Introduction to MapReduce

Louis Jachiet
Example: Counting the occurrences of each item in a list

A, B, D, A, C, C, D, A
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A, B, D, A, C, C, D, A

⇒ A: 3, B: 1, C: 2, D: 2

A very basic and classical problem in data mining! e.g. anomaly / spam / bots detection
Example: Counting the occurrences of each item in a list

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⇒

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>3</td>
</tr>
<tr>
<td>B</td>
<td>1</td>
</tr>
<tr>
<td>C</td>
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</tr>
<tr>
<td>D</td>
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Example: Counting the occurrences of each item in a list

Easily solved in Python:

```python
nb = dict()
for item in inputList:
    if not item in nb:
        nb[item] = 0
    nb[item] += 1
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*How to make this program run on many machines?*
Example: Counting the occurrences of each item in a list

- Each machine will host a part of the input
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<th>D, C, C, D →</th>
<th>Machine C-D</th>
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<tbody>
<tr>
<td>A, B, A, A</td>
<td>← A, B, A, A</td>
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<tr>
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<td>C: 5</td>
</tr>
<tr>
<td>B: 2</td>
<td>D: 3</td>
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Example: Counting the occurrences of each item in a list

What needs to be done for very large data?

- Partition data
Example: Counting the occurrences of each item in a list

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- Partition data
- Start computation
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- Shuffle data
Example: Counting the occurrences of each item in a list

What needs to be done for very large data?

- Partition data
- Start computation
- Shuffle data
- Handle failure (data + computation)

Very hard to get right!
The MapReduce Model
A typical Big Data problem can be divided into 5 phases

1. Iterate over a large number of records
2. Extract something of interest from each
3. Shuffle and sort intermediate results
4. Aggregate intermediate results
5. Generate final output
A typical Big Data problem can be divided into 5 phases

1. Iterate over a large number of records
2. Extract something of interest from each –MAP–
3. Shuffle and sort intermediate results
4. Aggregate intermediate results –REDUCE–
5. Generate final output
For a MapReduce job, the programmer needs to provide:

- A **MAP** function: \( \text{value} \rightarrow (\text{key}, \text{value}) \text{ list} \)

  *Transforms each record into a (possibly empty) list of key-value pairs*
For a MapReduce job, the programmer needs to provide:

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  *Transforms each record into a (possibly empty) list of key-value pairs*

- A **REDUCE** function: \((\text{key}, \text{list of values}) \rightarrow \text{value}\)
  
  *Take a key and the list of values with this key*
MapReduce Model

Input

Phase 1: Map

Phase 2: Shuffle

Phase 3: Reduce

(K,V)

Shuffled

Final
MapReduce Model

Input

(K,V)

Phase 1: Map
MapReduce Model

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(K,V)
MapReduce Model

Phase 1: Map
Phase 2: Shuffle
Phase 3: Reduce

(K,V) Shuffled Final

Phase 3: Reduce
Example: Counting the occurrences of each item in a list

**MAP**

Each item $i$ is transformed into the singleton list key-value pair $[(i, 1)]$

**REDUCE**

Given a pair $(i, l)$ where $i$ is an item and $l$ a list, the reducer returns $(i, \text{length}(l))$
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(A,1), (B,1), (D,1), (A,1), (C,1), (C,1), (D,1), (A,1)

↓ SHUFFLE ↓

(A,[1,1,1]), (B,[1]), (D,[1,1]), (C,[1,1])

↓ REDUCE: \( (i, l) \rightarrow (i, \text{length}(l)) \) ↓

(A,3), (B,1), (D,2), (C,2)
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(A,3), (B,1), (D,2), (C,2)
It is possible to chain several MapReduce jobs!
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It is possible to use several inputs for a MapReduce job!
Example: Keep distinct items appearing more than twice

\[ A, B, D, A, C, C, D, A \]

↓ MAP: \( i \rightarrow [(i, 1)] \) ↓

\((A,1), (B,1), (D,1), (A,1), (C,1), (C,1), (D,1), (A,1)\)

↓ SHUFFLE ↓

\((A,[1,1,1]), (B,[1]), (D,[1,1]), (C,[1,1])\)

↓ REDUCE: \((i, l) \rightarrow (i, \text{length}(l))\) ↓

\((A,[3]), (B,[1]), (D,[2]), (C,[2])\)
Example: Keep distinct items appearing more than twice

↓ MAP: $i \rightarrow [(i, 1)]$ ↓

(A,1), (B,1), (D,1), (A,1), (C,1), (C,1), (D,1), (A,1)

↓ SHUFFLE ↓

(A,[1,1,1]), (B,[1]), (D,[1,1]), (C,[1,1])

↓ REDUCE: $(i, l) \rightarrow (i, length(l))$ ↓

(A,[3]), (B,[1]), (D,[2]), (C,[2])

↓ MAP: $(i, l) \rightarrow \begin{cases} 
[[]] & \text{when } sum(n) < 2 \\
[(i, sum(n))] & \text{otherwise}
\end{cases}$ ↓
Example: Keep distinct items appearing more than twice

