]
                             |  ParallelCollectionRDD[1] at parallelize at
PageRankMain.scala:64 []
```

How you determined what was actually executed by a job triggered by your program:

This is evident by looking at Pagerank job execution in Spark UI. Looking at various stages executed in the UI reveals what happened under the hood.



13	flatMap at PageRankMain.scala:78	+details	2020/11/07 00:57:51	0.3 s	4/4	820.4 KB	
12	sortBy at PageRankMain.scala:94	+details	2020/11/07 00:57:51	0.2 s	4/4		
11	sortBy at PageRankMain.scala:94	+details	2020/11/07 00:57:51	88 ms	4/4		
7	sortBy at PageRankMain.scala:94	+details	2020/11/07 00:57:51	84 ms	4/4		
3	lookup at PageRankMain.scala:86	+details	2020/11/07 00:57:51	42 ms	1/1		
2	flatMap at PageRankMain.scala:78	+details	2020/11/07 00:57:50	0.5 s	4/4		
1	map at PageRankMain.scala:70	+details	2020/11/07 00:57:50	98 ms	4/4		
0	map at PageRankMain.scala:66	+details	2020/11/07 00:57:50	0.5 s	4/4		

▸ Skipped Stages (330)

Startup:

It can be seen clearly the first stage points to the map at line 66 of the program. That is when we try to create the graph RDD:

```
val rddGraph = pairV1V2RDD.map(row => (row(0), List(row(1))))
  .reduceByKey(_++_)
  .cache()  //Cache the graph in the memory
```

The second stage (1) is similar creation of pageRankRDD using map.
Then in Stage(2) we have a flatMap that represents the join between these two tables and calculating the contribution.
Then finally we have a lookup for getting the dangling mass from dummy node.
This is followed by the sortBy() which sorts the data based on the key.

Iterations:
The next set of execution include the same set of steps I.e:

- flatMap → For joining the two RDD's.
- Lookup to get the dangling mass.
- SortBy to sort the data based on key as received from the map job.

Sequence followed:

