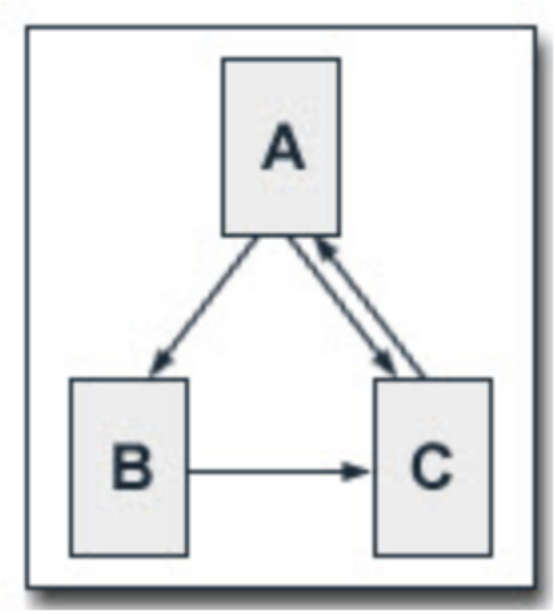
About the question

- the relation of the webpages is:



Base on the relations, A's PageRank is

PR(A) = (1-d) + d * (PR(C) / 1)

PR(B) = (1-d) + d * (PR(A) / 2)

PR(B) = (1-d) + d * (PR(A) / 2 + PR(B)/1)

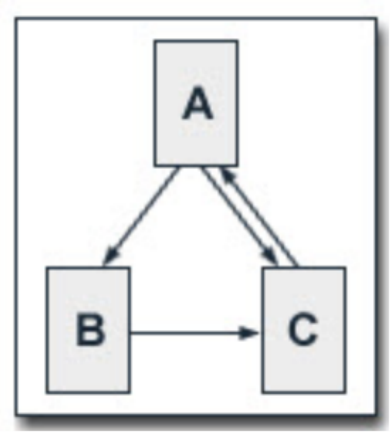
The initial PageRank value for each webpage is 1, and the damping factor is 0.85

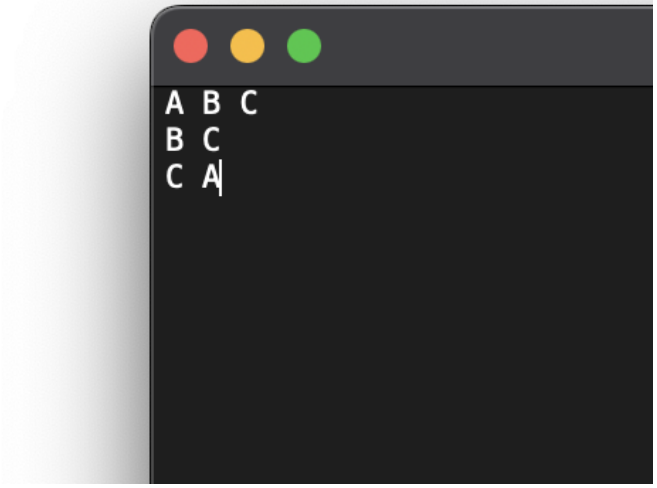
PageRank + PySpark + GCP

1. **Create an input.txt.**

I use an adjacency list to represent the graph with web page connections.