\[(A,1), (B,1), (D,1), (A,1), (C,1), (C,1), (D,1), (A,1)\]

\[\downarrow \text{SHUFFLE} \downarrow\]

\[(A,[1,1,1]), (B,[1]), (D,[1,1]), (C,[1,1])\]

\[\downarrow \text{REDUCE: } (i, l) \mapsto (i, \text{length}(l)) \downarrow\]

\[(A,[3]), (B,[1]), (D,[2]), (C,[2])\]

\[\downarrow \text{MAP: } (i, l) \mapsto \begin{cases} [] & \text{when } \text{sum}(n) < 2 \\ [(i, \text{sum}(n))] & \text{otherwise} \end{cases} \downarrow\]

\[(A,3), (D,2), (C,2)\]
Example: Keep distinct items appearing more than twice

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\[(A,[1,1,1]), (B,[1]), (D,[1,1]), (C,[1,1]) \]

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\[(A,[1,1,1]), (B,[1]), (D,[1,1]), (C,[1,1])\]

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\[(A,3), (D,2), (C,2)\]

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\[(A,3), (D,2), (C,2)\]

\[\downarrow \text{SHUFFLE} \downarrow\]

\[(A,3), (D,2), (C,2)\]

\[\downarrow \text{REDUCE: } (i, l) \rightarrow i \downarrow\]
Example: Keep distinct items appearing more than twice

\[(A,[3]), (B,[1]), (D,[2]), (C,[2])\]

\[\downarrow MAP: (i, l) \rightarrow \begin{cases} \emptyset & \text{when } \text{sum}(n) < 2 \\ [(i, \text{sum}(n))] & \text{otherwise} \end{cases} \downarrow \]

\[(A,3), (D,2), (C,2)\]

\[\downarrow \text{SHUFFLE} \downarrow \]

\[(A,3), (D,2), (C,2)\]

\[\downarrow \text{REDUCE: } (i, l) \rightarrow i \downarrow \]

A, D, C
Exercise (easy)

Input
You are given a list of pairs \((k_i, v_i)\) where \(k_i\) is a string and \(v_i\) an integer.

Problem
Compute the average value for each key.

Example

<table>
<thead>
<tr>
<th>INPUT</th>
<th>OUTPUT</th>
</tr>
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<tbody>
<tr>
<td>A 42</td>
<td>A (\frac{42 + 12}{2} = 27)</td>
</tr>
<tr>
<td>B 17</td>
<td>B (\frac{17 + 99}{2} = 58)</td>
</tr>
<tr>
<td>A 12</td>
<td></td>
</tr>
<tr>
<td>B 99</td>
<td></td>
</tr>
</tbody>
</table>
Exercise (medium)

Input
You are given two lists of items.

Problem
Compute the list of item appearing in the first one but not in the second.

Example

<table>
<thead>
<tr>
<th>INPUT 1</th>
<th>INPUT2</th>
<th>OUTPUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>C</td>
<td>B</td>
</tr>
<tr>
<td>C</td>
<td>E</td>
<td></td>
</tr>
</tbody>
</table>
Exercise (hard)

Input
You are given the Twitter following list: each record is a pair $(A_i, B_i)$ indicating that account $A_i$ follows $B_i$.

Problem
Compute the accounts that have more followers than followees.

Example

<table>
<thead>
<tr>
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<th>OUTPUT</th>
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</thead>
<tbody>
<tr>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>A</td>
<td>D</td>
</tr>
<tr>
<td>B</td>
<td>C</td>
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<table>
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<th>E</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>D</td>
</tr>
<tr>
<td></td>
<td>C</td>
</tr>
</tbody>
</table>
**Input**

You are given the Twitter following list: each record is a pair \( (A_i, L_i) \) indicating that account \( A_i \) follows the accounts in the list \( L_i \).

**Problem**

Compute for each account \( A \) the list of accounts that are followed by an account followed by \( A \).

**Example**

<table>
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<tr>
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<tbody>
<tr>
<td>A</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>B,D</td>
</tr>
<tr>
<td>C</td>
<td>C,D</td>
</tr>
<tr>
<td></td>
<td>E</td>
</tr>
<tr>
<td>A</td>
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</tr>
<tr>
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MapReduce Beyond Map and Reduce
MapReduce extensions: Combiner

**Context**
Counting the number of times each item appears.

**Problem**
A few set of words appear very often.
Context

Counting the number of times each item appears.

Problem

A few set of words appear very often.

Solution: Combiner

A Combiner is similar to a reduce phase but applied before the shuffle on each local output of mappers.
Example: Counting the occurrences of each item in a list

A, B, D, A, C, C, D, A
Example: Counting the occurrences of each item in a list

A, B, D, A, C, C, D, A

↓ MAP: $i \rightarrow (i, 1)$ ↓
Example: Counting the occurrences of each item in a list

A, B, D, A, C, C, D, A

\[\downarrow \text{MAP: } i \rightarrow (i, 1) \downarrow\]

(A,1), (B,1), (D,1), (A,1), (C,1), (C,1), (D,1), (A,1)
Example: Counting the occurrences of each item in a list

A, B, D, A, C, C, D, A

↓ MAP: $i \rightarrow (i, 1)$ ↓

(A,1), (B,1), (D,1), (A,1), (C,1), (C,1), (D,1), (A,1)

↓ COMBINE: $(i, l) \rightarrow (i, \text{length}(l))$ ↓

(A,2), (B,1), (D,1), (C,2), (D,1), (A,1)

↓ SHUFFLE ↓

(A,[2,1]), (B,[1]), (D,[1,1]), (C,[2])

↓ REDUCE: $(i, l) \rightarrow (i, \Sigma l)$ ↓

(A,3), (B,1), (D,2), (C,2)
Example: Counting the occurrences of each item in a list

A, B, D, A, C, C, D, A

