MJCIS Vol.15 No.1 Jun 2019

Mansoura Journal of Computers and Information Sciences

An efficient uniform model to integrate SQL and NoSQL databases

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ABSTRACT

In recent years, systems become more complex due to massive growth and variety of data which stored in different formats (structured and unstructured). In many cases the organizations need to use both SQL and NoSQL databases to store their data and get the advantages of both systems. A big challenge for organizations is how to integrate these data and retrieve it in a uniform format. The difficulty of integration is not only because the heterogeneity of query language and the data format but also the heterogeneity of semantic and structure. Although many researches were done to overcome these challenges, it introduced a specific solution for a special case or limited feature rather than a general model. This paper introduces a standard solution to integrate SQL with NoSQL databases and retrieve data from them in a unified form. The proposed model allows developers to write and execute queries against different data sources easily at the same time. This model solves the problems of heterogeneous data integration along three diagonal structure, semantic, and syntax heterogeneity. A web-based application is developed to ensure the usefulness of the proposed solution.

General Terms

Database System, Data Integration

Keywords

NoSQL, SQL, Integration, Uniform Database Access

1. INTRODUCTION

Recently, Database domain becomes more heterogeneous than ever due to the rapid growth in digital data generated by real-time web applications and social networking websites which is very huge and unstructured. [1, 2]

Although Relational databases provide the easiest way to store and retrieve data as they follow a predefined schema with a well-known structured relation and a standard query language called SQL (Structured Query Language), they can't handle such huge amount of digital unstructured and semi-structured data generated by current applications. As a result, new database model is gaining significant attention in the enterprise called NoSQL (Not Only SQL). [2, 3] NoSQL emerged to serve as the core system of Big Data applications because it can handle massive volumes of unstructured data and it is characterized by its high availability, scalability, and performance. [1, 4] NoSQL databases fall into four models (key-value, columnar, document, and graph) each is convenient for specific scenario. [1]

The "one size fits all" thinking about database systems has been questioned because new current applications started to require unprecedented needs that can't be fulfilled easily by relational databases. These needs are not only managing huge amounts of data but also providing more flexible schemas to handle rapidly changing needs of organizations, high throughput, and quick scaling up or down. [1, 3] Relational databases can handle large volumes of data but with some weaknesses; unstructured and semi-structured are hard to be handled, it is very complicated in scaling up as well as higher cost, and performance is affected when data is distributed over geographically distant sites. [1]

There are many situations where NoSQL databases are the right tool for the job, but many others are well suited for traditional relational data storage. For example, a software application requires data storage where a part of the data is perfectly suitable for traditional relational databases, whereas the other part of data is stored ideally in NoSQL databases. This raises a problem regarding which type of data storage is the perfect choice for the application. Since, different parts of data are suitable for different types of data storage, then choosing one type of database means that a part of the data is stored in a less convenient way. [5]

A compromise solution is to store structured data in SQL database and unstructured data in NoSQL database. [5] By this way, it will be possible to take advantage of both relational and NoSQL databases, but this solution raises a problem of how to retrieve and provide users with a unified output from these different data sources. The best solution to this problem is to integrate data from different sources and retrieve it as if stored in one place. As a result, ERP (Enterprise Resource Planning) systems emerged to support the integration of different systems in organization and handle communication between them. Over time, ERP systems become more painful to implement due to a serious drawback which is the incompatibility between ERP standards and organization's business model. [6, 7]

So, organization starts to seek for new approaches to integrate their disparate systems. A new class called EAI (Enterprise Application Integration) spotted in the community of software integration to merge different systems within organization. [8] EAI is handled through four levels: Data Level, Application

Interface Level, Method Level, and User Interface Level. [7] However, applying EAI in the process of integrating and retrieving data from different sources is facing an important challenge of semantic, structural, and syntactic heterogeneities of data described as follows:

- Semantic Heterogeneity of data means that the same real-world entity has different names in different database systems (synonym), or different real-world entities have the same name in different database systems (homonym). [9]
- Structural Heterogeneity of data means heterogeneity in data models. Because of different approaches of database design, the same data can be modeled in different ways (schemas). [9]
- Syntactic Heterogeneity of data means differences of data access methods due to heterogeneity of data sources. Although SQL is the standard language to manage relational databases, it is not appropriate for managing NoSQL databases because they follow different data models with different access methods. [9]

There exist many solutions that aim to integrate data from different relational and NoSQL databases and solve problems of data heterogeneities as explained in the following section.

