Lab 10 Hadoop Distributed File System and MapReduce

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Learning outcome

By the end of this lesson, you are able to

- Setup a Multi-node Hadoop cluster (and Spark cluster)
- Manage HDFS using Command Line Interface
- Execute Simple MapReduce Job
- Design and implement mapreduce job

Prelude - Please attempt this before the lab

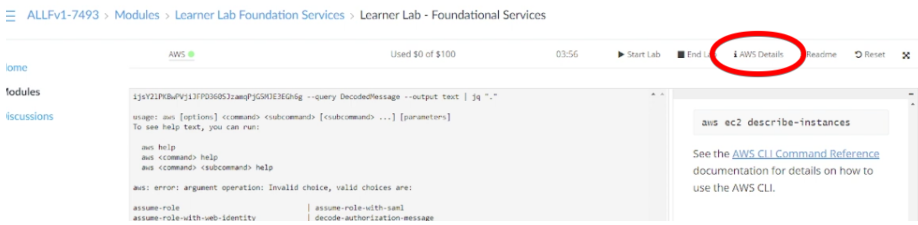
Since we are using AWS EC2, setting up a hadoop cluster is pretty straight forward.

We are going to rely on an open source project `Flintrock` which aims to automate the setup of a Spark cluster. Since in most of the use cases, Spark requires a distributed data storage, Flinkrock supports HDFS out of the box.

Step 1: Preparation

Assume that we have already setup an AWS IAM user with an access key and an access secret. If the user has not been created, create one by recalling the steps from Lab 1, `boto3` exercise.

If you are using AWS educate account you should be able to find the IAM access id and secret here



We also need to have a client machine which is running Linux or Mac OS X. If Windows is the only installed OS, we can try to install a Windows Linux Subsystem or a VM.

Make sure `boto3` is installed.

Step 2: Setup

1. Launch a bash / zsh terminal and install flintrock

```
$ sudo pip3 install flintrock
```

when the installation completes, type

```
$ flintrock

Usage: flintrock [OPTIONS] COMMAND [ARGS]...

  Flintrock

  A command-line tool for launching Apache Spark clusters.

Options:
  --config TEXT          Path to a Flintrock configuration file.
  --provider [ec2]
  --version              Show the version and exit.
  --debug / --no-debug   Show debug information.
  --help                 Show this message and exit.

Commands:
  add-slaves     Add slaves to an existing cluster.
  configure      Configure Flintrock's defaults.
  copy-file      Copy a local file up to a cluster.
  describe       Describe an existing cluster.
  destroy        Destroy a cluster.
  launch         Launch a new cluster.
  login          Login to the master of an existing cluster.
  remove-slaves  Remove slaves from an existing cluster.
  run-command    Run a shell command on a cluster.
  start          Start an existing, stopped cluster.
```

```
  stop           Stop an existing, running cluster.
```

2. Initialize the Flintrock configuration file

```
$ flintrock configure
```

A configuration file `~/.config/flintrock/config.yaml` is generated.

3. Open the `config.yaml` file with a text editor and update the content similar to the following

```yaml
services:
  spark:
    version: 3.1.2
    download-source: "https://archive.apache.org/dist/spark/spark-3.1.2/"
  hdfs:
    version: 3.2.0
    download-source: "https://archive.apache.org/dist/hadoop/common/hadoop-3.2.0/"

provider: ec2

providers:
  ec2:
    key-name: <the_pem_key_name_you_used_when_creating_pem_file>
    identity-file: <path_to_your_pem_file.pem>
    # key-name: kenny_lu_sutd_aws_us_east1
    # identity-file: /home/luzm/kenny_lu_sutd_aws_us_east1.pem
    instance-type: t2.micro
    # instance-type: m5.large
    region: us-east-1
    # availability-zone: <name>
    ami: ami-0aeeebd8d2ab47354  # Amazon Linux 2, us-east-1
    user: ec2-user
    tenancy: default  # default | dedicated
    ebs-optimized: no  # yes | no
    instance-initiated-shutdown-behavior: terminate  # terminate | stop

launch:
  num-slaves: 3
  install-hdfs: true
  install-spark: true
  java-version: 8

debug: true
```

4. Export the AWS IAM key id and secret as environment variables.

```
$ export AWS_ACCESS_KEY_ID=<YOUR_KEY_ID>
$ export AWS_SECRET_ACCESS_KEY=<YOUR_ACCESS_KEY>
```

