Selection of the Best DBMS: A Fuzzy based Multi-objective Decision Making Approach

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***Abstract*—Evolution of computer starts from human dependent to self-management in order to reduce time and complexity with increase in accuracy, reliability and efficiency. The need of self-management is realized due to maximum functionality, huge complexity and data structures to process huge data. The autonomic behavior is important in systems, networks, communication as well as database management systems (DBMSs). The tasks that a Database Administrator (DBA) performs can be made autonomic. Moreover, skilled DBAs are rare and expensive. All these factors motivated IT industry to develop Autonomic DBMSs (ADBMSs) that can manage themselves without human intervention. This paper addresses the autonomic characteristics of IBM DB2, Oracle and Microsoft SQL Server. Autonomic components of these DBMSs are identified and analyzed to illustrate the level of Autonomic Computing (AC). We have identified human intervention in these autonomic components, tools and utilities. In order to find the autonomic maturity level of a DBMS, we calculated a value against each AC characteristic of that DBMS. To get autonomic maturity value we used Multi Objective Decision Making (MODM) approach based on Fuzzy logic.**

***Index Terms*—Autonomic computing, Multi-objective, Human intervention, Oracle, DB2, SQL Server.**

I. Introduction

Autonomic Computing (AC) is a technology towards self-managing system with a minimum human intervention and hiding the low level complexities from the users. AC system contains set of elements that includes Managed, Monitor, Analyze, Plan, Execute, Sensor and Effecter. All these elements are connected with each other in a loop. The Process Control theory is the basis of self-managing systems where different activities are monitored and managed [1-3]. There are five levels of AC, which are Basic, Managed, Predictive, Adaptive and Autonomic level [4]. The main purpose of AC technology is to make each component autonomic with respect to external interface and behavior. The systems are operated by humans; however this human intervention may be the cause of most of the errors. This may happen even by the trained operators and managers due to complexity. So less experience is required to users as AC environment is more responsive and real time. Moreover, due to human intervention, cost of ownership also increases [5]. In DBMS all the functions such as memory management, storage management, backup and recovery had been performed by the DBA. Managing, tuning and testing of a DBMS is difficult and time consuming task especially in complex and real time systems. To handle these kinds of errors there is a need to make DBMS that have self-managing capabilities i.e. Autonomic DBMS. The ADBMS has six basic AC characteristics (self-*) [1-6], which are Self-Optimization, Self-Configuration, Self-Healing, Self-Protection, Self-Inspection and Self-Organization.

Considerable research has been done in DBMSs with respect to AC and it provides introduction of algorithms, framework and methodologies to develop AC components, utilities and tools. The research [7-15] discussed the architecture of AC components that are used for different database features such as statistics collection, physical design recommendation, memory and storage management etc. Other researchers discussed the autonomic elements w.r.t. AC characteristics to show that how much DBMSs are autonomic [16-22]. In the context of AC, some vendors and researchers have performed the comparison of DBMSs that reveals their strengths and weaknesses [23, 24]. There is an extensive literature on AC in databases; however none of the research has provided any mechanism for evaluation of autonomicity in different components, tools and utilities. To the best of our knowledge none of the researcher or vendor has addressed this problem. Our work is different from the previous work by incorporating the analysis of AC elements and identification of human intervention; finally based on fuzzy logic we have evaluated the autonomic maturity level of DB2, Oracle and SQL Server against each AC characteristic.

The organization of the paper is as follows: section II presents the discussion on the state of autonomicity in Oracle, DB2 and SQL Server, section III provides a comparative analysis over autonomic computing features in three database management systems, section IV identifies the optional and mandatory human intervention found in the autonomic elements, features and utilities, section V calculates the AC maturity level of each DBMS Multi Objective Decision Making (MODM) approach based on fuzzy logic and finally section VI concludes the paper and provides the future work.

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II. Autonomic Capabilities in DBMSs

This section provides the characteristic-wise AC capabilities incorporated in Oracle, DB2 and SQL Server; more detail can be seen in [20-22].

