ELEN 4020 Project - Comparison of Parallel Equi-Join using MPI and OpenMP

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Abstract—**Join operations are the most intensive operations in database queries. This project aims to compare two different approaches to performing an equi-join of two very large tables. The first approach is to use OpenMP to perform a merge join and the second is to use MPI to perform a hash join. Each algorithm was tested with varying sized data sets with string key value pairs with different numbers of threads being used. The results show that MPI as a parallelisation method far exceeds the performance the OpenMP method in terms of how fast the join result is generated. This is due to the amount of control that MPI allows when determining how the data is paralellilised.**

I. Introduction

The join operation concerns the combining of two different tuples on a common join attribute [1]. It is important in information systems, in particular the use of databases since the join operation is the most expensive operation in database query operations in terms of time and data-intensity [2]. This project explores two different approaches to performing a join of two very large tables. The purpose of the project are twofold, the primary task is to use parallelism to implement two different join algorithms and the secondary is to compare the algorithms efficiency in joining. The problem is described in Section II and the two different approaches discussed in Sections III and IV. The method of experimentation is outlined in Section V and the results of the experiment are analysed in Section VI. Section VII reviews the project and concludes this document.

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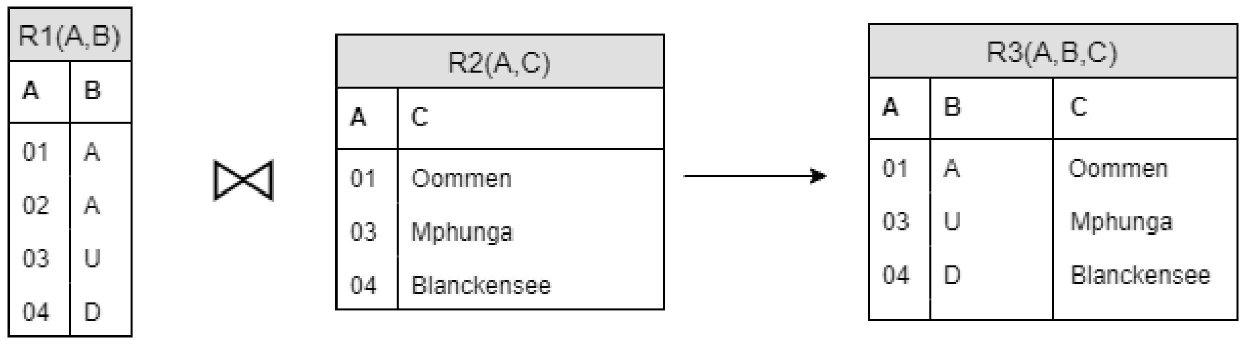
II. Problem Description

The objective of this project is to perform an equi-join of two very large tables. An equi-join is a type of join that uses the equality operator as a basis for the join [3] that is if the join attribute in $R_1(A, B)$ is strictly equal to the join attribute in $R_2(A, C)$ the result of the join is inserted into a third table $R_3(A, B, C)$. An illustrated example can be seen in Figure 1. The join must be



R1(A,B)	
A	B
01	A
02	A
03	U
04	D

$\bowtie$

R2(A,C)	
A	C
01	Oommen
03	Mphunga
04	Blanckensee

$\longrightarrow$

R3(A,B,C)		
A	B	C
01	A	Oommen
03	U	Mphunga
04	D	Blanckensee

Fig. 1. An example of equi-join between two relational tables

done using two different algorithms, one that is based in MPI (Message Passing Interface), and one that uses another high-level parallel programming model. The programming model chosen in this project is OpenMP. The two programs need to be compared with one another in terms of speed-up and scalability when increasing the number of processors and nodes that the program uses. The speed-up comparison is performed by running the two programs with increasing number of processors and the scalability comparison is conducted by increasing the number of nodes the program uses in a cluster. Based on the literature, there are multiple join algorithms. The algorithms chosen by the authors are the hash algorithm and the merge algorithm, which form part of the equi-join family of join algorithms and are widely used [4].

The join algorithms are designed to read data from file of a specific format and to perform the required operations as per specific algorithm. The algorithms read data of the same file in order to be able to compare their performance. The algorithms are both implemented in C++. This allows for accurate comparisons of the algorithm performances and consequently prevents the possible time lags that may arise from the use of different programming languages. C++ was used instead of C due to the authors finding easier to use C++ under the given time constraints. Another reason that why C++ was found more favourable is that is offers more functionality than C and due to its Object Orientated Design (OOD) capabilities and the also due to the fact that the authors are familiar with C++. These algorithms were implemented using parallelism.

III. OpenMP Join Algorithm – Merge-Join

The OpenMP join algorithm being implemented is merge-join also known as sort-merge join [5]. The two table are sorted by join attribute. Then the table are scanned and join attributes are compared to one another. For an equi-join, if the join attribute of one entry is strictly equal to the join attribute of the other table's entry, the entries are joined in the output table [6], [7]. The implemented algorithm assumes that the sorting of the data has already taken place and proceeds to only perform the join algorithm under that assumption.

References [4], [8] take into account possible errors that may occur due to data skew for the merge join algorithm. According to [4], data skew can result in some of the processors being over-utilised and others under-utilised. Reference [4] proposes the use of a divide-and-conquer technique as a solution to handle data skew. Reference [8] approaches the issue of data skew in the merge algorithm by adding an extra scheduling phase. The implemented merge join does not take into account the possibility of data skew and instead relies on OpenMP's computational ability to process certain chunks of data and ability to make numerous threads [9]. This technique was chosen due to the resources available, namely a cluster, and time constraints.