Step 3: Launch the cluster

1. Launch the cluster

```
$ flintrock launch my_test_cluster
```

We should see something similar to the following

```
2021-06-29 10:23:24,074 - flintrock.ec2      - INFO  - Launching 4 instances...
2021-06-29 10:23:36,628 - flintrock.ec2      - DEBUG - 4 instances not in state 'running':
2021-06-29 10:23:39,781 - flintrock.ec2      - DEBUG - 4 instances not in state 'running':
2021-06-29 10:23:42,883 - flintrock.ec2      - DEBUG - 3 instances not in state 'running':
2021-06-29 10:23:45,954 - flintrock.ec2      - DEBUG - 3 instances not in state 'running':
2021-06-29 10:23:49,062 - flintrock.ec2      - DEBUG - 1 instances not in state 'running':
2021-06-29 10:23:52,731 - flintrock.ssh      - DEBUG - [13.212.89.251] SSH exception: [Errn
2021-06-29 10:23:55,727 - flintrock.ssh      - DEBUG - [13.250.65.255] SSH timeout.
2021-06-29 10:23:55,731 - flintrock.ssh      - DEBUG - [13.212.245.73] SSH timeout.
2021-06-29 10:23:55,731 - flintrock.ssh      - DEBUG - [52.77.217.139] SSH timeout.
2021-06-29 10:23:58,208 - flintrock.ssh      - INFO  - [13.212.89.251] SSH online.
2021-06-29 10:23:58,513 - flintrock.core     - INFO  - [13.212.89.251] Configuring ephemera
2021-06-29 10:24:00,860 - flintrock.ssh      - DEBUG - [52.77.217.139] SSH exception: [Errn
2021-06-29 10:24:01,178 - flintrock.ssh      - INFO  - [13.212.245.73] SSH online.
2021-06-29 10:24:01,444 - flintrock.ssh      - INFO  - [13.250.65.255] SSH online.
2021-06-29 10:24:01,476 - flintrock.core     - INFO  - [13.212.245.73] Configuring ephemera
2021-06-29 10:24:01,812 - flintrock.core     - INFO  - [13.250.65.255] Configuring ephemera
2021-06-29 10:24:07,219 - flintrock.ssh      - INFO  - [52.77.217.139] SSH online.
2021-06-29 10:24:07,504 - flintrock.core     - INFO  - [52.77.217.139] Configuring ephemera
2021-06-29 10:24:10,991 - flintrock.core     - INFO  - [13.212.89.251] Installing AdoptOpen
2021-06-29 10:24:14,126 - flintrock.core     - INFO  - [13.250.65.255] Installing AdoptOpen
2021-06-29 10:24:17,606 - flintrock.core     - INFO  - [13.212.245.73] Installing AdoptOpen
2021-06-29 10:24:17,848 - flintrock.core     - INFO  - [52.77.217.139] Installing AdoptOpen
2021-06-29 10:24:45,125 - flintrock.services - INFO  - [13.212.89.251] Installing HDFS...
2021-06-29 10:24:45,227 - flintrock.services - DEBUG - [13.212.89.251] Downloading Hadoop f
2021-06-29 10:24:50,611 - flintrock.services - INFO  - [13.250.65.255] Installing HDFS...
2021-06-29 10:24:50,702 - flintrock.services - DEBUG - [13.250.65.255] Downloading Hadoop f
2021-06-29 10:24:54,621 - flintrock.services - INFO  - [13.212.245.73] Installing HDFS...
2021-06-29 10:24:54,743 - flintrock.services - DEBUG - [13.212.245.73] Downloading Hadoop f
2021-06-29 10:24:56,392 - flintrock.services - INFO  - [52.77.217.139] Installing HDFS...
2021-06-29 10:24:56,488 - flintrock.services - DEBUG - [52.77.217.139] Downloading Hadoop f
2021-06-29 10:25:44,608 - flintrock.services - INFO  - [13.212.89.251] Installing Spark...
2021-06-29 10:25:44,720 - flintrock.services - DEBUG - [13.212.89.251] Downloading Spark fr
2021-06-29 10:25:53,303 - flintrock.services - INFO  - [13.250.65.255] Installing Spark...
2021-06-29 10:25:53,420 - flintrock.services - DEBUG - [13.250.65.255] Downloading Spark fr
2021-06-29 10:25:54,856 - flintrock.services - INFO  - [13.212.245.73] Installing Spark...
2021-06-29 10:25:54,966 - flintrock.services - DEBUG - [13.212.245.73] Downloading Spark fr
2021-06-29 10:25:58,834 - flintrock.services - INFO  - [52.77.217.139] Installing Spark...
2021-06-29 10:25:58,942 - flintrock.services - DEBUG - [52.77.217.139] Downloading Spark fr
```

```
2021-06-29 10:26:36,881 - flintrock.services  - INFO  - [52.77.217.139] Configuring HDFS mas
2021-06-29 10:27:01,910 - flintrock.services  - INFO  - [52.77.217.139] Configuring Spark ma
2021-06-29 10:27:11,842 - flintrock.services  - INFO  - HDFS online.
2021-06-29 10:27:12,049 - flintrock.services  - INFO  - Spark online.
2021-06-29 10:27:12,053 - flintrock.ec2       - INFO  - launch finished in 0:03:55.
Cluster master: ec2-52-77-217-139.ap-southeast-1.compute.amazonaws.com
Login with: flintrock login test_cluster
```

Step 4: Test drive the cluster

1. Login to the cluster

```
$ flintrock login <your_cluster_name>
```

We should see

```
Warning: Permanently added '52.77.217.139' (ECDSA) to the list of known hosts.
Last login: Tue Jun 29 02:27:01 2021 from 66.96.210.124

       __|  __|_  )
       _|  (     /   Amazon Linux 2 AMI
      ___|\___|___|

https://aws.amazon.com/amazon-linux-2/
29 package(s) needed for security, out of 38 available
Run "sudo yum update" to apply all updates.
[ec2-user@ip-172-31-41-151 ~]$
```

Trouble Shooting

1. We encounter the following error

```
Flintrock could not find your AWS credentials. You can fix this by providing your credentia
```

when launching the cluster

Make sure the ACCESS KEY and SECRET are exported as environment variables.

2. We encounter the following error when launching the cluster

```
error:
    raise Exception("HDFS health check failed.") from e
Exception: HDFS health check failed.
```

Edit the config.yaml to use Java 8

IF the Java version has already been set to 8. Try to destroy the cluster and launch again.