A. ORACLE by Oracle Corporation

Oracle has a number of components which have self-optimization characteristics that are Automatic Tuning Optimizer, SQL Tuning Advisor, Automatic Statistics Collection, Automatic Database Diagnostic Monitor (ADDM) and Automatic Workload repository (AWR). Automatic Tuning Optimizer identifies high load queries, generates candidate Query Execution Plan (QEP), improves the QEP and finally selects the best QEP for query execution. It uses cost and heuristic based techniques for the optimization of QEP. SQL Tuning Advisor [5] is used with automatic tuning optimizer that produces tuning advices for incoming queries so that best QEP can be generated. Oracle generates different types of statistics like database, operating system and interpreting statistics. ADDM [25] provides the central intelligence to Oracle database to improve efficiency. Its activities are SQL tuning, space fragmentation analysis, CPU bottlenecks, undersized memory structures, I/O capacity issues, top SQL or PL/SQL execution & compilation, configuration and concurrency issues. AWR [26] collects the performance statistics about the wait events, time model, active session history, system, object usage, resource intensive, top SQL statements and supports other Oracle components.

Three components are used for automatic configuration in Oracle, which includes Configuration Management (CM) Pack, SQL Access Advisor and Automatic Memory Management component. The CM pack [19] collects configuration information about the system's hardware and software components. SQL Access Advisor [26] recommends partitions, materialized views and indexes on the basis of workload. It considers the space usage and query performance to recommend an efficient and cost effective configuration. Automatic Memory [7, 24, 27] tuning is performed by distributing and redistributing the memory as required by the system global area (SGA) and program global area (PGA). Memory is allocated according to given workload and object's requirement.

Oracle has components to heal database that include Oracle Manager Console and Recovery manager. Oracle Manager Console observes the system health regularly and collects performance data. When un-healthiness occurs within the database system, it informs and provides proper suggestions to maintain the system health. However, the Recovery Manager performs backup and recovery.

Oracle has number of self-protection components such as Oracle Resource Manager (ORM), authentication and security mechanism. ORM handles and controls all the processes running in parallel. It tracks the consumption of CPU time, concurrently active sessions and performs scheduling of processes and threads. Service level agreements are also specified and triggered when some specified event occurs. Authentication and security [24] is provided by allocating privileges to different users. Oracle security components and tools are Single Sign On, Encrypted Network Traffic, Virtual Private Databases, Label Security, Row and Column Level Data Encryption.

Oracle performs organization of data through Automatic Storage Management (ASM) component and Reorganization feature. ASM manages disk groups and disk redundancy, I/O balancing etc [23, 26]. Oracle has reorganization features like online index creation, online index rebuild, online index join and table redefinition [26].

B. IBM Universal Database DB2

DB2 has a number of components which have self-optimization characteristic such as LEarning Optimizer (LEO), Automatic Statistics Component (ASC), Performance Expert (PE) and Load utility. Parallelism enhances optimization and is used for query I/O, CPU and scalable query [14]. LEO generates best QEP for a given query by using existing materialized view instead of actual query automatically [15]. Different statistics are collected through ASC component. ASC monitors activities such as update, delete, insert and collects performance data or statistics to improve performance [28]. ASC uses CORDS [8] to find the correlation and soft functional dependencies between a pair of columns and recommends the statistics for query optimizer. PE [11] monitors statistics, events and applications to resolve the critical performance issues such as locking conflicts and number of threads. Load utility collects data through parallel subagents & maintains the indexes for the destination tables either rebuilding or extending these [16].

DB2 provides Configuration Advisor, Design Advisor and Self-Tuning Memory Manager (STMM) to achieve self-configuration characteristic. Configuration advisor [16, 29] defines a set of initial database configuration parameters and memory allotments for different database objects and users. It provides recommendations and has ability to apply these. Design advisor recommends physical design for a given workload [16, 19, 30] automatically. STMM [12] tunes the memory by distribution and redistribution according to the workload. It allocates appropriate memory for each database and configures critical memory usage for two or more users without user involvement.

Health Centre, Maintenance Advisor and Recovery expert Tool are used for healing the database. Health Centre [16] observes the database systems, storage and memory consumption, logging behavior and concurrent applications to ensure the database strength and system health. Maintenance Advisor [18] uses already collected statistics to identify the objects that require maintenance, type of the maintenance, its schedule and estimated time for the maintenance. Recovery Expert Tool [16, 19] recovers the database to a consistent state by analyzing available information and suggesting a suitable recovery technique.

