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Optimization of Query Processing in Versatile Database Using Ant Colony Algorithm

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Abstract

Nowadays, with the advancement of database information technology, databases has led to large-scale distributed databases. According to this study, database management systems are improved and optimized so that they provide responses to customer questions with lower cost. Query processing in database management systems is one of the important topics that grabs attentions. Until now, many techniques have been implemented for query processing in database system. The purpose of these methods is to optimize query processing in the database. The main topics that is interested in query processing in the database makes run-time adjustments of processing or summarizing topics by using the new approaches. The aim of this research is to optimize processing in the database by using adaptive methods. Ant Colony Algorithm (ACO) is used for solving optimization problems. ACO relies on the created pheromone to select the optimal solution. In this article, in order to make adaptive hybrid query processing. The proposed algorithm is fundamentally divided into three parts: separator, replacement policy, and query similarity detector. In order to improve the optimization and frequent adaption and correct selection in queries, the Ant Colony Algorithm has been applied in this research. In this algorithm, based on Versatility (adaptability) scheduling, Queries sent to the database have been attempted be collected. The simulation results of this method demonstrate that reduce spending time in the database. According to the proposed algorithm, one of the advantages of this method is to identify frequent queries in high traffic times and minimize the time and the execution time. This optimization method reduces the system load during high traffic load times for adaptive query Processing and generally reduces the execution runtime and aiming to minimize cost. The rate of reduction of query cost in the database with this method is 2.7%. Due to the versatility of high-cost queries, this improvement is manifested in high traffic times. In the future Studies, by adapting new system development methods, distributed databases can be optimized.

Keywords: Database; Ant Colony Algorithm; Query Processing; Versatility; Optimization.

1- Introduction

Query processing is the technique of data transmissions in a database system. The efficiency of a database depends on the technique used by it to obtain and retrieve data. usually, the database must have the ability to respond to the queries of the users and provide information [1]. In fact, the main part of database-management system is query processing and optimizing it [1]. Several methods have been presented to optimize query processing in the database nowadays. Some of these methods have proposed proper solutions for optimizing the queries and running relational, textual, and Xml data [2].

The main reason for this need is the essential need to optimize queries. When optimization queries made with Selinger-Style (Application systems database) failed, the obtained outcomes (system chaos and creation of new algorithms) struck a blow for large companies' increase of research in the comparative features of their database products [3].

Ant Colony optimization algorithm was presented by Dorigo et al. for the first time for difficult issues of theoretical optimizing of the traveling salesman. So far, this algorithm has been used for optimization problems, such as traveling salesman, balanced scheduling in networks, various data mining techniques such as clustering, and so on [4].

The Ant Colony algorithm is inspired by studies and observations on Ant colonies [5,6]. These studies have

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shown that Ants are social insects that live in colonies and their behavior is more towards the survival of the Colony than towards the survival of a part of it. One of the most important and interesting behavior of Ants is their behavior to find food and especially how to find the shortest path between food sources and nest [7, 8].

This type of behavior of Ants has a kind of mass intelligence that has recently attracted the attention of scientists [9,10]. In the real world, Ants first randomly go back and forth to find food [11]. Then they return to the nest and leave a trail of pheromone. Such traces turn white after rain and are visible. When other Ants find this path, they sometimes stop roaming and follow it. Then, if they get food, they return home and leave another mark next to the previous one; And in other words, they strengthen the previous path [12,13]. The pheromone evaporates over time, which is useful in three ways [15,16]:

- Makes the path less attractive for subsequent Ants. Since an Ant in a long-time travel more and reinforces shorter paths, any path between home and food that is shorter (better) is reinforced more and the one that is farther is less.
- If the pheromone did not evaporate at all, the paths that were traveled multiple times would become so over-attractive that they would greatly limit random foraging.
- When the food at the end of an attractive path runs out, the trace remains.

Figure 1 shows these ways [17]. In this figure, for example, different ways of getting from the origin to the destination and back are shown. These paths have been improved over time and based on the routing Algorithm of Ants, and the short path in the three parts of the image has been selected in red color.

Therefore, when an Ant finds a short (good) path from home to food, the rest of the Ants will most likely follow the same path, and by continuously strengthening that path and evaporating other traces, eventually all Ants will follow the same path.

The purpose of the Ant Algorithm is to imitate this behavior by artificial Ants that are moving on the graph. The problem is to find the shortest path and the solution is these artificial Ants [18].