High level of Architecture of Hadoop

Recall that Hadoop consists of the following three major components

- MapReduce - Data Processing Layer
- Hadoop Distributed File System - Data Storage Layer
- Yarn - Resource Management Layer

HDFS

Recall the HDFS architecture

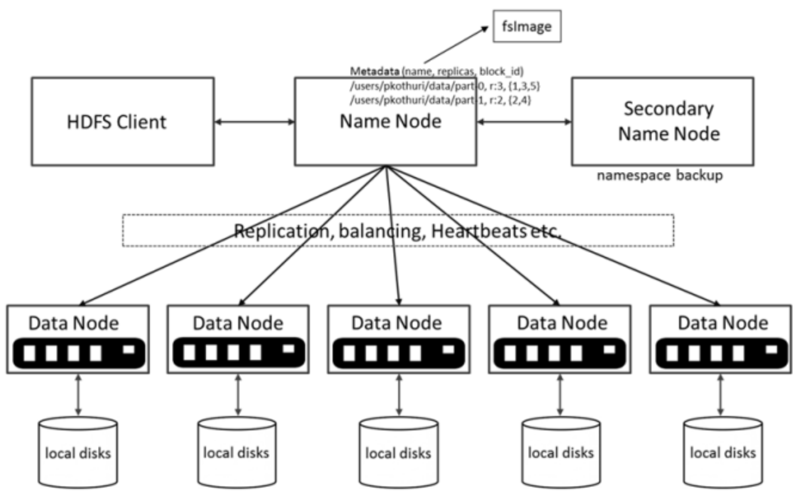


Figure 1: HDFS Architecture

- A Master-worker architecture
- Block Size (default 64MB v1, 128MB v2+)
- Each block is replicated (Recommended 3 or any odd number > 3)
- Name node maps filename/path to block IDs
- Client fetches actual data using the block IDs

HDFS dfs operations

- File uploading

```
hdfs dfs -put <local_file_path> <hdfs_file_path>
```

Note that the file path in hdfs must be a full path.

- File downloading

```
hdfs dfs -get <hdfs_file_path> <local_file_path>
```

- File listing

```
hdfs dfs -ls [optios] <hdfs_file_path>
```

- File deleting

```
hdfs dfs -rm [optios] <hdfs_file_path>
```

- File copying

```
hdfs dfs -cp [optios] <src_hdfs_file_path> <target_hdfs_file_path>
```

- File moving/renaming

```
hdfs dfs -mv [optios] <src_hdfs_file_path> <target_hdfs_file_path>
```

- For more hdfs dfs commands, try `hdfs dfs`. You may realize many HDFS dfs sub commands are *borrowed* from Linux bash.

HDFS namenode operations

- Namenode format (for setting up only)

```
hdfs namenode -format
```

HDFS admin operations

- Admin report

```
hdfs dfsadmin -report
```

- Safemode - the name node is in read-only mode.
  - If your cluster (in particular namenode) crashes, its next startup might be stuck in safe mode.
  - to check

  ```
  hdfs dfsadmin -safemode get
  ```

  - to manually exit safemode

  ```
  hdfs dfsadmin -safemode leave
  ```

- For more hdfs admin, try `hdfs dfsadmin`

Prelude Exercise

Assuming we have launch the hadoop cluster using FlintRock

1. clone the lab work repo from github (if git is not installed, install it by issuing `sudo yum install git`)

```
$ mkdir -p ~/git
$ cd ~/git
$ git clone https://github.com/istd50043-2021-fall/50043-labs/
```

2. transfer the file in `~/git/50043-labs/lab10/data/TheCompleteSherlockHolmes.txt` to the folder `/input/` in HDFS.

After the transfer, you should find the file `TheCompleteSherlockHolmes.txt` in the HDFS folder `/input/`.

3. test your cluster with the following map reduce job.

```
$ hadoop jar /home/ec2-user/hadoop/share/hadoop/mapreduce/hadoop-mapreduce-examples-3.2.0.ja
wordcount /input /output
```

Note: you might need to make sure that the output folder DOES NOT exist before the execution of the above command.

4. transfer the result from the folder `/output/` in hdfs back to the linux file system.

End of Prelude: Terminate the cluster (Do it when you need to)

Back to our client machine.

```
$ flintrock destroy <your_cluster_name>
```

Start with the Toy MapReduce library

During the lecture, we developed a toy MapReduce library in Python. It is sometimes useful to design Map Reduce jobs in this toy library before diving into the specific implementation such as Hadoop MapReduce or Spark.

Recall that `map` and `reduce` are the two basic combinators/functions that enable data parallelism.

Leveraging the two combinators, we built the following combinators

- `filter`
- `flatMap`
- `shuffle`
- `reduceByKey` and `reduceByKey2`

Exercise 1:

Define `min()` and `max()` using `reduce()`.

Sample test cases

```
>>> import ex1
>>> min([32,63,7,10, 100])
7
>>> max([32,63,7,10, 100])
100
```

Exercise 2:

Suppose you have a big data set (many terabytes) with many records of the following form: `(productID, supplierID, price)` where `productID` identifies a unique product, `supplierID` identifies a unique supplier, and price is the sale price. You want a list of suppliers, listing for each supplier the average sale price of all items by the supplier. Write a MapReduce job for this task using the toy MapReduce library.

You may find the toy MapReduce library `mapreduce.py` in `~/git/50043-labs/lab10/ex2/` with some example code `wordcount.py`.

Complete the following

```
from mapreduce import *

def read_db(filename):
    db = []
    with open(filename, 'r') as f:
        for l in f:
            db.append(l)
    f.close()
    return db

test_db = read_db("./data/price.csv")

# TODO: FIXME
# the result should contain a list of suppliers,
# with the average sale price for all items by this supplier.
result = []

# print the results
for supplier,avg_price in result:
    print(supplier, avg_price)
```

It's ok if you can't start straight from the toy MapReduce library. In that case you may want to start with a version using for loops and dictionaries. Then from there you can start to replace loops with map, reduce and other combinators found in the toy MapReduce library.

mini discussion

Besides `reduceByKey2` itself, name one operation can only be defined using `reduceByKey2` but not `reduceByKey`. Explain why it can't be implemented using `reduceByKey`.

