Big Data Project Report

Shenwei Liao, Anthony Ou, Jacqueline Terlaan
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1 Introduction to Cassandra

1.1 What is NoSQL?

NoSQL is a term that describes any database system which does not strictly conform to the relational database model. We may have any one of the following:

- Does not meet all "ACID" properties.
- May store data in a fashion other than a strictly relational set of tables.

1.2 Why NoSQL?

- We have some BIG data to deal with (several TB), and growing!
- Big Data implies distribution;
- Distribution implies CAP theorem;
- CAP theorem implies compromises!

1.3 What is Apache Project's Cassandra?

Apache Cassandra is an open-source NoSQL DBMS based on a column-oriented data model. Features:

- Available, Partition-tolerant
- Eventually consistent
- High scalability
- "Schemaless" (implicit schema)
- Has its own query language: Apache cql
- Data compaction

1.4 Why Cassandra?

- Partition-tolerant (essential for clustered systems).
- Available: mirrors "real-world" constraints on call-detail record systems.
- Eventual consistency is an acceptable compromise; we are not running a mission-critical system (like a bank), and most of our data insertion is similar to logging data.
- Cassandra is especially well-suited to storing logs.
- Widely used and relatively bug-free, especially for such "new" software.
- Handles map-reduce and low-level details of storage process for nodes, as well as performing maintenance (as specified by DB admin), such as compaction.
- Very low chance of data loss (except if the DBA makes a mistake), even when upgrading Cassandra.

2 Goals and Objectives

- To successfully implement a distributed database system which will reliably store at least 16TB of random data consisting of random numbers and strings organized into large tables with many columns (attributes).
- To distribute the data in the above tables across 8 "nodes" (servers), which form our "cluster".
- To generate additional tables distributed throughout the cluster to be optimally configured for the queries to meet their own requirements (see below).
- To query the above tables such that all of the following requirements are met by five queries.
  1. Four of five queries must retrieve data across from all of the distributed nodes.
  2. At least one of the queries must contain at least ten atomic conditions (formulas) in the WHERE clause.
  3. At least two of the queries must utilize both the GROUP BY and ORDER BY clauses. Since Cassandra does not yet support GROUP BY aggregation, the same functionality must be acheived in another way.
  4. At least three of the five queries must be range queries which specify an upper and lower bound on some ordered attribute that is used for the purposes of querying.

5. None of the five queries can be trivial. That is, there can be no simple key searches or anything that is of little practical interest for measuring how a database system can deal with computationally expensive requests.

- To record the execution time of each query.

3 Methodology, Tools and Equipment Used

8 server instances were used, each with 32GB virtual memory and 1TB secondary storage

4 Implementation

5 Shell Script

A shell script was written to wrap all functionality of the OLAP project, including server setup for all nodes, table creation and population and executing the queries. To run it, cd into the directory containing group3.sh, and call sh group3.sh, and follow the prompts interactively.

5.1 Configuration Changes

Many different aspects of Cassandra cluster and the table were tuned so that we can achieve a high write availability and high performance for generating a randomly generated dataset. Here are some of the more notable configuration changes that we applied:

- Cluster-wide changes (in cassandra.yaml):

  1. Use of RoundRobinScheduler over NoScheduler. Having a request scheduler allowed for requests to be assigned to nodes faster by the coordinating node, speeding up concurrent reads and writes.
  2. Reducing commit log sync frequency. Writing to the commit log must happen for every transaction, as is necessary for write durability. For the purposes of this project, we can sacrifice some durability to go faster.
  3. Concurrent writes increased.
  4. Memtable flush writers increased. Memtable is the in-memory data structure cassandra uses to hold batched writes.
  5. Disabling automatic backups and snapshots of the keyspace.
  6. Removed the throttling on compaction throughput.

- Table-specific changes:

1. Replication factor set to 3.
2. Durable writes are disabled. The commit log doesn't need to be written to just for table generation. This and the next setting are only off because we are randomly generating data and there isn't such a thing as a wrong random value.
3. Consistency level for inserts was set to 0 for maximum write availability.
4. Compression is disabled.

5.2 Table Schemas

The cdr table follows the assignment specification's schema, with 400 columns. It and 10 column keys, indexed on MONTH_DAY and MOBILE_ID_TYPE. QUERY3 shows the performance The role of the last two tables is to make the substitute aggregate queries both possible (as Cassandra has no explicit support for GROUP BY aggregation) and efficient (preprocessing data to be optimal for queries).

