The Map-Reduce Programming Paradigm

M.Sc. course on "Technologies for Big Data Analysis" - Assignment 2

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1 Introduction

The current document is a technical report for the second programming assignment in the M.Sc. course on *Technologies for Big Data Analysis*, offered by the *DWS M.Sc Program*[1] of the Aristotle University of Thessaloniki, Greece. The course is taught by Professor Apostolos Papadopoulos [2]. The authors attended the course during their first year of Ph.D. studies at the Institution.

The assignment contains 4 sub-problems and is part of a series, comprising 3 programming assignments on the following topics:

Assignment 1 Multi-threading Programming and Inter-Process Communication
Assignment 2 The Map-Reduce Programming Paradigm
Assignment 3 Big Data Analytics with Scala and Apache Spark

In this document we focus on Assignment 2 and its 4 sub-problems. We refer to them as *problems* in the rest of the document for simplicity. The source code of our solution has been made available at the following public repository in the GitHub platform: `https://github.com/Bilpapster/big-data-playground`.

Roadmap. The rest of our work is structured as follows. We devote one section to each one of the 4 problems. That means problems 1, 2, 3 and 4 are presented in sections 2, 3, **??** and 4 respectively. For each problem, we first provide the problem statement, as given by the assignment. Next, we thoroughly present the reasoning and/or methodology we have adopted to approach the problem and devise a solution. Wherever applicable, we also provide insights about the source code implementation we have developed. Finally, we conclude our work in section 5. The appendix includes the evaluation results for any issues that necessitated them.

2 Problem 1: Numeronyms

We discuss here the first problem of the assignment. The main target of the assignment is to get acquainted with the MapReduce programming model in Hadoop framework in Java programming language. This is a WordCount problem's variation.

2.1 Problem Statement

Implement a **MapReduce** program, a variation of the **word-count** problem, to generate and count "numeronyms". Numeronyms correspond to words as shown below:

- s5n – shorten
- h7k – hyperlink
- l10n – localization
- i18n – internationalization

[1] https://dws.csd.auth.gr/
[2] https://datalab-old.csd.auth.gr/~apostol/

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A numeronym of a word is defined as an alphanumeric string formed by taking the first and last character of the word and inserting between them the count of characters between the first and the last. More specifically, the program should process words with a length of 3 characters or more, generate numeronyms, and then output the frequency of each numeronym.

The program should ignore:

- words shorter than 3 characters
- punctuation marks
- uppercase/lowercase differences, i.e., it should be *case-insensitive*

Additionally, a parameter k will be given, representing the minimum number of occurrences of a numeronym that we are interested in. The program output should be a list of numeronyms and the frequency of each numeronym that is greater than or equal to the parameter k specified by the user.

2.2 Proposed approach

2.2.1 Setting. Our implementation is run and tested in a Linux environment with 12 cores, using the Java programming language. We have used the Java Development Kit (JDK) version 11.0.11. The source code is developed in IntelliJ IDEA Community Edition 2021.1.1 and managed using Maven as the build tool.

The project's dependencies, including Hadoop libraries, are defined in the `pom.xml` file located in the root of the repository. The project is compiled and executed directly from IntelliJ IDEA.

To run the project, open the `NumeronymsMaster` class in IntelliJ IDEA, and execute the main method. You will need to specify the following command-line arguments:

- `<input_path>` specifies the directory containing the input text files, located at `map-reduce/ numeronyms /input`.
- `<output_path>` specifies the directory where the MapReduce output will be written, which will be created in the `out` folder.
- `<k>` is the minimum frequency threshold for numeronyms to be included in the results.

IntelliJ IDEA will handle the compilation and execution automatically when the main method is run. Make sure to configure the input and output paths as required for your specific run.

Note that the command-line arguments must follow the specified order and format. If any of the arguments are missing or invalid, the program will terminate with an appropriate error message.

2.2.2 Implementation. The proposed approach leverages the MapReduce programming model to compute numeronyms from a given input dataset. A numeronym is a concise representation of a word, typically formed by retaining the first and last letters while replacing the intervening characters with their count. This section outlines the methodology implemented across three key components: the driver class, the mapper, and the reducer. This methodology supports flexible configuration through command-line arguments, enabling users to specify the threshold k and the minimum word length for numeronym generation. The use of the MapReduce paradigm ensures scalability and parallel processing for large datasets, making the approach well-suited for distributed systems.

The driver class, `NumeronymsMaster`, orchestrates the overall MapReduce job. It takes command-line arguments for the input and output directories as well as a threshold parameter k, which determines the minimum frequency for numeronyms to be included in the final output. The following steps are executed:

- Input and output paths are parsed, and any pre-existing output directory is deleted using the `Utilities.deleteDirectory` method.
- A Hadoop configuration object is initialized with two parameters:
  - `numeronyms.k`: The threshold k.

  - `numeronyms.l`: The minimum word length (default value is 3) required for numeronym generation.
- The job is configured to use the `NumeronymMapper` and `NumeronymReducer` classes, with input and output formats set to `TextInputFormat` and `TextOutputFormat`, respectively.
- Finally, the job waits for completion before terminating.

The `NumeronymMapper` class is responsible for processing each line of the input text file and emitting numeronym -frequency pairs. The following steps are performed:

- During setup, the minimum word length (`numeronyms.l`) is retrieved from the configuration.
- Each input line is tokenized into individual words, and non-alphabetic characters are removed from each token.
- For valid words (those with lengths greater than or equal to the specified minimum), a numeronym is constructed by concatenating the first character, the number of intervening characters, and the last character.
- A key-value pair is emitted, where the key is the numeronym and the value is a count of one.

The `NumeronymReducer` class aggregates the frequency counts for each numeronym and filters out those below the specified threshold k. The process includes:

- Retrieving the threshold value (`numeronyms.k`) from the configuration during the setup phase.
- Summing the values for each numeronym key received from the mapper.
- Emitting numeronyms that meet or exceed the threshold k along with their corresponding frequencies.