1.1 Related Work

This section gives an overview of related work performed regarding the intended goal of this paper which is bridging the gap between relational databases and NoSQL databases.

Roijackers presented a framework based on creating an abstraction layer responsible for retrieving relevant data from SQL and NoSQL, transforming NoSQL data to a triple representation, and integrating fetched data into single query result. Obviously, his approach required much work to be done in transforming data from one form to another which could lead to data loss and delay in data access. [5]

Adeyi et al presented DualFetchQL platform for integrating data from relational database and NoSQL databases. They introduced new aggregate query syntax to present a unified output of the system. Their approach required manual alteration by users before full knowledge of data pulls from database, and the aggregate query could be reviewed to merge both components into one to avoid learning two languages. [10]

Ooju et al presented TripleFetchQL platform which was based on the idea of DualFetchQL with the introduction of transformation agent. The system eliminated any manual alteration by users and unified results of involved databases into one tabular SQL-Like format. Their approach could be enhanced by looking into transformation time and merging the aggregate query components into one. [3]

Agnes et al introduced a data integration methodology to query data individually from relational and NoSQL databases. The solution was based on a meta-modeling approach where results of database queries were translated to JSON objects and finally data merge was done by concatenating separate JSON files. The model could be more useful when new different databases are added to the application. [9]

Although there were many researches try to solve problems of integrating data from different sources, there are still some shortages that have not been resolved definitively.

The rest of the paper is organized as follows. In section 2, the proposed framework is explained from a theoretical perspective as well as presenting the application that implements the proposed framework. Section 3 handles the evaluation of the proposed framework. Finally, section 4 concludes the paper.

2. The Proposed Model

This paper proposes a generic framework to integrate data from different SQL and NoSQL data sources into a unified format without the burden of moving data between different stores. To fulfill this goal, the paper aims to achieve the following objectives:

- Integrate data from different databases in uniform format.
- Provide a standard access method to query data from different sources without moving data between data stores or any conversion between NoSQL and SQL data.
- Solve problems of syntax, semantic, and structure heterogeneities of data by developing an intermediate model between different sources and users.

2.1 System Architecture

The architecture of the proposed solution consists of five major components namely, Controller, View, EF Layer, ADO.Net Providers, and data stores represented as SQL Data Store, Cassandra Data Store, and MongoDB Data Store as seen in Figure (1).

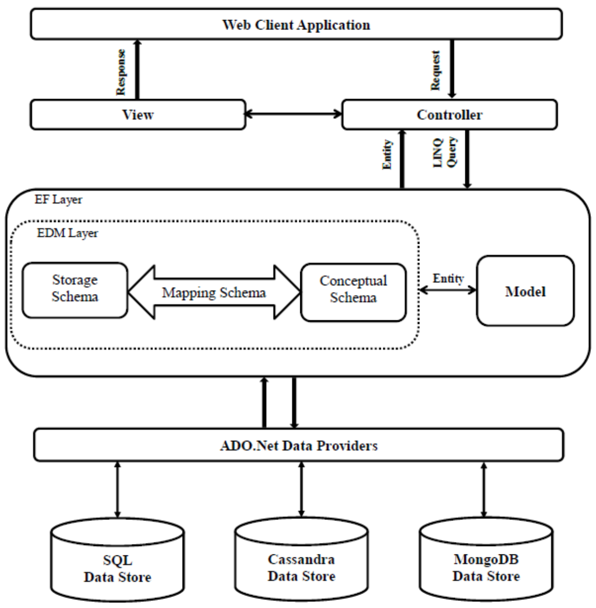


Fig 1: Architecture of proposed model

The architecture is based on the Model-View-Controller (MVC) architectural pattern which separates the application's logic from its data and presentation. [11]

Controller is a middle layer between the Model and the View. It is responsible for handling user requests from the view, implementing business logic, communicating with Model layer to call database queries, and sending result back to the view. [11, 12]

View is a layer responsible for displaying data from the Model to the user in a particular format triggered by decision of the controller. [11, 12]

EF (Entity Framework) Layer is built based on Microsoft's ADO.NET Entity Framework architecture which is a platform designed to help developers create data access applications by programming against a conceptual model instead of directly programming against a data storage schema, and it supports both relational and NoSQL databases. [13, 14] EF layer consists of a Model layer and an EDM (Entity Data Model) layer.