DB2 has self–protection characteristic that is provided through Query Patroller, authentication and security mechanism. Query Patroller controls [16] the flow of requests by accepting, analyzing, prioritizing and organizing the requests according to the available resources and workload.

DB2 implements self–inspection characteristic through Autonomic Health Monitor and Consistency Checking mechanism [18]. Autonomic Health Monitor examines the system availability, storage & memory usage and application concurrency. Consistency Checking Mechanism detects the corrupted data through a consistency bit and ensures the integrity of data.

In DB2, reorganization is performed through IBM Storage Manager, Space Estimation tool and dynamic online index reorganization. The IBM Storage manager [10] collects the valuable statistics and defines thresholds for automatic alarms. It tracks free space in DB storage paths, storage consumption; resize table-space status and its utilization. Online or offline reorganization can be done for table as well as indexes [18, 19]. Due to the reorganization, effective use of system resources is achieved for performance and efficiency.

C. *Microsoft SQL Server*

SQL Server has a number of components such as Query optimizer, Statistic management component, Performance Monitor (PM) and Dynamic Management views (DMV) that perform self-optimization. Query optimizer parses, analyzes and executes a given query in an efficient way. SQL Server performs optimization by analyzing query, selection of indexes & join, selection of best QEP and finally its execution. Statistic management component [9] is used to collect the statistics that are further utilized by the query optimizer and other SQL Server components.

It specifies the object on which statistics creation is required, when and how it will be created. PM [13] observes and controls CPU activity, memory, paging and disk I/O. Dynamic management views and functions are used to watch health, find out the problems and tune.

SQL Server provides the configuration tools which are Configuration Manager, Database Tuning Advisor (DTA) and Dynamic Self Tuning Memory Manager (DSTMM). The Configuration Manager [17] manages different services, configuration of network protocols and connectivity between client and server. DTA [31] is a design tool that provides the recommendations for horizontal partitioning, materialized views and indexes. DTA can handle large databases and workloads by using different techniques such as workload compression, reduced statistics collection etc. DSTMM [12] is used for automatic memory management and is based on Non Uniform Memory Access (NUMA) architecture. It tunes the database memory as a whole instead of tuning in parts.

Self-protection is provided through Resource Governor, Maintenance Plan, authentication and security mechanism. Resource Governor [32] manages the workload and resources with business intelligence. It provides a consistent, balanced and predictable response by imposing limits on resource consumption. It provides performance for concurrent workload by using a profile created by DBA. Automatic backup and recovery [20] is provided through a feature called Online Restore. This feature allows DBA to perform a restore operation and during the process data remain available to user for other operations. SQL Server provides authentication and security mechanisms [24] for databases by assigning privileges to users.

SQL Server provides components and tools with respect to self-inspection such as monitoring tools and Database Consistency Checking (DBCC). There are three monitoring tools that are SQL Server Profiler, System Monitor and Activity Monitor [33]. These tools are used for performance monitoring and tuning of the database. System Monitor tracks resource usage such as memory utilization and server performance. DBCC [17, 23] checks the database consistency, fragmentation, performance statistics and corrupted data.

SQL Server provides Automatic Storage Management (ASM) component, Dynamic Online Index Reorganization, Storage and Partition Wizard for the self-organization of data. ASM [32] divides large tables across multiple files, stores text and image column in different files and places it on the specific disks spindles so that I/O throughput can be improved. Storage and Partition Wizard [19] are used to layout data cubes on disks. Partition wizard provides flexible options for table and index partitions. Storage wizard specifies the data storage and query performance by joining on a cube. Dynamic online index reorganization is used to re-organize the indexes to improve performance.