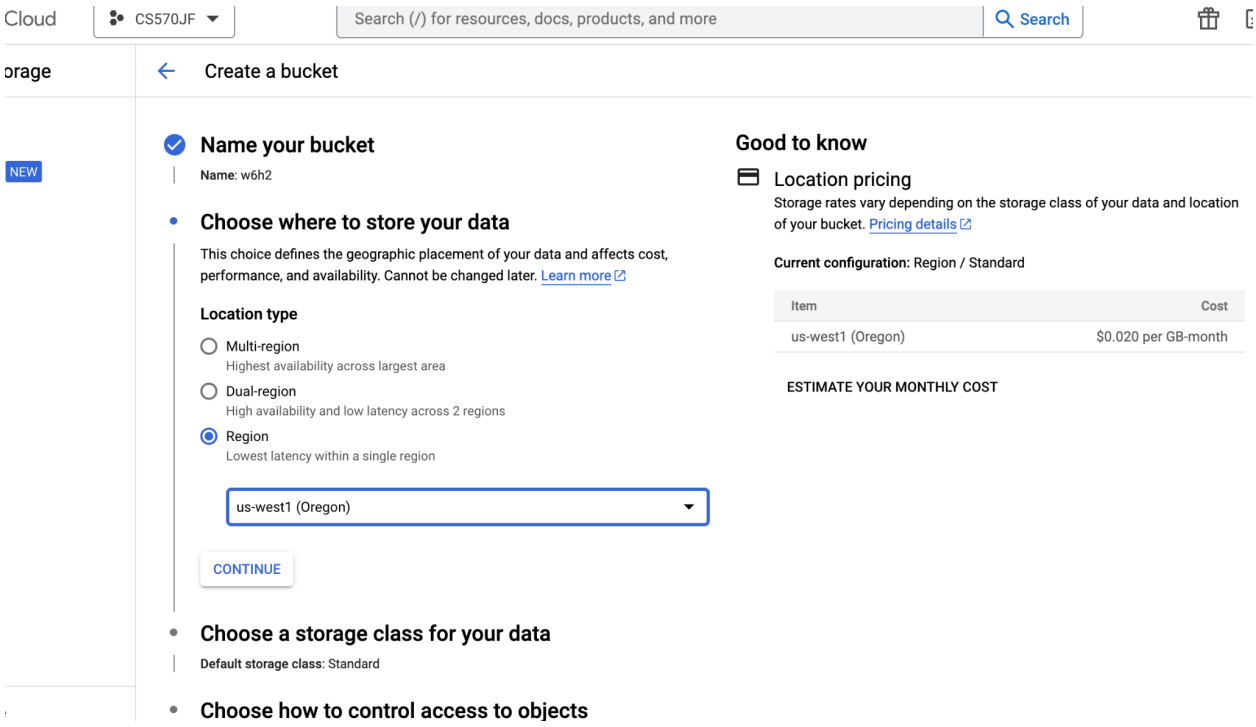
- the relation of the webpages is:



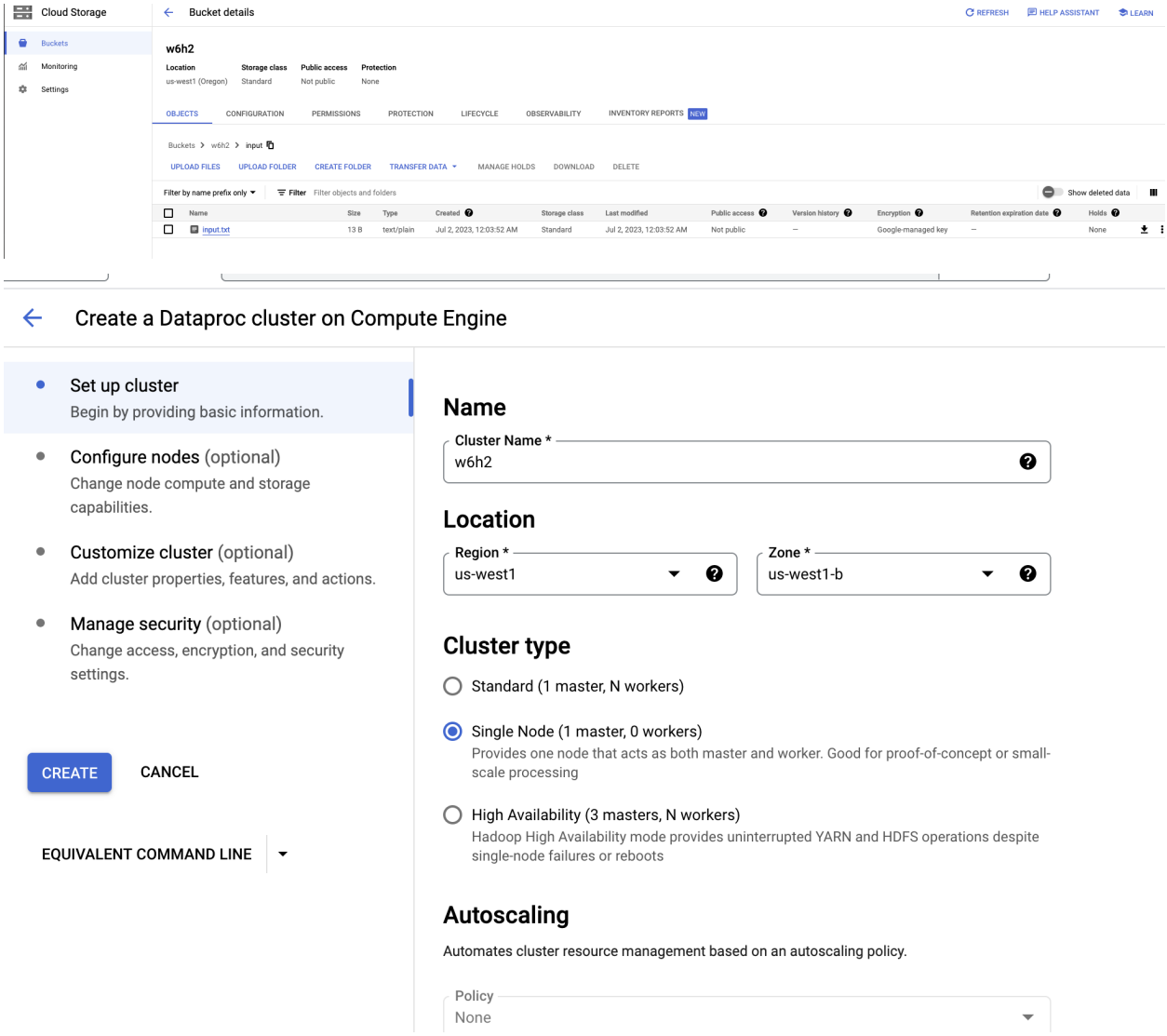


In the graph:
Web page A is connected to pages B and C.
Web page B is connected to page C.
Web page C is connected to pages A