Model is a layer responsible for application data management routines to handle database operations. [11] It contains a set of domain classes to represent each element in the database in the form of entity within the application regardless of real database structure and type. This facilitates the communication between application and data source.

EDM is a mapping layer responsible for creating a relationship between application data and data stored in database. It describes the structure of data despite how it is stored. [13, 15] It consists of three basic components:

- Conceptual Schema is responsible for representing the structure of data in form of entities and relationships using a domain-specific language called Conceptual Schema Definition Language (CSDL). [15]
- Mapping Schema contains information about how entities and relationships from conceptual layer are mapped to actual tables at logical layer. Mapping information is represented using an XML-based language called Mapping Specification Language (MSL). [16]
- Storage Schema contains the entire database schema (tables, relations, views, and keys) represented using an XML-based language called Store Schema Definition Language (SSDL). [16]

ADO.Net providers are responsible for communicating with specific data store. Each database has its own provider that allows easier and faster access to data. [17]

Data Stores represent databases where data is stored in (SQL data store, Cassandra data store, and MongoDB data store). Choices of data stores are made mainly because of their wide popularity and the fact that they are supported by EF architecture, so they implement their own database providers.

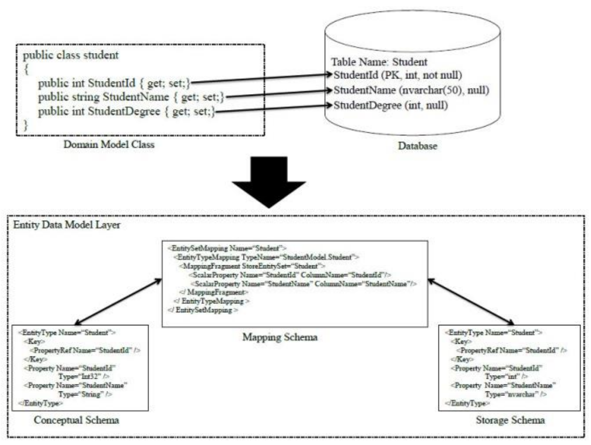
2.2 Resolving data integration problems

The proposed solution to resolve problems of semantic, structural, and syntactic heterogeneities of source systems is introduced in following sections.

2.2.1 *EF Layer: Solve semantic and structural heterogeneity problem*

The basic idea is to create a middle layer between data source and user to retrieve and execute queries easily. Then, merge results and display them in a unified form to the user.

EF layer represents the middle layer in the proposed architecture. This layer is built automatically through EF graphical user interface or manually by writing codes of domain model classes and EDM schemas. In case that data in data stores are identical (e.g. the same table in SQL server refers to the same collection in MongoDB) then the developer can generate EF layer automatically. If data is not identical in data stores, then the developer will create the EF layer manually to handle semantic differences easily. Figure (2) shows how EF layer works.



```
public class student
{
    public int StudentId { get; set;}
    public string StudentName { get; set;}
    public int StudentDegree { get; set;}
}
```

```
Table Name: Student
StudentId (PK, int, not null)
StudentName (nvarchar(50), null)
StudentDegree (int, null)
```

```
<EntitySetMapping Name="Student">
  <EntityTypeMapping TypeName="StudentModel.Student">
    <MappingFragment StoreEntitySet="Student">
        <ScalarProperty Name="StudentId" ColumnName="StudentId"/>
        <ScalarProperty Name="StudentName" ColumnName="StudentName"/>
    </ MappingFragment>
  </ EntityTypeMapping >
</ EntitySetMapping >
```

```
<EntityType Name="Student">
  <Key>
    <PropertyRef Name="StudentId" />
  </Key>
  <Property Name="StudentId"
            Type="Int32" />
  <Property Name="StudentName"
            Type="String" />
</EntityType>
```

```
<EntityType Name="Student">
  <Key>
    <PropertyRef Name="StudentId" />
  </Key>
  <Property Name="StudentId"
            Type="int" />
  <Property  Name="StudentName"
            Type="nvarchar" />
</EntityType>
```

Fig 2: Example of how EF Layer works

Domain Classes allow the developer to focus on domain object instead of database object. Each object in database (e.g. table in SQL, collection in MongoDB) has a domain model class that contains all its metadata information (e.g. table name, column name, and column datatype) in form of properties to facilitate developer's work.

EDM is responsible for generating general and independent descriptions of the data models of source systems called SS (Storage Schema), CS (Conceptual Schema), and MS (Mapping Schema).

