# Introduction

One of the benefits of using NoSQL databases has usually been performance over traditional SQL databases. With an appropriate use case, NoSQL databases might offer significant performance benefits. Key-value based queries is one typical use case when NoSQL can give better performance. A graph database is one of the NoSQL database types. As the graph model consists of nodes and edges, the model has its benefits when handling relational data.. While in SQL database multiple tables have to be joined for a relational query, in graph databases relational information can be queried by navigating through the graph.

There are already several studies where graph databases, especially Neo4J, have been compared with the traditional SQL databases. In many cases the results often show better performance in favor of graph databases. This study takes a practical approach to compare the databases. A generalized example of an invoicing database is used. One of the key use cases for the databases are to calculate the invoice price. The calculation is done using queries. This study will show how the databases perform when query complexity grows. Recursive query performance and how indexing affects the performance is also studied.

The databases compared in this study are MySQL 5.1.41, MariaDB 10.5.6 and Neo4J 4.1.3. MySQL version 5.1.41 is already old and considered as "end-of-life". However, it that was used in previous study [10] and version 5.1.42 in [9] which are referred in other studies as will be shown in related studies. There was interest to see how the old MySQL compares with the new versions of MariaDB and Neo4J and whether it was possible to repeat the previous results. As Neo4J has performed well in previous studies, it was chosen as a reference database to which MySQL and MariaDB are compared with.

Instead of using existing benchmarks such as [1] or [2], a dedicated test bench was implemented for this study. The test bench is called InvoicingDB Test Bench and its source code is available from GitHub [3]. The program generates given amount of data into the test invoicing database schema and performs various query tests. This approach was taken in order to simulate a program that queries the data.

The rest of the paper is organized as follows. Section 2 is the related study where previous performance related study related to Neo4J and MariaDB is reviewed. Section 3 presents the schema that is used for the test data. Section 4 presents the implemented benchmarking program. Section 5 presents the test queries. Section 6 presents the query tests. Section 7 is analysis and section 8 is conclusions.

# Related study

Various studies about graph database performance exist including [4], [5], [6] and [7]. [4] conducts the qualitative and performance comparison of 12 databases which are capable of storing and querying a graph. Algorithms single source shortest path (SSSP), connected components (SV) and PageRank (PR) are computed on these databases. Besides these, the graph update performance is measured on databases. All the databases successfully completed the tests with small graph (32K vertices and 256K unidirected egdes) and medium graph (1M vertices and 8M unidirected edges). Only 5 of the original 12 databases completed the tests with a large graph (16M vertices and 128M unidirected edges). The top five performers in these tests are STINGER, MTGL, Boost, Graph and NetworkX. Neo4J is one of the compared databases but does not fit into top performers in these tests.

In [5] Neo4J enterprise version 1.9.1 query performance is tested with two datasets and two kinds of queries. The queries were executed 11 times and the first time was thrown away as it warms up Neo4J caches. The dataset consists of author nodes and paper nodes. The relationship between these nodes is called ref. The first query is “find coAuthor of a paper written by an author” and the second query is “find a paper written by an author”. The queries are done three ways. With Java APi, with TraverserFrameWork and with Cypher. This study shows the clear differences between them. Both Core Java API and TraverserFrameWork offer faster response time compared with Cypher. Based on this study, Core Java API should be chosen for shorter response times. Cypher’s strength is its easiness and maintainability. TraverseFrameWork is a good compromise between the two.

[6] compares tuned Oracle 11g and Neo4J 3.03 Community Edition. Healthcare data is used including data about patients, medicines and medical staff. Performance of the databases is evaluated with ten different count(\*) queries. Many of the queries also perform some table joins. Physical database tuning technique called tablespaces is used for Oracle. The same databases were compared without physical database tuning in [8]. The physical database tuning technique decreased the overall average query time of Oracle from 4.34 to 2.78 seconds. However, the overall average query time for Neo4J in query tests was only 0.67 seconds. Thus, Neo4J performed better compared to Oracle.