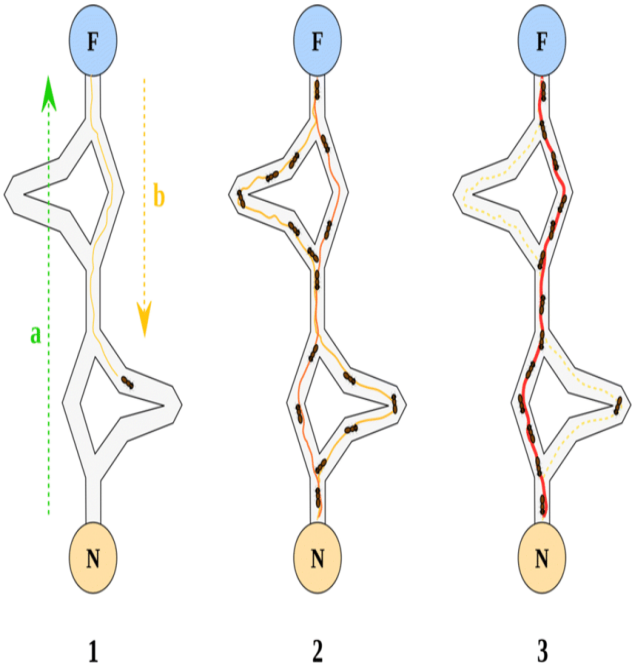

Fig. 1: Ant Colony ways

One of the applications of this algorithm is to optimize various problems. So that all kinds of Ant algorithms have been prepared to solve this problem. Because this numerical method has an advantage over analytical and genetic methods in cases where the graph constantly changes with time; and that it is an algorithm with repeatability; and therefore, with the passage of time, it can change the answer live; that this feature is used in computer network routing and caching. Urban transportation system is important [19].

Fig 2. Show the Ant Colony Algorithm and formula [20].

As shown in this algorithm. This method is a convergent method. In this method, the paths are selected by choosing random methods, but based on which paths are smaller, the amount of pheromone of the path is increased, and in the other part of the algorithm, the probability of choosing this path for other Ants is increased. With the passage of time and after the implementation of the algorithm, the convergence towards the optimal path has been done.

In this paper, we have tried to present a new method for optimization of query processing in database by using versatility methods and Ant Colony algorithm.

Step 1: [Initialization]

t:=0; NC:=0;

For each edge (I,j), initialize trail intensity to $(0):=T_{ij}(0):=T_0$

Step 2: [String node]

For each ant k:

Place ant k on a randomly chosen city and store this information in $Tabu_k$

Step 3: [Build a tour for each ant]

For i from 1 to n:

For k from 1 to m:

Choose the next city I,j € Tabu$_k$, among the c candidate cities according

$$J = \{arg\ max\{[Ti(t)] \propto .[\mu]\beta\}$$

Where J is chosen according to the probability:

$$P_{ij}^{k}(t) = \frac{[Tij].[\mu]\beta}{\sum[Tij(t)\alpha.[\mu]\beta}$$

Store the chosen city in $Tabu_k$

Local update of trail for chosen edge (I,j):

$$Tij=\rho.Tij(t) + (1-\rho t).\Delta Tij \quad where\ \Delta Tij = T0$$

Step 4: [Global update of trail]

Compute length of tour, L_k*, for each ant k*

Apply local improvement method for the tours of all ants k and recompute L_k

For each edge (I,j) € Cycle, update the trail according to:*

Step 5: [Termination Conditions]

Memorize the shortest tour found to this point

IF (NC<NC_{MAX} *) and (Not stagnation behavior)*

THEN empty all $Tabu_k$ *and go step #2*

ELSE Stop

Fig. 2: Ant Colony Algorithm and formula

In this article, firstly, the previous work done regarding the optimization of processing in the database is examined, and then the proposed algorithm is explained in three parts, and then the proposed method is evaluated and examined with other parts, and finally, the results of the plan are also presented. The purpose of this research is to adapt database queries in order to reduce the execution time of queries in the database.

2- A Review of Previous Studies

Query-processing optimization is carried out with the aim of reducing resources, time, and so on. Optimization in the database can be done in three general categories. The three categories include server, query, and sessions [19]. In server method, hardware techniques are used to optimize. In the second method, using query process optimization, it is tried to optimize [21,22]. The third method is among the groups placed neither in the first nor in the second method.

In this paper, the third methods are used to optimize query processing in the database.

Among approaches to optimize query processing in database is using selection techniques [23]. In this method, the selected orders change. Some of the methods have used data classification for query processing [24]. Using caching mechanism to optimize query processing in the database is another method used for query processing in the database [25].

In this database query processing is used [26]. the results of the queries in this method are stored based on Xml model and when needed they are available [21]. Other versatility-based methods have been done in the database. These methods have been proposed in the past few years. In one of the methods, by versatility of the queries sent to the database, response time has reduced [22]. In another method, versatility method has been used to optimize the processing of queries distributed in the database [23]. In this method, using identification of the frequently-used queries in database and based on its implementation plan, it is attempted to optimize query processing. In this method, based on identification of similar and frequently-used queries, over time, it is attempted to optimize the query processing in database [27,28].