EDM schemas contain all metadata about source system that will help in resolving semantic and structural heterogeneities. The data model descriptions are based on XML elements as mentioned in section (2.1) because XML is a text based markup language with self descriptive tags that provide easy and understandable structure of the data of schemas.

SS allows the developer to overcome the problem of differences in the data model of source databases by representing the real information of the source database as XML tags regardless of its structure. For example, in SQL database, it stores database name and type, table name, table columns metadata (name, datatype, length… etc.), and table keys. The same SS schema with the same structure can created for MongoDB and Cassandra DB.

Domain Classes and CS help the developer solve the semantic differences between source databases by defining aliases for elements that have the same meaning in different databases as properties in Domain Classes. These alias properties guarantee consistent name conversion for database elements. CS contains a description for each domain class by storing all its properties as XML tags (e.g. property name, datatype, keys, and relationships).

MS contains information about linking both SS and CS together to guarantee consistent semantic mapping of database elements. It consists of XML entities where each entity contains SS element and its matched CS element.

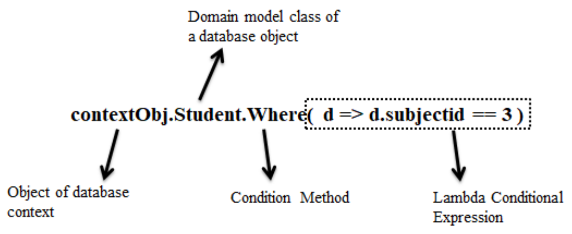
As it can be seen, EF layer is a flexible intermediate layer that describes schemas of source databases independently from the implemented data model's type. The proposed solution proved that the principle of generating general and independent schemas of source systems is applicable for different relational databases (SQL), NoSQL document-oriented data stores (MongoDB), and NoSQL column-oriented data stores (Cassandra DB). It can be possible to describe schemas of other NoSQL databases easily with EDM general schemas.

2.2.2 Database Providers & LINQ Query: Solve syntactical heterogeneity problem

Syntactic heterogeneities can be resolved by developing database providers which can translate different queries to different database query languages. In the proposed solution, database queries are integrated into the programming language of the application, written as a set-based queries, and are called LINQ (Language Integrated Query).

LINQ queries help the developer handle data as objects when retrieve, as well as generating queries in one format without the need for separate query language for each database. Providers connect to the database, translate LINQ queries into the appropriate database query language, execute queries against data source, and retrieve results.

Figure (3) shows an example of a LINQ query. In this example, the developer wants to query all students' information that is recorded in a specific subject. The query consists of database context object that contains all database connection information and allows the provider to identify in which data store information is stored. The domain model class contains all information about the student object identical to its counterpart in the database as explained in section (2.2.1). The condition method allows the developer to apply specific conditions on the domain class and accepts the conditional parameters in form of Lambda Expression.

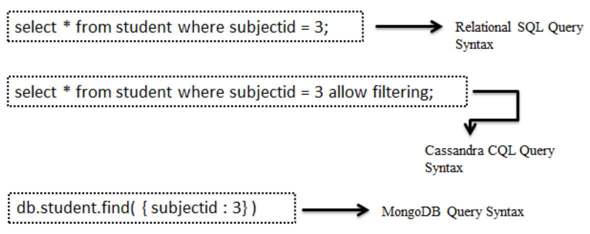


```
contextObj.Student.Where( d => d.subjectid == 3 )
```

Domain model class of a database object
Object of database context
Condition Method
Lambda Conditional Expression

Fig 3: Example of a LINQ Query

The LINQ query is expressed as a set of standard declarative operators. These operators are translated by EF to command trees representation and with the help of database providers the CS and SS descriptions map entities of domain model class to their counterparts in the data store, generate native query expressions as presented in Figure (4), and execute them in the appropriate data store.