III. Comparative Analyses of ORACLE, DB2 and SQL Server

The comprehensive analysis of the selected DBMSs over the AC characteristics is discussed as:

A. *Self-Optimization Analysis*

All three optimizers use the cost based model for estimation and are autonomic i.e. performing most of the tasks without any human intervention. Some additional features of LEO are feedback exploitations, analysis daemon, skeleton and monitor component. Oracle optimizer has strong analysis mechanism including statistics, estimates, access path, parameter setting and sql structure analysis. The SQL Server optimizer performs an additional step after best QEP generation where again the optimization is performed for serial and parallel execution. When there is no or poor indexes, DB2 and Oracle optimizer creates new indexes by using performance data while SQL Server optimizer uses heuristic based methodology. Oracle optimizer finds error estimation against cardinalities during the selection of best QEP while LEO performs the error estimation only for final QEP. In Oracle and SQL Server, query optimization is influenced by hints while LEO does not allow such type of influence and relies on its automatic optimization. LEO has ability to rewrite queries on objects residing on a remote DBMS and can perform semantic optimization. SQL Server has less time based numeric statistics as compared to Oracle views and takes online statistics using PM. Correlated statistics are used by all three DBMSs for optimization. In case of missing or old statistics, LEO takes the statistics from the base parameters of table, Oracle uses the total number of occupied extents of the table while SQL Server uses Use Plan & Plan Guide features manually. In DB2, PE is used to resolve the critical performance issues, manages and monitors DB2 instances, system statistics, parameters, recent events and applications provides recommendations over bottlenecks. PE also

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maintains exception log and provide information about buffer pool. In Oracle, ADDM performs SQL tuning, space fragmentation analysis, CPU bottlenecks, high load PL/SQL execution & compilation, database configuration and concurrency issues. In SQL Server PM stores, monitors and tunes the database server. Oracle's AWR and SQL Server's DMV provide information to other components for intelligent decisions. DMV automatically monitors and captures statistics for dynamic reconfiguration where AWR configures by explicit instructions. Load utility is only available in DB2 to load data by optimal selection of memory and maintains indexes.

B. Self-Configuration Analysis

DB2 Configuration Advisor identifies configuration parameters (I/O optimization, parallelism, memory distribution, recovery and logging and memory allotments). In Oracle, CM pack collects the information about CPU, memory, storage, operating system, database, applications and third party software. Its features are identification of the dependence relationship, historical change tracking, faster problem resolution and root cause analysis. SQL Server Configuration Manager manages various services, network protocols configuration and client server connectivity. DB2 Design Advisor, Oracle SQL Tuning Advisor and SQL Server's DTA are used for the physical design. DB2 Design Advisor performs the selection of indexes, materialized views, shared-nothing database partitioning and multi-dimensional clustering of the tables. Oracle's SQL Access Advisor provides recommendations over partitions, materialized views and indexes. DTA provides recommendations for horizontal partitioning, materialized views, indexes, performance and manageability. DB2 uses STMM, Oracle uses ASMM and SQL Server uses DSTMM for the self management of memory. STMM allocates memory dynamically while ASMM performs this task via human input. STMM can configures all the critical memory consumers while ASMM cannot tune two memory consumers (sort and buffer pools). STMM tunes distributed memory while DSTMM tunes the total memory. The architecture used by the DSTMM is NUMA and its additional features are uniform dynamic caching framework and common memory brokerage.

C. Self-Healing Analysis

DB2 Recovery Expert Tool recovers the database to a consistent state. Backup is restored by using database history and necessary incremental images. In Oracle, DBMS Scheduler collects statistics, recognizes database objects and monitors steps to perform backup and recovery. While in SQL Server, Online Restore is responsible for backup and recovery. When database corrupts, Oracle provides more recovery options than SQL Server. When system tablespace is lost in SQL Server, it uses a utility for the recreation of master database that is comparably better than Oracle. Oracle provides reliable mechanism of recovery, backups and online files via logical dumps as compare to DB2 and SQL Server. DB2 Health Center ensures DB strength while Oracle performs this via OMC.