Ant Algorithm has various applications and it is used to optimize and solve various problems. Among these issues, can mention for using of this algorithm in improving route optimization. For example, this algorithm has been used in improving the balance of wireless sensor networks and in its routing based on the Internet of Things. In this issue, the purpose include to balance the traffic load and increase the speed of transferring packets in the network. So that the data packets reach the destination through paths with minimum density. As a result, one of the main methods to solve routing and load balancing problems is to use Ant-based algorithms. The aim of this research was to provide a suitable routing algorithm in order to shorten and improve the route in IoT-based systems [29].

In another research, Colony's Algorithm has been used to provide a nonlinear regression model for signal processing. In this issue, the goal was to provide a model and improve time [30].

One of the other finding for query optimizer processing in the database is DeepO. In this method, interactive optimization has been done in the PostgreSQL database with the help of machine learning which is presented in 2022 [31]. Another research in query processing optimization is a practical learner [32]. In this method, by creating an trial-and-error Agent, it can be used to reduce the number of transactions in the database with the memory-based learning method [33]. In another study, the query optimization process is redefined so that compiler optimizations come into high-speed transactions than previous data distributions, and compiler optimization

employ as a driving force in query optimization. This new generation of query optimizers will be capable to optimize queries for significantly better performance than modern query optimizers [34]. Another effective way, with the applying of a margin generator, it has been added to provide a Matcher based on SQL customization to optimize descriptions. The purpose of this method is to preserve textual connections so that optimization can be done based on these connections. It has been presented due to its features and characteristics, including robustness, global optimization, Data parallelism involved the ability to act simultaneously and independently, and the ability to integrate [35]. In another research, to accelerate query operations and faster enrollment is Key performance indicators that has been added to the scalability of the distributed database. These indicators are aimed at improving the database query efficiency and speeding up the database query process and are provided with the help of the Ant Colony Algorithm [36].

In another study, the Clone Algorithm was used to generate test data for the database. In this research, search-based test data generation reformulates the test objectives as fitness functions, therefore, test data generation can be automated by meta-heuristic algorithms. Meta-heuristic algorithms search the domain of input variables in order to find input data that cover the objectives [37,38].

In another research, Ant Algorithm has been presented to provide a model for an intelligent virtual assistant. In this research, in order to increase reliability in education, an optimal model has been presented using the Ant method [39].

In this paper, we have tried to use the versatility of the above method for query processing in the database, but in this method, Ant Algorithm is used to enhance versatility.

3- The Proposed Algorithm

Today, the use of free and nature methods in solving complex problems are of the strategies used to solve complex problems [40,41].

In this study, we have tried to develop the previous methods ways to provide a new method to optimize query processing used in the database. Ant Colony Algorithm has been used to develop the method. The goal of the study is to examine the versatility of query processing in the database. In this paper, we try to identify the frequently-used queries sent to the database, so that by maintaining the implementation plans related to these queries and reducing implementation steps optimize query processing.

Utility software has databases sending queries to database according to user needs, based on which the needs of the users are met. This software usually sends queries to database according to which receives the responses and meets users' needs. In this software, the sent queries usually have the same structure, and these queries are iterated over time.

So far, various solutions have been proposed for query processing in the database. Some of these solutions are based on caching information and some are based on caching questions. The main reason for using query caching is related to the ٧ stages of query processing in the database. One of the most important points is the implementation of the question. For example, in stored procedures, the ready execution plan is used to provide the output and the execution time is reduced. In the proposed method, our main approach is high traffic times and identifying frequent questions by making them adaptable. Naturally, this method and maintenance of execution plans for subsequent executions can be effective, as in the proposed method, the identification Ant's Algorithm is used.

In this paper, we have tried to present a model by using Ant Colony method, so that the database, over time [42,43], identifies the queries of the same type with high iteration and respond to them with specific implementation plans. In other words, the database matches the data to use ready implementation plans processes the queries at lower cost and faster.

There are several stages to process the queries in the database. With this method and with the help query implementation plan, one can reduce the cost of processing frequent queries in the database.

Various methods have been proposed for this type of versatility in the database [44, 45]. One of the four methods uses four parts to process the query in the database. These three parts include:

- Separator of commands
- Replacement policy
- Detector of the similar queries

By changing the method in replacement policy in this paper, we try to use Ant Colony Algorithm to optimize act query processing in the database.

The study uses the three components below to optimize query processing in the database.

3-1- Separator of Commands

The purpose of this part of the algorithm is to separate low-cost or non-optimizable commands. Commands such as Insert are among the commands that cannot be optimized and are added to the database by specific implementation plan, so these commands should be separated from optimizable ones.