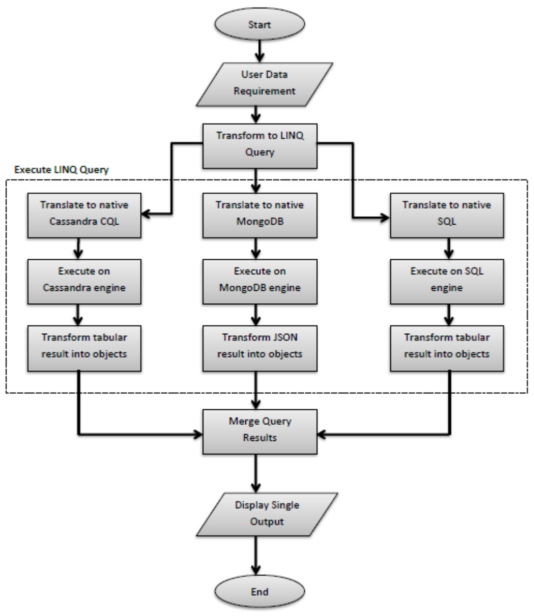


```
select * from student where subjectid = 3;

select * from student where subjectid = 3 allow filtering;

db.student.find( { subjectid : 3} )
```

Fig 4: Example of different query syntaxes

2.2.3 System Flow Chart

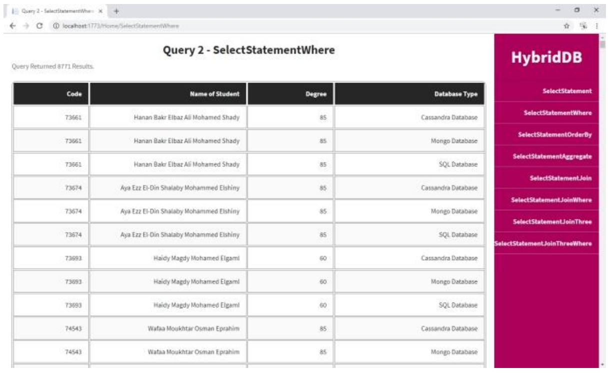
Figure (5) presents a flow chart of the proposed solution and illustrates how different queries are executed and merged into single output.



Start
User Data Requirement
Transform to LINQ Query
Execute LINQ Query
Translate to native Cassandra CQL
Translate to native MongoDB
Translate to native SQL
Execute on Cassandra engine
Execute on MongoDB engine
Execute on SQL engine
Transform tabular result into objects
Transform JSON result into objects
Transform tabular result into objects
Merge Query Results
Display Single Output
End

Fig 5: Flow Chart of the proposed solution

The user defines the requirements through the application (e.g. the user needs to retrieve all student data in a particular subject) and the controller receives these requirements and translates them into a LINQ query. Then, the LINQ query is sent to the EF layer which specifies the query type and sends it to the appropriate data provider. The data provider translates the LINQ query to the appropriate native query language and executes it on the original data store. Results of queries are materialized into a collection of objects identical to domain classes, then, it will be easy to perform the integration process by concatenating the resulting objects. The merged result is sent to the user in a unified format (e.g. tabular form) as shown in Figure (6).



Query 2 - SelectStatementWhere

Query Returned 8771 Results.

Code	Name of Student	Degree	Database Type
73661	Hanan Bakr Elbaz Ali Mohamed Shady	85	Cassandra Database
73661	Hanan Bakr Elbaz Ali Mohamed Shady	85	Mongo Database
73661	Hanan Bakr Elbaz Ali Mohamed Shady	85	SQL Database
73674	Aya Ezz El-Din Shalaby Mohammed Elshiny	85	Cassandra Database
73674	Aya Ezz El-Din Shalaby Mohammed Elshiny	85	Mongo Database
73674	Aya Ezz El-Din Shalaby Mohammed Elshiny	85	SQL Database
73693	Haidy Magdy Mohamed Elgaml	60	Cassandra Database
73693	Haidy Magdy Mohamed Elgaml	60	Mongo Database
73693	Haidy Magdy Mohamed Elgaml	60	SQL Database
74543	Wafaa Moukhtar Osman Eprahim	85	Cassandra Database
74543	Wafaa Moukhtar Osman Eprahim	85	Mongo Database

Fig 6: Flow Chart of the proposed solution

3. The Proposed Model Evaluation

The proposed model was evaluated for its performance and types of queries supported using hardware and software configurations displayed in Table (1).

Table 1: System Hardware and Software Configurations.

Hardware	Intel(R) Core i7 3.40GHz, 8 GB RAM, and Windows 10 Pro 64-bit operating system.

Software	Microsoft SQL Server 2014 x64, MongoDB 3.4.4, Cassandra 3.0.9, and Microsoft Visual Studio 2015 x64.	
Data Providers	**Cassandra**	CData.Cassandra v18.0.6719
	MongoDB	CData.MongoDB v18.0.6705
Implementation	C# Language.	