In [7] Neo4J version 1.8 performance is tested with different backend solutions. Neo4J is benchmarked as embedded with native object access, as a dedicated server through RESTful Web Services, with embedded Cypher queries, with Cypher through REST optimized for remote execution and with Gremlin queries through REST. MySQL version 5.5.27 is also included with Java Persistence API based backend. Queries are done using Cypher, Gremlin and SQL query languages. The test data consist of people related data. Relational test queries are executed such as friends of friends. As the database gets larger the advantages of Neo4J over MySQL become more prevalent. Neo4J performance stays nearly constant when MySQL performance drops by factors 5 and 7-9. Both Neo4J query languages Gremlin and Cypher have performance benefits over MySQL with JPA. Gremlin and Cypher were also compared Gremlin having performance benefits in certain queries. When comparing Cypher with Neo4J native object access Cypher was between 10% and 200% worse.

There also exist previous studies that compare Neo4J and MySQL [9], [10]. Both of these articles demonstrate Neo4J performance over MySQL. Article [9] is from the year 2010 and compares MySQL Community Server version 5.1.42 and Neo4J version 1.0-b11. In the article the graph database is stored into a relational database as nodes and edges. Three types of structural and three types of data queries are made. First structural query finds all the orphan nodes and the two other ones traverse the graph in the depths of 4 and 128. The data queries are count(\*) queries counting nodes with certain payload. Neo4J performed better in structural queries. However, with the integer based queries MySQL was more efficient due to the fact that the tested Neo4J used Lucene indexing. As it treated the data as text by default, conversions had to be made and thus they impacted the performance. The article [9] is referenced in articles [4], [6], [7] and [8].

Article [10] is from the year 2012 and compares MySQL version 5.1.41 and Neo4J Community version 1.6. A schema with tables user, friends, fav\_movies and actors is used for testing. The databases are tested with three queries: “Find all friends of Esha”, “Find all favourite movies of Esha’s friends” and “Find the lead actors of Esha’s friends favourite movies”. Queries are done with 100 and 500 objects. Neo4J has 2-5 times lower query times with 100 objects data set and 15-30 times lower in 500 objects data set. The article [10] is referenced in articles [5] and [7].

There also exist previous performance studies where MariaDB is involved. In [11] the performance of MariaDB 10.0.21 and MySQL 5.6 is compared using Sysbench and OLTP [2] software. OLTP-Simple and OLTP-Seats workloads are used. Both databases consumed the same number of resources. However, when an increasing number of threads in OLTP-Simple and a number of workers in OLTP-Seats MySQL is clearly more effective outperforming MariaDB. The Common Table Expression capabilities of MariaDB are studied in [12] along with PostgresSQL. This study showed that Postgres has better results when only a few steps of recursion is needed. However, MariaDB is a better choice for a long recursive process on a huge amount of data.

# Invoicing database

The test database is a general example of an invoicing database. One of the most important use cases is the calculation of the price for a customer invoice. This is done by calculating the used time for work of different work types and the price of the items used when working. Invoices might also have relations to other invoices if several invoices are sent to the customer.

The database has 10 tables. The basic tables are customer, invoice, target, work, worktype and item. These tables contain the customer information, customer’s invoices, the target where the work is done, a listing of each work, a listing of different worktypes with different prices and information about the items used for each work. Relational data between the tables is stored into M:N tables worktarget, workinvoice, useditem and workhours.

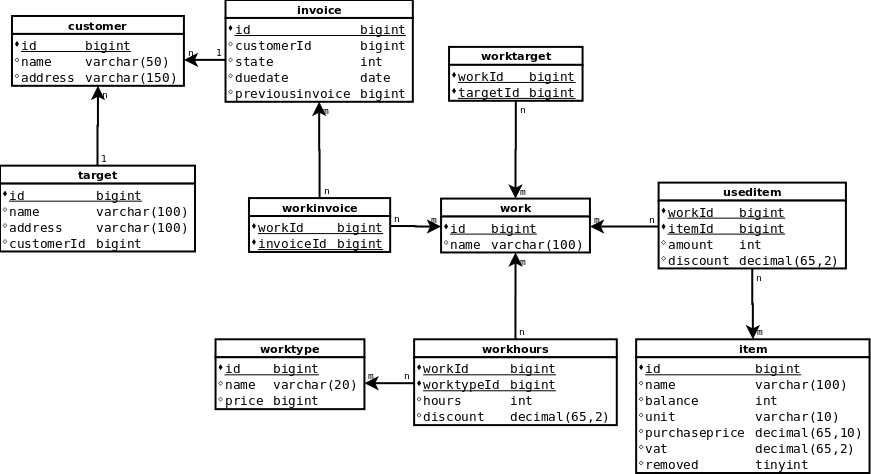
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Figure 1: Invoicing database in relational format.