2. Create bucket and cluster



Upload the input.txt to bucket



3. Code

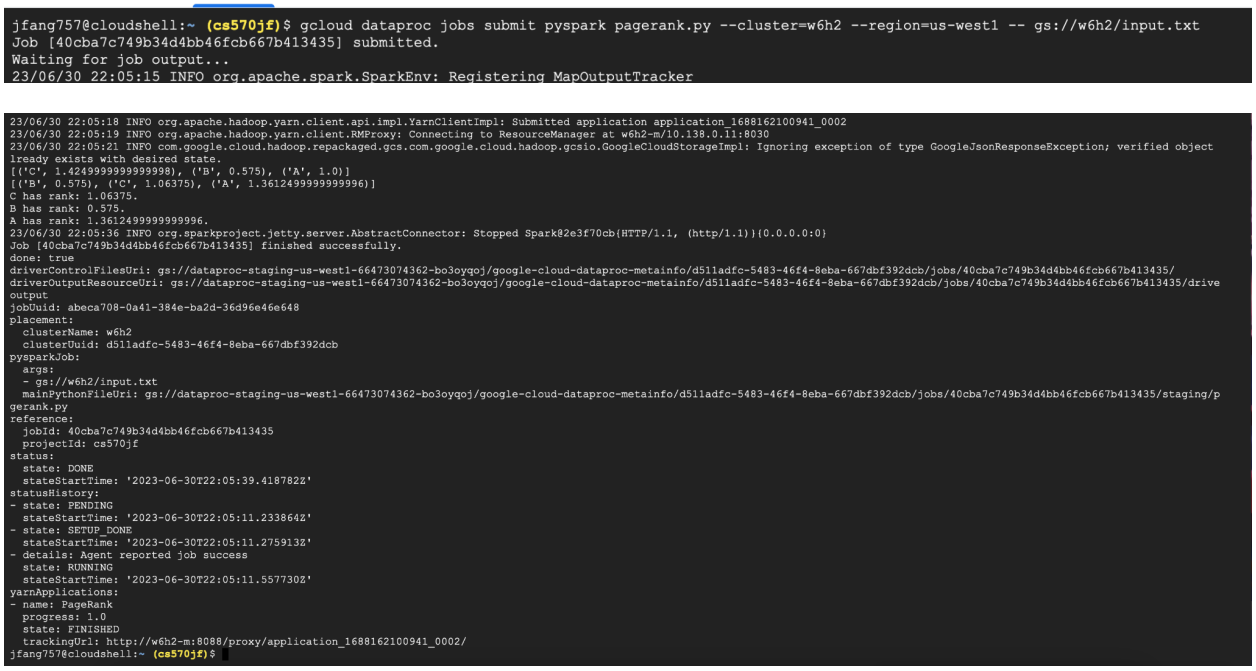
```
from pyspark.sql import SparkSession
import sys

# Initialize SparkSession
spark = SparkSession.builder.appName("PageRank").getOrCreate()

# Read input data from GCS
```

```
if len(sys.argv) != 2:
  raise Exception("Exactly 1 arguments are required:
<inputUri>")
inputUri = sys.argv[1]

lines = spark.read.text(inputUri).rdd.map(lambda r: r[0])

# Create an RDD of (destination page, list of links) pairs
def parse_links(link):
  links = link.split(" ")
  destination = links[0]
  source = links[1:]
  return (destination, source)

links = lines.map(parse_links)

# Initialize the PageRank values 1.0 for each web page
ranks = links.map(lambda page: (page[0], 1.0))

damping_factor = 0.85

# 2 iterations
for i in range(2):
   contributions = links.join(ranks).flatMap(lambda x: [(page,
x[1][1] / len(x[1][0])) for page in x[1][0]])
   ranks = contributions.reduceByKey(lambda x, y: x +
y).mapValues(lambda rank: (1-damping_factor) + damping_factor *
rank)
   # Print each iteration result
   print(ranks.collect())

# Print
```

```
for (page, rank) in ranks.collect():
    print("%s has rank: %s." % (page, rank))

# Stop the SparkSession
spark.stop()
```