This section proceeds as follows. Section 3.1 analyzes the performance of the developed system. Section 3.2 discusses different types of queries supported by the developed system.

3.1 Performance Evaluation

Performance tests were based on Training Center databases. Same database schema was used for SQL, MongoDB, and Cassandra databases. Tables of Student, Subjects, and Cert were used during the tests. Tests were performed on two databases with different sizes. All tests were performed 15 times to avoid result's skewing. Different database queries were performed on these datasets.

Each query contained only a few selected attributes. Two queries performed select statement that affected only one object in the source system, one without a condition and the other one with a condition. Two queries performed join statement; the first join statement was performed on two objects of the source systems while the second join statement was performed on three objects of the source systems. Data rows resulting from executing previous queries on both Dataset 1 and Dataset 2 are listed as follows in Table (2).

Table 2: Data rows of test queries

	Dataset 1	Dataset 2
Query 1	87401	276444
Query 2	8771	9567
Query 3	87401	182208
Query 4	8051	39622

Each query was evaluated regarding to the application's entire running time and data retrieval time. Entire running time starts when the user sends a request to the system and ends when the queried data is available in HTML table format. It includes execution time on the application and execution time on the database as illustrated in Equation (1).

$$ERT = AET + DET \qquad (1)$$

Where:

ERT refers to Entire Running Time.

AET refers to Application Execution Time.

DET refers to Database Execution Time.

Equation (1.1) illustrates the execution time on the application which includes sending query request to the controller, identifying type of query and translating it to data source's appropriate query language, transforming native query result into objects, and merging results in single output. Execution time on the database includes executing translated queries on the data source and sending native query results to the application.

$$AET = QTN + QTO + QMT \qquad (1.1)$$

Where:

AET refers to Application Execution Time.

QTN refers to Query Translation Time to Native Language.

QTO refers to Query Result Transformation Time to Object.

QMT refers to Query Merge Time.

Data retrieval time starts when a user request is sent from the system to the data source and ends when the queried data is available in object format. The data retrieval time includes executing translated queries on original data source, retrieving native query results, and transforming them to objects of the system as illustrated in Equation (2).

$$DRT = QET + QTO \qquad (2)$$

Where:

DRT refers to Data Retrieval Time.

QET refers to Query Execution Time on database.

QTO refers to Query Result Transformation Time to Object.

The performance of the tested queries according to previously mentioned time measures is presented in Figure (7) and Figure (8).

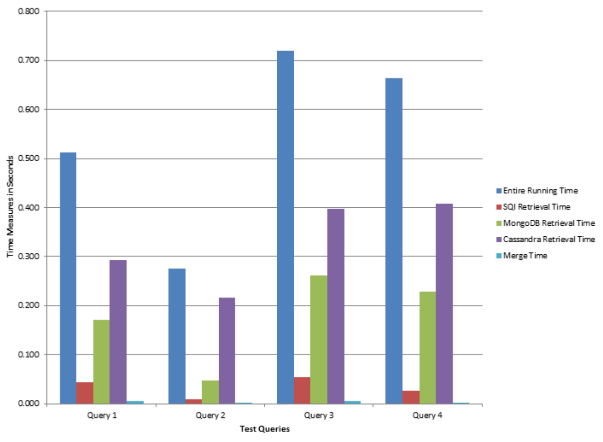


Fig 7: Time measures of Dataset 1

The time measures of tested queries performed on the first dataset of the test are shows in Figure (7). In Dataset 1, the highest average values of the entire running time were in third and fourth query with values 0.719 and 0.663 seconds respectively. These values were affected by many factors the number of records returned from the queries about 87401 and 8051 records respectively, the complexity of join operation (query 3 affects 2 objects of source systems and query 4 affected 3 objects of source systems), and the execution time on each data source separately.

The next step after data was retrieved from each data source was to merge them in single output. The concatenation process is very fast. It required about 0.005 seconds merging 29151 records from SQL with 29099 records from Cassandra with 29151 records from MongoDB which was highest average value according to Figure (7), and in case of smaller number of records the merge took about 0.000 seconds.