On a graph format edges are used to represent the relationships. For N:M relationships, bidirectional edges are used. The tables customer, invoice, target, work, worktype are represented as nodes. The edges between the nodes are PAYS between the customer and invoice, CUSTOMER\_TARGEsT between the customer and target, WORK\_TARGET between work and target, WORK\_INVOICE between work and invoice, WORKHOURS between the work and worktype and USED\_ITEM between work and item.



Figure 2: Invoicing database in graph format.

# Test program

The test data is generated using a Java program. The program uses sample data that is based on openly available name and address data sets [13], [14]. The sample data is used when generating customer and target names. The generation process is divided into three parts. Items and work types should be generated first, then work and customer data. The Java program has threaded classes for each part. Multiple threads can be used to insert data as well as factors for related data. In data generation, seed numbers are used every time when there is something defined by random. This way the test data is repeatable.

When generating the work data, amount of the related worktypes and items can be defined by setting the worktype factor and item factor. When generating customer data, the number of the related invoices, targets and work can be defined by setting the invoice factor, target factor and work factor. When generating work and customers, the given amount of work and customers are generated. For each work, the given factor of relations for worktypes and invoices are generated. For each customer, the given number of invoices and targets are generated. The generator will also generate workinvoice and worktarget relationships based on the given factor.

The program has a class called QueryTester that used to perform the query tests. Query tests are repeated the selected number of times. The test program collects the results into a list structure. The program removes the biggest and the smallest number from the list and calculates an average and a standard deviation from the rest of the results.

# Test queries

The query tests contain different relational queries for calculating the price of work and invoice and a recursive query. These queries test different capabilities of the databases. As both relational and graph databases are tested, the queries are in SQL and Cypher form. The query tests are ordered from simple to complex starting from the work price and the work price with items ending in the work prices and work prices for a given customer. There is also a recursive query test.

Calculating the invoice prices is one of the most important queries. The schema does not store invoice prices explicitly. The price has to be calculated based on the amount of the workhours and the items used. The “price of work” and the “price of work with items” are the subqueries for calculating this price. The query calculating invoice prices for a given customer add customer information into this query. The recursive query will query all the interrelated invoices. One practical example is that customer has not paid the invoice and there will be additional invoices based on the same invoice.

## Query optimization

In addition to just testing databases with the queries, it was interesting to find out how to make the query performance better. Indexing is one of the ways making queries faster. It has to be taken into consideration when comparing MySQL, MariaDB and Neo4J that both MySQL and MariaDB index primary key and foreign key by default. Neo4J does not create indexes for properties by default. The effect of indexing is also different when comparing an SQL database with a graph database. When querying relations, in SQL databases the relations are formed by joining the tables based on primary key and foreign key information. Thus, SQL databases usually benefit from the indexing of primary key and foreign key. In a graph database, we are traversing the graph when querying data. As such it does not benefit indexing the properties the way SQL databases do.

In order to study the effects of indexing, certain columns and properties that were used in queries were indexed in all the databases. Table 1 shows the extra indexes created. As Ids in customer and invoice tables are indexed by default in MySQL and MariaDB, an extra index was not needed.

|  |  |  |
| --- | --- | --- |
| Table/Node | SQL | Neo4J |
| Customer | - | customerId |
| Invoice | previousinvoice | invoiceId, previousinvoice |
| Item | purchaseprice | purchaseprice |
| Workhours | hours, discount | hours, discount |
| Worktype | price | price |
| Useditem | amount, discount | amount, discount |

Table 1: Indexed columns/properties in SQL and Neo4J.

