IERG4300 / ESTR4300/ IEMS5709 Fall 2021 Homework 2

Release date: Oct 12, 2021

Due date: Oct 30, 2021 (Saturday) 11:59pm

The solution will be posted right after the deadline, so no late homework will be accepted!

Every Student MUST include the following statement, together with his/her signature in the submitted homework.

I declare that the assignment submitted on the Elearning system is original except for source material explicitly acknowledged and that the same or related material has not been previously submitted for another course. I also acknowledge that I am aware of University policy and regulations on honesty in academic work, and of the disciplinary guidelines and procedures applicable to breaches of such policy and regulations, as contained in the website http://www.cuhk.edu.hk/policy/academichonesty/.

Signed (Student Qi Jiadun) Date: 29.10.2021

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Submission notice:

- Submit your homework via the elearning system

General homework policies:

A student may discuss the problems with others. However, the work a student turns in must be created COMPLETELY by oneself ALONE. A student may not share ANY written work or pictures, nor may one copy answers from any source other than one's own brain.

Each student **MUST LIST** on the homework paper the **name of every person he/she has discussed or worked with**. If the answer includes content from any other source, the student **MUST STATE THE SOURCE**. Failure to do so is cheating and will result in sanctions. Copying answers from someone else is cheating even if one lists their name(s) on the homework.

If there is information you need to solve a problem but the information is not stated in the problem, try to find the data somewhere. If you cannot find it, state what data you need, make a reasonable estimate of its value and justify any assumptions you make. You will be graded not only on whether your answer is correct but also on whether you have done an intelligent analysis.

Question 1 [20 marks]: Frequent Itemsets

Considering running the PCY algorithm on a data set with 500 million baskets to count frequent pairs of items. Suppose each basket contains ***n*** items and there are ***d*** distinct item-pairs amongst all of the baskets. Consider the following setup during the first pass of PCY: Besides keeping the counters for every singleton itemset observed during the first pass, we can still afford to store in main memory 300 million integers, each of which is a bucket. Assume further that ***d*** is much larger than the total number of buckets available, *i.e.*, ***d*** >> 300 million.

(a) [10 marks] As a function of *n* and/or *d*, what is the minimum support threshold *s* we can allow if the average count for a bucket should be no more than 40% of the threshold?

(b) [10 marks] Suppose that A, B, C, D, E, and F are all the items under consideration. For a particular support threshold, the maximal frequent itemsets are {A, B, D} and {C, E}. What are all the other frequent itemsets?

Q2 [80 marks + 20 Bonus marks]: Finding frequent itemsets

In this problem, we use the Shakespeare data set. The original data set has been pre-processed as follows:

- Apply a sliding window of 40 words on each work. All the 40 words in one window make up a basket.
- Delete duplicate words in one basket, then filter out some common words
- You can download the pre-processed data from the following link: https://drive.google.com/file/d/1A5Qx1bRdOFMyFuh5Qe9HnZofabclvhCx/view?usp=sharing
- Each line of this input is a tab-separated list of words that corresponds to one basket.

The threshold for a frequent pair is defined as s=0.005. The relative frequency of a pair = *Occurrence of pair (i, j)* / *Total number of baskets*. For Q2(a), (b), (c), and (d), if the number of frequent pairs is larger than 40, please only submit the **Top** 40 pairs (if any). Your results should consist of the frequent pairs and their corresponding count.

- You are allowed to use Linux command *sort* to post-process your results.

(a) [25 marks] Implement the A-Priori algorithm to find frequent pairs on a single machine

Refer to the lecture slides, Page 30, 31 to implement the A-Priori algorithm. You do not need to use MapReduce Framework for this sub-question. You can run this job on one single AWS/GoogleCloud machine. Note that dicvmc4.ie.cuhk.edu.hk is only a client for our DIC cluster. Please do NOT run the job on this machine.

(b) [30 marks] Implement the SON algorithm on MapReduce to find frequent pairs

Implement the SON algorithm under the MapReduce framework to find the frequent pairs. Note that your code should be scalable. In other words, your code should allow multiple mappers or reducers in both jobs. You need to implement two MapReduce jobs:

- The First MapReduce job should use **A-priori** algorithm to find the candidate pairs, which are frequent in at least one input file.
- Second MapReduce job counts only the candidate frequent pairs.

Tips:

- In the second MapReduce job, each mapper will load all the candidate pairs. You can pass them as a supplementary file.

Streamline and performance comparison:

- Wrap the two MapReduce rounds as a single executable by putting those commands you type before in a shell script.
- Compare the overall execution time of (a) and (b) .
- Output the command you use to submit the Hadoop job.

You can use the IE Data-Intensive Cluster (DIC) or any other Hadoop cluster (e.g., the AWS/GoogleCloud cluster built in HW#0) in various cloud computing platforms of your choice to do this problem.

(c) [25 marks] SON on MapReduce to find frequent triplets

The threshold for frequent triplets is defined as s=0.0025. The relative frequency of a triplet (i, j, k) = *Occurrence of triplet (i, j, k)* / *Total number of baskets*. If the number of frequent triplets is larger than 20, please only submit the top 20 triplets (if any).

Tip:

- In case of memory error, you may need to use multiple mappers/ reducers (*e.g.* 20+).

(d) [20 Bonus marks] Use the PCY algorithm to filter the candidate pairs in the SON algorithm

Implement the SON algorithm under the MapReduce framework. And use the PCY algorithm to filter the candidate pairs in the first MapReduce job. You can use the following Python hash function.

HashFunction=hash(word_1 + word_2) mod 100000

For example, the result of the word pair (‘Monday’, ‘Tuesday’) can be implemented as follows:

HashFunction=hash(‘Monday’ + ‘Tuesday’) % 100000

Streamline and performance comparison:

- Wrap the two MapReduce rounds as a single executable by putting those commands you type before in a shell script.
- Compare the overall execution time of (a), (b), and (d).
- Output the command you use to submit the Hadoop job.

Part (d) is an optional (bonus) part for IERG4300 and IEMS5709, but mandatory for ESTR4300.

Submission requirement:

- You need to submit BOTH your code and your result. Please place the relevant code and the result in **a SINGLE PDF** file.

Homework2 Report

Question1 (a)

The requirement and relation between buckets average count, total number of buckets and threshold is $AverageCount = \frac{d}{total\#buckets} \leq 0.4 * s$.

Since the total number of buckets is $total\#buckets = 300million = 3 * 10^8$.

Therefore, $s \geq 0.834 * 10^{-9} * d$.

Question1 (b)

According to a nice property of maximal frequent itemset, all subset of a maximal frequent itemset are frequent.