Relational Algebra and MapReduce

Recall that in Lecture 2, we learned about Relational Algebra in the context of RDBMS. Assuming that we are dealing with tabular (CSV / TSV) data in HDFS and we stick to bag semantics instead of set semantics, can we implement a subset of Relational Algebra using MapReduce?

As a POC, we can use the toy MapReduce library as our MapReduce framework and the product-supplier-price dataset in Exercise 2 as the data.

```
test_db = read_db("./data/price.csv")
priceTable = map(lambda ln:ln.strip().split(','),test_db)
```

- Projection $\Pi_{supplierID}(priceTable)$, can be implemented as

```
def supplierID(cols): return cols[1]
map(supplierID, priceTable)
```

- Selection $\sigma_{price>100}(priceTable)$, can be implemented as

```
def price(cols):return cols[2]
filter(lambda x:price(x) > 100, priceTable)
```

- Aggregation $\gamma^{supplierID}_{avg(price)}(priceTable)$, we have done it in exercise 2.
- What about the join $\bowtie$? Suppose we have another CSV dataset `stockTable` with schema "productID, stockLevel", can we implement `priceTable` $\bowtie_{productID}$ `stockTable`?

Exercise 3:

Assuming that we have enough memory to accomodate one table in the RAM, implement the join operation using the toy MapReduce library.

Exercise 4:

The concept of `map` and `reduce` is applicable even to non-linear data structure.

Ex 4.1 Binary Tree Data

Given the following data structure

```
class Tree:
    def __init__(self,value,left=None,right=None):
        self.value = value
        self.left = left
        self.right = right
    def __str__(self):
        return "{value:%s, left:%s, right:%s}" %
```

```
        (str(self.value), str(self.left), str(self.right))

mytree = Tree(17, Tree(11, Tree(4), Tree(13)), Tree(5, None, Tree(30)))
```

```
>>> str(mytree)
'{value:17, left:{value:11, left:{value:4, left:None, right:None},
 right:{value:13, left:None, right:None}}, right:{value:5, left:None,
 right:{value:30, left:None, right:None}}}'
```

- Define a `tmap(f,t)` which applies `f` to all `value` elements in tree `t`. e.g.

```
>>> str(tmap(lambda x: x + 1, mytree))
'{value:18, left:{value:12, left:{value:5, left:None, right:None},
 right:{value:14, left:None, right:None}}, right:{value:6, left:None,
 right:{value:31, left:None, right:None}}}'
```

- Define a `treduce(f,t,acc)` which aggregates all `value` elements in tree `t` with a binary function `f` and `acc` as the (initial) accumulator, e.g.

```
>>> treduce(lambda x,y:x + y, mytree, 0)
80
```

Ex 4.2 List of List Data

Given the following data

```
myllist = [ ["one", "two", "two", "three", "three", "three"],
            ["four", "four", "four", "four", "five"],
            ["five", "five", "five", "five"] ]
```

- Define a `llmap(f,ll)` function which applies `f` to all elements in the list of lists. e.g.

```
>>> ll1 = llmap(lambda w:1, myllist)
>>> ll1
[[1, 1, 1, 1, 1, 1], [1, 1, 1, 1, 1], [1, 1, 1, 1]]
```

- Define a `llreduce(f, ll, acc)` function which applies `f` to aggregate all alements in the list of lists `ll`, e.g.

```
>>> llreduce(lambda x,y: x + y, ll1, 0)
15
```

Hadoop JVM API

Hadoop's JVM API is the native API. It offers

- Better performance
- Better debugging info
- Compiler and Type checking

Wordcount

The Hadoop MapReduce WordCount job is decribed as follows in JVM API

```java
import java.io.IOException;
import java.util.StringTokenizer;

import org.apache.hadoop.conf.Configuration;
import org.apache.hadoop.fs.Path;
import org.apache.hadoop.io.IntWritable;
import org.apache.hadoop.io.Text;
import org.apache.hadoop.mapreduce.Job;
import org.apache.hadoop.mapreduce.Mapper;
import org.apache.hadoop.mapreduce.Reducer;
import org.apache.hadoop.mapreduce.lib.input.FileInputFormat;
import org.apache.hadoop.mapreduce.lib.output.FileOutputFormat;

public class WordCount {

  public static class TokenizerMapper
       extends Mapper<Object, Text, Text, IntWritable>{

    private final static IntWritable one = new IntWritable(1);
    private Text word = new Text();

    public void map(Object key, Text value, Context context
                    ) throws IOException, InterruptedException {
      StringTokenizer itr = new StringTokenizer(value.toString());
      while (itr.hasMoreTokens()) {
        word.set(itr.nextToken());
        context.write(word, one);
      }
    }
  }

  public static class IntSumReducer
       extends Reducer<Text,IntWritable,Text,IntWritable> {
    private IntWritable result = new IntWritable();

    public void reduce(Text key, Iterable<IntWritable> values,
                       Context context
                       ) throws IOException, InterruptedException {
      int sum = 0;
      for (IntWritable val : values) {
        sum += val.get();
      }
```

```java
      result.set(sum);
      context.write(key, result);
    }
  }

  public static void main(String[] args) throws Exception {
    Configuration conf = new Configuration();
    Job job = Job.getInstance(conf, "word count");
    job.setJarByClass(WordCount.class);
    job.setMapperClass(TokenizerMapper.class);
    job.setCombinerClass(IntSumReducer.class);
    job.setReducerClass(IntSumReducer.class);
    job.setOutputKeyClass(Text.class);
    job.setOutputValueClass(IntWritable.class);
    FileInputFormat.addInputPath(job, new Path(args[0]));
    FileOutputFormat.setOutputPath(job, new Path(args[1]));
    System.exit(job.waitForCompletion(true) ? 0 : 1);
  }
}
```

In the above example, the `WordCount` class contains two inner classes, `TokenizedMapper` and `IntSumReducer`. The former describes the mapper task and the latter defines the reducer task.