1. "CDR" The large 400 column table (column family) with 10 column keys and 1 partition key. This table is
2. "QUERY3" Contains the same data as cdr, but the column keys are ordered MSC_CODE first in an attempt to optimize for range-queries based on values of those column keys.
3. "GROUP_BY_MONTH"
   - Keys are between 1 and 31.
   - Reduces data to facilitate completion of a query equivalent to one in SQL containing 'GROUP BY MONTH_DAY'.
   - Uses 'WITH CLUSTERING ORDER BY(MONTH_DAY)' to facilitate ordering the resulting tables contents by the day of the month.
4. "GROUP_BY_MOBILE_ID_TYPE"
   - Keys are between 0 and 7.
   - Similar to "GROUP_BY_MONTH", but instead the assignment of the rows' locations is based on its insertion number modulo 8.
   - 'CLUSTERING ORDER BY(MOBILE_ID_TYPE)' used to order the rows with respect to MOBILE_ID_TYPE instead of the aggregate group MONTH.

5.3 Programs

We wrote two main Python 2.7 scripts: generate.py and query.py.

generate.py generates data -generate.py -Begins with attempting to establish a connection to the local machine which is part of the cluster. Constructs a connection object called 'session'. -Expects program arguments: -The number of days to generate data for. -Different seed values to prevent collisions of data insertions. -Cassandra has no support for primary keys; collisions result in overwriting data. -Allows for multiple concurrent instances of data generation. -Without seed argument, the script will use its default seed value (typically used for consistency in generation of data) and will drop all of the data before completely regenerating it. -Depending on the results from stat.py (see below), -Asynchronously executes the insertion statements -randword() function -Accepts parameter 'length' (intended to be a positive, nonzero numeric type) -Generates a random lowercase string which is 'length' characters long. -generate() function -Allows for custom ranges on specified columns. -Allows for custom data for specified data types.

-stat.py (mainly for testing) -Reads in the contents of "partial_data_table.txt" and "cdr_table.txt", then counts the number of non-empty columns for each row. -Prints the resulting number (frequency) of items for each column.

5.4 CQL Queries

1. Query 1

```
SELECT count (*) as ten_atomic
FROM cdr
WHERE (MSC_CODE, CITY_ID, SERVICE_NODE_ID,
  RUM_DATA_NUM, DUP_SEQ_NUM, SEIZ_CELL_NUM,
  FLOW_DATA_INC, SUB_HOME_INT_PRI, CON_OHM_NUM,
  SESS_SFC)
> (10000, 10000, 10000, 3, 10000, 1, 10000, 10000,
  10000, 10000)
AND (MSC_CODE, CITY_ID,SERVICE_NODE_ID, RUM_DATA_NUM,
   DUP_SEQ_NUM, SEIZ_CELL_NUM, FLOW_DATA_INC,
  SUB_HOME_INT_PRI, CON_OHM_NUM, SESS_SFC)
< (150000, 150000, 150000, 30, 150000, 6, 150000,
  150000, 150000, 150000)
LIMIT 4000
ALLOW FILTERING;
```

   Cluster-wide range query with 10 atomic formulas. Searches on every column key of the CDR table, as this is the only conceivable way to properly execute a range query. Returns results from each node, satisfies the range query requirement and has 10 atomic formulas.

   Potential uses: many 'outliers' are eliminated from the selection because they are above and below the minimum and maximum values of all the columns respectively, by approximately 10%. In other words, any 'extreme' data points in the CDR table can be ignored for statistical analysis.

Query 1 ('Alternate')

```
SELECT  count (*) as ten_atomic
FROM    cdr_alt
WHERE        (MSC_CODE, CITY_ID, SERVICE_NODE_ID,
  RUM_DATA_NUM, DUP_SEQ_NUM,
SEIZ_CELL_NUM, FLOW_DATA_INC, SUB_HOME_INT_PRI,
  CON_OHM_NUM, SESS_SFC)
> (10000, 10000, 10000, 3, 10000, 1, 10000, 10000,
  10000, 10000)
AND (MSC_CODE ,CITY_ID,SERVICE_NODE_ID, RUM_DATA_NUM,
   DUP_SEQ_NUM, SEIZ_CELL_NUM,
FLOW_DATA_INC, SUB_HOME_INT_PRI ,CON_OHM_NUM,
  SESS_SFC)
< (150000, 150000, 150000, 30, 150000, 6, 150000,
  150000, 150000, 150000)
LIMIT   4000
ALLOW FILTERING;
```

Performs the same cluster-wide query as Query 1, but over the table cdr_alt, which resides in the keyspace 'group3alt' instead of 'group3'.