The maximum frequent itemsets are {A, B, D} and {C, E}, then all the other frequent itemsets are:

{A}, {B}, {D}, {A, B}, {A, D}, {B, D}, {C}, {E}

Question2 (a)

1.Download and prepare dataset

```
wget https://drive.google.com/u/0/uc?
id=1A5Qx1bRdOFMyFuh5Qe9HnZofabclvhCx&export=download
mv uc?id=1A5Qx1bRdOFMyFuh5Qe9HnZofabclvhCx shakespeare_basket.zip
unzip shakespeare_basket.zip
# 将两个文件合并
cat shakespeare_basket1 shakespeare_basket2 > shakespeare_basket
# 执行python script
python3 hw2_a.py shakespeare_basket/shakespeare_basket
```

2.Python script: hw2_a.py

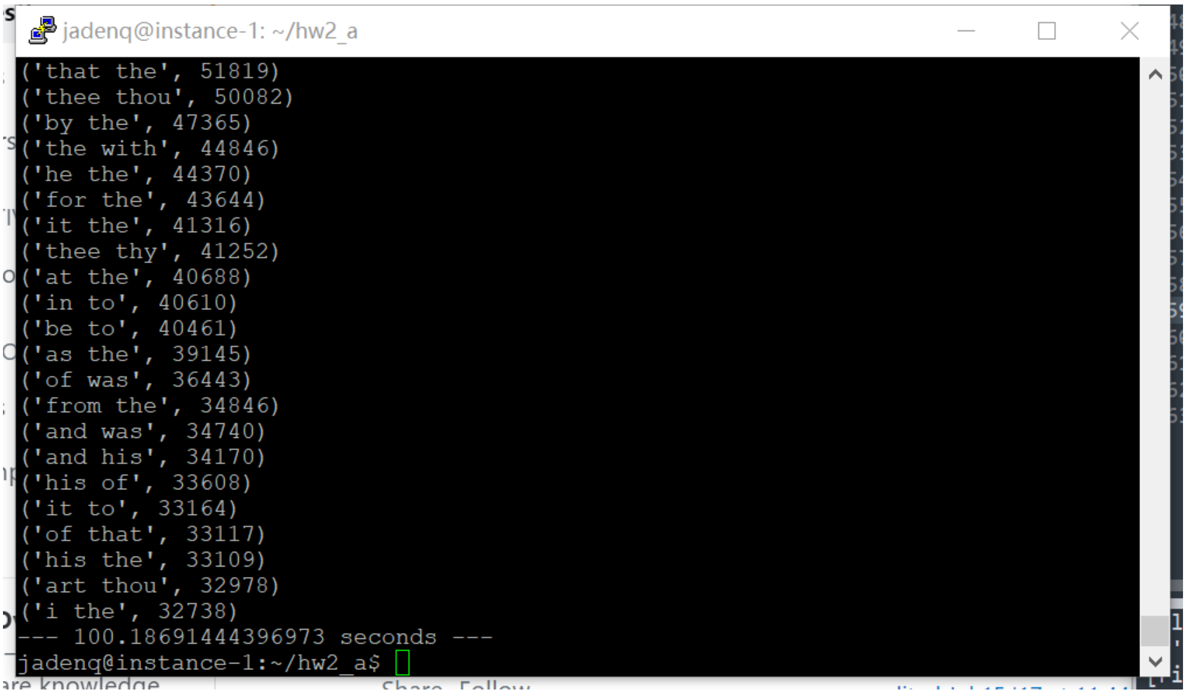
```
import sys
import time
start_time = time.time()

fname = sys.argv[1] # input file
basket_num = 0 # num of baskets
word_count = {} # key: word (individual item), value: frequency
freq_item = {} # key:word (frequent individual item), value: frequency
threshold = 0.005 # support threshold
freq_pairs = {} # key: item pair, value: frequency
topK = 40

# Pass1
with open(fname) as f:
    for line in f.readlines():
        basket_num += 1 # count the number of baskets
        line = line.strip()
        words = line.split(' ')
        words = list(set(words)) # remove the duplicates in one basket
        for word in words:
            if word not in word_count:
                word_count[word] = 1
            else: word_count[word] += 1
```

```
# s = threshold * basket_num
s = threshold * basket_num
for word in word_count:
    if word_count[word] >= s:
        freq_item[word] = word_count[word]

# Pass2

# get the candidate pair
with open(fname) as f:
    for line in f.readlines():
        line = line.strip()
        words = line.split(' ')
        words = list(set(words)) # remove the duplicates in one basket
        for i in range(0, len(words) - 1):
            for j in range(i+1, len(words)):
                if (words[i] in freq_item) and (words[j] in freq_item): # both
elements are frequent
                    # there should be no order within item pair
                    if (words[i] <= words[j]):
                        pair = words[i] + " " + words[j]
                    else: pair = words[j] + " " + words[i]
                    if pair in freq_pairs:
                        freq_pairs[pair] += 1
                    else: freq_pairs[pair] = 1

# get the frequent pair
result = {}
for pair in freq_pairs:
    if freq_pairs[pair] > s:
        result[pair] = freq_pairs[pair]

# sort the frequent item pairs according to frequency
if len(freq_pairs) > topK:
    result = sorted(result.items(), key = lambda x:x[1], reverse = True)[:topK]
    # sort according to value
else:
    result = sorted(result.items(), key = lambda x:x[1], reverse = True)

for pair in result:
    print(pair)

print("--- %s seconds ---" % (time.time() - start_time))
```

Output

```
('of the', 352310)
('and the', 174876)
('in the', 146017)
('the to', 145171)
('and of', 106824)
('a of', 100121)
('a the', 84377)
('and to', 74266)
('in of', 73828)
('of to', 68015)
('a and', 66899)
```

```
('and in', 62592)
('the was', 62453)
('thou thy', 61455)
('a to', 57495)
('a in', 54897)
('is the', 54866)
('on the', 53910)
('that the', 51819)
('thee thou', 50082)
('by the', 47365)
('the with', 44846)
('he the', 44370)
('for the', 43644)
('it the', 41316)
('thee thy', 41252)
('at the', 40688)
('in to', 40610)
('be to', 40461)
('as the', 39145)
('of was', 36443)
('from the', 34846)
('and was', 34740)
('and his', 34170)
('his of', 33608)
('it to', 33164)
('of that', 33117)
('his the', 33109)
('art thou', 32978)
('i the', 32738)
```



```
('that the', 51819)
('thee thou', 50082)
('by the', 47365)
('the with', 44846)
('he the', 44370)
('for the', 43644)
('it the', 41316)
('thee thy', 41252)
('at the', 40688)
('in to', 40610)
('be to', 40461)
('as the', 39145)
('of was', 36443)
('from the', 34846)
('and was', 34740)
('and his', 34170)
('his of', 33608)
('it to', 33164)
('of that', 33117)
('his the', 33109)
('art thou', 32978)
('i the', 32738)
--- 100.18691444396973 seconds ---
jadenq@instance-1:~/hw2_a$
```

It takes a single node Google Cloud instance 100 seconds to finish this task.