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(A,2), (B,1), (D,1), (C,2), (D,1), (A,1)
Example: Counting the occurrences of each item in a list

\[\text{A, B, D, A, C, C, D, A}\]

\[\downarrow \text{MAP: } i \rightarrow (i, 1) \downarrow\]

\[\text{(A,1), (B,1), (D,1), (A,1), (C,1), (C,1), (D,1), (A,1)}\]

\[\downarrow \text{COMBINE: } (i, l) \rightarrow (i, \text{length}(l)) \downarrow\]

\[\text{(A,2), (B,1), (D,1), (C,2), (D,1), (A,1)}\]

\[\downarrow \text{SHUFFLE} \downarrow\]
Example: Counting the occurrences of each item in a list

A, B, D, A, C, C, D, A

↓ MAP: $i \rightarrow (i, 1)$ ↓

(A,1), (B,1), (D,1), (A,1), (C,1), (C,1), (D,1), (A,1)

↓ COMBINE: $(i, l) \rightarrow (i, \text{length}(l))$ ↓

(A,2), (B,1), (D,1), (C,2), (D,1), (A,1)

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Louis JACHIET

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↓ REDUCE: \((i, l) \rightarrow (i, \Sigma l)\) ↓

\[(A,3), (B,1), (D,2), (C,2)\]
Exercise on combiner

Input
You are given a list of pairs \((k_i, v_i)\) where \(k_i\) is a string and \(v_i\) an integer.

Problem
Compute the average value for each key.

Example

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<td>B</td>
<td>(\frac{17 + 99}{2} = 58)</td>
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<tr>
<td>A</td>
<td>42</td>
</tr>
<tr>
<td>B</td>
<td>17</td>
</tr>
<tr>
<td>A</td>
<td>12</td>
</tr>
<tr>
<td>B</td>
<td>99</td>
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In MapReduce, each reducer task is responsible for a subset of the keys. Deciding which reducer is in charge of what key is the job of the **Partitioner**.
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By default, keys are assigned to reducers *pseudo-randomly* using a hash function.

\[ K \rightarrow \text{hash}(K) \mod \text{nbReducers} \]
In MapReduce, each reducer task is responsible for a subset of the keys. Deciding which reducer is in charge of what key is the job of the Partitioner.

By default, keys are assigned to reducers pseudo-randomly using a hash function.

\[ K \rightarrow \text{hash}(K) \% \text{nbReducers} \]

You can manually control the partitioning.
public class HashPartitioner\<K2, V2\> implements Partitioner\<K2, V2\> {

    public void configure(JobConf job) {}

    /** Use {@link Object#hashCode()} to partition. */

    public int getPartition(K2 key, V2 value, int numReduceTasks) {
        return (key.hashCode() & Integer.MAX_VALUE) % numReduceTasks;
    }
}

Figure 1: Default Partitioner in Hadoop
HADOOP Implementation of MapReduce
• Data is stored in plain text files that are split into chunks

*Chunks are typically 64 or 128 MB*
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    Chunks are typically 64 or 128 MB

• Each chunk is replicated

    For resiliency, the replication factor is 3
Storage

- Data is stored in plain text files that are split into **chunks**
  
  _Chunks are typically 64 or 128 MB_

- Each chunk is **replicated**
  
  _For resiliency, the replication factor is 3_

- The **Namenode** handles where the chunks of files are stored
• Data is stored in plain text files that are split into chunks
  
  *Chunks are typically 64 or 128 MB*

• Each chunk is replicated
  
  *For resiliency, the replication factor is 3*

• The Namenode handles where the chunks of files are stored
  
• A Secondary Namenode handles resiliency
Storage

Block Replication

Namenode (Filename, numReplicas, block-ids, …)
/users/sameerp/data/part-0, r:2, {1,3}, ...
/users/sameerp/data/part-1, r:3, {2,4,5}, ...

Datanodes

Figure 2: source
https://hadoop.apache.org/docs/r1.2.1/hdfs_design
Figure 3: source
https://hadoop.apache.org/docs/r1.2.1/hdfs_design
Computation

- The **Ressource Manager** will start a number $M$ of mapper tasks to process chunks

  *Mapper tasks are allocated where the data is!*
Computation

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Practical Hadoop
Hadoop is **OPEN SOURCE** and developed in **JAVA**
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Submitting a MapReduce jobs is usually done by submitting a JAR file. The code will control and launch one or several MapReduce jobs.
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DEMO
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DEMO
Installing Hadoop
Installing Hadoop 1/3

Requirement

- Optional: a VM for hosting hadoop
- Java
- Create an account that can ssh localhost with ssh keys

Get Hadoop

- Download Hadoop 3.2
  https://www.apache.org/dyn/closer.cgi/hadoop/core
- Unzip it (e.g. in a Hadoop folder)
Modify .bashrc or .profile of the account:

- `export HADOOP_HOME=/path/to/hadoop/folder`
- `export JAVA_HOME=/usr/lib/jvm/default-runtime`
- `alias hls='fs -ls'`
- `export PATH=$PATH:$HADOOP_HOME/bin`

Adapt values to your configuration!

Launch Hadoop single node

- `hdfs namenode -format` #initialize namenode
- `cd $HADOOP_HOME/sbin`
- `bash start_all.sh`

#don't forget to bash stop_all.sh at the end!
- `hadoop fs -mkdir /data /out`
Putting data on Hadoop:

```bash
hadoop fs -copyFromLocal /path/to/local /data/filename
```

Getting data from Hadoop:

```bash
hadoop fs -copyToLocal /data/filename /path/to/local
```

Explore data on Hadoop:

```bash
hadoop fs -cat /data/filename
hadoop fs -head /data/filename
hadoop fs -tail /data/filename
```
Hands On: exploring BAN
The BAN contains addresses and we want to find out the most popular street names.
BAN csv files

What the file look like

```
hadoop fs -head /datasets/ban/ban-01.csv
```

```
id_ban_position;id_ban_adresse;cle_interop;id_ban_group;id_fantoir;numero;suffixe;nom_voie;code_postal;nom_commune;code_insee;nom_complementaire;x;y;lon;lat;typ_loc;source;date_der_ma
```
BAN csv files

```
hadoop fs -head /datasets/ban/ban-01.csv | tr ';' ''\n' | nl
1    id_ban_position
2    id_ban_adresse
3    cle_interop
4    id_ban_group
5    id_fantoir
6    numero
7    suffixe
8    nom_voie
9    code_postal
10   nom_commune
11   code_insee
12   nom_complementaire
13   x
14   y
15   lon
16   lat
17   typ_loc
```
Counting street name

What is a unique street?

Each street appears multiple times