Potential uses: essentially the same as those for Query 1, but in cases where less information from each row is required to complete the query, or when query execution must be fast.

Query 1 ('Small')

```
SELECT  count (*) as ten_atomic
FROM    smallcdr
WHERE        (MSC_CODE, CITY_ID, SERVICE_NODE_ID,
  RUM_DATA_NUM, DUP_SEQ_NUM,
SEIZ_CELL_NUM, FLOW_DATA_INC, SUB_HOME_INT_PRI,
  CON_OHM_NUM, SESS_SFC)
> (10000, 10000, 10000, 3, 10000, 1, 10000, 10000,
  10000, 10000)
AND (MSC_CODE ,CITY_ID,SERVICE_NODE_ID, RUM_DATA_NUM,
   DUP_SEQ_NUM, SEIZ_CELL_NUM,
FLOW_DATA_INC, SUB_HOME_INT_PRI ,CON_OHM_NUM,
  SESS_SFC)
< (150000, 150000, 150000, 30, 150000, 6, 150000,
  150000, 150000, 150000)
LIMIT   4000
ALLOW FILTERING;
```

Performs the same cluster-wide query as Query 1, but over the table smallcdr, which resides in the keyspace 'group3alt' instead of 'group3'. This query is intended to take less time than the previous query, because fewer columns have to be read into memory in order for the atomic conditions to be evaluated.

Potential uses: essentially the same as those for Query 1, but in cases where less information from each row is required to complete the query, or when query execution must be even faster than Query 1 'Alternate'.

2. Query 2

```
SELECT   count (*) as range_city_id
FROM     cdr
WHERE    CITY_ID > 5000 AND CITY_ID < 90000
LIMIT    40000000
ALLOW FILTERING;
```

Satisfies two requirements: cluster-wide and range query. Retrieves the number of cdr entries for cities with IDs strictly greater than 5000 and strictly less than 90000. Limits the maximal number of elements counted to 40000000. Filtering of results is enabled.

Potential uses: In some cases companies may wish to know how many calls were made in a given range of cities, based on certain CITY_IDs. While those cities may not have any major features in common, this query can be used in cases where only a small sample of all cities is required.

3. Query 3

```
SELECT count(*) as range_DUP_SEQ_NUM
FROM cdr
WHERE (CITY_ID, SERVICE_NODE_ID, RUM_DATA_NUM,
  MONTH_DAY, DUP_SEQ_NUM)
> (0, 0, 0, 0, 30000)
AND
(CITY_ID, SERVICE_NODE_ID, RUM_DATA_NUM, MONTH_DAY,
  DUP_SEQ_NUM)
< (9900000, 9900000, 9900000, 9900000, 300000)
LIMIT 40000000
ALLOW FILTERING;
```

Satsifies two requirements: cluster-wide and range query. Counts the number of cdr entries such that DUP_SEQ_NUM is strictly greater than 30000 and strictly less than 300000. All other atomic conditions in the range query are used to ensure that all of the results fall within a valid range and have no null-valued entries for CITY_ID, SERVICE_NODE_ID, and so on. Because we are trying to query mainly by DUP_SEQ_NUM, we allow filtering on the query in order to speed up execution.

Potential uses: Suppose that statistical data is to be generated for rows in the CDR table for which there are no null-valued entries in the columns

CITY_ID, SERVICE_NODE_ID, RUM_DATA_NUM, MONTH_DAY and DUP_SEQ_NUM, and that DUP_SEQ_NUM falls within a more specific range, that is 30000-300000 (not inclusive). The records could then be analyzed and compared to data for which not all of the attributes above are null, to compare behaviors of callers with different amounts of privacy. This could address questions such as "do people with more privacy make certain types of calls compared to people who do not?".

4. Query 4

```
SELECT MOBILE_ID_TYPE, count
FROM GROUP_BY_MOBILE_ID_TYPE;
```

   Satisfies two requirements: group-by and order-by clause, and cluster-wide query.

   A table of counters aggregates the keys of the MOBILE_ID_TYPE columns with the count of each number of rows in the CDR table with matchine MOBILE_ID_TYPE. Ordering by mobile_id_type is acheived by using a the 'USE CLUSTERING ORDER' clause in the data definition statement in generate.py. We then retrieve GROUP_BY_MOBILE_ID_TYPEs contents and the count of its rows in order of appearance, i.e., the order in which the aggregated rows are sorted.