Question2 (b)

Data Preparation

```
hdfs dfs -mkdir hw2
hdfs dfs -copyFromLocal hw2/shakespeare_basket/shakespeare_basket ./hw2
```

MapReduce Job1

Mapper_b1.py

- Run A-Priori algorithm on the chunk using support threshold, use the same threshold s and the corresponding basket number for each node.
- Output the frequent pairs for that chunk (F, c), where F is the key (itemset) and c is count (or proportion)

```python
#!/usr/bin/env python
import sys
import gc
# Mapper for Job1
# Run A-Priori Algorithm in each chunk
basket_num = 0 # num of baskets
word_count = {} # key: word (individual item), value: frequency
freq_item = {} # key:word (frequent individual item), value: frequency
threshold = 0.005 # support threshold
freq_pairs = {} # key: item pair, value: frequency
baskets = [] # the list to store baskets for counting pass
# income from standard input
for line in sys.stdin:
    line = line.strip()
    words = line.split(' ')
    words = list(set(words))
    baskets.append(words)
    for word in words:
        if word not in word_count:
            word_count[word] = 1
        else: word_count[word] += 1

# find frequent itemset in subsets

basket_num = len(baskets)

# s = threshold * basket_num * p
s = threshold * basket_num

for word in word_count:
    if word_count[word] >= s:
        freq_item[word] = word_count[word]

# garbage collect
del word_count
gc.collect()

for basket in baskets:
    for i in range(0, len(basket) - 1):
        for j in range(i+1, len(basket)):
            if (basket[i] in freq_item) and (basket[j] in freq_item): # both
elements are frequent
                # there should be no order within item pair
                if (basket[i] <= basket[j]):
                    pair = basket[i] + " " + basket[j]
                else: pair = basket[j] + " " + basket[i]
                if pair in freq_pairs:
                    freq_pairs[pair] += 1
                else: freq_pairs[pair] = 1

# save intermediate result
# only pairs more frequent than s can be saved
for pair in freq_pairs:
    if (freq_pairs[pair] >= s):
        print("%s\t%s" % (pair, freq_pairs[pair]))

# a b   count
```

Reducer_b1.py

- Output the candidate pairs to be verified in the Job 2, aggregate the candidate pairs of each chunk
- Given (F,c), discard c and output all candidate pairs F's

```
#!/usr/bin/env python
import sys
# aggregate the result of candidate pairs from multiple chunks
current_pair = None
for line in sys.stdin:
    line = line.strip()
    pair, count = line.split('\t')
    if pair == current_pair:
        continue
    else:
        if current_pair:
            print(current_pair)
        current_pair = pair
    # discard c and output all candidate itemsets F's
if current_pair == pair:
    print(current_pair)
```

MapReduce Job2

Firstly, we get the total number of basket using the following script to simplify the reduce2 procedures.

```
import sys
basket_num = 0
fname = './shakespeare_basket/shakespeare_basket'
with open(fname) as f:
        for a in f.readlines():
                basket_num += 1
print('basket_num is:',basket_num)

[Output] basket_num is: 4340061
```

Mapper_b2.py

- For all the candidate pairs produced by Job 1, count the frequency in local chunk

```
#!/usr/bin/env python
```

```
import sys

# Mapper for Job2
# for all the candidate itemsets produced by Job1, count the frequency in local chunk

# stdin: the output result of last MR work
fname = 'candPair_b.txt'
freq_pairs = {} # key: item pair, value: frequency
with open(fname) as f:
    for line in f.readlines():
        pair = line.strip()
        freq_pairs[pair] = 0 # reset to 0

for line in sys.stdin:
    line = line.strip()
    words = line.split(' ')
    words = list(set(words)) # remove the duplicates in one basket
    for i in range(0, len(words) - 1):
        for j in range(i+1, len(words)):
                # there should be no order within item pair
                if (words[i] <= words[j]):
                    pair = words[i] + " " + words[j]
                else: pair = words[j] + " " + words[i]
                # only count the frequent pairs
                if pair in freq_pairs:
                    freq_pairs[pair] += 1


for pair in freq_pairs:
    print("%s\t%s" % (pair, freq_pairs[pair]))
```

Reducer_b2.py

- Aggregate the o/p of the Mapper of Job 2 and sum the count to get the frequency of each candidate pairs across the entire input file.
- Filter out the pairs with support smaller than s

```
#!/usr/bin/env python

import sys

# Aggregate the output of the Job2 mapper
current_pair = None # a itemset checker used to aggregate the same candidate itemset from different chuncks
overall_count = 0 # the frequency of each candidate itemsets across the overall input file
threshold = 0.005 # support threshold
basket_num = 0 # num of baskets

# Since we aggregate the counts of frequent pairs across all chunks(the same pairs goes to the same reducer, we can just use total number of baskets to evaluate)
basket_num = 4340061

s = threshold * basket_num
# get the pair - count
```

```
for line in sys.stdin:
    line = line.strip()
    pair, count = line.split('\t')
    count = int(count)
    if pair == current_pair:
         overall_count += count # the same itemset, agg_sum
    else:
        if current_pair:
            if overall_count >= s: # if the iteration is not over AND s is more
than the threshold
                print("%s\t%s" % (current_pair, overall_count))
        overall_count = count
        current_pair = pair # update the itemset checker
```

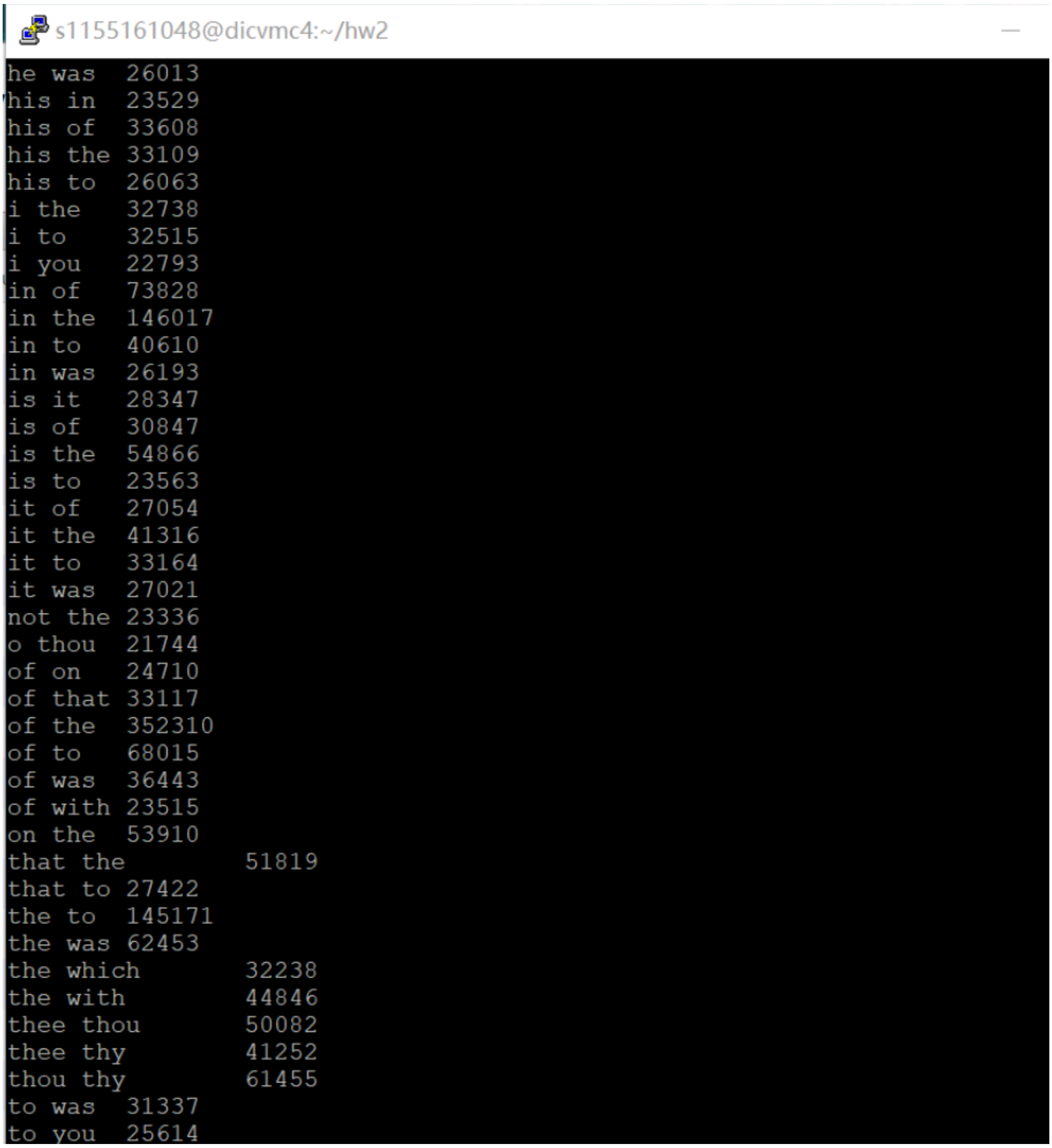
Debug

```
cat ./shakespeare_basket/shakespeare_basket | python3 ./mapper_b1.py
cat ./shakespeare_basket/shakespeare_basket | python3 ./mapper_b1.py | sort -k1
| python3 ./reducer_b1.py
cat ./shakespeare_basket/shakespeare_basket | python3 ./mapper_b1.py | sort -k1
| python3 ./reducer_b1.py | python3 ./mapper_b2.py
cat ./shakespeare_basket/shakespeare_basket | python3 ./mapper_b1.py | sort -k1
| python3 ./reducer_b1.py | python3 ./mapper_b2.py | python3 ./reducer_b2.py
```