2.2.3 Evaluation. The experiments were executed using the dataset 'SherlockHolmes.txt' with a parameter setting of $k = 10$. This configuration was chosen to evaluate the performance and the behavior of the system under moderate conditions. The dataset, containing a series of textual records, was processed to analyze various patterns and results.

To provide a comprehensive overview, the results of the experiment, including the detailed values derived from the dataset, are presented in Appendix A in a 2-column format.

3 Problem 2: Movie Analytics

The second problem focuses on producing analytic insights from an IMDB dataset.

3.1 Problem Statement

Implement a **MapReduce** program to perform analytics tasks on an IMDB dataset about movies. The utter goal of your analysis would be to extract useful insights from the available movie data that will assist the IMDB team provide better recommendations for movies, based on their genre and/or country. In particular, the dataset (`movies.csv`) contains the following fields:

- imdbID: unique identifier of the movie in the IMDB database
- title: the movie title
- year: the year the movie was first released
- duration: the duration of the movie
- genre(s): the genre or genres in which the movie is classified
- premier date: the date of the first showing of the movie
- score: the IMDB score of the movie
- country/-ies: the country or countries the movie was produced in

You are asked to implement Map-Reduce source code in Java programming language for the following analytics tasks:

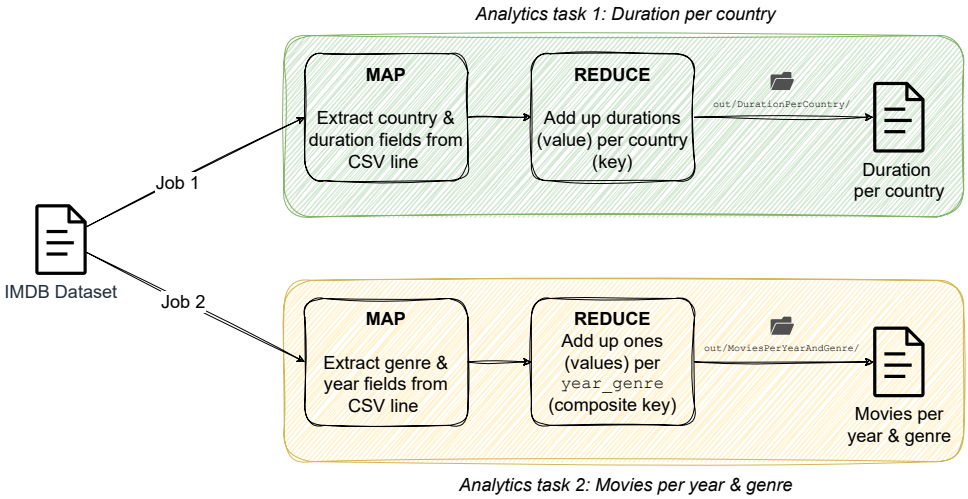


Fig. 1. The MapReduce solution architecture for the movie analytics problem. Two separate jobs are executed to solve the two tasks, namely duration per country (green) and movies per year & genre (yellow). The two tasks also create separate subdirectories for writing the results.

- Calculate the total duration of all movies per country. Note that in case multiple countries are recorded for a movie, the respective duration should be counted for all of them separately.
- Calculate the total number of movies per year and genre, having IMDB score over 8. For movies that have more than one genre, the sum should be separate for each genre.

3.2 Proposed approach

3.2.1 Setting. Our implementation is run and tested in a Linux environment with 12 cores, using the Java programming language. We have used the Java Development Kit (JDK) version 11.0.11. The source code is developed in IntelliJ IDEA Community Edition 2021.1.1 and managed using Maven as the build tool.

The project's dependencies, including Hadoop libraries, are defined in the `pom.xml` file located in the root of the repository. The project is compiled and executed directly from IntelliJ IDEA.

To run the project, open the `MovieAnalyticsMaster` class in IntelliJ IDEA, and execute the main method. You will need to specify the following command-line arguments:

- `<input_path>` specifies the directory containing the input text files, located at `map-reduce/movieAnalytics/input`.
- `<output_path>` specifies the directory where the MapReduce output will be written, which will be created in the `out` folder.

IntelliJ IDEA will handle the compilation and execution automatically when the main method is run. Make sure to configure the input and output paths as required for your specific run. Note that the command-line arguments must follow the specified order and format. If any of the arguments are missing or invalid, the program will terminate with an appropriate error message.

3.2.2 Implementation. The proposed approach leverages the MapReduce programming paradigm to compute the analytical insights for the two tasks. Figure 1 depicts the architecture of our solution as a diagram. We opt for executing two separate jobs; one for each task presented by the problem statement.

Task 1: Duration per country. One map-reduce cycle is enough to handle this task, as depicted in the top part of Figure 1 in green color. The map function parses the CSV file line by line and extracts the useful fields from each line. In this case, the useful fields are the country (or countries) the movie was produced and the movie duration, i.e., the fourth and ninth fields in the input line respectively. We employ more complex logic to handle cases where there are multiple countries in a single movie. In particular, we parse again the field and tokenize it into the separate countries, producing a key-value pair for each country-duration pair within a movie. The reduce function is, then, trivial; it just adds up the durations (value) per country (key) and outputs the results. The interested reader can refer to the `CSVProcessor.java` (mapper), `AnayticsEngine.java` (reducer) and `MovieAnalyticsMaster.java` (driver) files for the source code implementation of our solution.

Task 2: Movies per year & genre w.r.t. score constraint. The task is similar to the first one, with the only difference lying in the fields extracted from the input CSV line. In this case, we are interested about the year, the genre (or genres) and score fields, i.e., the third, fifth and seventh fields in the input CSV line. The map function produces key-value pairs in the form `(composite_key, 1)`, where the composite key consists of the year and the genre of the respective movie concatenated by an underscore, e.g., `2024_action`. We handle multiple genres per movie similarly with the multiple countries in task 1. We employ the same trivial reducer that adds up the values (ones) per (composite) key, as shown in the bottom part of Figure 1 in yellow color.