`TokenizedMapper` extends the base class `Mapper<Object, Text, Text, IntWritable>`. The type paraemters denote the types of the input key, input value, output key and output value respectively. `Text` is a serializable version of `String`. `IntWritable` is a serializable version of `Int`. Similar observation applies to the `IntSumReducer`.

In the `main` method, we create a job instance by reading the configuration from the current hadoop cluster. We specify the mapper and the reducer classes as well as the input and output format.

Exercise 5

Build and run WordCount job in JVM API.

Assuming we have some data in the HDFS folder `/input/`

We first install gradle (the Java project manager) via SDKMan

```bash
$ curl -s "https://get.sdkman.io" | bash
$ source "$HOME/.sdkman/bin/sdkman-init.sh"
$ sdk install gradle 4.4.1
```

Gradle needs more memory to run. Let's create a swapfile for it.

```
$ sudo dd if=/dev/zero of=/swapfile bs=1M count=2048
$ sudo mkswap /swapfile
$ sudo chmod 600 /swapfile
$ sudo swapon /swapfile
```

```
$ cd ~/git/50043-labs/lab10/ex5
$ gradle jar
$ hadoop jar build/libs/ex5.jar com.sutd50043.WordCount /input /output
```

Now rewrite the answer from exercise 2 using Java and run it in Hadoop.

Dont't forget to shutdown your hadoop cluster before shutting the VM.

Appendix 1: Optional Exercise - Enabling Yarn to FlintRock Hadoop cluster

Hadoop Python API

Pydoop is an open source library which provides Python API for Hadoop MapReduce and HDFS access.

PyDoop Script Mode

The easiest way to get a Hadoop is to write a python script containing a mapper and a reducer.

For instance, we have a `wordcount.py` as follows

```python
def mapper(key, text, writer):
    for word in text.split():
        writer.emit(word, "1")

def reducer(word, icounts, writer):
    writer.emit(word, sum(map(int, icounts)))
```

To run it

```
$ pydoop script wordcount.py /input /output
```

PyDoop Submit Mode

Besides script mode, Pydoop supports *submit* mode

For instance, the word count example can be written as follows,

```python
import pydoop.mapreduce.api as api
import pydoop.mapreduce.pipes as pipes

class Mapper(api.Mapper):
    def map(self, context):
```

```python
        for w in context.value.split():
            context.emit(w, 1)

class Reducer(api.Reducer):
    def reduce(self, context):
        context.emit(context.key, sum(context.values))

FACTORY = pipes.Factory(Mapper, reducer_class=Reducer)

def main():
    pipes.run_task(FACTORY)

if __name__ == "__main__":
    main()
```

`Factory` is an abstraction for a mapreduce job.

Suppose the above Python code is saved in a file named `wc.py`. we can submit it as a job,

```
pydoop submit --upload-file-to-cache wc.py wc input output
```

PyDoop HDFS api

PyDoop provides access to HDFS in Python. For details refer to the online documentation.

`https://crs4.github.io/pydoop/index.html`

Setup PyDoop in your Hadoop cluster

Prerequesite: You have setup your hadoop-spark cluster using flintrock.

By default, the Hadoop cluster produced by FlintRock does not enable Yarn. Jobs are executed as stand-alone mode. PyDoop cannot run in stand-alone mode. To enable YARN on a FlintRock Hadoop cluster, requires more work. Some of the following steps were adopted from `https://github.com/nchammas/flintrock/issues/175`.

1. Check out the script `setup_pydoop.sh` and configuration files `yarn-site.xml` and `mapred-site.xml` from the `~/git/50043_labs/lab10/` folder.

2. Edit the `yarn-site.xml` by replacing `<private ip of master note>` with the appropriate value

```xml
<configuration>

    <property>
        <name>yarn.resourcemanager.hostname</name>
```

```
        <value><private ip of master note></value>
    </property>
    <property>
        <name>yarn.log-aggregation-enable</name>
        <value>true</value>
    </property>

</configuration>
```

3. Run the following

```
$ flintrock copy-file my-test-cluster setup-pydoop.sh /home/ec2-user/
$ flintrock run-command my-test-cluster bash /home/ec2-user/setup-pydoop.sh
$ flintrock copy-file  my-test-cluster mapred-site.xml /home/ec2-user/hadoop/conf/
$ flintrock copy-file my-test-cluster yarn-site.xml ./hadoop/conf/
$ flintrock copy-file my-test-cluster enable-yarn.sh ./
$ flintrock run-command my-test-cluster 'sh ~/enable-yarn.sh'
```

4. Login to the master node

```
$ /home/ec2-user/hadoop/sbin/stop-all.sh
$ home/ec2-user/hadoop/sbin/start-all.sh
```

For some reason, the above scripts can't be run via flintrock

Exercise 6

Continue with the problem statement from exercise 2, solve the problem using Pydoop.

You may want to use the given script `generate.py` found in `~/git/50043_lab/lab10/ex6/` to generate data. The usage is as follow

```
$ python3 generate.py <number_of_records> <file_name>
```

Then you may upload the data to HDFS.

Hints

1. The answer to exercise 6 is a slight modification of the answer to exercise 2.
2. If you are using Python 3, the second arg of the reducer is a generator, not a list.