Shell script for execution

```
chmod +x mapper_b1.py
chmod +x reducer_b1.py
chmod +x mapper_b2.py
chmod +x reducer_b2.py

# hdfs dfs -rm -r ./hw2/output_b1
hadoop jar /usr/lib/hadoop-mapreduce/hadoop-streaming.jar \
-D
mapred.output.key.comparator.class=org.apache.hadoop.mapred.lib.KeyFieldBasedCom
parator \
-D mapred.job.name='Job_b1' \
-D mapred.map.tasks=3 \
-D mapred.reduce.tasks=1 \
-file mapper_b1.py -mapper mapper_b1.py \
-file reducer_b1.py -reducer reducer_b1.py \
-input ./hw2/shakespeare_basket \
-output ./hw2/output_b1

# candidate pair - intermediate result
hdfs dfs -getmerge ./hw2/output_b1 ~/hw2/candPair_b.txt

hadoop jar /usr/lib/hadoop-mapreduce/hadoop-streaming.jar \
-D
mapred.output.key.comparator.class=org.apache.hadoop.mapred.lib.KeyFieldBasedCom
parator \
-D mapred.job.name='Job_b2' \
-D mapred.map.tasks=3 \
-D mapred.reduce.tasks=1 \
-file ./candPair_b.txt \
-file mapper_b2.py -mapper mapper_b2.py \
-file reducer_b2.py -reducer reducer_b2.py \
-input ./hw2/shakespeare_basket \
-output ./hw2/output_b2

hdfs dfs -cat ./hw2/output_b2/* > output_b.txt

hdfs dfs -rm -r ./hw2/output_b1
hdfs dfs -rm -r ./hw2/output_b2
```

Result



```
he was  26013
his in  23529
his of  33608
his the 33109
his to  26063
i the   32738
i to    32515
i you   22793
in of   73828
in the  146017
in to   40610
in was  26193
is it   28347
is of   30847
is the  54866
is to   23563
it of   27054
it the  41316
it to   33164
it was  27021
not the 23336
o thou  21744
of on   24710
of that 33117
of the  352310
of to   68015
of was  36443
of with 23515
on the  53910
that the        51819
that to 27422
the to  145171
the was 62453
the which       32238
the with        44846
thee thou       50082
thee thy        41252
thou thy        61455
to was  31337
to you  25614
```

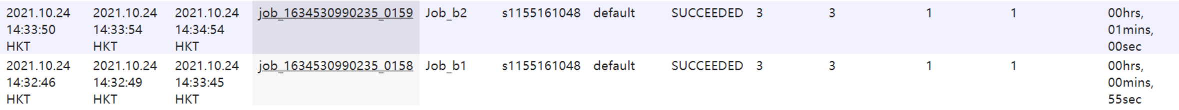
Time compare

Single node A-prior algorithm time (task A) is 100s

MapReduce1 time: 55s for A-prior Algorithm

MapRecude2 time: 60s

Overall time for task B is 115s.



2021.10.24 14:33:50 HKT	2021.10.24 14:33:54 HKT	2021.10.24 14:34:54 HKT	job_1634530990235_0159	Job_b2	s1155161048	default	SUCCEEDED	3	3	1	1	00hrs, 01mins, 00sec
2021.10.24 14:32:46 HKT	2021.10.24 14:32:49 HKT	2021.10.24 14:33:45 HKT	job_1634530990235_0158	Job_b1	s1155161048	default	SUCCEEDED	3	3	1	1	00hrs, 00mins, 55sec

Question2 (c)

Relationship with Task B

According to the requirement, we need a result of triplets with lower threshold than the Task B, which means if we still use the **definition of frequent pairs** result from above, that may leads to **some results missing** for Task C. So I implement the code (*mapper_b1.py, reducer_b1.py, mapper_b2.py, reducer_b2.py*) from Question2 (b) and **ONLY** change the threshold from 0.005 to 0.0025 (the scripts are modified into *mapper_c1.py, reducer_c1.py, mapper_c2.py, reducer_c2.py*) to get the intermediate result (with more frequent pairs) for Task C and save in folder *output_c2.*

MapReduce1 & MapReduce2

As mentioned above, I implemented the Task B code with lower threshold to help **find all the frequent pairs** with 0.0025 threshold, so to find the complete frequent triplets with 0.0025 threshold.