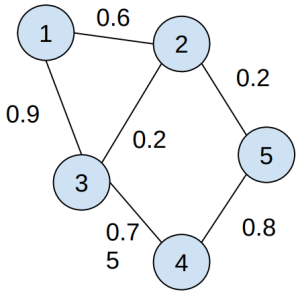
3.2.3 Evaluation. Our solution is tested using the provided IMDB dataset, namely `movies.csv`. We list the execution results in Appendix B.

4 Problem 4: Probabilistic graph

We discuss here the fourth problem of the assignment. The main target of the assignment is to get acquainted with performing various MapReduce phases on a pipeline frame.

4.1 Problem Statement

We are given an input file in text format where each line contains a connection between two vertices of a network and a probability value. For each edge e, there is a probability value $p(e)$ which indicates the probability that the two vertices are connected by the edge. Obviously, the values of $p(e)$ range between 0 and 1. The values in each line are separated by a space. Consider the network shown in the previous figure. The edge connecting vertices 4 and 5 has a probability of 0.8, the edge connecting vertices 2 and 3 has a probability of 0.2, etc.



The file corresponding to this graph would be:

1 2 0.6, 1 3 0.9, 2 3 0.2, 3 4 0.75, 2 5 0.2, 4 5 0.8,

The edges are generally stored in random order in the file, so we cannot assume they have a specific arrangement.

The following tasks are requested:

(1) Write a Java program that computes the average degree for all the vertices.
(2) The average degree is defined as the sum of the probabilities of the edges that fall on a vertex.
(3) For example, in the previous diagram, the average degree of vertex 3 is $0.9 + 0.2 + 0.75 = 1.85$.
(4) Before performing this calculation, you should ignore all edges with a probability less than a threshold T , which should be passed as a parameter to the main function.
(5) Modify the code from task 1 so that, at the end, only the vertices with an average degree greater than the average of the degrees of all the vertices are displayed in the output.

4.2 Proposed approach

4.2.1 Setting. Our implementation is run and tested in a Linux environment with 12 cores, using the Java programming language. We have used the Java Development Kit (JDK) version 11.0.11. The source code is developed in IntelliJ IDEA Community Edition 2021.1.1 and managed using Maven as the build tool.

The project's dependencies, including Hadoop libraries, are defined in the `pom.xml` file located in the root of the repository. The project is compiled and executed directly from IntelliJ IDEA.

To run the project, open the `GraphMaster` class in IntelliJ IDEA, and execute the main method. You will need to specify the following command-line arguments:

- `<input_path>` specifies the directory containing the input text files, located at `map-reduce/ probabilisticGraph /input`.
- `<output_path>` specifies the directory where the MapReduce output will be written, which will be created in the `out` folder.
- `<T>` is the minimum edge-degree threshold for vertices to be included in the results.

IntelliJ IDEA will handle the compilation and execution automatically when the main method is run. Make sure to configure the input and output paths as required for your specific run.

Note that the command-line arguments must follow the specified order and format. If any of the arguments are missing or invalid, the program will terminate with an appropriate error message.

4.2.2 Implementation. The problem at hand involves processing a probabilistic graph, where each edge connects two vertices with a probability value. The task is to compute the average degree for each vertex, considering only edges whose probability exceeds a given threshold T. The methodology proposed here utilizes a distributed MapReduce framework, implemented using Hadoop, to efficiently process and analyze large-scale graph data. The approach is divided into three main phases, each handled by separate MapReduce jobs, with intermediate results passed between the phases.

The `GraphMaster` class serves as the orchestrator of the entire MapReduce process. It manages the execution of the three phases, invoking the appropriate MapReduce jobs in sequence. The main steps executed by `GraphMaster` are:

(1) It retrieves the command-line arguments, including the input and output directories as well as the threshold value T, which determines which edges to consider in the graph.
(2) It initiates the first MapReduce job to compute the degree of each vertex in the graph. The input consists of edge data, and the output is a summation of edge probabilities for each vertex.
(3) After the first job completes, the `GraphMaster` starts the second MapReduce job to calculate the mean degree of the graph, using the results from the first job.
(4) Once the mean degree is computed, `GraphMaster` starts the third MapReduce job, which filters out the vertices with degrees lower than the mean degree.
(5) It cleans up intermediate directories after each phase and moves the final output to the desired location.

`GraphMaster` coordinates these steps by configuring and executing the MapReduce jobs, ensuring that each phase depends on the results of the previous one.

The entire process consists of three MapReduce jobs, executed sequentially:

(1) **Phase 1:** The first job computes the degree of each vertex by summing the probabilities of the edges connected to it. It produces intermediate results for each vertex.
(2) **Phase 2:** The second job calculates the mean degree by summing the degrees from the first phase and dividing by the total number of vertices.
(3) **Phase 3:** The third job filters out the vertices with a degree lower than the mean degree and produces the final filtered result.

After each job completes, intermediate data is written to disk and passed as input to the subsequent job. The final output consists of the vertices whose degree exceeds or equals the mean degree.

Phase 1: Calculating Vertex Degree The first MapReduce job is responsible for calculating the degree of each vertex in the graph, where the degree is defined as the sum of the probabilities of the edges connected to that vertex. The degree of each vertex is computed by the `GraphMapper` and `GraphReducer` classes.

The `GraphMapper` class reads each edge from the input data, which consists of lines containing two vertices and the associated probability value. It splits each line into two components (the two vertices), and for each vertex, it emits the corresponding probability value as the output. The mapper also checks if the probability value exceeds the threshold T, which is provided as a configuration parameter. If the probability is greater than or equal to T, it emits the vertex along with the corresponding probability.

The `GraphReducer` class receives the vertex and associated probability values emitted by the mapper. For each vertex, it sums up all the probabilities of the edges connected to that vertex, and emits the pair as output.

Phase 2: Calculating the Mean Degree The second phase of the approach calculates the mean degree of all vertices. This is done by summing the degree values from the previous phase and dividing by the total number of vertices.