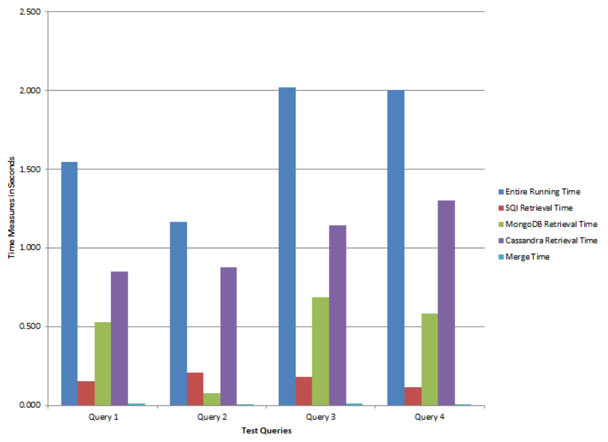


Fig 8: Time measures of Dataset 2

The time measures of tested queries performed on the second dataset of the test are shown in Figure (8). In Dataset 2, the entire running time increased dramatically in case of query 3 and query 4 with values 2.020 seconds and 2.004 seconds respectively. The reason for this increase was the complexity of join operation which in turn increased the execution time on each data source. Another reason was the big number of records retrieved, about 182208 records were retrieved from query 3 whereas about 39622 records were retrieved from query 4 which was smaller than records retrieved from query 3; however, joining three objects on three different data sources is a very complicated and exhausted process.

Concatenating records retrieved from each data source is a very fast process. To merge about 92148 records from each data source together, it needed about 0.014 seconds and with smaller number of records it needed about 0.004 seconds to perform the merge operation as shown in Figure (8).

Overall, it can be stated that the entire running time of the solution depends primarily on the speed of executing native queries on different databases and on the transfer time between application and databases. The transfer time can be enhanced by increasing the capabilities of the server which hosts the application (e.g. higher processor and bigger RAM).

3.2 Supported Queries

The purpose of the application of the proposed solution is to retrieve data from heterogeneous data sources (SQL, MongoDB, and Cassandra) regardless of how it is stored. This means that the application depends primarily on the SELECT statement in its multiple forms, which depends on the nature of the user's requirements. In the proposed solution, the application uses LINQ as a standard query language for different data sources with the help of data providers and EF layer. LINQ allows developers to execute almost all kinds of a select statement on different databases easily. Table (3) presents a list of some forms of a select statement which performed on the proposed solution.

Table 3: Supported Queries List.

	LINQ Query	**SQL DB**	**Mongo DB**	**Cassandra DB**
Select All	✓	✓	✓	✓
Select Where	✓ with restrictions on Cassandra	✓	✓	✓ with restrictions
Join	✓	✓	✗	✗
Order By	✓	✓	✓	✓ with restrictions
Aggregate Functions	✓	✓	✓	✓
Group By	✓	✓	✓	✗

According to Table (3) Cassandra allows filtering data on a select statement but with a restriction that the filtering column is a primary key or an indexed column. Unfortunately, the LINQ query couldn't solve this issue.

The join operation is not supported by MongoDB (until v. 2.3) and Cassandra (until v. 3.10). In the proposed solution, LINQ query succeeded in executing the join operation on both databases with the help of their data providers.

The group by operation can't be executed on Cassandra (until v. 3.10 with restriction that the group by column is a Partition Key or Partition Key and Clustering Key), but it was executed easily using LINQ query.

The order by operation is supported on Cassandra but only if the select statement has a where clause and the ordering column is a clustered column, this was solved by a LINQ query and data could be sorted easily.

As it can be seen in Table (3), the proposed solution focused on the most common used forms of the select statement and provided an efficient way to execute them despite of the restrictions mentioned above.

3.3 The Proposed Model Advantages and Disadvantages

Based on the model evaluation and the performance analysis, the proposed model advantages and disadvantages can be declared as following:

Advantages of the proposed model:

1. Only one query language LINQ.
2. Add any type of database if it has the appropriate ado.net provider.
3. Allow developers of any organization build their own integrated application easily using the same structure of the proposed model.
4. Overcome heterogeneity problems (syntax, structure, semantic).
5. Handle almost all common clauses used for retrieving data easily even if they are not supported by native database.
6. No data conversion from SQL to NoSQL or from NoSQL to SQL because data is executed on each data source and retrieved in uniform format.

Disadvantages of the proposed model:

1. Performance is not good enough due to slow running time but can be solved if host server has better specifications.
2. Support only Cassandra and Mongo but can be solved if provider of other types is available.
3. Support some selected clauses from SELECT statement but can be tested and applied in future.