Mapreduce1

```
#!/usr/bin/env python

import sys
import gc

# Mapper for Job1
# Run A-Priori Algorithm in each chunk
basket_num = 0 # num of baskets
word_count = {} # key: word (individual item), value: frequency
freq_item = {} # key:word (frequent individual item), value: frequency
threshold = 0.0025 # support threshold
freq_pairs = {} # key: item pair, value: frequency

baskets = [] # the list to store baskets for counting pass

# income from standard input
for line in sys.stdin:
    line = line.strip()
    words = line.split(' ')
    words = list(set(words))
    baskets.append(words)
    for word in words:
        if word not in word_count:
            word_count[word] = 1
        else: word_count[word] += 1

# find frequent itemset in subsets

basket_num = len(baskets)

s = threshold * basket_num

for word in word_count:
    if word_count[word] >= s:
        freq_item[word] = word_count[word]

# garbage collect
del word_count
```

```
gc.collect()

for basket in baskets:
    for i in range(0, len(basket) - 1):
        for j in range(i+1, len(basket)):
            if (basket[i] in freq_item) and (basket[j] in freq_item): # both
elements are frequent
                # there should be no order within item pair
                if (basket[i] <= basket[j]):
                    pair = basket[i] + " " + basket[j]
                else: pair = basket[j] + " " + basket[i]
                if pair in freq_pairs:
                    freq_pairs[pair] += 1
                else: freq_pairs[pair] = 1

# save intermediate result
# only pairs more frequent than s can be saved
for pair in freq_pairs:
    if (freq_pairs[pair] >= s):
        print("%s\t%s" % (pair, freq_pairs[pair]))

# a b   count
```

```
#!/usr/bin/env python
import sys
current_pair = None
for line in sys.stdin:
    line = line.strip()
    pair, count = line.split('\t')
    if pair == current_pair:
        continue
    else:
        if current_pair:
            print(current_pair)
        current_pair = pair
    # discard c and output all candidate itemsets F's
if current_pair == pair:
    print(current_pair)
```

Mapreduce2

```
#!/usr/bin/env python
import sys

# Mapper for Job2
# for all the candidate itemsets produced by Job1, count the frequency in local
chunk

# stdin: the output result of last MR work
fname = 'candPair_c.txt'
freq_pairs = {} # key: item pair, value: frequency

with open(fname) as f:
    for line in f.readlines():
        pair = line.strip()
        freq_pairs[pair] = 0 # reset to 0
```

```
for line in sys.stdin:
    line = line.strip()
    words = line.split(' ')
    words = list(set(words)) # remove the duplicates in one basket
    for i in range(0, len(words) - 1):
        for j in range(i+1, len(words)):
                # there should be no order within item pair
                if (words[i] <= words[j]):
                    pair = words[i] + " " + words[j]
                else: pair = words[j] + " " + words[i]
                # only count the frequent pairs
                if pair in freq_pairs:
                    freq_pairs[pair] += 1


for pair in freq_pairs:
    print("%s\t%s" % (pair, freq_pairs[pair]))
```

```
#!/usr/bin/env python

import sys

# Aggregate the output of the Job2 mapper
current_pair = None # a itemset checker used to aggregate the same candidate
itemset from different chuncks
overall_count = 0 # the frequency of each candidate itemsets across the overall
input file
threshold = 0.0025 # support threshold
basket_num = 4340061 # num of total baskets

s = threshold * basket_num
# get the pair - count
for line in sys.stdin:
    line = line.strip()
    pair, count = line.split('\t')
    count = int(count)
    if pair == current_pair:
         overall_count += count # the same itemset, agg_sum
    else:
        if current_pair:
            if overall_count >= s: # if the iteration is not over AND s is more
than the threshold
                print("%s\t%s" % (current_pair, overall_count))
        overall_count = count
        current_pair = pair # update the itemset checker
```

MapReduce3

mapper_c3.py

- Run A-Priori algorithm on the chunk using support threshold.
- Output the frequent triplets for that chunk (F, c), where F is the key (itemset) and c is count (or proportion)
- I use function *orderTriplets* to uniform the triplets and *orderPairs* to uniform the pairs.

```
#!/usr/bin/env python
import sys

# Mapper for Job2
# for all the candidate itemsets produced by Job1, count the frequency in local
chunk

# stdin: the output result of last MR work
fname = 'freqPair_c.txt'
freq_pairs = []
freq_triplets = {} # key: item triplet, value: frequency
threshold = 0.0025 # support threshold
basket_num = 0

# uniform the triplets
def orderTriplet(a, b, c):
    ordered_list = [a, b, c]
    ordered_list.sort()
    return ' '.join(ordered_list)

# uniform the pairs
# align with the process of Task B
def orderPair(a,b):
    if (a <= b):
        pair = a + " " + b
    else: pair = b + " " + a
    return pair

with open(fname) as f:
    for line in f.readlines():
        pair, count = line.strip().split('\t')
        freq_pairs.append(pair)


for line in sys.stdin:
    line = line.strip()
    words = line.split(' ')
    words = list(set(words)) # remove the duplicates in one basket
    basket_num += 1 # count the basket number for each chunk
    for i in range(0, len(words) - 2):
        for j in range(i+1, len(words) - 1):
            for k in range(j+1, len(words)):
                # find the frequent pairs
                pair1 = orderPair(words[i], words[j])
                pair2 = orderPair(words[j], words[k])
                pair3 = orderPair(words[i], words[k])
                # 1. pairs of frequent triplets should all be frequent
                # 2. there should be no order within item triplet
                if (pair1 in freq_pairs) and (pair2 in freq_pairs) and (pair3 in
freq_pairs):
                    triplet = orderTriplet(words[i], words[j], words[k])
                    if triplet in freq_triplets:
                        freq_triplets[triplet] += 1
                    else: freq_triplets[triplet] = 1

# save intermediate result
s = threshold * basket_num
# only triplets more frequent than s can be saved
```

```
for triplet in freq_triplets:
    if (freq_triplets[triplet] >= s):
        print("%s\t%s" % (triplet, freq_triplets[triplet]))
```

reducer_c3.py

- Output the candidate triplets to be verified in the Job 4
- Given (F,c), discard c and output all candidate triplets F’s

```
#!/usr/bin/env python
import sys

current_triplet = None
for line in sys.stdin:
    line = line.strip()
    triplet, count = line.split('\t')
    if triplet == current_triplet:
        continue
    else:
        if current_triplet:
            print(current_triplet)
        current_triplet = triplet
    # discard c and output all candidate itemsets F's
if current_triplet == triplet:
    print(current_triplet)
```

MapReduce4

mapper_c4.py

- For all the candidate triplets produced by Job 3, count the frequency in local chunk

```
#!/usr/bin/env python
import sys

# Mapper for Job2
# for all the candidate itemsets produced by Job1, count the frequency in local chunk

# stdin: the output result of last MR work
fname = 'candTriplet_c.txt'
freq_triplets = {} # key: item triplet, value: frequency


# uniform the triplets
def orderTriplet(a, b, c):
    ordered_list = [a, b, c]
    ordered_list.sort()
    return ' '.join(ordered_list)

with open(fname) as f:
    for line in f.readlines():
        triplet = line.strip()
        freq_triplets[triplet] = 0 # reset to 0

for line in sys.stdin:
    line = line.strip()
    words = line.split(' ')
    words = list(set(words)) # remove the duplicates in one basket
    for i in range(0, len(words) - 2):
        for j in range(i+1, len(words) - 1):
            for k in range(j+1, len(words)):
                # there should be no order within item triplet
                triplet = orderTriplet(words[i], words[j], words[k])
                # only count the frequent triplets
                if triplet in freq_triplets:
                    freq_triplets[triplet] += 1


for triplet in freq_triplets:
    print("%s\t%s" % (triplet, freq_triplets[triplet]))
```