D. Self-Protection Analysis

DB2 QP is used to accept, analyze, prioritize, and schedule workload; and shows the running and completion status of different tasks. It provides sufficient resources for different tasks and avoids saturations. The Oracle's ORM controls all the parallel running processes by observing CPU time, concurrently active sessions; performs processes scheduling and take decision about the process continuation or suspension. DBA can set scheduling policies for the workload in ORM. Resource Governor manages workload and resources by providing a consistent and predictable response. It provides performance for concurrent workload; suggests priorities and defines threshold. These DBMSs provide authentication and security to prevent unauthorized access. DB2 and SQL Server provide table level while Oracle provides row level security. DB2 and SQL Server use operating system capabilities for security as compared to Oracle. Oracle has many authentication methods (user, operating system and network authentication). Application roles are defined in Oracle and SQL Server to prevent user access from tables/ views but DB2 do not has such support.

E. Self-Inspection Analysis

DB2 Health Monitor and SQL Server Monitoring Tools track and monitor files, tables, events, activities and resources. DB2 provides consistency over corrupted data through a consistency bit. Oracle DBCC provides consistency over index, table fragmentation, index fragmentation, tuning of data and performance statistics. SQL Server DBCC observes the database consistency, fragmentation, performance statistics and corrupted data.

F. Self-Organization Analysis

The DB2 Storage Manager collects valuable statistics, defines thresholds and calculates the required database space. Oracle's ASM manages disk groups and disk redundancy, I/O balancing etc. SQL Server's ASM divides the large tables across multiple files, stores text & images in different files; and takes backup & restore. There are two types of temporary tables (user and global) in SQL Server while Oracle supports only global temporary table. As compare to user temporary table, global temporary table is either manually dropped or when server is restarted. DB2 and SQL Server allow online index reorganization while Oracle allows moving table as well as indexes. SQL Server provides limited online index reorganization in comparison with DB2 and Oracle. SQL Server Storage Design and Partition Wizard manage the data storage, query performance, table and index partitions.

IV. Human Intervention in DBMSs

Human intervention can be used to measure the autonomicity of the DBMS, i.e. less human intervention reveals more autonomic behavior and vice versa. We have discussed mandatory and optional human intervention in different autonomic components of three selected DBMSs.

Most of the tasks performed by all three optimizers are without any human interaction. Oracle query optimizer manually loads SQL plan baseline and amount of optimization. User has the option to set optimization goals

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in Oracle optimizer; whereas there is no such provision in LEO and SQL Server. In SQL Server query optimizer, when statistics are missing against any object, DBA collects statistics through Use Plan and Plan Guide features manually. In DB2, Oracle and SQL server statistics can be collected automatic and manual when required. In Oracle, when statistics mode or level is BASIC, then AWR statistics are captured manually. The high workload can be identified manually by watching the statistics and information available in AWR. In SQL Server, when statistics are missing or there are no statistics against any object then human intervention is required to provide he sufficient information.

DB2 PE, Oracle ADDM and SQL Server PM are used to monitors the database and provide tuning suggestions. DB2 Resource Limit facility allows the user to limit parallelism. In DB2, different activities for the configuration of scheduler can be performed manually like controlling scheduler activities. Oracle CM Pack is responsible for configuration with a little bit human intervention. In SQL Access Advisor, if table contains some bitmap indexes that cannot be migrated until their manual removal and replacement by executing advisor script. DB2 STMM configures memory automatically but for the first time DBA allocates memory to different consumers. However after first time allocation, memory is distributed among different consumers automatically. In Oracle ASMM user can limit the shared memory whereas DB2 STMM do not require such manual interaction. Similarly the buffer size in Oracle can be shrunk manually. The memory pools such as Log buffer, other buffer caches and Fixed SGA are manually sized by the DBA from available memory. During backup and recovery in SQL Server, database snapshot feature is automatic but if fails then lost changes will be recovered manually. Through DB2 Query Patroller, user can set the threshold for query execution cost and if some query exceeds this limit then query is handled by the DBA. ORM allows DBA to set execution time for queries and workload. SQL Server Resource Governor uses a profile that is created by the DBA; it contains the information about resource limits and priorities for different groups. Shrinking of database or file is performed through SQL Server Enterprise Manager and its scheduling is performed by DBA. ASM in Oracle allows the relocation of bad blocks to uncorrupted space of disk via a utility manually.