Besides indexing, in Neo4J 4.1.3 the queries can be optimized using CALL subqueries [15]. The CALL clause makes it possible to execute subqueries in other queries. It is like a function that gets input parameters from the main query and returns some values. The subquery is executed for each incoming input row from calling the query from the main query. CALL has been supported from Neo4J onwards. In this study Cypher queries with and without CALL are used in order for backward compatibility. This way it is also possible to see how much CALL subquery improves the query performance.

## Short query, price of work

The first query to be tested calculates the price of work. One work can have different work types with different prices. The price of one work is defined by the number of hours done of the work type. There can also be a discount on the prices and the discount is included in calculation. This query shows how databases perform with a fairly simple query. Table 2 shows the queries to query the price of work in SQL and Cypher.

|  |  |
| --- | --- |
| Type | Query |
| SQL | SELECT work.id AS workId, SUM( (worktype.price \* workhours.hours \* workhours.discount) ) AS price  FROM work  INNER JOIN workhours ON work.id = workhours.workId  INNER JOIN worktype ON worktype.id = workhours.worktypeId  GROUP BY work.id |
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| Cypher | MATCH (wt:worktype)-[h:WORKHOURS]->(w:work)  WITH SUM(h.hours\*h.discount\*wt.price) as price, w  RETURN w.workId as workId, price |  |
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| Cypher with CALL | MATCH (w:work) CALL {  WITH w  MATCH (wt:worktype)-[h:WORKHOURS]->(w)  RETURN SUM((h.hours\*h.discount\*wt.price)) as price  } RETURN w.workId as workId, price |  |
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Table 2: Price of work query in SQL and Cypher

## Long query, price of work with items

The query for the price of work with items is an extended version of the query for the price of work. This query adds item prices into work prices. As items are also included, the longer relational query is needed. With this query it is possible to see how databases perform when more relations and calculations are included in the query. Item purchase price is a floating-point number so this will add more challenges to the calculations. Table 3 shows the queries for the price of work with items in SQL and Cypher.

|  |  |
| --- | --- |
| Type | Query |
| SQL | SELECT work.id AS workId, SUM((worktype.price \* workhours.hours \* workhours.discount) + (item.purchaseprice \* useditem.amount \* useditem.discount) ) AS price  FROM work  INNER JOIN workhours ON work.id = workhours.workId  INNER JOIN worktype ON worktype.id = workhours.worktypeId  INNER JOIN useditem ON work.id = useditem.workId  INNER JOIN item ON useditem.itemId = item.id  GROUP BY work.id |
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| Cypher | MATCH (wt:worktype)-[h:WORKHOURS]->(w:work)-[u:USED\_ITEM]->(i:item)  WITH SUM((h.hours\*h.discount\*wt.price)+(u.amount\*u.discount\*i.purchaseprice)) as price, w  RETURN w.workId as workId, price |  |
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| Cypher with CALL | MATCH (w:work)  CALL {  WITH w  MATCH (wt:worktype)-[h:WORKHOURS]->(w)-[u:USED\_ITEM]->(i:item) RETURN SUM((h.hours\*h.discount\*wt.price)+(u.amount\*u.discount\*i.purchaseprice)) as price }  RETURN w.workId as workId, price |  |
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Table 3: The price of work with items query in SQL and Cypher.

## Complex query, invoice price

This query calculates the sum of a work price for each invoice. The query contains two subqueries. The first one finds the relation of the invoices and work. The second query is the previously presented “price of work with items”. The results of these queries are joined and the sums of prices are aggregated based on the id of the invoice. This is one of the heaviest queries and as such it is useful to see the performance differences when executing a complex query. Table 4 present the queries for calculating the invoice price in SQL and Cypher.