reducer_c4.py

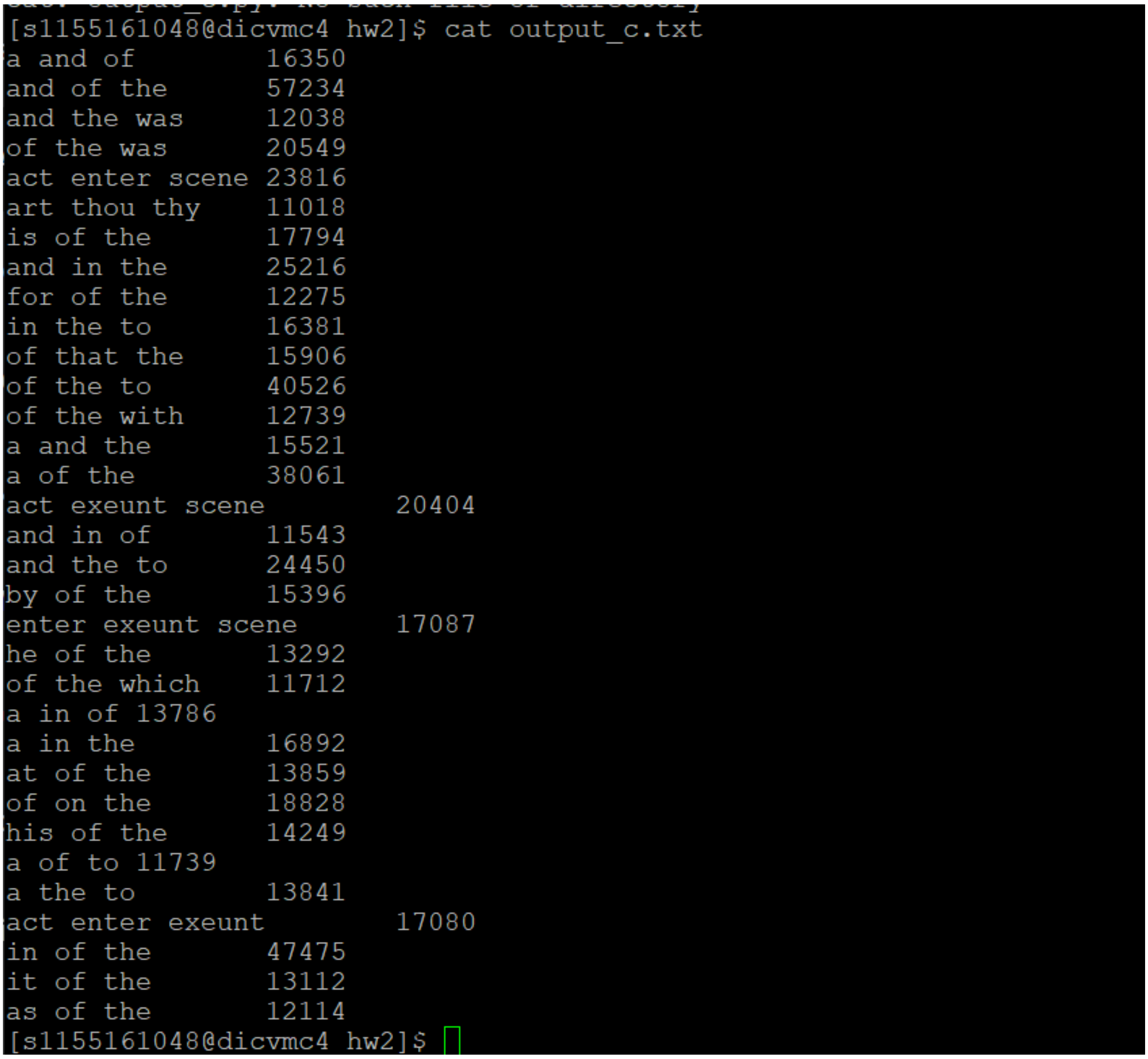
- Aggregate the o/p of the Mapper of Job 3 and sum the count to get the frequency of each candidate triplets across the entire input file.
- Filter out the triplets with support smaller than s

```
#!/usr/bin/env python

import sys

# Aggregate the output of the Job2 mapper
current_triplet = None # a itemset checker used to aggregate the same candidate
itemset from different chuncks
overall_count = 0 # the frequency of each candidate itemsets across the overall
input file
threshold = 0.0025 # support threshold
basket_num = 4340061 # aggregate all the node

s = threshold * basket_num
# get the triplet - count
for line in sys.stdin:
    line = line.strip()
    triplet, count = line.split('\t')
    count = int(count)
    if triplet == current_triplet:
         overall_count += count # the same itemset, agg_sum
    else:
        if current_triplet:
            if overall_count >= s: # if the iteration is not over AND s is more
than the threshold
                print("%s\t%s" % (current_triplet, overall_count))
        overall_count = count
        current_triplet = triplet # update the itemset checker
```

Shell script for execution

```
chmod +x mapper_c1.py
chmod +x reducer_c1.py
chmod +x mapper_c2.py
chmod +x reducer_c2.py
chmod +x mapper_c3.py
chmod +x reducer_c3.py
chmod +x mapper_c4.py
chmod +x reducer_c4.py

# mapreduce1
hadoop jar /usr/lib/hadoop-mapreduce/hadoop-streaming.jar \
-D
mapred.output.key.comparator.class=org.apache.hadoop.mapred.lib.KeyFieldBasedCom
parator \
-D mapred.job.name='Job_c1' \
-D mapred.map.tasks=3 \
-D mapred.reduce.tasks=1 \
-file mapper_c1.py -mapper mapper_c1.py \
-file reducer_c1.py -reducer reducer_c1.py \
-input ./hw2/shakespeare_basket \
-output ./hw2/output_c1

hdfs dfs -getmerge ./hw2/output_c1 ~/hw2/candPair_c.txt
# mapreduce2 - result is the frequent pairs (0.0025 threshold), more than that
from Task B
hadoop jar /usr/lib/hadoop-mapreduce/hadoop-streaming.jar \
-D
mapred.output.key.comparator.class=org.apache.hadoop.mapred.lib.KeyFieldBasedCom
parator \
-D mapred.job.name='Job_c2' \
-D mapred.map.tasks=3 \
-D mapred.reduce.tasks=1 \
-file ./candPair_c.txt \
-file mapper_c2.py -mapper mapper_c2.py \
-file reducer_c2.py -reducer reducer_c2.py \
-input ./hw2/shakespeare_basket \
-output ./hw2/output_c2

hdfs dfs -getmerge ./hw2/output_c2 ~/hw2/freqPair_c.txt

# mapreduce3
hadoop jar /usr/lib/hadoop-mapreduce/hadoop-streaming.jar \
-D
mapred.output.key.comparator.class=org.apache.hadoop.mapred.lib.KeyFieldBasedCom
parator \
-D mapred.job.name='Job_c3' \
-D mapred.map.tasks=40 \
-D mapred.reduce.tasks=10 \
-file ./freqPair_c.txt \
-file mapper_c3.py -mapper mapper_c3.py \
-file reducer_c3.py -reducer reducer_c3.py \
-input ./hw2/shakespeare_basket \
-output ./hw2/output_c3

hdfs dfs -getmerge ./hw2/output_c3 ~/hw2/candTriplet_c.txt

# mapreduce4 - result is the frequent triplets with 0.0025 threshold
hadoop jar /usr/lib/hadoop-mapreduce/hadoop-streaming.jar \
-D
mapred.output.key.comparator.class=org.apache.hadoop.mapred.lib.KeyFieldBasedCom
parator \
-D mapred.job.name='Job_c4' \
-D mapred.map.tasks=50 \
-D mapred.reduce.tasks=10 \
-file ./candTriplet_c.txt \
-file mapper_c4.py -mapper mapper_c4.py \
-file reducer_c4.py -reducer reducer_c4.py \
-input ./hw2/shakespeare_basket \
-output ./hw2/output_c4

hdfs dfs -cat ./hw2/output_c4/* > output_c.txt

hdfs dfs -rm -r ./hw2/output_c1
hdfs dfs -rm -r ./hw2/output_c2
hdfs dfs -rm -r ./hw2/output_c3
hdfs dfs -rm -r ./hw2/output_c4
```