An overview of the implemented code can be found in Algorithm 1. The program is implemented in C++ and makes use of OpenMP to implement parallelism. The "key" being referred to in this context is the join attribute and the "values" are the other two attributes.

```
Data: Table $R_1(A, B)$, Table $R_2(A, C)$
Result: $R_3(A, B, C)$
sort both tables on key;
read in keys from each table and store them in vectors;
for all key-value pairs in each vector do
    if key from $R_1$ == key from $R_2$ then
        write key-value output to $R_3$;
    end
end
```

Algorithm 1: OpenMP Implementation of merge-join

IV. MPI Join Algorithm – Hash-Join

A hash join can be generalised into two stages [10], the split phase and the join phase [11]. In the split phase the hash function is used to partition the data into a number of sets and in the join phase each partition is joined and the result is sent to a common table. Hash join algorithms are considered to be the most efficient join algorithms in terms of speed [2].

The reviewed literature for the hash join is also concerned about data skew. Some of the said literature include references [8], [10] and other documents. Reference [8] addresses the issue of data skew by implementing multiple hash phases along with the use of a heuristic optimisation algorithm in order to isolate skew elements[8].

An overview of the algorithm being used is listed in Algorithm 2. The program is implemented in C++ and makes use of MPI to send and receive messages between nodes. The hash function simply takes the sum of all the character's ASCII values to produce a unique hash value. As before, the "key" being referred to in this context is the join attribute and the "value" the other attributes.

```
Data: Table $R_1(A, B)$, Table $R_2(A, C)$
Result: $R_3(A, B, C)$
for all key-value pairs in $R_1$ do
    read key;
    calculate hash as sum(ASCII) of key;
    calculate (hash%(no. of processes - 1) +
    1);
end
send key-value pairs of $R_1(A, B)$ to slave
nodes in vector;
for all key-value pairs in $R_2$ do
    read key;
    calculate hash as sum(ASCII) of key;
    calculate (hash%(no. of processes - 1) +
    1);
    //This is to determine which slave node the
    key-value pair is sent to.
end
send key-value pairs of $R_2(A, C)$ to slave
nodes in vector;
IN EACH SLAVE NODE:
for all key-value pairs in each vector do
    if key from $R_1$ == key from $R_2$ then
        write key-value output to $R_3$;
    end
end
```
Algorithm 2: MPI Implementation of hash-join

V. Experiment Description

Due to limited time constraints and late completion of the development of the hash-join and merge-join algorithms, the code could only be run on the authors local machines.

The conditions of the experimental environment, where the join algorithms are run, are summarised in the list below:

- Processor: Intel Code i5-7200U CPU at 2.5 GHz.
- RAM: 4.00 GB
- Sockets: 1
- Core per Socket: 2
- Threads per Socket: 4
- CPU: 4
- Operating System: Ubuntu 17.10
- Message Passage Standard: MPICH-3.2.1
- Input File Type: Text file storing string key-value pairs, using a delimiter of |
- Input Test File Size Range: 104 164650 bytes
- Join Technique: Hash-Join and Merge-Join Algorithm

In order to run the tests and compare the results, three sets of varying-sized relational databases were created. Each set consists of two files, made of string key-value pairs, separated by the | delimiter.

To perform the join on the two relational databases, the number of processes was varied in successive powers of 2, from 2 to 128 threads. The time it takes for each algorithm to perform the join was measured and recorded in Table I below.

TABLE I

TABLE OF RESULTS FOR MPI IMPLEMENTATION OF HASH JOIN

Number of Processes	Average Time (s)
Input file size: 104 bytes, Output file size: 156 bytes	
2	0.009648497
4	0.00520476
8	0.025301533
16	0.051812267
32	0.081754133
64	0.190590333
128	0.472530667
Input file size: 3380 bytes, Output file size: 4732 bytes	
2	0.034936833
4	0.020234043
8	0.195012667
16	0.329481
32	0.503516
64	1.043186667
128	2.149046667
Input file size: 164650 bytes, Output file size: 258996 bytes	
2	16.14963333
4	4.488146667
8	8.62297
16	18.92766667
32	31.46646667
64	59.38203333
128	114.329

VI. Analysis of Results

From the specifications given above, it is clear that the physical infrastructure of the authors machine could only support a maximum of four actual threads. As a result, any number of threads larger than four, are virtual threads; what this means, is that the computer will attempt to parallelize the operation, by allowing a virtual thread to run for a specified period of time within a certain window. Hence, for any number of threads greater than four, we can expect that the performance of the machine will be poorer.

A. Hash Join

From Table 1 below, it is clear that the authors machine consistently had the best performance when four threads were used. This is consistent with the description above. Furthermore, it is clear from the results, that as the size of the input databases increased, so is there an increase in time to join the results.

VII. Conclusion

Join operations are one of the most important operations in the use of databases, however, the operations are expensive in terms of time and data-intensity. In an effort to find an efficient algorithm, two parallel approaches were implemented and compared. The first approach uses OpenMP to perform a merge join on two large tables with its pragma directives while the second performs a hash join using MPI as a basis for the code. The MPI results show that when the amount of threads used is increased, so long as the number of threads is less than or equal to the number of actual threads that the infrastructure can support, the time taken to compute the join decreases significantly. However increasing the number of threads beyond this number results in a slowing down of the time taken to join. As the implementation of OpenMP was unable to generate results when the input file size was large it is clear that MPI is the superior method.

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