For this method, the same method used in the previous work has been used [19,20]. This method has used comparison to separate query processing in database.

3-2- Replacement Policy

One of the most important parts of the versatility methods is determining how, when, and with what policy the placement is done. This means how database identifies the frequently used commands to maintain its implementation plan in the database.
For versatility, the system would listen to the queries submitted to the database and replace the implementation plans of the similar queries with the highest frequency sent to the database and wait for responses to the future queries (It should be noted that only the queries will be sent to this section that have been accepted by separator).
To identify the frequently-used queries, Ant Colony Algorithm is used.
Ant Colony optimization algorithm, which was presented by Dorigo et al. for the difficult problems of theoretical optimizing of the traveling salesman, is the important aspect of the behavior of Ants to find the shortest path between the nest and the food source [11].
Figure 3 shows how the random paths converge to the shortest path.

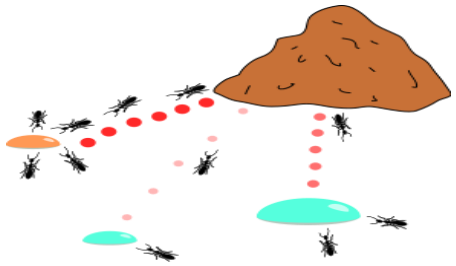

Fig. 3: Ant Colony Algorithm Procedure

One of the features of this algorithm is based on iteration and accidents that in case of increase in the number of iterations can help reach the response of solving problems [11].
In this method, for the queries, we develop the paths and based on the queries sent to the database, we enhanced the pheromones of the path. After a while, by identifying high pheromone queries and based on their frequency, one can identify frequently-used queries.
It is noted that due to the number of queries submitted to the database, in lack of exposure of pheromones after a certain period of time, paths (queries) are deleted.
Concerning the interval between two versatility actions, it should be stated that this interval will be calculated based on the frequency of pheromones of the queries made versatile in a dynamic way. This means that if the frequency of pheromones is high, the database will use these versatility queries for a long time for query processing in, and if pheromone frequency is low, it will work for a shorter time with this versatility.
Not only, versatility operation is conducted on queries that are sent to the database in high-traffic time, but also stores the sent queries at versatility and high traffic time, and then the versatility is done on run queries in less time.

3-3- Detector of Similar Queries

This algorithm uses previous methods to detect similar queries [48,49]. The general approach in this part is that the queries submitted to relational data database are different based on parametric values. Thus, similarity detector can identified detecting excess similarity by sequence comparison. Obviously, implementation plan of similar queries is the same.

3-4- The Overall Approach of Algorithm

The Overall classification of algorithm approach is similar to previous studies [5]. In this algorithm, based on versatility scheduling is attempted to collect queries sent to the database. By versatility, exception queries are separated with the help of separator and are not stored.
Then with the help of any Colony Algorithm and replacement policy, frequently used queries are detected, and actions a taken to replace and maintain their implementation plans.
The task of the part related to the similarity of queries is detecting the similar queries in the database.
Figure 4 shows the general Algorithm of this procedure. In this algorithm, the way to implement the optimal algorithm is provided by three main procedures. In this algorithm, first, the commands of optimization ability are separated, then in the next section, the most common basic commands are selected, and in the last part, the replacement policy based on Ant Colony Algorithm.

Query Optimization Algorithm

1. Begin
2. Examine query by separator
3. Produce query execution plan if query is one of exceptions
4. If it's not an exception check its execution plan availability on the system by similarity recognizer
   4.1 If execution plan exists select it
   4.2 otherwise, send it in order to produce execution plan
5. Executing plan for replying to query
6. Check whether it is time to substitute or not?

6.1 If so, do the substitution.

7. END

Fig. 4 The overall algorithm

It should be noted that in the case of implementation of the database, Database Management system can use the available implementation plan to implement similar queries. It is suggested that this part be added as a factor to the database.

4- Assessment of System

In operations research as explained, technique for solving computational problems is to optimize query processing in the database based on adapting queries (during high traffic times) by minimizing the processing time in the database.

This technique includes three parts: separating part, replacement policy, and query similarity detector, and the Ant Colony Algorithm has been applied to make it adaptable. Due to the approach of this algorithm with high-traffic times and identification of adaptive questions, the necessary cost to produce the query execution plan was reduced and as a result, the execution time was reduced. On the other hand, according to the adaptive mode commands based on the time of high traffic loading is also decreased cause of the cost reduction.

Currently, some methods are used for measuring performance of database system, the most primitive of the above-mentioned methods is implementation time in the system, which is the time required for implementation from the moment of sending until the response of the system. This time is calculated based on hours, minutes, and seconds [11].