```
sortBy at PageRankMain.scala:94
sortBy at PageRankMain.scala:94
sortBy at PageRankMain.scala:94
lookup at PageRankMain.scala:86
flatMap at PageRankMain.scala:78
```

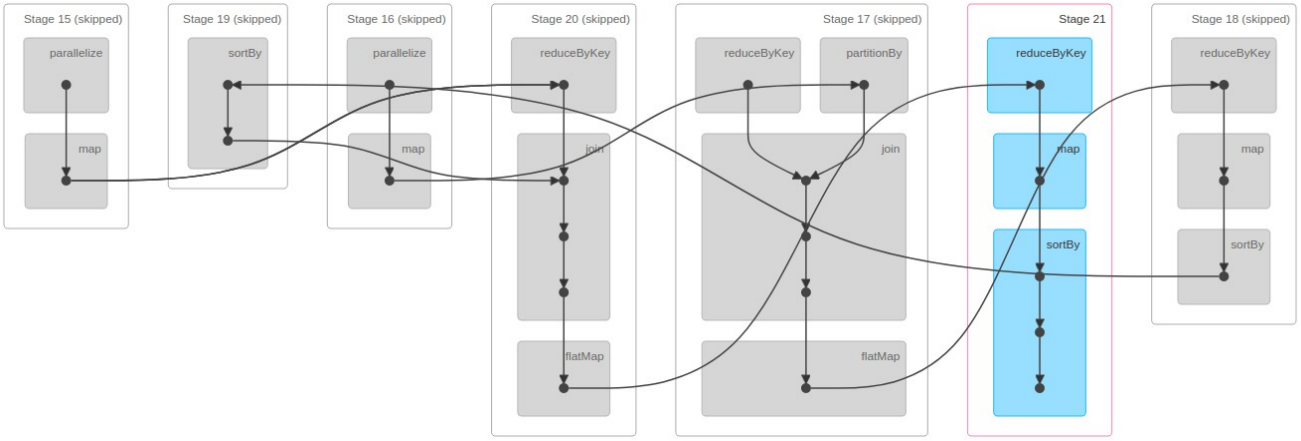
Last stage:
The last stage is saveAsTextFile(), this is evident from the last job we see in the completed stages:

Stage Id ▼	Description	Submitted	Duration	Tasks: Succeeded/Total	Input	Output	Shuffle Read
381	runJob at SparkHadoopWriter.scala:78 +details	2020/11/07 00:57:54	0.1 s	4/4		283.6 KB	108.1 KB
380	sortBy at PageRankMain.scala:94 +details	2020/11/07 00:57:54	34 ms	4/4			105.5 KB

<u>Report your observations:</u>

(1) Is Spark smart enough to figure out that it can re-use RDDs computed for an earlier action?

Yes, The Spark is smart enough to not recompute RDD's from previous action and use it to improve the performance. As seen in below DAG visualization the previous steps were skipped as they were served from the memory.



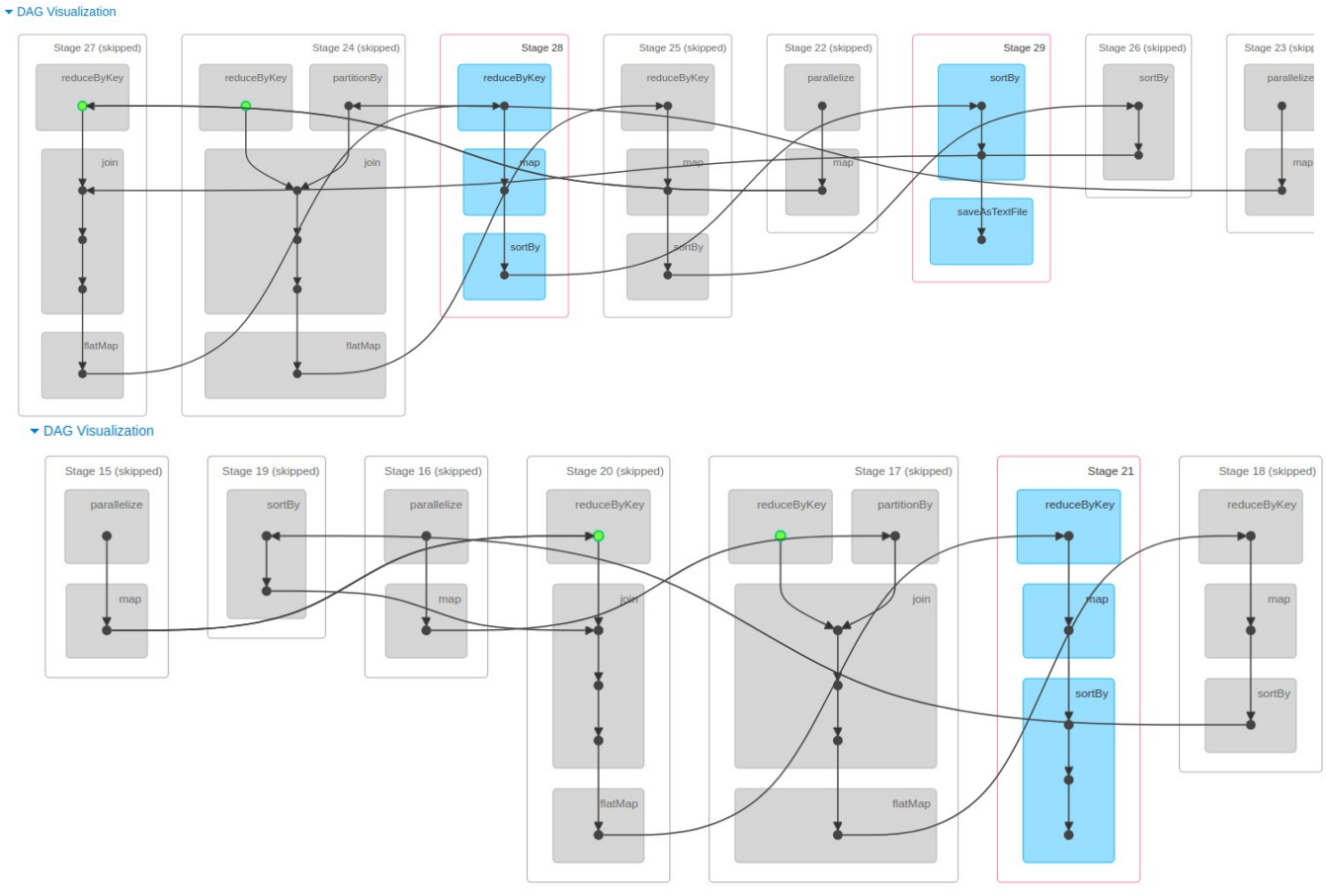
Looking at process status the locality level is ANY as we have not explicitly asked spark to cache() or persist() this and it is just one of the performance optimization it is doing in the background.

Tasks (4)

Index ▲	ID	Attempt	Status	Locality Level	Executor ID	Host
0	8	0	SUCCESS	ANY	driver	localhost
1	9	0	SUCCESS	ANY	driver	localhost
2	10	0	SUCCESS	ANY	driver	localhost
3	11	0	SUCCESS	ANY	driver	localhost

(2) How do persist() and cache() change this behavior?

By using cache() and persist() we are telling the spark explicitly to store the data in cache and during further processing serve it from the memory. Though the locality level changes to **PROCESS_LOCAL** from **ANY**



As seen from the above DAG visualization there are several steps that were skipped as it was served from the memory. The green dot in the image show the RDD was cached.

Tasks (4)

Index ▲	ID	Attempt	Status	Locality Level	Executor ID	Host
0	4	0	SUCCESS	PROCESS_LOCAL	driver	localhost
1	5	0	SUCCESS	PROCESS_LOCAL	driver	localhost
2	6	0	SUCCESS	PROCESS_LOCAL	driver	localhost
3	7	0	SUCCESS	PROCESS_LOCAL	driver	localhost

<u>PageRank in MapReduce</u> (20 points total)
The input to the program is generated beforehand and each row in the input looks like:
pageId1 pageId2, pageRank e.g : *1 2,0.00010*

The input is generates using a separate program present within the code.

Here pageId1 has a outlink to pageId2 and pageRank is the pageRank for pageId1
The code is run for 10 iterations and k=1000 where each job output is input to the next as we keep updating the pagerank value in each iteration. Also, we have global counters **DELTA_SUM** and **PAGE_RANK_SUM** to keep track of dangling mass sum that will be distributed over nodes and pagerank sum to ensure the final pagerank sum is close to 1.

PsuedoCode:

```
//Custom writable class that represents the node in the graph
class PageNode {

  id = -1
  pageRank = -1
  adjList = ""

  PageNode() {
  }


//Constructor to create
  PageNode(int id, double pageRank, String adjList) {
    id = id
    pageRank = pageRank
    adjList = adjList
  }
```

```
  public void write(DataOutput dataOutput) throws IOException {
    dataOutput.writeInt(id)
    dataOutput.writeUTF(adjList)
    dataOutput.writeDouble(pageRank)
  }
  //Readfields
  public void readFields(DataInput dataInput) throws IOException {
    id = dataInput.readInt()
    adjList = dataInput.readUTF()
    pageRank = dataInput.readDouble()
  }

  //String value used to write to output
  public String toString() {
    return "" + adjList + "," + this.pageRank
  }
}


//Global counter
enum PageRankGlobalCounter {
  PAGE_RANK_SUM,  //Keep track of page rank sum for the last job
  DELTA_SUM  // used to calculate dangling mass sum
}


class PageRankFromSyntheticData {

  k = 1000;

  class PageRankMapper {
    totalNumberOfPages
    delta


   setup(context) {
      // get total number of pages effectively |V|
      totalNumberOfPages = getFromJobConfig("totalNumberOfPages"))

     // Get delta from previous iteration as passed from previous run
      delta = getFromJobConfig("delta"))
    }


    map(key, value, context) {

      // separate pagerank data from graph data
      graphAndPageRank[] = value.toString().split(",")


      //For input vertex X in row: X Y
      inputSplit[] = graphAndPageRank[0].split(" ")


      //Distribute dangling mass value
      calculatedPageRank = graphAndPageRank[1] + (0.85) * delta /
totalNumberOfPages
```