4. Conclusion & Future Work

This paper focuses on solving problems which result from integrating and retrieving data stored in different data sources. A uniform model to integrate SQL and NoSQL databases is introduced. The proposed solution depended on an EF layer to represent meta-data information about different data sources in EDM schemas and map them to original database objects in order to execute queries. The solution used LINQ as a standard query language to write different database queries in single format, and then translated by database providers to native queries. The results were concatenated and displayed in single tabular form.

The proposed solution provides the developer with an easy and effective solution to write queries against different data sources using one query language. The solution succeeded in performing operations that are not supported by Cassandra and MongoDB. Also, it provided an efficient way to retrieve data in uniform format.

4.1 Future Work

In the future, supporting all other forms of the select statement is an important issue to be considered. Also, the proposed system was built specifically for SQL, MongoDB, and Cassandra databases so an area to be researched will be to add other NoSQL databases to the system.

5. ACKNOWLEDGMENTS

I would like to thank Dr. A. Rezk and Dr. Sh. I. Barakat for their help and guidance when supervising this research. Thanks and gratitude goes to my family and friends for their support in my study.

6. References

[1] Bc. Ondrej Pánek. Integration of Heterogeneous Data Sources Based on a Catalog of Master Entities (May 2015). Czech Technical University in Prague - Faculty of Electrical Engineering - Department of Computer Science and Engineering. Pages (1-4)

[2] Sunita Ghotiya, Juhi Mandal, Saravanakumar Kandasamy. Migration from relational to NoSQL database (2017). IOP Conference Series: Materials Science and Engineering. Vol (263). Page (1)

[3] Oluwafemi E. Ooju, Sahalu B. Junaidu, S.E. Abdullahi. TripleFetchQL: A Platform for Integrating Relational and NoSQL Databases (February 2016). International Journal of Applied Information Systems (IJAIS). Vol (10) - No. (5). Pages (54-56)

[4] Ayman E. Lotfy, Ahmed I. Saleh, Haitham A. El-Ghareeb, Hesham A. Ali. A middle layer solution to support ACID properties for NoSQL databases (2015). Journal of King Saud University - Computer and Information Sciences. Vol (28). Page (134)

[5] John Roijackers. Bridging SQL and NoSQL (2012). Eindhoven University of Technology - Department of Mathematics and Computer Science. Pages (2-4, 65-67)

[6] Tommi Kähkönen. Understanding and managing enterprise systems integration (2017). Page (13)

[7] Ananias Laftsidis. Enterprise Application Integration. IBM Sweden. Pages (1-3, 8)

[8] Marinos Themistocleous, Zahir Irani, Peter E.D. Love. Enterprise Application Integration: An Emerging Technology for Integrating ERP and Supply Chains (2002). ECIS 2002 Proceedings, 88. Page (1089)

[9] Agnes Vathy-Fogarassy, Tamas Hugyak. Uniform data access platform for SQL and NoSQL database systems (September 2017). Journal of Elsevier - Information Systems. Vol (69). Pages (8-11, 31)

[10] ThankGod S. Adeyi, Saleh E. Abdullahi, Sahalu.B Junaidu. DualFetchQL System: A Platform for Integrating Relational and NoSQL Databases (December 2013). International Journal of Engineering Research & Technology (IJERT). Vol (2) - Issue (12). Pages (1975 – 1980)

[11] Leon Forte. Building a modern web application using an MVC framework (2016). Oulu University of Applied Sciences. Page (11)

[12] Basic MVC Architecture (24/12/2018). URL: https://www.tutorialspoint.com/struts_2/basic_mvc_architecture.htm.

[13] Atul Adya, José A. Blakeley, Sergey Melnik, S. Muralidhar. Anatomy of the ADO.NET entity framework (2007). SIGMOD '07 Proceedings of the 2007 ACM SIGMOD international conference on Management of data. Pages (878-879)

[14] The ADO.NET Entity Framework Data Provider (24/12/2018). URL: http://docs.actian.com/psql/PSQLv13/index.html#page/adonet/psqldotntty.htm.

[15] Entity Data Model (24/12/2018). URL: https://docs.microsoft.com/en-us/dotnet/framework/data/adonet/entity-data-model.

[16] Entity Framework Architecture (24/12/2018). URL: http://www.entityframeworktutorial.net/EntityFramework-Architecture.aspx.

[17] Suela Isaj , Moditha Hewasinghage. Entity Framework Advanced Databases (2015). Page (4)