To simulate this system, the proposed algorithm is classified and implemented in four classes. Then the results of implementation have been compared with the previous method using this method. In addition, we need DBMS and the intended data based on relation dependence, and we use SQL database and simulator SQLToolbelt to create data and identify the dependency of the tables. Moreover, in order to implement the algorithm and the intended comparisons, we will use VB.NET and API SQL functions. Code piece in Figure 5 shows the necessary implementation time of the query in milliseconds.

In this figure, the time of execution of questions has been compared with existing plans and without plans (creating a plan). As it is known, some time has been spent on creating the execution plan since the execution of the queries in the database.

After simulation of the query system, we obtained the following results:

- The cost of query implementation time as normal
- The cost of implementing the proposed algorithm
- The cost of versatile query as implementation plan

After obtaining these results, we added up the second and third costs and compared them and obtained the results of proposed method.

```
DECLARE @StartTime
datetime,@EndTime datetime
SELECT @StartTime=GETDATE

‘query in database for sample
select * from tblKala

‘query in database
SELECT @EndTime=GETDATE
SELECT
DATEDIFF(ms,@StartTime,@EndTime)
```

Fig. 5 Code piece to send implementation time

We added this factor on the software and compared its results with the normal case, and the results obtained as follows.

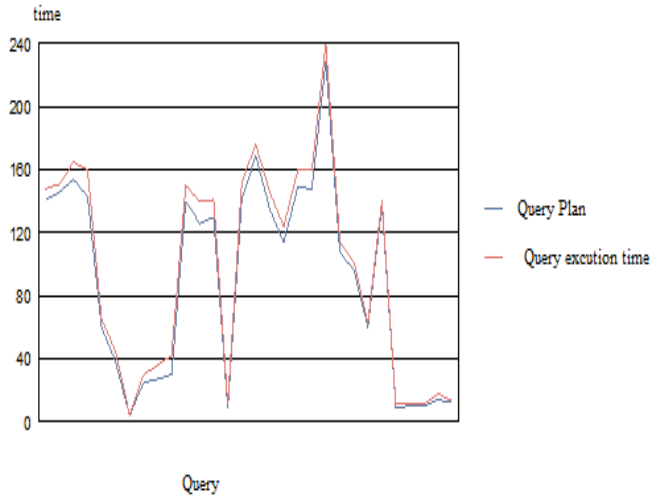

Figure 6: The reports of the response time per day for versatile queries (X: Questions sent toVersatile Database, Y: Sum of execution time)

Figure 6 shows the amount of time required to respond to queries and implementation plan.

Figure 7 shows the implementation in two modes along with plus the cost of versatility.

As shown in this figure for a sample question, in this algorithm, the difference between the start and end times of each algorithm's execution is the duration of the algorithm's execution, which is used in the evaluation.

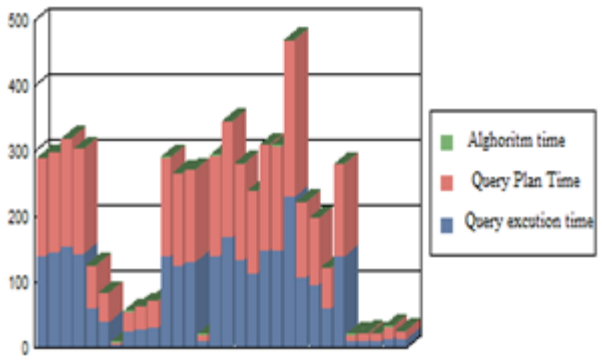

Fig. 7 The breakdown of implementation costs)X: Questions sent to Versatile Database in a day, Sum of Cost Time in a days)

Figure 7 represents the total time to respond to queries, reduction of response time to all versatile queries, as well as the cost required for the versatility of the queries. In this figure, the blue part is the execution time of the plan, the red part is the time of creating the implementation plan, and the green part is the policy duration of the proposed method. which has been tried over time to reduce the cost of creating plans for frequently used questions by maintaining plans for implementing frequently used questions.

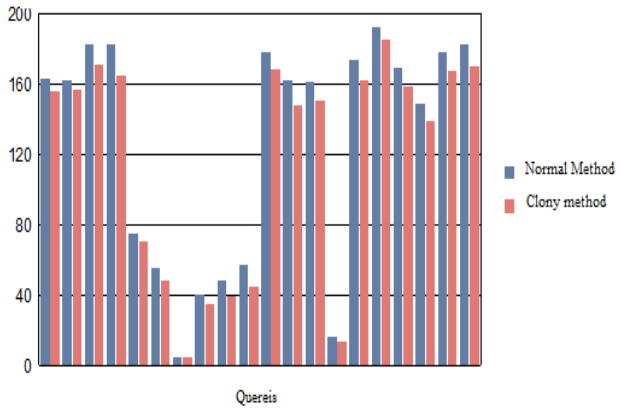

Fig. 8 The amount of reduction of the response time for versatile queries costs (X: Questions sent to Versatile Database in Days, Sum of execution time)

As is shown in this figure, the system has significantly reduced system response time to queries.
In this figure, it shows the duration of execution and reduction of the cost of execution of questions in normal mode and after applying the proposed method. In this algorithm, it shows the response time of two methods for the total number of questions sent to the database in a specified time.