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| --- | --- |
| Type | Query |
| SQL | SELECT q1.invoiceId, SUM(q2.price) AS invoicePrice  FROM (  SELECT workinvoice.invoiceId, workinvoice.workId  FROM workinvoice  INNER JOIN invoice ON workinvoice.invoiceId = invoice.id  ) AS q1 INNER JOIN (  SELECT workhours.workid AS workId, SUM( (worktype.price \* workhours.hours \* workhours.discount) + (item.purchaseprice \* useditem.amount \* useditem.discount) ) AS price  FROM workhours  INNER JOIN worktype ON workhours.worktypeid = worktype.id  INNER JOIN useditem ON workhours.workid = useditem.workid  INNER JOIN item ON useditem.itemid = item.id  GROUP BY workhours.workid ) AS q2 USING (workId)  GROUP BY q1.invoiceId |
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| Cypher | MATCH (inv:invoice)-[:WORK\_INVOICE]->(w:work)  WITH inv, w  OPTIONAL MATCH (wt:worktype)-[h:WORKHOURS]->(w:work)-[u:USED\_ITEM]->(i:item)  WITH inv, w, SUM((h.hours\*h.discount\*wt.price)+(u.amount\*u.discount\*i.purchaseprice)) as workPrice RETURN inv, SUM(workPrice) as invoicePrice |  |
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| Cypher with CALL | CALL {  WITH inv  MATCH (inv)-[:WORK\_INVOICE]->(w:work)  RETURN w }  CALL {  WITH w  MATCH (wt:worktype)-[h:WORKHOURS]->(w)-[u:USED\_ITEM]->(i:item)  RETURN SUM((h.hours\*h.discount\*wt.price)+(u.amount\*u.discount\*i.purchaseprice)) as workPrice  }  RETURN inv, SUM(workPrice) as invoicePrice |  |
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Table 4:The query for Invoice prices in SQL and Cypher.

## Query with defined key, invoice prices for customer with id 0

It is often needed to find out all the invoice prices for a given customer. The query that calculates invoice prices for a given customer is an extended query from the query that calculates invoice prices. A subquery to get customer’s relation to invoices is included. This query is the most complex of the tested queries. From the technical point of view this query shows how databases perform when there is a certain key defined for which the data should be related to. Table 5 presents the queries for calculating invoice prices for a given customer.

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| --- | --- |
| Type | Query |
| SQL | SELECT q1.customerId, q2.invoiceId, SUM(q3.price) AS invoicePrice  FROM (  SELECT customer.id AS customerId, invoice.id AS invoiceId  FROM invoice  INNER JOIN customer ON invoice.customerId=customer.id  ) AS q1  INNER JOIN ( SELECT workinvoice.invoiceId, workinvoice.workId  FROM workinvoice  INNER JOIN invoice ON workinvoice.invoiceId = invoice.id ) AS q2 USING (invoiceId) INNER JOIN (  SELECT workhours.workid AS workId, SUM( (worktype.price \* workhours.hours \* workhours.discount) + (item.purchaseprice \* useditem.amount \* useditem.discount) ) AS price  FROM workhours  INNER JOIN worktype ON workhours.worktypeid = worktype.id  INNER JOIN useditem ON workhours.workid = useditem.workid  INNER JOIN item ON useditem.itemid = item.id GROUP BY workhours.workid ) AS q3 USING (workId) WHERE q1.customerId=0 GROUP BY q2.invoiceId |
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| Cypher | MATCH (c:customer)-[:PAYS]->(inv:invoice) WHERE c.customerId=0  WITH c, inv  OPTIONAL MATCH (inv)-[:WORK\_INVOICE]->(w:work)  WITH c, inv, w  OPTIONAL MATCH (wt:worktype)-[h:WORKHOURS]->(w:work)-[u:USED\_ITEM]->(i:item)  WITH c, inv, w, SUM((h.hours\*h.discount\*wt.price)+(u.amount\*u.discount\*i.purchaseprice)) as workPrice RETURN c, inv, SUM(workPrice) as invoicePrice |  |
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| Cypher with CALL | MATCH (inv:invoice) WHERE inv.customerId=0  CALL {  WITH inv  MATCH (c:customer)-[:PAYS]->(inv)  RETURN c  } CALL {  WITH c, inv  MATCH (inv)-[:WORK\_INVOICE]->(w:work)  RETURN w  }  CALL {  WITH w  MATCH (wt:worktype)-[h:WORKHOURS]->(w)-[u:USED\_ITEM]->(i:item)  RETURN SUM((h.hours\*h.discount\*wt.price)+(u.amount\*u.discount\*i.purchaseprice)) as workPrice  }  RETURN c, inv, SUM(workPrice) as invoicePrice |  |
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Table 5: The query for the Invoice prices of a defined customer in SQL and Cypher.