V. Autonomic Maturity of DBMSs

We have surveyed the literature and case studies of DB2, Oracle and SQL Server. A comparative autonomic maturity value has been assigned against each autonomic characteristic based on fuzzy logic [34]. These values are based on survey [20-22], previous case studies, existing human intervention and by taking opinion from different database experts of DB2, Oracle and SQL Server. The autonomic maturity value against each autonomic component of three DBMSs is calculated and assigned, which can be seen in [35] .We have used fuzzy logic to choose the database according to required preferences. Fuzzy logic is related with fuzzy set theory that gives approximate value with range from 0 to 1. It is used in all fields such as control theory, engineering, networks, artificial intelligence etc.

A. *Fuzzy based Multi-objective Decision Making*

Suppose to solve multi-objective problem you have 'A' attributes, that should meet 'O' objectives, where 'P' preferences are given by the problem solver.

A = [a1, a2, a3, ..., an]
O = [O1, O2, O3,…, Om]
P = [b1, b2, b3, …, bm] ⟶ [0, 1]
Overall best alternative is
D* = Max [D(a1), D(a2), D(a3), ..., D(an)]

Where D(ai) = (b1' U O1) ∩ (b2' U O2) ∩....∩ (bm' U Om)

This approach has been applied to find the best DBMS with respect to autonomic characteristics.

Problem: An organization requires a DBMS, the choices for DBMS are DB2, Oracle and SQL Server. There are six evaluating criteria which are self-Optimization (sO), self-Configuration (sC), self-Healing (sH), self-Protection (sP), self-Inspection (sI) and self-Organization (sOr).

A = [DB2, Oracle, SQL Server]
O = [sO, sC, sH, sP, sI, sOr]

From [35], Autonomic maturity values with respect to six self-* characteristics are shown in Table 1.

Table 1
Autonomic maturity values

Self-*	DB2	Oracle	SQL Server
sO	0.4	0.4	0.2
sC	0.5	0.2	0.3
sH	0.4	0.3	0.3
sP	0.3	0.6	0.1
sI	0.5	0.2	0.3
sOr	0.3	0.3	0.4

Case 1: Let we take scenario with preferences, where a database is required to be more optimized, configured and heal features.

P = [0.8, 0.9, 0.7, 0.4, 0.2, 0.1]
D* = Max [D(a1), D(a2), D(a3)]
D* = Max [0.4, 0.2, 0.2]
D* = 0.4

Case 2: Let we take a scenario with preferences, where a database is required to be more secure and optimized.

P = [0.8, 0.1, 0.4, 0.9, 0.3, 0.1]
By performing above calculation, we will get:
D* = Max [0.3, 0.4, 0.1]
D* = 0.4

Case 3: Let we take another scenario with preferences, where a database is required to be more re-organized with some optimized and secure feature as compared to others.

P = [0.4, 0.3, 0.2, 0.4, 0.2, 0.9]
By performing above calculation, we will get:
D* = Max [0.3, 0.3, 0.4]
D* = 0.4

In Case 1, we get highest value that corresponds to DB2 for the given preferences (P). Therefore in this scenario DB2 is the best choice as compared to Oracle and SQL Server. If first choice is not selected due to some circumstances then Oracle will be second selection. In Case 2, highest value is obtained against Oracle, so Oracle is the best choice as compared to DB2 and SQL Server. For the second and third choice DB2 and SQL Server can be selected against given preferences. Case 3 gives the maximum value that corresponds to SQL Server for the given preferences.

VI. Conclusion & Future Work

We have explored and analyzed the AC components, utilities and tools of DB2, Oracle and SQL Server with identification of human intervention. We are the first who have provided a way to measure the AC maturity level by identifying human intervention and representing it in the form of fuzzy set. The autonomic maturity value against each component has been reported in this research. From this discussion, we have identified the strengths and weaknesses of DBMSs; that will provide the basis for improving the current autonomous status in DBMSs. Further robustness requires incorporation of analytical models, intelligent and mining algorithms and techniques. The techniques, models and algorithms adopted by these components can still be enhanced to achieve the higher level of autonomicity. We have identified human intervention in AC elements of DB2, Oracle and SQL Server; this type of study can be performed on other DBMSs to improve their AC maturity level. There is a need to introduce intelligent algorithms, techniques and models to minimize human intervention in DBMSs.

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