```bash
hadoop fs -cat /datasets/ban/ban-75.csv | grep -i barrault

ban-position-f7b26917d0e7483b81140c9c3abea54e;
ban-housenumber-927804e4ca734591a257d1fc91771c02;75113_0679_93;
ban-group-d94295ec4c1a409a893c3aaa21ebcca6;751130679;93;;
Rue Barrault;75013;Paris 13e Arrondissement;75113;;
652047.483621478;6858292.61265954;2.346877;48.822911;
entrance;ign;2018-10-21

ban-position-cfe9a6c883184b448930656d2a021862;
ban-housenumber-927804e4ca734591a257d1fc91771c02;75113_0679_93;
ban-group-d94295ec4c1a409a893c3aaa21ebcca6;751130679;93;;
Rue Barrault;75013;Paris 13e Arrondissement;75113;;
652054.959452335;6858311.8481202;2.346979;48.823083;
parcel;dgfip;2018-10-21

ban-position-411cce6058474e53bb95ee3aea3466fd;
ban-housenumber-92d8c6bc6d5c433eb1ed5c310177db3c;75113_0679_94;
```

Louis JACHIET
Counting street name

What is a unique street?
A street is a name and a zip code.
BAN csv files

Columns 8 and 9!

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>id_ban_position</td>
</tr>
<tr>
<td>2</td>
<td>id_ban_adresse</td>
</tr>
<tr>
<td>3</td>
<td>cle_interop</td>
</tr>
<tr>
<td>4</td>
<td>id_ban_group</td>
</tr>
<tr>
<td>5</td>
<td>id_fantoir</td>
</tr>
<tr>
<td>6</td>
<td>numero</td>
</tr>
<tr>
<td>7</td>
<td>suffixe</td>
</tr>
<tr>
<td>8</td>
<td>nom_voie</td>
</tr>
<tr>
<td>9</td>
<td>code_postal</td>
</tr>
<tr>
<td>10</td>
<td>nom_commune</td>
</tr>
<tr>
<td>11</td>
<td>code_insee</td>
</tr>
<tr>
<td>12</td>
<td>nom_complementaire</td>
</tr>
<tr>
<td>13</td>
<td>x</td>
</tr>
<tr>
<td>14</td>
<td>y</td>
</tr>
<tr>
<td>15</td>
<td>lon</td>
</tr>
<tr>
<td>16</td>
<td>lat</td>
</tr>
<tr>
<td>17</td>
<td>typ_loc</td>
</tr>
</tbody>
</table>
Counting occurrences of pairs of (zip code, street name)

Map
record $\rightarrow ((\text{street name}, \text{zip code}), 1)$

Reduce
Classical word count ($l \rightarrow \text{length}(l)$)
#!/usr/bin/python

import sys

for myline in sys.stdin:
    myline = myline.strip()
    subs = myline.split(';')
    if len(subs)>8:
        voie = subs[7]
        zipcode = subs[8]
        print('%s %s	%s' % (zipcode,voie, 1))
from operator import itemgetter
import sys

current_word = ""
current_count = 0
word = ""

for myline in sys.stdin:
    myline = myline.strip()
    subs = myline.split(\t',1)
    if len(subs)>1:
        count = int(str(subs[1]))
        word=subs[0]
        if current_word == word:
            current_count += count
        else:
            if current_word:
                print('%s\t%s' % (current_word, current_count) )
            current_count = count
            current_word = word

if current_word == word:
    print('%s\t%s' % (current_word, current_count))
Counting number of zip code for each street name

Map

\[ ((\text{street name}, \text{zip code}), n) \rightarrow (\text{street name}, 1) \]

Reduce

Classical word count reducer
#!/usr/bin/python

import sys

for myline in sys.stdin:
    myline = myline.strip()
    subs = myline.split('	',1)
    if len(subs)>1:
        subs2 = subs[0].split(' ',1)
        if len(subs2)>1:
            print('%s\t1' % (subs2[1]))
Map

(street name, n) → (street name, n) when n > 1000

Reduce

Identity
#!/usr/bin/python

import sys

for myline in sys.stdin:
    myline = myline.strip()
    subs = myline.split('	')
    if len(subs) > 1:
        print('%.9d\t%s' % (int(subs[1]), subs[0])))