The `MeanMapper` class receives the degree values from the output of the first MapReduce job. It emits two key-value pairs for each input line: a count of the number of vertices and the sum of the degree values. These are emitted with fixed keys (`"count"` and `"sum"`) so that they can be aggregated in the reducer.

The `MeanReducer` class processes the count and sum values emitted by the mapper. It calculates the total sum and count of vertices and then writes these values as output. The mean degree is calculated by dividing the sum by the count, and the result is stored for use in the next phase.

Phase 3: Filtering Vertices by Mean Degree In the third phase, the vertices whose degree is greater than or equal to the mean degree calculated in Phase 2 are selected. This phase uses the results from Phase 1 and Phase 2, applying the filtering criteria to retain only those vertices with a degree greater than or equal to the mean.

The `FilterMapper` class takes the degree values emitted by the first reducer and writes them as key-value pairs. Each key is a vertex, and the value is the degree of that vertex. The mapper does not perform any filtering; instead, it simply passes the values along to the reducer.

The `FilterReducer` class filters out the vertices whose degree is less than the mean degree. It retrieves the mean degree from the configuration, and for each vertex, it compares the degree value to the mean. If the degree is greater than or equal to the mean, it emits the vertex along with its degree. This final output contains only the vertices that satisfy the filtering criteria.

4.2.3 Evaluation. The experiments were executed using the dataset ‘collins.txt‘ with a parameter setting of $T = 0.8$.

To provide a comprehensive overview, the results of the experiment, including the detailed values derived from the dataset, are presented in subsection B.1 in a 2-column format.

5 Conclusion

TODO: In this document we have presented our solutions and rational for solving the first assignment of the M.Sc. course on *Technologies for Big Data Analysis*, offered by the *DWS M.Sc. Program*.

A Problem 1

In the following 8-columned pages, the experimental results of section's 2 problem are presented, as the raw output of the MapReduce execution.

a10c: 34
a10d: 486
a10e: 386
a10g: 175
a10h: 58
a10l: 131
a10m: 15
a10n: 260
a10p: 48
a10r: 68
a10s: 429
a10t: 72
a10y: 190
a10z: 50
a11a: 36
a11c: 36
a11d: 165
a11e: 136
a11g: 101
a11n: 202
a11p: 16
a11r: 13
a11s: 266
a11t: 115
a11y: 119
a12c: 18
a12d: 94
a12e: 95
a12g: 47
a12l: 20
a12n: 65
a12s: 139
a12t: 59
a12y: 36
a13e: 10
a13g: 19
a13n: 22
a13s: 112
a13t: 36
a13y: 36
a14c: 12
a14e: 16
a14n: 114
a14s: 16
a14t: 17
a14y: 38
a15s: 33
a16s: 18
a3d: 38224
a3e: 3767
a3k: 248
a3l: 4077
a3m: 353
a3o: 106
a3r: 198
a3t: 428
a3y: 1193
a4a: 458
a4d: 166
a4e: 249
a4h: 13
a4n: 15
a4o: 773
a4s: 483
a4t: 47
a4y: 1588
a5a: 41
a5d: 1360
a5e: 1377
a5g: 841
a5i: 11
a5l: 112
a5m: 56
a5n: 916
a5r: 1604
a5s: 213
a5t: 1767
a5w: 94
a5y: 201
a6a: 112
a6d: 785
a6e: 615
a6g: 214
a6h: 21
a6k: 151
a6l: 192
a6m: 20
a6n: 456
a6p: 84
a6r: 523
a6s: 1197
a6t: 811
a6w: 1078
a6y: 204
a7a: 431
a7c: 52
a7d: 1076
a7e: 685
a7g: 71
a7h: 12
a7l: 116
a7n: 83
a7r: 843
a7s: 1203
a7t: 1011
a7x: 17
a7y: 756
a8a: 28
a8c: 37
a8d: 1790
a8e: 386
a8g: 625
a8h: 328
a8l: 125
a8m: 239
a8n: 982
a8r: 98
a8s: 469
a8t: 440
a8x: 10
a8y: 328
a9a: 27
a9c: 23
a9d: 531
a9e: 369
a9g: 548
a9l: 62
a9n: 555
a9r: 235
a9s: 622
a9t: 287
a9v: 38
a9y: 286
b10a: 17
b10d: 86
b10e: 58
b10g: 28
b10l: 20
b10m: 12
b10n: 13
b10r: 33
b10s: 227
b10t: 43
b10y: 10
b11a: 10
b11d: 79
b11g: 15
b11m: 34
b11n: 21
b11o: 48
b11s: 75
b11t: 13
b11y: 19
b12d: 36
b12e: 20
b12g: 10
b12l: 18
b12s: 25
b12t: 10
b12w: 10
b12y: 21
b13e: 10
b13v: 13
b3d: 352
b3e: 11
b3g: 145
b3r: 22
b3t: 5674
b3w: 35
b3x: 66
b3y: 223
b4d: 268
b4e: 883
b4f: 10
b4g: 96
b4h: 538
b4k: 969
b4l: 288
b4m: 16
b4n: 2688
b4r: 102
b4s: 119
b4t: 458
b4w: 98
b4y: 459
b5a: 77
b5d: 934
b5e: 330
b5f: 29
b5g: 1080
b5h: 103
b5k: 342
b5l: 11
b5m: 29
b5n: 1190
b5r: 60
b5s: 1288
b5t: 212
b5w: 111
b5y: 101
b6a: 42
b6d: 865
b6e: 3041
b6f: 52
b6g: 84
b6h: 123
b6i: 20
b6l: 39
b6m: 41
b6n: 329
b6r: 436
b6s: 390
b6t: 347
b6u: 17
b6w: 15
b6y: 181
b7a: 31
b7c: 25
b7d: 248
b7e: 1005
b7g: 339
b7h: 371
b7i: 31
b7k: 28
b7l: 16
b7m: 61
b7n: 861
b7o: 15
b7r: 238
b7s: 741
b7t: 494
b7u: 16
b7y: 196
b8a: 121
b8d: 308
b8e: 83
b8g: 451
b8h: 15
b8l: 55
b8m: 41
b8n: 53
b8o: 105
b8r: 55
b8s: 795
b8t: 62
b8v: 148
b8y: 78
b9a: 26
b9d: 95
b9e: 232
b9g: 271
b9h: 18
b9i: 161
b9l: 175
b9n: 274
b9r: 19
b9s: 163
b9t: 150
b9y: 19
c10a: 49
c10d: 460
c10e: 395
c10g: 362
c10l: 129
c10n: 689
c10r: 18
c10s: 818
c10t: 97
c10y: 256
c11a: 21
c11d: 116
c11e: 272