```
      PageNode pageNode = PageNode(inputSplit[0], calculatedPageRank,
(inputSplit.length > 1 ? inputSplit[1] : ""))

adjSize = inputSplit.length - 1
      emit(new Text(pageNode.id, pageNode)

      if (adjSize > 0) {
        pgRnkToDistribute = ((calculatedPageRank) / (adjSize))

      for (i = 1; i < inputSplit.length; i++) {

         //emit node with distributed page rank for each vertex
          emit(inputSplit[i]), PageNode(-1, pgRnkToDistribute, ""))
        }
      }
    }
  }


class PageRankReducer {

    totalNumberOfPages = getFromJobConfiguration("totalNumberOfPages"))

    reduce(key, Iterable<PageNode> values,  context){
      double sum = 0.0
      PageNode newNode = new PageNode()

      for (PageNode node <- values) {
        if (node.id != -1) { //The vertex was found, recover graph
          newNode = PageNode(node.id, node.pageRank, node.adjList)
        } else {
          sum += node.pageRank;  //Sum inlink contribution
        }
      }


      if (key!= 0) //If not the dummyNode and not null
        newNode.pageRank = (0.15) * (1.0) / (totalNumberOfPages) + (0.85 * sum)
      else
        newNode.pageRank = 0.0

      // emit(id adjList, pageRank)
      emit(key, newNode)

      //If dummyNode, pass pageRank to next node
      if (newNode.id == 0) {  //
        getGlobalCounter(DELTA_SUM).setValue((sum))
      }
    }
  }


class LastJobMapper {

    totalNumberOfPages =getFromJobConfiguration("totalNumberOfPages"))
    delta = getFromJobConfiguration("delta"))


    map(key, value,context) {
```

```
// retrieve graph and pagerank data
      graphAndPageRank[] = value.toString().split(",")

      if (graphAndPageRank.length != 2)
        return

      //For input vertex X in row: X Y
      inputSplit[] = graphAndPageRank[0].split(" ")

       PageNode pageNode = PageNode(inputSplit[0], 0.0, (inputSplit.length > 1 ?
inputSplit[1] : ""))

//If not dummy node, distribute dangling mass
      if (pageNode.id != 0) {
        pageNode.pageRank = graphAndPageRank[1] + ((0.85 * delta) /
(totalNumberOfPages))

}

      emit(pageNode.id, pageNode)

     // Sum pagerank for last ob to ensure it is close to 1
      getGlobalCounter(PAGE_RANK_SUM).increment((pageNode.pageRank))
    }
  }


  DriverCode(input_CLI) {
    conf = getConf()
    iterationNum = 1
    delta = 0.0

    //Job 0
    Job job = Job.getInstance(conf, "PageRank MR: " + iterationNum)

    jobConf = job.getConfiguration()
    jobConf.set("delta", "" + delta) // set initial delta value
    jobConf.set("totalNumberOfPages", "" + k * k)  // set total_pages to k*k value

    job.setMapperClass(PageRankMapper.class)
    job.setReducerClass(PageRankReducer.class)

     //For 20 map tasks, using NLINEINPUTFORMAT

    job.setInputFormatClass(NLineInputFormat.class)
    job.setOutputKeyClass(Text.class)
    job.setOutputValueClass(PageNode.class)



    //Setting input and output path from console

   NLineInputFormat.addInputPath(job, new Path(args[0]))
    jobConf.setInt("mapreduce.input.lineinputformat.linespermap", k * k / 20)

    FileOutputFormat.setOutputPath(job, new Path(args[1] + "/Job" + iterationNum))
    job.waitForCompletion(true)
```

```
    iterationNum++ // Increase iteration



    //Next set of Jobs (Each job output is passed to next job as input)
   //The delta is read for each previous job as currentDelta and passed to next Job
    while (iterationNum <= 10) {

      currDelta = getGlobalCounter(DELTA_SUM)  // previous job delta

      conf = getConf()
      job = Job.getInstance(conf, "PageRankMR: " + iterationNum)

      jobConf = job.getConfiguration()
      jobConf.set("mapreduce.output.textoutputformat.separator", " ")

      job.setMapperClass(PageRankMapper.class)
      job.setReducerClass(PageRankReducer.class)

      job.setInputFormatClass(NLineInputFormat.class)

      job.setOutputKeyClass(Text.class)
      job.setOutputValueClass(PageNode.class)

      //Setting global accessible data for job
      jobConf.set("delta", "" + currDelta);
      jobConf.set("totalNumberOfPages", "" + k * k)

      NLineInputFormat.addInputPath(job, new Path(args[1] + "/Job" + (iterationNum
- 1)))
      jobConf.setInt("mapreduce.input.lineinputformat.linespermap", k * k / 20)