Appendix 2: Optional Exercise - Setting up Hadoop Cluster Manually

Let's setup a multi node hadoop cluster manually.

Step 1: Preparation

Assuming we are using AWS EC2, provision 4 Linux servers, (you can choose to have more). It is recommended to have the following configuration for each node

- Ubuntu 18.04 LTS
- t2.xlarge
- disk space 32GB +
- they must be in the same region, same subnet
- port 22 must be open

For instance, we name the 4 nodes as follows,

- fury (namenode with IP 172.20.129.147)
- ironman (datanode1 with IP 172.20.170.15)
- capt (datanode2 with IP 172.20.170.16)
- hulk (datanode3 with IP 172.20.170.17)

The IP addresses are fictional, we need to replace them obtain the actual ones

Create a common user, e.g. `hadoop` for all the nodes.

Step 2: Setup the hostname

In this section, we illustrate on how to setup the host names. The objective of setting up the host names is to ensure that nodes in the cluster have a common naming convention for inter host communication. It is recommended to use fully qualified domain names (FQDNs). We do not need to register these names with DNS nor setup a DNS server for now.

- com.avg.fury
- com.avg.ironman
- com.avg.capt
- com.avg.hulk

Edit the file `/etc/hosts` in all nodes in the cluster according to the following,

```
127.0.0.1       localhost

172.20.129.147  com.avg.fury
172.20.170.15   com.avg.ironman
172.20.170.16   com.avg.capt
172.20.170.17  com.avg.hulk

# The following lines are desirable for IPv6 capable hosts
::1     ip6-localhost ip6-loopback
fe00::0 ip6-localnet
ff00::0 ip6-mcastprefix
ff02::1 ip6-allnodes
ff02::2 ip6-allrouters
```

You might want to update the `/etc/hostname` individually for the ease of identification during ssh sessions.

For AWS EC2, you are recommended to use the internal IPs as it costs nothing for transfer data internally and they will not be changed as frequently as the public IPs.

Step 3 : Setting up sudoers

To allow our hadoop user gain the super user right without password, we run the following in all the nodes in the cluster.

Run the following to all nodes in the cluster

```
$ sudo sh -c 'echo "hadoop ALL=(ALL) NOPASSWD:ALL" >> /etc/sudoers.d/90-hadoop'
```

Step 4 : Change the Swappiness

To reduce the rate of writing to the swap files, we run the following in all nodes in the cluster.

```
$ sudo sysctl vm.swappiness=10
```

`swappiness`, in range of (0-100) is a system parameter for linux which sets the threshold of how frequent the system should push pages from memory to the swap file (virtual memory).

Step 5 : Setup SSH keys

In this section, we generate SSH key pairs on all the member nodes in the cluster. We will illustrate how to distribute the key pairs so that the user hadoop can ssh from the name node to all the others nodes without keying in the password.

Step 5.1: Perform the following steps on the namenode (at least)

1. install ssh

```
$ sudo apt-get install -y ssh
```

2. generate the public and private key pairs

```
$ ssh-keygen
```

3. Press `Enter` to use all the default setting. For instance,

```
Generating public/private rsa key pair.
Enter file in which to save the key (/home/hadoop/.ssh/id_rsa):
Enter passphrase (empty for no passphrase):
Enter same passphrase again:
Your identification has been saved in /home/hadoop/.ssh/id_rsa.
Your public key has been saved in /home/hadoop/.ssh/id_rsa.pub.
```

```
The key fingerprint is:
b3:e1:c7:56:b4:ec:4d:a7:5c:ec:f3:71:f2:11:ee:a3 hadoop@com.avg.fury
The key's randomart image is:
+--[ RSA 2048]----+
|                 |
|                 |
|             .   |
|            o . .|
|         S   + ..+|
|        . = o +.=.|
|         o + . ==o|
|          o    .+*|
|              E..+|
+-----------------+
```

Step 5.2: Copy the public key from the name node to worker nodes

Perform the following in the name node only.

```
$ ssh-copy-id hadoop@com.avg.fury
$ ssh-copy-id hadoop@com.avg.ironman
$ ssh-copy-id hadoop@com.avg.capt
$ ssh-copy-id hadoop@com.avg.hulk
```

Hold on a second, the above would work the nodes allow password based ssh login. However password based ssh is disabled on EC2 by default.

Walkaround I To get around that, one way is to modify the line in `/etc/ssh/sshd_config` file on all the nodes to the following

From

```
PasswordAuthentication no
```

to

```
PasswordAuthentication yes
```

Restart the sshd sevice after the configuration change

```
$ sudo service sshd restart
```

Walkaround II A second way is to use our client machine which has ssh access to all 4 nodes as a "routing" mechanism.

For instance, we use the following command to copy the ssh public key from the hadoop user in the namenode and append it to the `authorized_keys` file in the hadoop ser in the datanode.

```
ssh ubuntu@namenode_public_ip -i .ssh/your_aws.pem \
"sudo cat /home/hadoop/.ssh/id_rsa.pub" \
```

```
| ssh ubuntu@datanode_public_ip -i .ssh/your_aws.pem \
"sudo cat - | sudo tee -a /home/hadoop/.ssh/authorized_keys"
```

Repeat the above for all the data nodes.

Back to the name node with `hadoop` login

```
$  cat .ssh/id_rsa.pub >> .ssh/authorized_keys
```

Step 5.3: Test it

To test it, we can try to ssh from the name node to one of the worker node (or all of them).

```
$ ssh hadoop@com.avg.capt
```

It should allow us to login without using a password

Step 6: Setup Java

In this section, we will setup Java compiler and runtime system for the rest of the components. In all the nodes, execute the following

```
$ sudo apt-get update
$ sudo apt-get install -y openjdk-8-jdk
```

Run the following to do a test

```
$ javac -version
javac 1.8.0_256
```

The subversion `(_256)` is not important.