5- Conclusion

Various methods have been proposed to optimize query processing in the database. These optimizations have been aimed at reducing processing time or reducing the use of resources. These methods try to make query processing versatile in the database.
This method for versatility of database is composed of three parts: separator, replacement policy, and query. To detect frequently-used queries in the database, Ant Colony algorithm is used. This method is based on the created pheromone to choose the optimal solution. The aim of this algorithm has been reducing implementation stages for frequently asked questions in the database.
The generality of this method is based on identifying frequent questions in the database. Then, by maintaining the query execution plan, it reduces the time in subsequent executions.
In fact, we get help from the Ant algorithm to identify repetitive questions and reduce the execution cost by caching the execution plan. At the same time, due to the fact that adaptability takes place at times with less load and based on the identified questions.
The results of this study demonstrate minimizing in implementation time of queries in 2.7%. Moreover, due to identifying the frequently-used queries in high traffic time and maintaining implementation plan, system traffic in times of high traffic load is reduced. In the future, the system can be made more optimized and be used for distributed database by developing the methods used. For example, machine learning methods can be used to identify execution patterns of plans.

Reference

[1] Saurabh gupta, Gopal Singh Tandel, Umashankar Pandey, "A Survey on Query Processing and Optimization in Relational Database Management System", International Journal of Latest Trends in Engineering and Technology, Vol. 5 Issue 1 January 2015
[2] Amol Deshpande, Zachary Ives, and Vijay Shankar Raman. Adaptive query processing. Foundations and Trends in Databases, 1(1), 2007. To appear. January 7-10, 2007, Asilomar, California, USA.
[3] Sybase, Performance and Tuning Series Query Processing and Abstract Plans, Sybase, Inc., One Sybase Drive, Dublin, CA 94568.
[4] Navid mohseni, mehdi mokhtarpor, hosein shirgah,"Application of Ant Colony Algorithm in data mining", National Conference on Emerging Trends in Computer Engineering and Data Recovery,2014
[5] Gupta, D.K.; Gupta, J.P.; Arora, Y.; Shankar, U., "Recursive Ant Colony optimization: a new technique for the estimation of function parameters from geophysical field data," Near Surface Geophysics , vol. 11, no. 3, pp.325-339
[6] Serap Ulusam Seçkiner, Yunus Eroğlu, Merve Emrullah, Türkay Dereli, Ant Colony optimization for continuous