## Recursive query, invoices related to invoice id 100000

The recursive query gets all the sequential invoices related to given invoice id. The query is useful to test the recursive query capabilities of the databases. In SQL Common Table Expressions is used to make the query. In Cypher there is a way to optimize the recursive query by negating irrelevant relationships. The optimized query does not return exactly the same result as the basic query. While the basic query returns a set of nodes the optimized query returns a list of nodes. However, it still returns similar results and as such it is a relevant query. Table 6 presents the queries for finding sequential invoices for a given invoice.

|  |  |
| --- | --- |
| Type | Query |
| SQL | WITH RECURSIVE sequential\_invoices AS ( SELECT id, customerId, state, duedate, previousinvoice  FROM invoice  WHERE id=10000  UNION ALL  SELECT i.id, i.customerId, i.state, i.duedate, i.previousinvoice  FROM invoice AS i  INNER JOIN sequential\_invoices AS j ON i.previousinvoice = j.id  WHERE i.previousinvoice <> i.id)  SELECT \* FROM sequential\_invoices |
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| Cypher | MATCH (i:invoice { invoiceId:10000 })-[p:PREVIOUS\_INVOICE \*0..]->(j:invoice) RETURN \* |  |
| Cypher optimized | MATCH inv=(i:invoice { invoiceId:10000})-[p:PREVIOUS\_INVOICE \*0..]->(j:invoice) WHERE NOT (j)-[:PREVIOUS\_INVOICE]->() RETURN nodes(inv) |  |

Table 6: The Recursive query to get the sequential invoices related to defined invoice in SQL and Cypher.

# Query tests

## Test settings

The query tests were performed with MacBook Pro Laptop with following specifications:

* macOS Catalina version 10.15.5
* 1,4 GHz quad core Intel Core i5
* 8 GB 2133 MHz LPDDR3
* Intel Iris Plus Graphics 645, 1536 MB

MySQL version 5.1.41, MariaDB version 10.5.6 and Neo4J community edition version 4.1.3 were installed on this computer. MariaDB driver version 2.7 and Neo4J driver version 4.1.1 were used. A dataset was generated using the test program. Table 7 presents the number of rows/objects generated for the dataset. A double the amount of useditem, workhours, workinvoice and worktarget relationships were generated into Neo4J as in graph form. An M:N relationship is expressed as a bidirectional relationship.



Table 7: The numbers of the generated rows/objects in SQL and Neo4J.

## Test results

Each query test was executed with 12 iterations. Each query result contains an average time for the query in the milliseconds and standard deviation of the result list. As Neo4J has outperformed SQL databases in many previous studies, MySQL and MariaDB results are compared with Neo4J results. Non-indexed tests show percentage slower related to non-indexed Neo4J and indexed tests show percentage slower related to indexed Neo4J.

* + 1. Short query, price of work

Results for the query that queries price of work can be found in table 8. From the generated dataset the query returned 10000 rows/objects. With this query Neo4J outperforms SQL databases as in several previous studies. MySQL is the slowest and MariaDB the second. Inclusion of CALL does not seem to bring benefits in Neo4J with this query. Indexing does not also seem to bring benefits either.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Database | Avg | Sd | Slower than Neo4J 4.1.3 CALL | Avg indexed | Sd indexed | Slower than Neo4J 4.1.3 CALL indexed |
| MySQL 5.1.41 | 405 | 10,39 | 64 % | 413 | 2,93 | 65 % |
|  |
| MariaDB 10.5.6 | 209 | 18,59 | 31 % | 204 | 14,55 | 28 % |  |
|  |
| Neo4J 4.1.3 | 144 | 1,66 | -1 % | 148 | 7,35 | 1 % |  |
|  |
| Neo4J 4.1.3 CALL | 145 | 1,55 |  | 146 | 2,37 | 0 % |  |
|  |

Table 8: Results for the query for the price of work.