Output



```
[s1155161048@dicvmc4 hw2]$ cat output_c.txt
a and of        16350
and of the      57234
and the was     12038
of the was      20549
act enter scene 23816
art thou thy    11018
is of the       17794
and in the      25216
for of the      12275
in the to       16381
of that the     15906
of the to       40526
of the with     12739
a and the       15521
a of the        38061
act exeunt scene        20404
and in of       11543
and the to      24450
by of the       15396
enter exeunt scene      17087
he of the       13292
of the which    11712
a in of 13786
a in the        16892
at of the       13859
of on the       18828
his of the      14249
a of to 11739
a the to        13841
act enter exeunt        17080
in of the       47475
it of the       13112
as of the       12114
[s1155161048@dicvmc4 hw2]$
```

Question2 (d)

MapReduce1

I build a hash table to encode the pairs and allocate them into 100000 buckets in the first pass of A-prior algorithm, then eliminate the pairs from infrequent buckets to get less candidate pairs in the second pass.

mapper_d1.py

```
#!/usr/bin/env python
```

```
import sys
import gc

# Mapper for Job1
# Run A-Priori Algorithm in each chunk
basket_num = 0 # num of baskets
word_count = {} # key: word (individual item), value: frequency
freq_item = {} # key:word (frequent individual item), value: frequency
threshold = 0.005 # support threshold
freq_pairs = {} # key: item pair, value: frequency

baskets = [] # the list to store baskets for counting pass

def orderPair(a,b):
    if (a <= b):
        pair = a + " " + b
    else: pair = b + " " + a
    return pair

# income from standard input
hashTable = [0 for i in range(100000)]

for line in sys.stdin:
    line = line.strip()
    words = line.split(' ')
    words = list(set(words))
    baskets.append(words)
    for word in words:
        if word not in word_count:
            word_count[word] = 1
        else: word_count[word] += 1
    for i in range(0, len(words) - 1):
        for j in range(i+1, len(words)):
        # define a hashtable
        # hash all the pairs into 100000 bucktes
            hashIndex = hash(orderPair(words[i], words[j])) % 100000 # index of the hash table
            hashTable[hashIndex] += 1 # count into the hash table

# find frequent itemset in subsets
basket_num = len(baskets)

s = threshold * basket_num

for word in word_count:
    if word_count[word] >= s:
        freq_item[word] = word_count[word]

# garbage collect
del word_count
gc.collect()

for basket in baskets:
    for i in range(0, len(basket) - 1):
        for j in range(i+1, len(basket)):
            if (basket[i] in freq_item) and (basket[j] in freq_item): # both elements are frequent
```

```
                # there should be no order within item pair
                pair = orderPair(basket[i], basket[j])
                # verify freq pairs using hashtable
                hashIndex = hash(pair) % 100000
                if hashTable[hashIndex] >= s:
                    if pair in freq_pairs:
                        freq_pairs[pair] += 1
                    else: freq_pairs[pair] = 1

# save intermediate result
# only pairs more frequent than s can be saved
for pair in freq_pairs:
    if (freq_pairs[pair] >= s):
        print("%s\t%s" % (pair, freq_pairs[pair]))

# a b   count
```

reducer_d1.py

```
#!/usr/bin/env python
import sys

current_pair = None
for line in sys.stdin:
    line = line.strip()
    pair, count = line.split('\t')
    if pair == current_pair:
        continue
    else:
        if current_pair:
            print(current_pair)
        current_pair = pair
    # discard c and output all candidate itemsets F's
if current_pair == pair:
    print(current_pair)
```

MapReduce2

mapper_d2.py

```
#!/usr/bin/env python
import sys

# Mapper for Job2
# for all the candidate itemsets produced by Job1, count the frequency in local chunk

# stdin: the output result of last MR work
fname = 'candPair_d.txt'
freq_pairs = {} # key: item pair, value: frequency


with open(fname) as f:
    for line in f.readlines():
        pair = line.strip()
        freq_pairs[pair] = 0 # reset to 0

```

```
for line in sys.stdin:
    line = line.strip()
    words = line.split(' ')
    words = list(set(words)) # remove the duplicates in one basket
    for i in range(0, len(words) - 1):
        for j in range(i+1, len(words)):
                # there should be no order within item pair
                if (words[i] <= words[j]):
                    pair = words[i] + " " + words[j]
                else: pair = words[j] + " " + words[i]
                # only count the frequent pairs
                if pair in freq_pairs:
                    freq_pairs[pair] += 1


for pair in freq_pairs:
    print("%s\t%s" % (pair, freq_pairs[pair]))
```

reducer_d2.py

```
#!/usr/bin/env python

import sys

# Aggregate the output of the Job2 mapper
current_pair = None # a itemset checker used to aggregate the same candidate
itemset from different chuncks
overall_count = 0 # the frequency of each candidate itemsets across the overall
input file
threshold = 0.005 # support threshold
basket_num = 0 # num of baskets

basket_num = 4340061

s = threshold * basket_num
# get the pair - count
for line in sys.stdin:
    line = line.strip()
    pair, count = line.split('\t')
    count = int(count)
    if pair == current_pair:
         overall_count += count # the same itemset, agg_sum
    else:
        if current_pair:
            if overall_count >= s: # if the iteration is not over AND s is more
than the threshold
                print("%s\t%s" % (current_pair, overall_count))
        overall_count = count
        current_pair = pair # update the itemset checker
```