      FileOutputFormat.setOutputPath(job, new Path(args[1] + "/Job" +
iterationNum))

      waitForCompletion

      iterationNum++  //Increment counter to complete 9 iterations
    }

    //Last job to add delta values of last iteration via @LastJobMapper
    double currDelta = getGlobalCounter(DELTA_SUM)

    conf = getConf()
    job = Job.getInstance(conf, "PageRank MR: " + iterationNum)
    job.setJarByClass(PageRankFromSyntheticData.class)

    jobConf = job.getConfiguration()
    jobConf.set("mapreduce.output.textoutputformat.separator", " ")

    job.setMapperClass(LastJobMapper.class)
    job.setNumReduceTasks(0); // No reduce, map only job

    job.setInputFormatClass(NLineInputFormat.class)

   job.setOutputKeyClass(Text.class)
    job.setOutputValueClass(PageNode.class)

   //Setting global accessible data for job
```

```
    jobConf.set("delta", "" + currDelta) //set delta as receiveed from previous job
    jobConf.set("totalNumberOfPages", "" + k * k) //set totalPages to k*k


    NLineInputFormat.addInputPath(job, new Path(args[1] + "/Job" + (iterationNum -
1)))
    jobConf.setInt("mapreduce.input.lineinputformat.linespermap", k * k / 20)

    FileOutputFormat.setOutputPath(job, new Path(args[1] + "/Job" +
"LastJobOutput"))

    waitForCompletion()

    System.out.println("The sum of all pages pageRank is: " + (double)
getGlobalCounter(PAGE_RANK_SUM)/ (10000000));  //output total pagerank sum

  }
```

How you solved the dangling-page problem ?

The dangling page problem was solved using the dummy node as described in the course module.

1. The job starts with initializing the delta I.e dummy node pagerank to 0.
2. The map phase reads this delta as zero and in the reduce phase while calculating pagerank for each page, check if page is dummy node.
3. The gobal counter value is set to this value and it is made available to the next job via global counters.
4. The next map phase on receiving this value distributes it over all nodes.
5. An extra map only job is created at the end to add all delta values for the last iteration.

Running 20 Map Tasks:

```
job.setInputFormatClass(NLineInputFormat.class);
NLineInputFormat.addInputPath(job, new Path(args[1] + "/Job" + (iterationNum –
1)));
jobConf.setInt("mapreduce.input.lineinputformat.linespermap", k * k / 20);
```

The 20 Map task are created using the the above code. It is evident from the logs and the final map task output that 20 output files are created.

***RUN RESULTS* (FOR MR)**

Program for k=1000 and 10 iterations on the following two configurations(- Machine (m4.large)):

***5 cheap machines** (1 master and 4 workers)*

Running time: 14 Mins
ClusterID: j-2U2VYU5JUVNH7

***9 cheap machines** (1 master and 8 workers)*

Running time: 11Mins
ClusterID: j-10FGYNMXODGJ4

Syslogs Link:*(Small Cluster: m4.large (4 +1), Large Cluster m4.large(8+1))*

Spark Local Run: *(K=100, 10 iterations)*

https://github.com/2020-F-CS6240/homework-4-spark-rahulpandeycs/blob/master/logs/SparkLocal_K100/K100_LocalRun.txt

MR AWS Small Cluster: *(K=1000, 10 iterations)*

https://github.com/2020-F-CS6240/homework-4-mapreduce-rahulpandeycs/tree/master/logs/MR_AWS_SMALL

MR AWS Large Cluster: *(K=1000, 10 iterations)*

https://github.com/2020-F-CS6240/homework-4-mapreduce-rahulpandeycs/tree/master/logs/MR_AWS_LARGE

Output Folder Link:(Includes output from all iteration but final output in `JobLastJobOutput` , For MR folder)

SPARK Local Run: *(K=100, 10 iterations)*
https://github.com/2020-F-CS6240/homework-4-spark-rahulpandeycs/tree/master/localOutputK100

AWS Small cluster run: *(K=1000, 10 iterations)*
https://github.com/2020-F-CS6240/homework-4-mapreduce-rahulpandeycs/tree/master/MROutputAWSSmall

AWS Large cluster run: *(K=1000, 10 iterations)*
https://github.com/2020-F-CS6240/homework-4-mapreduce-rahulpandeycs/tree/master/MROutputAWSLarge