c11g: 141
c11l: 92
c11n: 403
c11p: 12
c11r: 16
c11s: 341
c11t: 74
c11y: 181
c12d: 107
c12e: 284
c12g: 46
c12h: 11
c12l: 15
c12n: 673
c12r: 10
c12s: 173
c12t: 45
c12y: 124
c13d: 80
c13e: 35
c13g: 61
c13l: 29
c13n: 220
c13s: 379
c13y: 83
c14a: 14
c14c: 94
c14e: 47
c14l: 93
c14n: 20
c14s: 84
c14y: 29
c15d: 11
c15e: 12
c15s: 24
c15y: 18
c16e: 39
c16f: 10
c3b: 34
c3n: 872
c3p: 117
c3t: 210
c3y: 140
c4a: 35
c4b: 72
c4d: 333
c4e: 2548
c4f: 18
c4k: 36
c4l: 246
c4m: 88
c4n: 92
c4p: 105
c4r: 31
c4s: 42
c4t: 739
c4w: 12
c4y: 285
c5a: 45
c5c: 10
c5d: 2428
c5e: 804
c5f: 320
c5g: 24
c5h: 168
c5i: 18
c5k: 237
c5l: 318
c5m: 77
c5n: 161
c5p: 33
c5r: 479
c5s: 1360
c5t: 1031
c5y: 130
c6a: 44
c6c: 40
c6d: 871
c6e: 1144
c6g: 247
c6h: 125
c6l: 61
c6m: 30
c6n: 676
c6r: 706
c6s: 929
c6t: 568
c6x: 23
c6y: 363
c7a: 23
c7c: 148
c7d: 1329
c7e: 561
c7g: 328
c7h: 15
c7k: 80
c7l: 690
c7m: 35
c7n: 703
c7o: 27
c7r: 658
c7s: 834
c7t: 612
c7x: 23
c7y: 1192
c8a: 125
c8c: 46
c8d: 582
c8e: 638
c8g: 570
c8h: 26
c8l: 573
c8n: 523
c8o: 18
c8r: 285
c8s: 2081
c8t: 341
c8x: 16
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o8s: 467
o8t: 117
o8w: 18
o8y: 100
o9a: 13
o9d: 111
o9e: 220
o9g: 218
o9h: 11
o9n: 252
o9p: 28
o9s: 367
o9t: 11
o9w: 19
o9y: 56
p10a: 38
p10c: 17
p10d: 138
p10e: 184
p10g: 464
p10h: 54
p10l: 128
p10m: 121
p10n: 521
p10r: 124
p10s: 413
p10t: 142
p10y: 317
p11c: 22
p11d: 50
p11e: 166
p11g: 88
p11n: 117
p11r: 25
p11s: 289
p11t: 24
p11y: 240
p12a: 159
p12d: 37
p12e: 46
p12g: 14
p12l: 106
p12n: 115
p12r: 13
p12s: 131
p12t: 18
p12y: 223
p13e: 19
p13g: 10
p13k: 11
p13l: 20
p13n: 38
p13r: 22
p13s: 62
p13y: 20
p14s: 14
p15s: 11
p3a: 11
p3d: 19
p3n: 31
p3r: 88
p3s: 170
p3t: 465
p3y: 123
p4a: 67
p4d: 122
p4e: 410
p4h: 115
p4k: 99
p4l: 60
p4m: 39
p4n: 463
p4p: 11
p4r: 186
p4s: 205
p4t: 1040
p4y: 256
p5a: 255
p5c: 17
p5d: 98
p5e: 1330
p5f: 30
p5h: 143
p5k: 10
p5l: 69
p5n: 102
p5o: 26
p5p: 31
p5r: 766
p5s: 870
p5t: 299
p5y: 332
p6a: 44
p6c: 307
p6d: 1413
p6e: 4994
p6g: 85
p6h: 106
p6l: 75
p6n: 277
p6o: 11
p6r: 213
p6s: 813
p6t: 205
p6w: 26
p6y: 342
p7a: 93
p7c: 94
p7d: 592
p7e: 843
p7g: 540
p7k: 18
p7l: 134
p7m: 147
p7n: 223
p7r: 246
p7s: 1374
p7t: 1435
p7x: 39
p7y: 237
p8a: 149
p8c: 136
p8d: 819
p8e: 1405
p8g: 312
p8h: 16
p8i: 16
p8k: 12
p8l: 356
p8m: 66
p8n: 539
p8r: 160
p8s: 2343
p8t: 221
p8y: 390
p9a: 56
p9c: 35
p9d: 714
p9e: 216
p9g: 257
p9h: 43
p9l: 405
p9m: 20
p9n: 169
p9o: 13
p9r: 73
p9s: 633
p9t: 494
p9y: 262
q10d: 23
q10g: 13
q10s: 20
q11g: 27
q13n: 10
q13r: 16
q14s: 26
q3e: 16
q4t: 11
q5e: 500
q5k: 75
q5n: 18
q5r: 13
q5t: 145
q6s: 12
q6y: 15
q7l: 31
q7r: 62
q7y: 276
q8d: 17
q8n: 339
q8s: 77
q8y: 38
q9d: 28
q9g: 18
q9s: 218
r10d: 398
r10e: 234
r10g: 175
r10l: 75
r10m: 39
r10n: 640
r10r: 11
r10s: 168
r10t: 29
r10y: 99
r11d: 110
r11e: 78
r11g: 87
r11h: 14
r11l: 13
r11n: 151
r11s: 259
r11t: 28
r11y: 55
r12d: 15
r12e: 26
r12g: 29
r12n: 115
r12s: 72