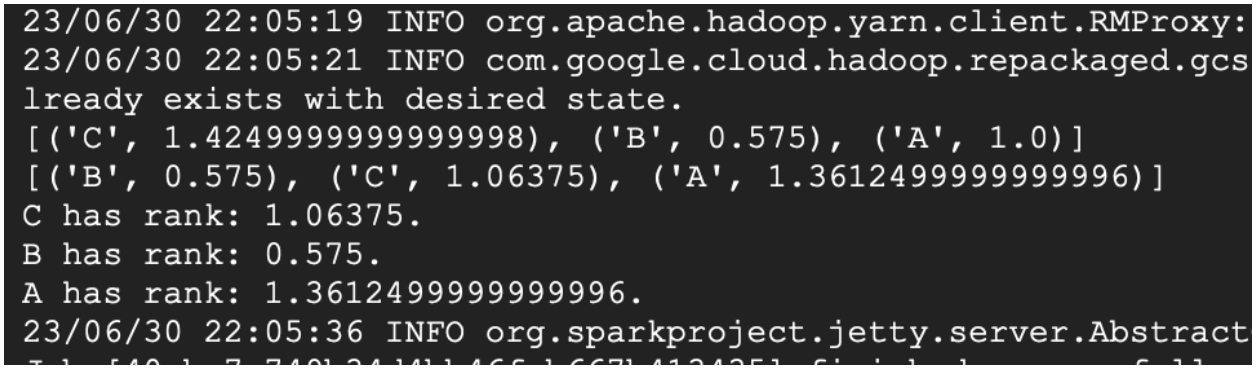
4. Execution

```
gcloud dataproc jobs submit pyspark pagerank.py
--cluster=w6h2 --region=us-west1 -- gs://w6h2/input.txt
```



```
jfang757@cloudshell:~ (cs570jf)$ gcloud dataproc jobs submit pyspark pagerank.py --cluster=w6h2 --region=us-west1 -- gs://w6h2/input.txt
Job [40cba7c749b34d4bb46fcb667b413435] submitted.
Waiting for job output...
23/06/30 22:05:15 INFO org.apache.spark.SparkEnv: Registering MapOutputTracker
23/06/30 22:05:18 INFO org.apache.hadoop.yarn.client.api.impl.YarnClientImpl: Submitted application application_1688162100941_0002
23/06/30 22:05:19 INFO org.apache.hadoop.yarn.client.RMProxy: Connecting to ResourceManager at w6h2-m/10.138.0.11:8030
23/06/30 22:05:21 INFO com.google.cloud.hadoop.repackaged.gcs.com.google.cloud.hadoop.gcsio.GoogleCloudStorageImpl: Ignoring exception of type GoogleJsonResponseException; verified object
lready exists with desired state.
[('C', 1.4249999999999998), ('B', 0.575), ('A', 1.0)]
[('B', 0.575), ('C', 1.06375), ('A', 1.3612499999999996)]
C has rank: 1.06375.
B has rank: 0.575.
A has rank: 1.3612499999999996.
23/06/30 22:05:36 INFO org.sparkproject.jetty.server.AbstractConnector: Stopped Spark@2e3f70cb{HTTP/1.1, (http/1.1)}{0.0.0.0:0}
Job [40cba7c749b34d4bb46fcb667b413435] finished successfully.
done: true
driverControlFilesUri: gs://dataproc-staging-us-west1-66473074362-bo3oyqoj/google-cloud-dataproc-metainfo/d511adfc-5483-46f4-8eba-667dbf392dcb/jobs/40cba7c749b34d4bb46fcb667b413435/
driverOutputResourceUri: gs://dataproc-staging-us-west1-66473074362-bo3oyqoj/google-cloud-dataproc-metainfo/d511adfc-5483-46f4-8eba-667dbf392dcb/jobs/40cba7c749b34d4bb46fcb667b413435/drive
output
jobUuid: abeca708-0a41-384e-ba2d-36d96e46e648
placement:
  clusterName: w6h2
  clusterUuid: d511adfc-5483-46f4-8eba-667dbf392dcb
pysparkJob:
  args:
  - gs://w6h2/input.txt
  mainPythonFileUri: gs://dataproc-staging-us-west1-66473074362-bo3oyqoj/google-cloud-dataproc-metainfo/d511adfc-5483-46f4-8eba-667dbf392dcb/jobs/40cba7c749b34d4bb46fcb667b413435/staging/p
gerank.py
reference:
  jobId: 40cba7c749b34d4bb46fcb667b413435
  projectId: cs570jf
status:
  state: DONE
  stateStartTime: '2023-06-30T22:05:39.418782Z'
statusHistory:
- state: PENDING
  stateStartTime: '2023-06-30T22:05:11.233864Z'
- state: SETUP_DONE
  stateStartTime: '2023-06-30T22:05:11.275913Z'
- details: Agent reported job success
  state: RUNNING
  stateStartTime: '2023-06-30T22:05:11.557730Z'
yarnApplications:
- name: PageRank
  progress: 1.0
  state: FINISHED
  trackingUrl: http://w6h2-m:8088/proxy/application_1688162100941_0002/
jfang757@cloudshell:~ (cs570jf)$
```