functions by using novel pheromone updating, Applied Mathematics and Computation
Volume 219, Issue 9, 1 January 2013, Pages 4163-4175
[7] Xiao. M.Hu, J. ZHANG, and H. Chung, "An Intelligent Testing System Embedded with an Ant Colony Optimization Based Test Composition Method", IEEE Transactions on Systems, Man, and Cybernetics--Part C: Applications and Reviews, Vol. 39, No. 6, pp. 659-669, Dec 2009.
[8] B. Pfahring, "Multi-agent search for open scheduling: adapting the Ant-Q formalism," Technical report TR-96-09, 1996.
[9] A. Shmygelska, R. A. Hernández and H. H. Hoos, "An Ant Colony optimization algorithm for the 2D HP protein folding problem [permanent dead link]," Proceedings of the 3rd International Workshop on Ant Algorithms/ANTS 2002, Lecture Notes in Computer Science, vol.2463, pp.40-52, 2002.
[10] Gupta, D.K.; Arora, Y.; Singh, U.K.; Gupta, J.P., "Recursive Ant Colony Optimization for estimation of parameters of a function," Recent Advances in Information Technology (RAIT), 2012 1st International Conference on, vol., no., pp.448-454, 15–17 March 2012
[11] Zhang, Y. (2013). "A Rule-Based Model for Bankruptcy Prediction Based on an Improved Genetic Ant Colony Algorithm". Mathematical Problems in Engineering. 2013: 753251. doi:10.1155/2013/753251.
[12] Jevtić, A.; Melgar, I.; Andina, D. (2009). 2009 35th Annual Conference of IEEE Industrial Electronics. 35th Annual Conference of IEEE Industrial Electronics, 2009. IECON '09. pp. 3353–3358. doi:10.1109/IECON.2009.5415195. ISBN 978-1-4244-4648-3. S2CID 34664559.
[13] Warner, Lars; Vogel, Ute (2008). Optimization of energy supply networks using Ant Colony optimization (PDF). Environmental Informatics and Industrial Ecology — 22nd International Conference on Informatics for Environmental Protection. Aachen, Germany: Shaker Verlag. ISBN 978-3-8322-7313-2. Retrieved 2018-10-09.
[14] Zaidman, Daniel; Wolfson, Haim J. (2016-08-01). "PinaColada: peptide–inhibitor Ant Colony ad-hoc design algorithm". Bioinformatics. 32 (15): 2289–2296. doi:10.1093/bioinformatics/btw133. ISSN 1367-4803. PMID 27153578.
[15] J. ZHANG, H. Chung, W. L. Lo, and T. Huang, "Extended Ant Colony Optimization Algorithm for Power Electronic Circuit Design", IEEE Transactions on Power Electronic. Vol.24,No.1, pp.147-162, Jan 2009.
[16] L. Wang and Q. D. Wu, "Linear system parameters identification based on Ant system algorithm," Proceedings of the IEEE Conference on Control Applications, pp. 401-406, 2001.
[17] Martins, Jean P.; Fonseca, Carlos M.; Delbem, Alexandre C. B. (25 December 2014). "On the performance of linkage-tree genetic algorithms for the multidimensional knapsack problem". Neurocomputing. 146: 17–29. doi:10.1016/j.neucom.2014.04.069.
[18] L.M. Gambardella and M. Dorigo, "Solving Symmetric and Asymmetric TSPs by Ant Colonies", Proceedings of the IEEE Conference on Evolutionary Computation, ICEC96, Nagoya, Japan, May 20–22, pp. 622-627, 1996;
[19] Mohammad_Reza Feizi_Derakhshi, Hasan Asil, Amir Asil, "Proposing a New Method for Query Processing Adaption in DataBase, JOURNAL OF COMPUTING,NY,USA, VOLUME 2, ISSUE 1, JANUARY 2010, ISSN 2151-961
[20] Mohammad_Reza Feizi_Derakhshi, Hasan Asil, Amir Asil " Proposing a New Method for Query Processing Adaption in Data Base " WCSET 2009: World Congress on Science, Engineering and Technology Dubai, United Arab Emirates VOLUME 37, January 28-30, 2009 ISSN 2070-3740
[21] D. Martens, M. De Backer, R. Haesen, J. VAnthienen, M. Snoeck, B. Baesens, Classification with Ant Colony Optimization, IEEE Transactions on Evolutionary Computation, volume 11, number 5, pages 651—665, 2007.
[22] L.M. Gambardella and M. Dorigo, "Ant-Q: a reinforcement learning approach to the traveling salesman problem", Proceedings of ML-95, Twelfth International Conference on Machine Learning, A. Prieditis and S. Russell (Eds.), Morgan Kaufmann, pp. 252–260, 1995
[23] V. Donati, V. Darley, B. Ramachandran, "An Ant-Bidding Algorithm for Multistage Flowshop Scheduling Problem: Optimization and Phase Transitions", book chapter in Advances in Metaheuristics for Hard Optimization, Springer, ISBN 978-3-540-72959-4, pp.111-138, 2008.
[24] Warner, Lars; Vogel, Ute (2008). Optimization of energy supply networks using Ant Colony optimization (PDF). Environmental Informatics and Industrial Ecology — 22nd International Conference on Informatics for Environmental Protection. Aachen, Germany: Shaker Verlag. ISBN 978-3-8322-7313-2. Retrieved 2018-10-09.
[25] A. Deshpande and J. M. Hellerstein. Lifting the burden of history from adaptive query processing. In VLDB, 2004.
[26] Bingsheng He, Qiong Luo,“Cache-Oblivious Query Processing” Biennial Conference on nnovative Data Systems Research (CIDR)
[27] Wanhong Xu, “Xml Query Processing – SemAntic Cache System”, IJCSNS International Journal of Computer Science and Network Security, VOL.7 No.4, April 2007
[28] Elnaz zafarani , Mohammad_Reza Feizi_Derakhshi , Hasan Asil , Amir Asil “Presenting a New Method for Optimizing Join Queries Processing in Heterogeneous Distributed Databases
[29] Farhang Pedearan Moghadam, Hamid Maghsoudi, " Improved routing for load balancing in wireless sensor networks on the Internet of things, based on multiple Ant Colony algorithm", " Journal of Information Systems and Telecommunication (JIST) " Number 51, Volume 14
[30] Farid Ahmadi ,Mohammad Pourmahmood Aghababa , Hashem Kalbkhani, Nonlinear Regression Model Based on Fractional Bee Colony Algorithm for Loan Time Series, Journal of Information Systems and Telecommunication (JIST), 2022-04-21, Page: 141 – 1
[31] Luming Sun, Tao Ji, Cuiping Li, Hong ChenDeepO: A Learned Query Optimizer,SIGMOD '22: Proceedings of the 2022 International Conference on Management of DataJune 2022Pages 2421–2424https://doi.org/10.1145/3514221.3520167
[32] Ryan Marcus, Parimarjan Negi, Hongzi Mao, Nesime Tatbul, Mohammad Alizadeh, and Tim Kraska. 2021. Bao: Making Learned Query Optimization Practical. Proceedings of the 2021 International Conference on Management of Data (2021)