r12y: 59
r13d: 11
r13e: 17
r13n: 13
r13s: 25
r13y: 71
r14e: 39
r14g: 10
r14n: 87
r14s: 24
r14y: 39
r15s: 104
r3b: 10
r3d: 252
r3e: 18
r3g: 12
r3m: 24
r3n: 458
r3p: 15
r3t: 11
r3w: 79
r4d: 472
r4e: 1174
r4f: 30
r4g: 78
r4h: 129
r4k: 124
r4l: 129
r4m: 905
r4n: 90
r4o: 22
r4p: 11
r4r: 49
r4s: 142
r4t: 262
r4y: 39
r5d: 675
r5e: 195
r5h: 130
r5l: 142
r5m: 20
r5n: 75
r5r: 210
r5s: 525
r5t: 714
r5w: 12
r5y: 426
r6a: 185
r6d: 791
r6e: 290
r6f: 65
r6g: 174
r6k: 46
r6l: 115
r6m: 135
r6n: 775
r6r: 415
r6s: 464
r6t: 710
r6v: 715
r6w: 43
r6y: 402
r7a: 32
r7d: 1139
r7e: 542
r7g: 496
r7h: 25
r7i: 15
r7l: 179
r7n: 502
r7r: 111
r7s: 1095
r7t: 329
r7y: 473
r8c: 69
r8d: 2212
r8e: 325
r8g: 237
r8h: 68
r8l: 24
r8n: 327
r8r: 184
r8s: 560
r8t: 254
r8y: 147
r9c: 15
r9d: 317
r9e: 186
r9g: 642
r9m: 32
r9n: 141
r9r: 21
r9s: 475
r9t: 164
r9y: 15
s10c: 158
s10d: 321
s10e: 125
s10g: 230
s10l: 69
s10m: 50
s10n: 196
s10o: 32
s10r: 44
s10s: 469
s10t: 204
s10y: 114
s11a: 24
s11c: 28
s11d: 98
s11e: 98
s11g: 154
s11h: 43
s11l: 141
s11m: 17
s11n: 206
s11r: 21
s11s: 151
s11t: 51
s11w: 12
s11y: 108
s12d: 79
s12e: 107
s12g: 40
s12h: 15
s12i: 17
s12n: 81
s12r: 15
s12s: 239
s12t: 10
s12y: 148
s13d: 49
s13e: 38
s13g: 17
s13l: 15
s13n: 29
s13r: 10
s13s: 67
s13t: 43
s13y: 51
s14e: 17
s14n: 11
s14s: 29
s14t: 55
s14y: 47
s15n: 10
s15r: 10
s15y: 10
s16n: 14
s16s: 10
s3a: 74
s3b: 18
s3c: 72
s3d: 87
s3e: 4950
s3m: 55
s3n: 409
s3r: 176
s3t: 801
s3w: 600
s3x: 160
s3y: 858
s4a: 109
s4b: 23
s4d: 3697
s4e: 3848
s4f: 26
s4g: 123
s4h: 1441
s4k: 207
s4l: 309
s4m: 135
s4n: 1527
s4p: 361
s4r: 148
s4s: 446
s4t: 1025
s4w: 355
s4y: 85
s5a: 449
s5d: 886
s5e: 2969
s5f: 189
s5g: 42
s5h: 371
s5k: 522
s5l: 2431
s5m: 131
s5n: 545
s5o: 17
s5p: 350
s5r: 145
s5s: 1274
s5t: 1035
s5w: 24
s5y: 451
s6a: 44
s6b: 12
s6c: 51
s6d: 3507
s6e: 1353
s6g: 824
s6h: 368
s6k: 162
s6l: 238
s6m: 373
s6n: 423
s6r: 559
s6s: 2097
s6t: 927
s6w: 135
s6y: 689
s7a: 153
s7b: 12
s7c: 26
s7d: 1327
s7e: 1364
s7g: 1121
s7h: 163
s7i: 13
s7l: 555
s7m: 74
s7n: 390
s7o: 14
s7r: 627
s7s: 1252
s7t: 434
s7v: 34
s7w: 29
s7y: 655
s8a: 29
s8c: 43
s8d: 882
s8e: 550
s8g: 1342
s8h: 211
s8k: 203
s8l: 219
s8m: 19
s8n: 509
s8r: 325
s8s: 1622
s8t: 287
s8v: 15
s8x: 30
s8y: 1160
s9a: 35
s9c: 50
s9d: 806
s9e: 371
s9g: 1178
s9h: 14
s9i: 67
s9k: 21
s9l: 98
s9m: 13
s9n: 429
s9o: 13
s9r: 137
s9s: 1044
s9t: 194
s9y: 486
t10a: 13
t10d: 74
t10e: 100
t10g: 49
t10h: 15
t10l: 32
t10n: 41
t10r: 53
t10s: 521
t10t: 128
t10y: 60
t11d: 112
t11e: 135
t11g: 36
t11h: 33
t11l: 27
t11n: 68
t11r: 11
t11s: 324
t11t: 32
t11y: 34
t12d: 29
t12e: 58
t12g: 18
t12h: 23
t12n: 10
t12s: 121
t12y: 42
t13d: 10
t13e: 14
t13n: 16
t13s: 23
t13y: 18
t14n: 32
t14s: 22
t15n: 11
t3a: 104
t3e: 79438
t3n: 223
t3o: 1608
t3p: 45
t3t: 20
t3x: 75
t3y: 137
t4d: 590
t4e: 2747
t4k: 903
t4l: 849
t4m: 2353
t4n: 3322
t4p: 45
t4r: 83
t4s: 4312
t4t: 12263
t4u: 40
t4y: 3875
t5a: 66
t5b: 50
t5c: 30
t5d: 552
t5e: 6460
t5f: 10
t5g: 303
t5h: 365
t5k: 820
t5l: 88
t5n: 516
t5p: 12
t5r: 3002
t5s: 1525
t5t: 146
t5w: 142
t5y: 165
t6a: 40
t6d: 1075
t6e: 817
t6f: 115
t6g: 502
t6h: 658
t6l: 94
t6n: 384
t6r: 481
t6s: 1255
t6t: 198
t6x: 17
t6y: 417
t7a: 30
t7c: 48
t7d: 340
t7e: 126
t7f: 32
t7g: 579
t7h: 891
t7l: 104
t7n: 101
t7o: 49
t7r: 119
t7s: 882
t7t: 950
t7y: 163
t8a: 23
t8c: 32
t8d: 414
t8e: 370
t8g: 350
t8h: 15

