PART 1. LARGE SCALE DATA ANALYSIS USING MAPREDUCE

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Today’s topics
• FAQs
• Anatomy of a MapReduce

Job submission process in Classic framework
• Asks the jobtracker for a new jobID
  - Step 2
• Checks the output specification of the job
• Computes the input splits for the job
• Copies the resources to the jobtracker’s filesystem in a directory named after the jobID
  - The job JAR file, the configuration file, and the computed input splits
• Tells the jobtracker that the job is ready for execution by calling submitJob() on JobTracker
  - Step 4

Task assignment
• Jobtracker select a job to run
  - Default algorithm
  - Based on the priority list of jobs
• Tasktrackers have a fixed number of slots for map tasks and reduce tasks
  - These are set independently
  - These are selected based on the number of cores and the memory
  - The default scheduler fills empty map task slots first
    - Before it fills the reduce task slots
    - Scheduling the reduce task does not need to consider data locality
• Tasktrackers run a simple loop that periodically sends heartbeat method calls to the jobtracker
Task execution

- Tasktracker
  - Copies the job jar to the tasktracker’s file system
  - Any files needed from the distributed cache to the local file system
  - Creates a local working directory
  - Creates instance of TaskRunner

- TaskRunner
  - Launches a new Java Virtual Machine to run each task
  - Any failed map or reduce does not affect the tasktracker

Streaming and Pipe

- Runs special map and reduce tasks
  - To launch the user supplied executable
  - To communicate with it
  - Streaming task communicates with the process using standard input and output streams

```
$HADOOP_HOME/bin/hadoop jar $HADOOP_HOME/hadoop-streaming.jar
    -input myInputDirs
    -output myOutputDir
    -mapper /bin/cat
    -reducer /bin/wc
```

Hadoop Pipes task

- Allows C++ application code to be used in MapReduce program through Pipes
  - Passes the C++ process a port number in its environment via socket
    - On startup, the C++ process establish a persistent socket connection back to the parent Java Pipes task

Progress and status updates

- A Job and each of its tasks have a status
  - State of the job or task
    - E.g. running, successfully complete, failed
  - The progress of maps and reduces
  - The values of the job’s counters
  - A status message or description
Progress and status updates [2/4]

- Progress of a task
  - The proportion of the task completed
- Map task
  - The proportion of the input that has been processed
- Reduce task
  - Divides the total progress into 3 parts (copy/sort/reduce)
  - If the task has run the reducer on half its input
  - \( \frac{1}{3} \text{ (copy)} + \frac{1}{3} \text{ (sort)} + \frac{1}{2} \text{ (reduce phase)} = \frac{5}{6} \)

Progress and status updates [3/4]

- Tasks
  - have a set of counters
  - Count various events at the task run
  - e.g. the number of map output records written
  - If a task reports progress
    - It sets a flag to indicate that the status change should be sent to the tasktracker
    - Checked every 3 seconds
- Tasktracker
  - Tasks notify the current task status to the tasktracker
    - If the flag is set
    - Tasktracker sends heartbeats to the jobtracker every 5 seconds (minimum)

Progress and status updates [2/3]

- Jobtracker
  - Combines updates to produce a global view
- Job
  - Receives the latest status by polling the jobtracker every second
  - Prints job statistics and counters to the console

YARN Framework

YARN (MapReduce 2)

- To provide the scalability to MapReduce
  - Splitting responsibility of the jobtracker
    - Scheduling
    - Task progress monitoring
- MapReduce is one type of YARN application

YARN (MapReduce 2)

- Resource manager
  - Manages the use of resources across the cluster
- Node manager
  - Launches and monitors the compute containers on machines in the cluster
- Application master
  - Manages the lifecycle of applications running on the cluster
    - Application master negotiates with the resource manager for cluster resources
    - Number of container and certain memory limit
    - Node managers oversee containers not to use more resources than allocated
A MapReduce job using YARN

Job Initialization

- submitApplication()
  - Resource manager will hands off the request to the scheduler
  - The scheduler allocates a container
  - The resource manager then launches the application master’s process in the container

Job Initialization [1/3]

- Application master
  - Plans job execution
    - If the jobs is small, Application Master will run the tasks in the same JVM as itself
  - Uber task
    - The overhead of allocating and running tasks in new container outweighs the gain to be had it running them in parallel, compared to running them sequentially on one node

What is a small job?
A small job is one that has less than 10 mappers, only one reducer, and an input size that is less than the size of one HDFS block

Job Initialization [2/3]

- Application master
  - The application master for MapReduce jobs
    - MRAppMaster
    - Initializes the job by creating bookkeeping objects
    - To keep track of the job’s progress
  - Retrieves the input splits
  - Creates a map task object for each split
  - Creates reduce task object
    - Mapreduce.job.reduces property

Job Initialization [3/3]

Task assignment
Task assignment [1/2]

- Application Master requests container for all the map and reduce tasks in the job
  - From the resource manager (Step 8)
- All the requests includes information about each map tasks’ locality
  - Host and corresponding racks that the input split resides on
- Scheduler attempts to place tasks on data-local nodes in the ideal case
  - If it is not possible, the scheduler prefers rack-local placement
    - Job is running on a node in the same rack

Task assignment [2/2]

- Requests specify required memory
  - 1024MB (by default)
  - This is configurable
    - mapreduce.map.memory.mb
    - mapreduce.reduce.memory.mb
- In YARN, resources are managed more fine-grained
  - Applications may request a memory capability that is anywhere between the minimum allocation and a maximum allocation
    - yarn.scheduler.capacity.minimum-allocation-mb
      - Default minimum: 1024MB
    - yarn.scheduler.capacity.maximum-allocation-mb
      - Default maximum: 10240 MB
  - Tasks can request any memory allocation between 1 and 10GB (default) in multiple of 1GB
    - mapreduce.map.memory.mb
    - mapreduce.reduce.memory.mb