[33] Kristian F. D. Rietveld and Harry A. G. Wijshoff,Redefining The Query Optimization Process,IEEE TKDE 2022,arXiv:2203.01079v1,January 2022

[34] Yakov Kuzin, Anna Smirnova, Evgeniy Slobodkin, George Chernishev, Query Processing and Optimization for a Custom Retrieval Language,Proceedings of the First Workshop on Pattern-based Approaches to NLP in the Age of Deep Learning,October,2022

[35] Mohsin, S.A.; Younes, A.; Darwish, S.M. Dynamic Cost Ant Colony Algorithm to Optimize Query for Distributed Database Based on QuAntum-Inspired Approach. Symmetry 2021, 13, 70. https://doi.org/10.3390/sym13010070

[36] Zhiyong Ding,Study of Multi Ant Colony Genetic Algorithm in Query Optimization of Distributed Database, 2022 2nd International Conference on Artificial Intelligence and Advanced Manufacture (AIAM),202250,10.52547/jist.16015.10.38.141

[37] Mladineo, Marko; Veza, Ivica; Gjeldum, Nikola (2017). "Solving partner selection problem in cyber-physical production networks using the HUMANT algorithm". International Journal of Production Research. 55 (9): 2506–2521. doi:10.1080/00207543.2016.1234084. S2CID 114390939.

[38] Atieh Monemi Bidgoli, Hassan haghighi, Using Static Information of Programs to Partition the Input Domain in Search-based Test Data Generation, Journal of Information Systems and Telecommunication (JIST), 2021-01-13, Page: 219 – 229

[39] L. Bianchi, L.M. Gambardella et M.Dorigo, An Ant Colony optimization approach to the probabilistic traveling salesman problem, PPSN-VII, Seventh International Conference on Parallel Problem Solving from Nature, Lecture Notes in Computer Science, Springer Verlag, Berlin, Allemagne, 2002.

[40] Babu Kumar Ajay Vikram Singh Parul Agarwal, AI based Computational Trust Model for Intelligent Virtual AssistAnt, Journal of Information Systems and Telecommunication (JIST), Issue 32 Vol. 8 Autumn 2020, Page: 263 - 271 10.29252/jist.8.32.263,

[41] P. O'Neil and G. Graefe, "Multi-Table Joins Through Bitmapped Join Indices", ACM SIGMOD, 1995

", WKDD2010, Phuket, Thailand, 9-10 January, 2010.

[42] Rosa Karimi AdlEmail authorSeyed Mohammad Taghi Rouhani Rankoohi, "A new Ant Colony optimization-based algorithm for data allocation problem in distributed databases", Knowledge and Information Systems, September 2009, Volume 20, Issue 3, pp 349–373

[43] W. N. Chen and J. ZHANG "Ant Colony Optimization Approach to Grid Workflow Scheduling Problem with Various QoS Requirements", IEEE Transactions on Systems, Man, and Cybernetics--Part C: Applications and Reviews, Vol. 31, No. 1, pp.29-43, Jan 2009.

[44] Jevtić, A.; Quintanilla-Dominguez, J.; Cortina-Janich's, M.G.; Andina, D. (2009). Edge detection using Ant Colony search algorithm and multiscale contrast enhancement. IEEE International Conference on Systems, Man and Cybernetics, 2009. SMC 2009. pp. 2193–2198. doi:10.1109/ICSMC.2009.5345922. ISBN 978-1-4244-2793-2. S2CID 11654036.

[45] O. Okobiah, S. P. MohAnty, and E. Kougianos, "Ordinary Kriging Metamodel-Assisted Ant Colony Algorithm for Fast Analog Design Optimization Archived March 4, 2016, at the Wayback Machine", in Proceedings of the 13th IEEE International Symposium on Quality Electronic Design (ISQED), pp. 458--463, 2012.

[46] Gupta, D.K.; Arora, Y.; Singh, U.K.; Gupta, J.P., "Recursive Ant Colony Optimization for estimation of parameters of a function," Recent Advances in Information Technology (RAIT), 2012 1st International Conference on , vol., no., pp.448-454, 15–17 March 2012

[47] Muhammet Dursun Kaya, Hasan Asil, Dynamic Store Procedures in Database, German-Turkish Perspectives on IT and Innovation Management: Challenges and Approaches, 291-301,2018.