   MOBILE_ID is the insertion number modulo 8 (or however many nodes), therefore the rows of the MOBILE_ID table are evenly distributed throughout the cluster. This means that we can easily use this query as a check for correctness of the insertion process, as counting the number of rows in the MOBILE_ID_TYPE table on each node should total up to the number of unique items in the database.

   This is an atomic, yet seemingly asynchronous transaction. In other words, only small critical sections of execution are protected for short amounts of time to prevent collisions, but otherwise parallelism is fully exploited (with minimal constraints of Ahmdal's Law) due to the very even distribution of data across all 8 nodes.

   Updating counter columns is done in the following way:

   update group_by_MOBILE_ID_TYPE set count = count + 1 where MOBILE_ID_TYPE = ? and id = 1;

   Potential uses: Most likely for the generation of histograms, but other basic kinds of statistical analysis can be performed on these small MOBILE_ID_TYPE 'buckets' as well, such as calculating arithmetic averages, etc.

5. Query 5

```
SELECT month_day, count
FROM group_by_month;
```

Satisfies the group-by and order-by clause requirements. 'CLUSTERING ORDER BY (MONTH_DAY)' ensures that the GROUP_BY_MONTHs entries are ordered by MONTH_DAY, and GROUP BY functionality is acheived via aggregating the COUNT type column 'COUNTER' into MONTH_DAY groupings. The resulting COUNTER column typically contains values which are quite close in value, but with some differences between them due to the pseudorandom generation and distribution of data.

Potential uses: finding out which day(s) of each month of the year have the highest frequency of entries added to the CDR table can be of use for marketing to customers, optimizing billing rates, and so on. Similar queries can be written for different times of the day, months or weeks of the year, by aggregating CDR row counts into hourly, monthly or weekly groupings for more specific results which could be of use in billing plans with calls at different times incurring different costs.

6 Notes on GROUP BY Queries

Recall that a GROUP BY aggregation is basically a function which gathers rows of data retrieved by a query and groups them together based on an attribute. Since cassandra doesn't support doing GROUP BYs on the fly (a trade off to provide faster column-oriented reads and writes, they are done at insert time, by creating tables with redundant, sorted data.

7 Experimental Results

7.1 Table Population

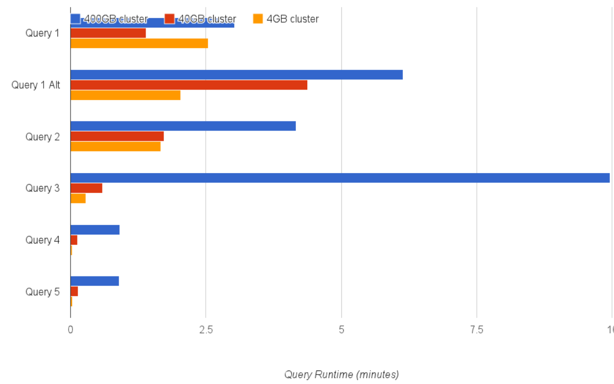
A test cluster was used for some preliminary tests. With the various configuration tweaks described above, insertion of about 300,000 entries — resulting about 40GB of data per node — took 35.5 minutes. The biggest table to generate took two and a half days, generating an average of 380GB per node for a total of just over 3TB of data, out of the 8TB that was available on the cluster. The average speed of insertions to the big table was roughly 15MB/s.

7.2 Query Results

Our queries ran pretty quickly as expected. The GROUP BY queries predictably executed the fastest, as the work was already done at insertion time.

8 Discussion

It was unclear why query 1 performed faster than query 2 even though query 1 has 6 more column keys and 200 fewer resulting rows. Another anomaly was



that removing column keys from query 1 did not improve performance as it was hypothesized to.

9 Conclusions

The most important changes that affected insert speed was using the round robin scheduler to have more nodes handle requests in parallel, and to disable the commit log/durable writes in order to get more disk IO.

The queries on the other hand were pretty straightforward, except for the fact that GROUP BYs have to be done a priori, as Cassandra has no facility to do them on the fly.

10 Notes on Possible Improvements

Some tests were run on query 1 to assess the performance increase of data partitioning. We weren't able to re-generate the large table to see the effects on that, but trials on a smaller table reduced the runtime of query 1 from 2.6 minutes down to 1.0 minute. We haven't tested it on a larger scale, but would say that it has lots of potential to speed up querying, without much hit to our table populating speed.

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