Step 7: Setup Hadoop

In this Section, we will setup and configure Hadoop in our cluster. First login to the name node (fury) as the user `hadoop` and execute the following

```
$ mkdir download
$ cd download
$ wget https://downloads.apache.org/hadoop/common/hadoop-3.3.0/hadoop-3.3.0.tar.gz
```

Assuming we are still in name node (fury)

```
$ cd ~/download
$ tar zxvf hadoop-3.3.0.tar.gz
# update the JAVA_HOME
$ export JH="\/usr\/lib\/jvm\/java-8-openjdk-amd64"
$ sed -i "s/# export JAVA_HOME=.*/export\ JAVA_HOME=${JH}/g" \
hadoop-3.3.0/etc/hadoop/hadoop-env.sh
```

```
$ MASTER=com.avg.fury
$ WORKERS="com.avg.ironman com.avg.capt com.avg.hulk"

# configure core-site.xml
$ echo -e "<?xml version=\"1.0\"?>
<?xml-stylesheet type=\"text/xsl\" href=\"configuration.xsl\"?>
<\x21-- Put site-specific property overrides in this file. -->
<configuration>
 <property>
   <name>fs.defaultFS</name>
   <value>hdfs://${MASTER}:9000</value>
  </property>
 </configuration>
" > hadoop-3.3.0/etc/hadoop/core-site.xml


# configure hdfs-site.xml
$ echo -e "<?xml version=\"1.0\"?>
<?xml-stylesheet type=\"text/xsl\" href=\"configuration.xsl\"?>
<\x21-- Put site-specific property overrides in this file. -->
<configuration>
 <property>
   <name>dfs.replication</name>
   <value>3</value>
  </property>
  <property>
   <name>dfs.namenode.name.dir</name>
   <value>file:/mnt/hadoop/namenode</value>
  </property>
  <property>
   <name>dfs.datanode.data.dir</name>
   <value>file:/mnt/hadoop/datanode</value>
  </property>
 </configuration>
" > hadoop-3.3.0/etc/hadoop/hdfs-site.xml


# configure yarn-site.xml
$ echo -e "<?xml version=\"1.0\"?>
<?xml-stylesheet type=\"text/xsl\" href=\"configuration.xsl\"?>
<\x21-- Put site-specific property overrides in this file. -->
<configuration>
 <\x21-- Site specific YARN configuration properties -->
 <property>
  <name>yarn.nodemanager.aux-services</name>
  <value>mapreduce_shuffle</value>
```

```
  <description>Tell NodeManagers that there will be an auxiliary
  service called mapreduce.shuffle
  that they need to implement
  </description>
 </property>
 <property>
  <name>yarn.nodemanager.aux-services.mapreduce_shuffle.class</name>
  <value>org.apache.hadoop.mapred.ShuffleHandler</value>
  <description>A class name as a means to implement the service
  </description>
 </property>
 <property>
  <name>yarn.resourcemanager.hostname</name>
  <value>${MASTER}</value>
 </property>
</configuration>
" > hadoop-3.3.0/etc/hadoop/yarn-site.xml

# configure mapred-site.xml
$ echo -e "<?xml version=\"1.0\"?>
<?xml-stylesheet type=\"text/xsl\" href=\"configuration.xsl\"?>
<\x21-- Put site-specific property overrides in this file. -->
<configuration>
 <\x21-- Site specific YARN configuration properties -->
 <property>
 <name>mapreduce.framework.name</name>
 <value>yarn</value>
 <description>Use yarn to tell MapReduce that it will run as a YARN application
 </description>
 </property>
 <property>
  <name>yarn.app.mapreduce.am.env</name>
  <value>HADOOP_MAPRED_HOME=/opt/hadoop-3.3.0/</value>
 </property>
 <property>
  <name>mapreduce.map.env</name>
  <value>HADOOP_MAPRED_HOME=/opt/hadoop-3.3.0/</value>
 </property>
 <property>
  <name>mapreduce.reduce.env</name>
  <value>HADOOP_MAPRED_HOME=/opt/hadoop-3.3.0/</value>
 </property>
</configuration>
" > hadoop-3.3.0/etc/hadoop/mapred-site.xml

$ rm hadoop-3.3.0/etc/hadoop/workers
```

```
$ for ip in ${WORKERS}; do echo -e "${ip}" >> hadoop-3.3.0/etc/hadoop/workers ; done
```

Step 8: Distributing the configured library

Assuming we are still in name node (fury) working directory ~/download

```
$ tar czvf hadoop-3.3.0.tgz hadoop-3.3.0
$ for h in $WORKERS ; do
    scp hadoop-3.3.0.tgz $h:.;
done;

$ cp hadoop-3.3.0.tgz ~/
$ cd
```

Step 9: Installation

For every node in the cluster,

```
$ tar zxvf hadoop-3.3.0.tgz
$ sudo mv hadoop-3.3.0 /opt/
```

For all the data nodes,

```
$ sudo mkdir -p /mnt/hadoop/datanode/
$ sudo chown -R hadoop:hadoop /mnt/hadoop/datanode/
```

For on the name node (fury)

```
$ sudo mkdir -p /mnt/hadoop/namenode/hadoop-${USER}
$ sudo chown -R hadoop:hadoop /mnt/hadoop/namenode
$ /opt/hadoop-3.3.0/bin/hdfs namenode -format
```

When it prompts for

```
Re-format filesystem in Storage Directory root= /mnt/hadoop/namenode;
location= null ?
(Y or N)
```

Press `y` and press `Enter`.