Shell script for execution

```
chmod +x mapper_d1.py
chmod +x reducer_d1.py
chmod +x mapper_d2.py
chmod +x reducer_d2.py
```

```
hadoop jar /usr/lib/hadoop-mapreduce/hadoop-streaming.jar \
-D
mapred.output.key.comparator.class=org.apache.hadoop.mapred.lib.KeyFieldBasedCom
parator \
-D mapred.job.name='Job_d1' \
-D mapred.map.tasks=3 \
-D mapred.reduce.tasks=1 \
-file mapper_d1.py -mapper mapper_d1.py \
-file reducer_d1.py -reducer reducer_d1.py \
-input ./hw2/shakespeare_basket \
-output ./hw2/output_d1

# candidate pair - intermediate result
hdfs dfs -getmerge ./hw2/output_d1 ~/hw2/candPair_d.txt

hadoop jar /usr/lib/hadoop-mapreduce/hadoop-streaming.jar \
-D
mapred.output.key.comparator.class=org.apache.hadoop.mapred.lib.KeyFieldBasedCom
parator \
-D mapred.job.name='Job_d2' \
-D mapred.map.tasks=3 \
-D mapred.reduce.tasks=1 \
-file ./candPair_d.txt \
-file mapper_d2.py -mapper mapper_d2.py \
-file reducer_d2.py -reducer reducer_d2.py \
-input ./hw2/shakespeare_basket \
-output ./hw2/output_d2

hdfs dfs -cat ./hw2/output_d2/* > output_d.txt

hdfs dfs -rm -r ./hw2/output_d1
hdfs dfs -rm -r ./hw2/output_d2
```

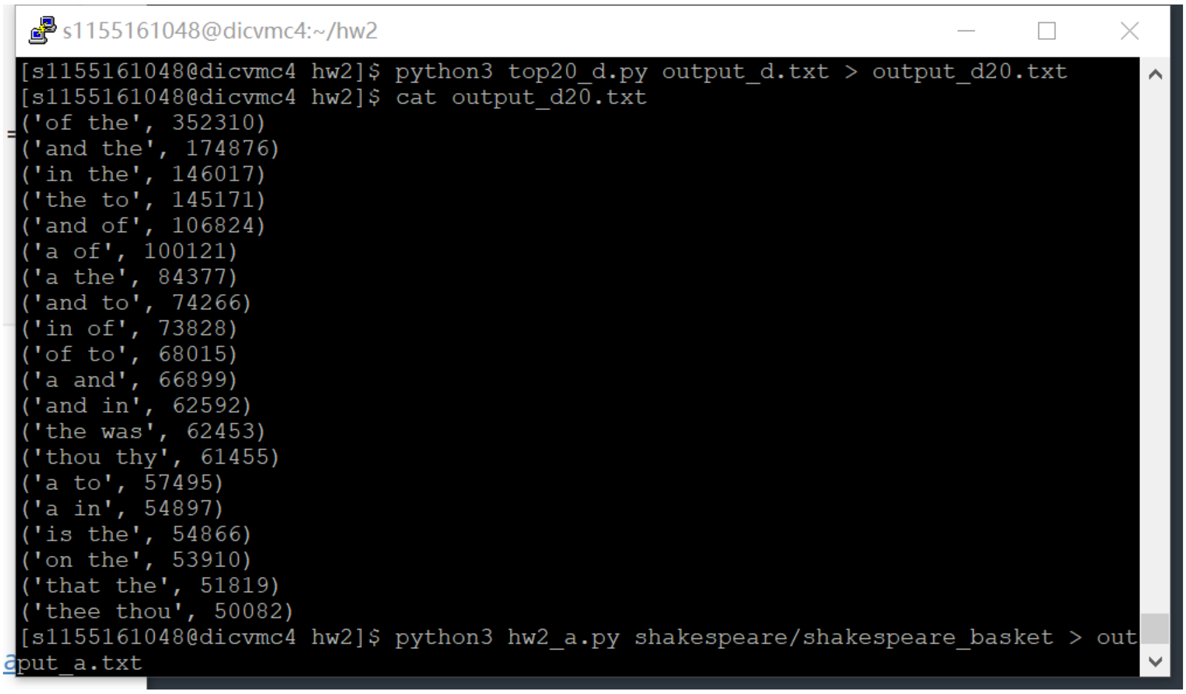
Top20 Result (python script)

```
# get the top20 result
import sys

fname = sys.argv[1] # input file
freq_pairs = {}
topK = 20

with open(fname) as f:
    for line in f.readlines():
        pair, count = line.strip().split('\t')
        freq_pairs[pair] = int(count)

if len(freq_pairs) > topK:
    result = sorted(freq_pairs.items(), key = lambda x:x[1], reverse = True)
[:topK]
    # sort according to value
else:
    result = sorted(freq_pairs.items(), key = lambda x:x[1], reverse = True)

for pair in result:
    print(pair)
```

Output

Correction check: the total result of task B and task D is the same, which are 86 lines. (output_b.txt and output_d.txt in supplementary files)

Output_d20.txt



```
[s1155161048@dicvmc4 hw2]$ python3 top20_d.py output_d.txt > output_d20.txt
[s1155161048@dicvmc4 hw2]$ cat output_d20.txt
('of the', 352310)
('and the', 174876)
('in the', 146017)
('the to', 145171)
('and of', 106824)
('a of', 100121)
('a the', 84377)
('and to', 74266)
('in of', 73828)
('of to', 68015)
('a and', 66899)
('and in', 62592)
('the was', 62453)
('thou thy', 61455)
('a to', 57495)
('a in', 54897)
('is the', 54866)
('on the', 53910)
('that the', 51819)
('thee thou', 50082)
[s1155161048@dicvmc4 hw2]$ python3 hw2_a.py shakespeare/shakespeare_basket > out
put_a.txt
```

Conclusion

Comparations

Comparing (a) and (b)

- Time

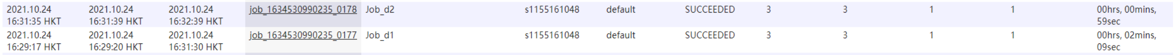
100s v.s. 55s for A-Prior process

Due to the use of multiple mapper and reducers, the distributed computing saves time.

Comparing (b) and (d)

- Time

For task d, the MapReduce1 time is 129s, and the MapReduce2 time is 59s.



2021.10.24 16:31:35 HKT	2021.10.24 16:31:39 HKT	2021.10.24 16:32:39 HKT	job_1634530990235_0178	Job_d2	s1155161048	default	SUCCEEDED	3	3	1	1	00hrs, 00mins, 59sec
2021.10.24 16:29:17 HKT	2021.10.24 16:29:20 HKT	2021.10.24 16:31:30 HKT	job_1634530990235_0177	Job_d1	s1155161048	default	SUCCEEDED	3	3	1	1	00hrs, 02mins, 09sec

For task b, the MapReduce1 time: 55s, MapRecude2 time: 60s.

The PYC algorithm takes longer time to hash the pairs in MapReduce1.

- Memory

The size of intermediate result is different, since the PYC use less memory to maintain a dictionary instead of pairs and corresponding values compared with SON algorithm.

Summary

SON algorithm is a distributed version of A-prior using the basic concept, the frequent itemset should be frequent in at least on subset, so we can find the candidates in different chunks to save time in computing in distributions.

PYC algorithm is a trade of between time and memory, the PYC use more time to hash but only need to maintain a smaller dictionary, we can use them in practice accordingly.

Supplementary files

Text version of outputs are stored in: https://pan.baidu.com/s/1n2JPlSI_zxQcb6HoLhbKvg , code is 8una.

Reference

1. Sort dictionary according to value: https://careerkarma.com/blog/python-sort-a-dictionary-by-value/
2. SON algorithm: https://www.geeksforgeeks.org/the-son-algorithm-and-map-reduce/