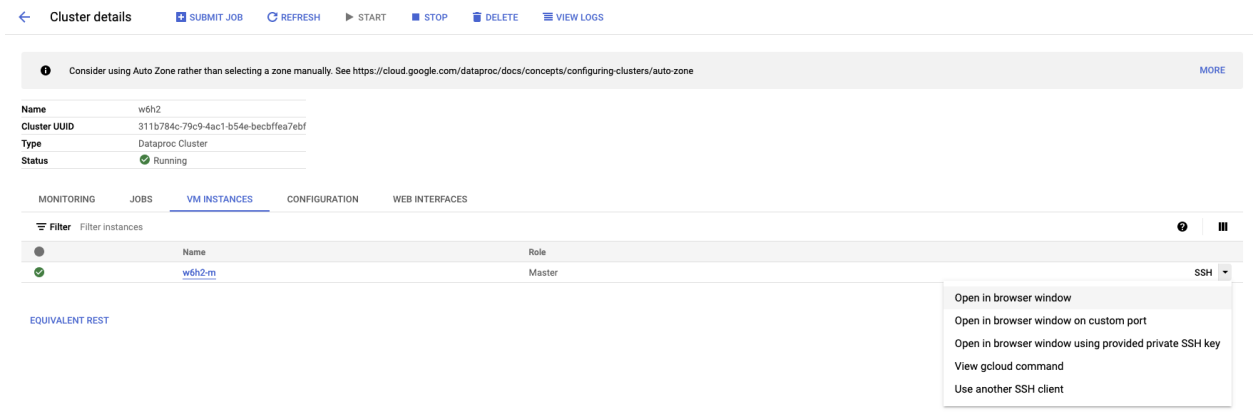
5. **Result**



The reduceByKey() function uses double precision floating point numbers, which have a precision of 15 decimal places. The mapValues() function also uses double precision floating point numbers. So when the mapValues() function adds the contributions to A,B and C, it may round the values to 15 decimal places. In the first iteration, this rounding can cause the final PageRank value for C to be 1.42499999, slightly less than 1.425.