Step 10: Let's start Hadoop

On the name node (fury)

```
$ /opt/hadoop-3.3.0/sbin/start-dfs.sh && /opt/hadoop-3.3.0/sbin/start-yarn.sh
```

To check whether the cluster is working, we visit `http://172.20.129.147:50070/`

or run

```
$  /opt/hadoop-3.3.0/bin/hdfs dfsadmin -report
```

You may consider adding `/opt/hadoop-3.3.0/bin` and `/opt/hadoop-3.3.0/sbin` to the `PATH` environment variable to save us from typing the fullpath.

You may want to re-run the exercises 1 and 2 on the multi-node cluster. Don't forget to shut it down gracefully.

Appendix 3: (Optional Exercise) Setup a Multi-node Spark cluster

Preparation

1. Make sure you have completed multi-node Hadoop Cluster Setup from Appendix 2.
2. Create snapshots for all the nodes in the your hadoop cluster. You might need to restore the snapshot in case of issues.

Step 1: Download

1. Login to the namenode (fury) using ssh
2. Login as user `hadoop`
3. change to the directory `~/download`

```
$ cd download
```

4. Download the latest Spark v3, at the time when this lab sheet was written, the latest is Spark v3.1.2

```
$ wget https://downloads.apache.org/spark/spark-3.1.2/spark-3.1.2-bin-hadoop3.2.tgz
```

5. Extract the archive

```
$ tar zxvf spark-3.1.2-bin-hadoop3.2.tgz
```

Step 2: Configuration

1. configure `spark-env.sh`, assuming we are in `~/download` as

```
$ cp spark-3.1.2-bin-hadoop3.2/conf/spark-env.sh.template \
  spark-3.1.2-bin-hadoop3.2/conf/spark-env.sh
$ echo -e "
export JAVA_HOME=/usr/lib/jvm/java-8-openjdk-amd64
export HADOOP_HOME=/opt/hadoop-3.3.0
export SPARK_HOME=/opt/spark-3.1.2-bin-hadoop3.2
export SPARK_CONF_DIR=\${SPARK_HOME}/conf
export HADOOP_CONF_DIR=\${HADOOP_HOME}/etc/hadoop
export YARN_CONF_DIR=\${HADOOP_HOME}/etc/hadoop
export SPARK_EXECUTOR_CORES=1
```

```
export SPARK_EXECUTOR_MEMORY=2G
export SPARK_DRIVER_MEMORY=1G
export PYSPARK_PYTHON=python3
" >> spark-3.1.2-bin-hadoop3.2/conf/spark-env.sh
```

2. configure `slaves`

```
$ WORKERS="com.avg.ironman com.avg.capt com.avg.hulk"

$ for ip in ${WORKERS};
  do echo -e "${ip}" >> spark-3.1.2-bin-hadoop3.2/conf/slaves;
  done
```

Step 3: Deployment

1. zip up the configured spark folder, and deploy them

```
$ tar czvf spark-3.1.2-bin-hadoop3.2.tgz spark-3.0.1-bin-hadoop3.2/
$ for i in ${WORKERS};
  do scp spark-3.1.2-bin-hadoop3.2.tgz $i:./spark-3.1.2-bin-hadoop3.2.tgz;
  done
$ mv spark-3.1.2-bin-hadoop3.2.tgz ~/.
```

Step 4: Installation

1. for all the nodes, (including name node and data nodes)

```
$ cd ~
$ tar zxvf spark-3.1.2-bin-hadoop3.2.tgz
$ sudo mv spark-3.1.2-bin-hadoop3.2 /opt/
$ sudo chown -R hadoop:hadoop /opt/spark-3.1.2-bin-hadoop3.2
```

Step 5: Test run

Go back to the namenode

1. Start the Hadoop cluster

```
$ /opt/hadoop-3.3.0/sbin/start-dfs.sh && /opt/hadoop-3.3.0/sbin/start-yarn.sh
```

2. Start the Spark cluster

```
$ /opt/spark-3.1.2-bin-hadoop3.2/sbin/start-all.sh
```

If we run `jps` on the namenode (fury), we should see the following

```
$ jps
15072 SecondaryNameNode
14776 NameNode
15306 ResourceManager
15627 Master
```

```
15743 Jps
```

if we ssh into any of the worker node and execute `jps`, we should see the following

```
$ jps
14994 Worker
14615 DataNode
15145 Jps
14795 NodeManager
```

3. Shutdown the cluster

```
$ /opt/spark-3.1.2-bin-hadoop3.2/sbin/stop-all.sh
$ /opt/hadoop-3.3.0/sbin/stop-yarn.sh && /opt/hadoop-3.3.0/sbin/stop-dfs.sh
```

4. Shutdown

```
$ /opt/zeppelin-0.10.0-preview2-bin-all/bin/zeppelin-daemon.sh stop
$ /opt/spark-3.0.1-bin-hadoop3.2/sbin/stop-all.sh
$ /opt/hadoop-3.3.0/sbin/stop-yarn.sh && /opt/hadoop-3.3.0/sbin/stop-dfs.sh
```

(Optional) Exercise: Enable Hadoop Erasure Coding Policy

Hadoop EC is disabled by default. If you want to enable it, you have to enable the policy on per HDFS directory level. For more information, refer to the following articles.

1. https://docs.cloudera.com/documentation/enterprise/latest/topics/admin_hdfs_deployec.html
2. https://hadoop.apache.org/docs/r3.0.0/hadoop-project-dist/hadoop-hdfs/HDFSErasureCoding.html
3. https://stackoverflow.com/a/51588284