* + 1. Long query, price of work with items

Results for the query that queries the price of work can be found in table 8. From the generated dataset, the query returned 10000 rows/objects. With this query, Neo4J outperforms SQL databases as in several previous studies. MySQL is the slowest and MariaDB the second. Inclusion of CALL does not seem to bring benefits to Neo4J with this query. Indexing does not seem to bring benefits either.

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| --- | --- | --- | --- | --- | --- | --- |
| Database | Avg | Sd | Slower than Neo4J 4.1.3 CALL | Avg indexed | Sd indexed | Slower than Neo4J 4.1.3 CALL indexed |
| MySQL 5.1.41 | 4952 | 31,28 | 62 % | 4901 | 16,48 | 40 % |
|  |
| MariaDB 10.5.6 | 2197 | 9,43 | 15 % | 2193 | 5,14 | -34 % |  |
|  |
| Neo4J 4.1.3 | 6880 | 1294,72 | 73 % | 8250 | 1797,56 | 64 % |  |
|  |
| Neo4J 4.1.3 CALL | 1859 | 161,23 | 0 % | 2931 | 396,45 | 0 % |  |
|  |

Table 9: Results for price of work with items query.

* + 1. Complex query, invoice price

Table 10 shows results for the query that calculates invoice prices. From the generated dataset, the query returns 100000 rows/objects. Without CALL included in query Neo4J performs again even worse than old MySQL 5.1.41. Inclusion of CALL gives significant performance benefit. However, MariaDB clearly outperforms Neo4J. Indexing gives also some performance benefits in MariaDB. However, with other databases it does not seem to improve performance.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Database | Avg | Sd | Slower than Neo4J 4.1.3 CALL | Avg indexed | Sd indexed | Slower than Neo4J 4.1.3 CALL indexed |
| MySQL 5.1.41 | 235817 | 2419,67 | 3 % | 236875 | 1801,43 | -28 % |
|  |
| MariaDB 10.5.6 | 4282 | 1047,05 | -5254 % | 3840 | 885,57 | -7800 % |  |
|  |
| Neo4J 4.1.3 | 753587 | 5517,32 | 70 % | 957325 | 12929,71 | 68 % |  |
|  |
| Neo4J 4.1.3 CALL | 229256 | 3805,37 | 0 % | 303365 | 59489,12 | 0 % |  |
|  |

Table 10: Results for the query for the invoice prices.

* + 1. Query with a defined key, invoice prices for a given customer

Results for the query that gets invoice prices for a given customer can be found in table 11. From the generated dataset, the query returns 10 rows/objects. MySQL 5.1.41 was left out as the performance was so poor. The query took over one hour on average. In practical use, it would be unusable. With Neo4J, the inclusion of CALL does not give performance benefits. However, indexing seems to bring improvements. With indexing Neo4J finds the customer 0 from the graph faster. Although Neo4J performs well, MariaDB outperforms it by a small margin.

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| --- | --- | --- | --- | --- | --- | --- |
| Database | Avg | Sd | Slower than Neo4J 4.1.3 CALL | Avg indexed | Sd indexed | Slower than Neo4J 4.1.3 CALL indexed |
| MariaDB 10.5.6 | 42 | 0,49 | -38 % | 30 | 5,41 | -97 % |
|  |
| Neo4J 4.1.3 | 56 | 14,09 | -4 % | 50 | 8,96 | -18 % |  |
|  |
| Neo4J 4.1.3 CALL | 58 | 0,94 | 0 % | 59 | 7,13 | 0 % |  |
|  |

Table 11: Results for the query for the invoice prices for a defined customer.

6.2.5 Recursive query, invoices related to invoice id 100000

The recursive query lists all the sequential invoices related to the invoice with given id. The tests were performed with 100 and 1000 invoices. With 10000 invoices Neo4J performance without optimization was so poor that it would have taken too long to complete. Table 12 presents the results when querying 100 sequential invoices and table 13 presents results when querying 1000 invoices.