t8l: 76
t8n: 157
t8o: 31
t8r: 292
t8s: 365
t8t: 34
t8w: 120
t8y: 235
t9c: 48
t9d: 151
t9e: 291
t9g: 139
t9h: 45
t9k: 31
t9l: 16
t9n: 39
t9o: 11
t9r: 13
t9s: 250
t9t: 406
t9x: 17
t9y: 166
u10d: 775
u10e: 20
u10g: 69
u10l: 22
u10n: 74
u10r: 12
u10s: 23
u10t: 56
u10y: 71
u11d: 54
u11e: 78
u11g: 42
u11s: 41
u11t: 15
u11y: 111
u12d: 29
u12e: 43
u12s: 17
u12y: 82
u13d: 21
u13e: 32
u13g: 85
u13s: 10
u13y: 43
u14e: 21
u14y: 16
u15y: 10
u16l: 15
u3e: 313
u3m: 11
u4a: 12
u4d: 271
u4h: 18
u4n: 1106
u4o: 13
u5d: 52
u5e: 192
u5g: 47
u5l: 497
u5n: 265
u5r: 1283
u5s: 17
u5t: 30
u5y: 17
u6d: 608
u6e: 216
u6g: 15
u6l: 87
u6n: 32
u6r: 19
u6s: 336
u6t: 45
u6y: 26
u7a: 10
u7d: 96
u7e: 19
u7g: 21
u7l: 37
u7m: 119
u7n: 97
u7o: 42
u7s: 93
u7y: 591
u8d: 65
u8e: 44
u8g: 38
u8l: 16
u8n: 50
u8s: 67
u8y: 68
u9d: 228
u9e: 42
u9g: 41
u9l: 77
u9n: 40
u9s: 56
u9t: 10
u9y: 56
v10d: 18
v10e: 18
v10n: 14
v10r: 16
v10s: 72
v10y: 46
v11n: 12
v11y: 12
v12n: 24
v13h: 11
v13t: 20
v3i: 32
v3l: 80
v3n: 27
v4a: 72
v4d: 20
v4e: 171
v4i: 39
v4l: 21
v4n: 136
v4s: 60
v4t: 65
v4w: 173
v4y: 1394
v5a: 93
v5d: 61
v5e: 630
v5l: 45
v5r: 25
v5s: 296
v5t: 134
v5x: 31
v6a: 77
v6d: 93
v6e: 97
v6i: 214
v6l: 144
v6m: 17
v6n: 29
v6r: 17
v6s: 372
v6t: 33
v6y: 118
v7a: 37
v7d: 31
v7e: 312
v7g: 42
v7k: 10
v7n: 31
v7o: 10
v7r: 72
v7s: 497
v7t: 68
v7y: 265
v8a: 153
v8d: 92
v8e: 152
v8g: 35
v8h: 31
v8l: 18
v8n: 37
v8r: 50
v8s: 242
v8t: 25
v8y: 104
v9a: 17
v9e: 86
v9g: 20
v9i: 12
v9l: 18
v9n: 24
v9r: 12
v9s: 164
v9y: 46
w10d: 28
w10e: 13
w10g: 28
w10l: 18
w10n: 180
w10r: 21
w10s: 62
w11d: 34
w11g: 21
w11s: 45
w12d: 11
w3b: 20
w3n: 74
w3o: 2992
w3r: 844
w3s: 11367
w3t: 64
w3x: 21
w3y: 1522
w4d: 469
w4e: 4923
w4f: 56
w4g: 47
w4h: 9956
w4k: 625
w4l: 2928
w4m: 556
w4n: 2930
w4p: 68
w4r: 28
w4s: 160
w4t: 4856
w4y: 16
w5d: 2652
w5e: 3284
w5f: 11
w5g: 116
w5h: 4911
w5l: 29
w5n: 664
w5r: 194
w5s: 1155
w5t: 165
w5y: 84
w6d: 743
w6e: 45
w6g: 66
w6h: 89
w6m: 25
w6n: 580
w6r: 152
w6s: 495
w6t: 114
w6w: 187
w6y: 187
w7d: 411
w7e: 173
w7g: 745
w7l: 10
w7m: 60
w7n: 260
w7r: 503
w7s: 213
w7t: 1070
w7w: 34
w7y: 80
w8d: 187
w8e: 13
w8g: 108
w8l: 16
w8n: 44
w8o: 19
w8r: 176
w8s: 160
w8t: 10
w8w: 41
w8y: 17
w9d: 139
w9e: 35
w9g: 81
w9i: 29
w9k: 20
w9l: 33
w9n: 96
w9r: 37
w9s: 72
w9t: 28
w9y: 21
x3i: 74
x3v: 34
x3x: 19
x4i: 56
x4y: 30
x5i: 33
x5s: 53
y10s: 20
y3s: 675
y3t: 476
y3u: 5361
y4d: 94
y4k: 193
y4r: 1539
y5d: 33
y5e: 119
y5g: 622
y5h: 65
y5l: 76
y5s: 656
y5v: 11
y6d: 11
y6s: 21
y6w: 55
y7d: 16
y7g: 11
y7r: 40
y8f: 160
y8g: 20
y8l: 15
y8n: 10
y8t: 11
y9l: 11
y9y: 56
z4e: 23
z4l: 24
z5m: 12
z6r: 12
z7s: 10
z7v: 37