Task execution

Task execution

- Application master starts the container by contacting node manager
  - The task is executed by YarnChild
  - YarnChild runs in a dedicated JVM

Progress and status updates

- Task reports its progress and status back to its application master
  - Every 3 seconds over the umbilical interface
- The client polls the application master every second
  - mapreduce.client.progressmonitor.pollinterval

Failures
Failures in Classic MapReduce
- The child task fails
  - Runtime exception from the user code
  - The child JVM reports the error back to its parent before it exits
  - Written in the user logs
  - Tasktracker marks the task attempt as failed
  - Frees a slot to run another task
  - Sudden exit of the child JVM
  - Tasktracker notices that the process has exited and marks the attempt as failed
- Hanging tasks
  - If there is no progress update for a while
  - Mark the task as failed
  - Timeout period is normally 10 minutes
  - mapred.task.timeout

Jobtracker failure in Classic MR
- The most serious failure mode
- Hadoop has no mechanism for dealing with jobtracker failure
  - Single point of failure
  - All running jobs fail
- After restarting a jobtracker
  - Job should be resubmitted
- This is improved with YARN

Tasktracker failure in Classic MR
- Tasktracker stops sending heartbeats
  - Jobtracker will notice if it hasn’t received one for 10 minutes (configurable)
  - Remove it from the pool of tasktracker
- Jobtracker arranges tasks including the completed jobs
  - Because the output may not be accessible
- Tasktracker can also be blacklisted if more than four tasks from the same job fail (set by mapred.max.tracker.failures)
  - Blocklisted tasktrackers are not assigned tasks.
  - Until faults expire

Application master failure in YARN
- No heartbeats to the resource manager from the application master
  - The resource manager will detect the failure and start a new instance of the master running in a new container
  - All tasks will be rerun (default)
  - Recovery can be enabled
- Client will access resource manager to get the new address of the application master

Node manager failure in YARN
- Resource manager will stop getting heartbeats
  - Remove the failed node manager from the pool of available nodes
- Any task or application master running on the failed node manager will be recovered
Resource manager failure

- After a crash and a new resource manager instance is brought up (by administrator)
  - It recovers from the saved state
    - Check points saved in the persistent storage
    - Non-completed jobs are included

Combiner functions

Hadoop Combiner

- Minimizes the data transferred between map and reduce tasks
- Users can specify a combiner function
  - To be run on the map output
  - To replace the map output with the combiner output
- Hadoop does not guarantee how many times it will call combiner for a particular map output record

Example: Find the maximum temperature

- First map produces
  - (1950, 0)
  - (1950, 20)
  - (1950, 10) → (1950, 20)
- Second map produces
  - (1950, 25)
  - (1950, 15) → (1950, 25)
- Input to the reduce function
  - (1950, {0, 20, 10, 25, 15})
- Output
  - (1950, 25)

If a combiner finds the maximum temperature for each map output:

- First map produces
  - (1950, 0)
  - (1950, 20)
  - (1950, 10) → (1950, 20)
- Second map produces
  - (1950, 25)
  - (1950, 15) → (1950, 25)
- Input to the reduce function
  - (1950, {0, 20, 10, 25, 15}) → (1950, {20, 25})
- Output

Can we use a combiner function for finding mean value?
**Shuffle and Sort**

- **Can combiners replace reducers?**
  - No. Combiner is run only on the map output.

**Specifying a combiner function**

```java
public class MaxTemperatureWithCombiner{
    ...
    job.setMapClass(MaxTemperatureMapper.class);
    job.setCombinerClass(MaxTemperatureReducer.class);
    job.setReducerClass(MaxTemperatureReducer.class);
    ...
}
```

- **Sort**
  - MapReduce makes the guarantee that the input to every reducer is sorted by key.

- **Shuffle**
  - MapReduce transfers the map outputs to the reducers as inputs.
Shuffle and sort

- Each map task has a circular memory buffer
  - For output
    - 100MB by default
    - io.sort.mb
  - When the contents of the buffer reaches the threshold, a background thread starts spill the contents to disk
    - Default 0.80
    - Spurs are written in round-robin-fashion to the local directory
      - mapred.local.dir

Partitioning

- Before the data is written to the local disk, data is divided into partitions corresponding to the reducers
- The background thread performs an in-memory sort by key
  - Within each partition
- Each time the memory buffer reaches the spill threshold, a new spill file is created
  - There can be several spill files after the last output record is written
  - The spill files are merged into a single partitioned and sorted output file

Copy phase

- The reduce task needs the map output from several map tasks across the cluster
- Copy phase
  - The reduce task starts copying their outputs as soon as each completes
    - The map tasks may finish at different times
    - Merges them into larger and sorted files
    - Decompresses the compressed files

Sort phase

- Sort phase
  - All of the map outputs should be moved and copied to the reduce task
  - Merging and sorting the map outputs
  - Sorting is done in rounds
    - If there are 50 map outputs and the merge factor was 10
      - 5 intermediate files
      - Merging intermediate files: additional round
      - 6 rounds will be required
      - Final round
        - A mixture of in-memory and on-disk segments
        - Directly feeds the reduce function
          - Without writes a single sorted file to disk

Output file

- Combiner is run
- Output files from map can be compressed
- The output file’s partitions are made available to the reducers over HTTP