PageRank + Scala + GCP

6. Use Spark-shell in the cluster to run Spark Scala code



Open SSH-in-browser in the cluster and type:
spark-shell

7. Scala code

```
import org.apache.spark.sql.SparkSession
// Initialize SparkSession
val spark =
SparkSession.builder.appName("PageRank").getOrCreate()

// Read input data from GCS
val inputUri = "gs://w6h2/input/input.txt"

val lines = spark.read.textFile(inputUri).rdd

// Create an RDD of (destination page, list of links) pairs
def parseLinks(link: String): (String, Array[String]) = {
   val links = link.split(" ")
   val destination = links(0)
   val source = links.slice(1, links.length)
```

```
   return(destination, source)
}

val links = lines.map(parseLinks)

// Initialize the PageRank values 1.0 for each web page
val ranks = links.mapValues(_ => 1.0)
val dampingFactor = 0.85
// In Scala, val is immutable, and cannot reassign a new value
to it. To fix this, use a mutable variable (var) for ranks
instead.
var currentRanks = ranks

for (i <- 0 until 2) {
 val contributions = links.join(currentRanks).flatMap { case (_,
(pages, rank)) => pages.map(page => (page, rank / pages.length))
}
 val newRanks = contributions.reduceByKey(_ + _).mapValues(rank
=> (1 - dampingFactor) + dampingFactor * rank)
 currentRanks = currentRanks.join(newRanks).mapValues { case
(oldRank, newRank) => newRank }
}

currentRanks.collect()
```

```
Debian GNU/Linux comes with ABSOLUTELY NO WARRANTY, to the extent
permitted by applicable law.
Last login: Sun Jul  2 08:22:24 2023 from 35.235.244.1
jfang757@w6h2-m:~$ spark-shell
Setting default log level to "WARN".
To adjust logging level use sc.setLogLevel(newLevel). For SparkR, use setLogLevel(newLevel).
23/07/02 08:41:15 INFO org.apache.spark.SparkEnv: Registering MapOutputTracker
23/07/02 08:41:15 INFO org.apache.spark.SparkEnv: Registering BlockManagerMaster
23/07/02 08:41:15 INFO org.apache.spark.SparkEnv: Registering BlockManagerMasterHeartbeat
23/07/02 08:41:15 INFO org.apache.spark.SparkEnv: Registering OutputCommitCoordinator
Spark context Web UI available at http://w6h2-m.us-west1-a.c.cs570jf.internal:34563
Spark context available as 'sc' (master = yarn, app id = application_1688285991443_0002).
Spark session available as 'spark'.
Welcome to
      ____              __
     / __/__  ___ _____/ /__
    _\ \/ _ \/ _ `/ __/  '_/
   /___/ .__/\_,_/_/ /_/\_\   version 3.1.3
      /_/

Using Scala version 2.12.14 (OpenJDK 64-Bit Server VM, Java 1.8.0_372)
Type in expressions to have them evaluated.
Type :help for more information.

scala> import org.apache.spark.sql.SparkSession
import org.apache.spark.sql.SparkSession

scala> val spark = SparkSession.builder.appName("PageRank").getOrCreate()
23/07/02 08:41:55 WARN org.apache.spark.sql.SparkSession$Builder: Using an existing SparkSession; some spark core configurations may not take effect.
spark: org.apache.spark.sql.SparkSession = org.apache.spark.sql.SparkSession@21890674

scala> val inputUri = "gs://w6h2/input/input.txt"
inputUri: String = gs://w6h2/input/input.txt

scala> val lines = spark.read.textFile(inputUri).rdd
lines: org.apache.spark.rdd.RDD[String] = MapPartitionsRDD[4] at rdd at <console>:25

scala> def parseLinks(link: String): (String, Array[String]) = {
     | val links = link.split(" ")
     | val destination = links(0)
     | val source = links.slice(1, links.length)
     | return(destination, source)
     | }
parseLinks: (link: String)(String, Array[String])

scala> val links = lines.map(parseLinks)
links: org.apache.spark.rdd.RDD[(String, Array[String])] = MapPartitionsRDD[5] at map at <console>:25

scala> val ranks = links.mapValues(_ => 1.0)
ranks: org.apache.spark.rdd.RDD[(String, Double)] = MapPartitionsRDD[6] at mapValues at <console>:24

scala> val dampingFactor = 0.85
dampingFactor: Double = 0.85

scala> var currentRanks = ranks
currentRanks: org.apache.spark.rdd.RDD[(String, Double)] = MapPartitionsRDD[6] at mapValues at <console>:24

scala> for (_ <- 0 until 2) {
     | val contributions = links.join(ranks).flatMap {case (_, (pages, rank)) => pages.map(page => (page, rank / pages.length))}
     | val newRanks = contributions.reduceByKey(_ + _).mapValues(rank => (1 - dampingFactor) + dampingFactor * rank)
     | currentRanks.join(newRanks).mapValues { case (oldRank, newRank) => newRank }.collect()
     | }

scala> currentRanks.collect()
res1: Array[(String, Double)] = Array((A,1.0), (B,1.0), (C,1.0))

scala> for (i <- 0 until 2) {
     | val contributions = links.join(currentRanks).flatMap { case (_, (pages, rank)) => pages.map(page => (page, rank / pages.length)) }
     | val newRanks = contributions.reduceByKey(_ + _).mapValues(rank => (1 - dampingFactor) + dampingFactor * rank)
     | currentRanks = currentRanks.join(newRanks).mapValues { case (oldRank, newRank) => newRank }
     | }

scala> currentRanks.collect()
res3: Array[(String, Double)] = Array((B,0.575), (A,1.3612499999999996), (C,1.06375))

scala>
```

8. Result

```
scala> for (i <- 0 until 2) {
     | val contributions = links.join(currentRanks).flatMap { case (_, (pages, rank)) => pages.map(page => (page, rank / pages.length)) }
     | val newRanks = contributions.reduceByKey(_ + _).mapValues(rank => (1 - dampingFactor) + dampingFactor * rank)
     | currentRanks = currentRanks.join(newRanks).mapValues { case (oldRank, newRank) => newRank }
     | }

scala> currentRanks.collect()
res3: Array[(String, Double)] = Array((B,0.575), (A,1.3612499999999996), (C,1.06375))
```