B Problem 2

We list here the execution results of our solution for the second problem (movie analytics) tested on the `movies.csv` dataset. Task 1 (duration per country) produces the following results:

Afghanistan: 815
Albania: 646
Algeria: 2115
American Samoa: 247
Angola: 357
Argentina: 28813
Armenia: 264
Aruba: 739
Australia: 66068
Austria: 22925
Bahamas: 560
Bahrain: 87
Bangladesh: 429
Barbados: 92
Belarus: 427
Belgium: 54192
Bermuda: 95
Bhutan: 291
Bolivia: 797
Bosnia and Herzegovina: 2207
Botswana: 295
Brazil: 27333
Bulgaria: 5430
Burkina Faso: 903
Burma: 95
Cambodia: 894
Cameroon: 615
Canada: 210826
Chad: 493
Chile: 6178
China: 42089
Colombia: 3810
Congo: 88
Costa Rica: 431
Croatia: 4340
Cuba: 2899
Cyprus: 948
Czech Republic: 15317
Czechoslovakia: 8434
Cóte d'Ivoire: 180
Denmark: 44186
Dominican Republic: 866
East Germany: 2095
Ecuador: 893
Egypt: 3090
El Salvador: 167
Estonia: 4651
Ethiopia: 537
Faroe Islands: 97
Federal Republic of Yugoslavia: 2167
Finland: 48990
France: 467279
Gabon: 80
Georgia: 1846
Germany: 226808
Ghana: 655
Greece: 20305
Greenland: 90
Grenada: 79
Guatemala: 638
Guinea: 90
Haiti: 498
Honduras: 80
Hong Kong: 66567
Hungary: 19668
Iceland: 7839
India: 110215
Indonesia: 3931
Iran: 11762
Iraq: 1365
Ireland: 26506
Isle Of Man: 396
Israel: 16662
Italy: 288407
Jamaica: 807
Japan: 178558
Jordan: 1313
Kazakhstan: 2145
Kenya: 523
Korea: 90
Kosovo: 188
Kuwait: 273
Kyrgyzstan: 400
Laos: 289
Latvia: 2297
Lebanon: 1289
Liberia: 283
Libya: 520
Liechtenstein: 1011
Lithuania: 3772
Luxembourg: 11976
Macao: 175
Madagascar: 204
Malaysia: 1338
Mali: 220
Malta: 885
Martinique: 103
Mauritania: 515
Mexico: 35560
Micronesia: 85
Moldova: 95
Monaco: 189
Mongolia: 186
Montenegro: 439
Morocco: 4525
Namibia: 105
Nepal: 797
Netherlands: 47054
New Zealand: 14561
Nicaragua: 183
Nigeria: 494
North Korea: 508
Norway: 26476
Pakistan: 1728
Palestine: 1530
Panama: 903
Papua New Guinea: 295
Paraguay: 317
Peru: 2436
Philippines: 7882
Poland: 35543
Portugal: 15232
Puerto Rico: 1322
Qatar: 1036
Republic of Macedonia: 1515
Reunion: 38
Romania: 15739
Russia: 50757
Rwanda: 527
Samoa: 110
Saudi Arabia: 490
Senegal: 1462
Serbia: 4337
Serbia and Montenegro: 1314
Singapore: 4557
Slovakia: 2525
Slovenia: 2956
Somalia: 90
South Africa: 14688
South Korea: 56245
Soviet Union: 51353
Spain: 116651
Sri Lanka: 318
Suriname: 105
Sweden: 68956
Switzerland: 34516
Syria: 447
Taiwan: 16618
Tajikistan: 351
Tanzania: 441
Thailand: 10189
The Democratic Republic Of Congo: 98
Trinidad and Tobago: 86
Tunisia: 2236
Turkey: 20068
UK: 492616
USA: 2276142
Uganda: 243
Ukraine: 4616
United Arab Emirates: 3202
Uruguay: 2038
Uzbekistan: 324
Vanuatu: 100
Venezuela: 2014
Vietnam: 1261
West Germany: 58480
Yugoslavia: 8742
Zaire: 80
Zimbabwe: 210

Task 2 (movies per year and genre) produces the following results:

1973_Adventure: 1
1973_Drama: 1
1973_History: 1
1976_Comedy: 2
1976_Drama: 1
1976_History: 1
1976_Mystery: 1
1976_Romance: 1
1979_Adventure: 1
1979_Crime: 1
1979_Mystery: 1
1982_Comedy: 1
1982_Drama: 1
1985_Documentary: 1
1985_History: 1
1988_Comedy: 1
1988_Drama: 2
1988_Sci-Fi: 1
1996_Documentary: 1
1996_Music: 1
2001_Documentary: 1
2001_Music: 1
2002_Documentary: 1
2002_Music: 1
2004_Adventure: 1
2004_Documentary: 2
2004_Drama: 1
2004_Music: 1
2004_Romance: 1
2006_Animation: 1
2006_Crime: 1
2006_Drama: 1
2007_Documentary: 1
2007_War: 1
2008_Action: 1
2008_Crime: 1
2008_Drama: 1
2009_Documentary: 1
2015_Action: 1
2015_Adventure: 1
2015_Animation: 1

B.1 Problem 4

In the following 4-columned pages, the experimental results of section's 4 problem are presented, as the raw output of the 3rd MapReduce phase execution.

102: 20.772281
104: 29.609879
105: 27.598046999999998
107: 14.800885000000003
109: 27.163701999999994
110: 16.304225
111: 42.771938
112: 9.670065000000001
113: 28.587929000000003
114: 17.573652999999997
115: 33.936378
116: 25.765458000000002
117: 30.000875
1180: 9.566474
1181: 8.554887
1182: 10.499468
1183: 8.272158999999998
1186: 8.551493
120: 8.667856
121: 24.678666000000003
122: 62.881582
124: 23.14891
128: 13.860000000000001
129: 13.828262
130: 12.778032
131: 14.548629
132: 13.780112000000003
133: 12.777426
134: 17.525341
135: 12.858882000000001
136: 13.721149
137: 13.660803000000001
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