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| --- | --- | --- | --- | --- | --- | --- |
| Database | Avg | SD | Slower than Neo4J 4.1.3 Optimized | Avg indexed | SD indexed | Slower than Neo4J 4.1.3 Optimized indexed |
| MariaDB 10.5.6 | 4473 | 14,94 | 81 % | 1 | 0,4 | -86800 % |
|  |
| Neo4J 4.1.3 | 150 | 18 | -468 % | 153 | 6,62 | -468 % |  |
|  |
| Neo4J 4.1.3 Optimized | 852 | 82,08 | 0 % | 869 | 108,07 | 0 % |  |
|  |

Table 12: Results for the recursive query query with 100 rows/objects.

With 100 invoices, Neo4J seems to have the best performance without query optimization. The optimized query does not seem to improve performance. However, when indexes are used MariaDB benefits dramatically from indexing. The query takes just 1ms average clearly making MariDB the best performer. Indexing does not improve performance for Neo4J.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Database | Avg | SD | Slower than Neo4J 4.1.3 Optimized | Avg indexed | SD indexed | Slower than Neo4J 4.1.3 Optimized indexed |
| MariaDB 10.5.6 | 45004 | 208,76 | 92 % | 10 | 0,64 | -51070 % |
|  |
| Neo4J 4.1.3 | 1239446 | 149799,53 | 100 % | 1637223 | 273613,61 | 100 % |  |
|  |
| Neo4J 4.1.3 Optimized | 3662 | 997,6 | 0 % | 5117 | 291,94 | 0 % |  |
|  |

Table 13: Results for the recursive query with 1000 rows/objects.

As the number of invoices was increased to 1000, Neo4J performance drops dramatically. With the optimized query though Neo4J becomes much faster outperforming MariaDB. However, as MariaDB benefits from indexing, with indexing the query takes only ten milliseconds on average making it yet again the best performer. Indexing does not improve performance for Neo4J.

# Analysis

With the query tests performed Neo4J is often outperformed by MariaDB in many cases. In some tests, Neo4J performs even worse than old MySQL 5.1.41. When comparing Neo4J with MySQL and MariaDB we are comparing a Java program with C/C++ program. Obviously, the latter can be optimized better. It has to be also taken into consideration that MariaDB indexes primary keys and foreign keys by default. This gives benefits in every query where the table joins are done. Neo4J does not seem to benefit from indexing in many cases. One such case where indexing had benefits was when Neo4J needs to find the starting point from the graph.

The benefit of indexing in MariaDB can also be seen as the benefit of the traditional relational database model. As the relations with the tables are created when executing the SQL query, indexing the keys becomes beneficial. The graph model does not benefit from such indexing as there are no tables that are joined by keys. Querying a graph database is done by traversing the graph. One of the benefits of the graph model can be seen in recursive query tests. By optimizing the query, performance becomes clearly better and, in this case, even better than SQL database with CTE query. However, with recursive queries, indexing still brings dramatical benefits for SQL database.

With the invoicing database schema used in this study, calculating the price is done with complex queries. If this database was used in some real case, the usage of table views would probably be preferred to simplify the queries. When it comes to using views, it is also a benefit of SQL databases over Neo4J as the time writing this article Neo4J does not have an exact equivalent of such feature as views in SQL databases.

# Conclusions

This study compared MySQL 5.1.41, MariaDB 10.5.6 and Neo4J 4.1.3 with various query tests related to the invoicing database. The data was generated and the query tests were performed using a Java program developed for this study. The query tests included relational queries with increasing complexity and recursive queries. With the first two queries, Neo4J had the best performance which correlates with previous results shown in [9] and [10]. However, with more complex queries MariaDB outperformed Neo4J.

This study indicated the benefit of indexing in SQL database in many of the tests. SQL databases seemed to benefit from indexing and in some cases very dramatically. However, the tested database Neo4J seemed often not to benefit from indexing. Neo4J benefited from indexing when a starting point in the graph was indexed.

Overall MariaDB is the clear winner in this study when it comes to performance with more complex queries. Especially the query test for querying the invoice prices, MariaDB shows its performance. Indexing also gives clear benefits in MariaDB. Especially with recursive queries the improvement was dramatical. The results in this study show how a relational database is still a strong alternative when it comes to performance compared with NoSQL graph database.

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