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Challenges and Research Progress of Big Data Management System Evaluation Benchmark

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Abstract: ***This paper presents a systematic review and prospective analysis of benchmarking methodologies for big data management systems. We begin by articulating the principal challenges inherent in benchmarking such systems, focusing on critical dimensions including data scale and complexity, data security and privacy preservation, data quality assurance, and consistency maintenance. Subsequently, we synthesize current research advancements in benchmarking big data management systems, which encompass dataset-centric evaluation methods, task-driven performance assessments, multi-faceted performance metrics, and user-experience-oriented analysis. Building upon this foundation, the paper proposes key directions for future research, emphasizing the development of multidimensional evaluation frameworks, the formulation of standardized benchmarking protocols, and the creation of automated, scalable evaluation tools. These contributions are intended to provide both theoretical insights and practical guidance for the design, implementation, and continuous evolution of effective benchmarks for big data management systems. The ultimate objective is to advance the state of the art in evaluating system performance, robustness, and usability, thereby facilitating the development of more reliable, efficient, and secure big data solutions.***

Keywords: Big data management system; Evaluation benchmark; Challenge; Research progress.

1. PREFACE

The benchmark for evaluating big data management systems is an important tool for assessing and comparing the performance of different big data management systems. However, due to the complexity and diversity of big data management systems, designing and implementing evaluation benchmarks face many challenges. These challenges include: how to choose appropriate datasets and workloads, how to design effective evaluation metrics and methods, how to consider system scalability and fault tolerance, and so on. Therefore, conducting research on evaluation benchmarks for big data management systems is of great significance [1]. As the volume, variety, and velocity of data continue to grow rapidly, the evaluation of big data management systems (BDMS) has become a critical yet complex area of research. The development of robust benchmarks is essential to objectively assess system performance, scalability, reliability, and usability. This paper systematically reviews the key challenges and recent progress in BDMS benchmarking. First, the challenges are analyzed across four dimensions: (1) data scale and complexity, which include dynamic data growth, multi-source heterogeneity, and real-time processing requirements; (2) data security and privacy protection, particularly in the context of regulatory compliance and anonymization techniques; (3) data quality and consistency, which affect evaluation reliability; and (4) system adaptability and resource efficiency. Second, we survey research progress in BDMS benchmarking, covering dataset-based evaluation methods (e.g., TPC-DS, BigBench), task-oriented benchmarks (e.g., batch processing, stream analytics, and machine learning pipelines), performance metrics (throughput, latency, fault tolerance, and energy efficiency), and user experience evaluation frameworks. Finally, this paper proposes future research directions, emphasizing multidimensional evaluation frameworks, standardization of benchmarking protocols, and the development of open, extensible evaluation tools. These contributions aim to provide theoretical and practical guidance for designing effective BDMS benchmarks, thereby facilitating advances in data-driven system optimization and innovation.

2. THE CHALLENGE OF BENCHMARKING FOR BIG DATA MANAGEMENT SYSTEM EVALUATION

Benchmarking big data management systems (BDMS) presents a multifaceted challenge that extends far beyond traditional database evaluation due to the unique characteristics of big data environments. The complexity stems from several interrelated dimensions that collectively define the benchmark design space. Benchmarks must increasingly incorporate security dimensions, including encryption overhead, access control granularity, and

privacy-preserving computation costs. Differential privacy implementations, homomorphic encryption, and secure multi-party computation introduce performance trade-offs that require standardized measurement approaches. Regulatory compliance overhead (GDPR, CCPA) further adds complexity to benchmark design, particularly for cross-border data scenarios. Traditional metrics like queries-per-second (QPS) and throughput provide incomplete pictures of BDMS performance. Modern evaluation requires multidimensional metrics including: ① latency distributions (p50, p95, p99 percentiles), ② resource efficiency (queries-per-joule, cost-per-terabyte), ③ scalability characteristics (strong/weak scaling efficiency), ④ fault tolerance (recovery time objectives, data durability), and ⑤ operational complexity (administrative burden, tuning requirements). The relative importance of these metrics varies by use case, complicating benchmark result interpretation.

2.1 Challenges of Data Scale and Complexity

In the benchmark evaluation of big data management systems, data scale and complexity are one of the important challenges. With the continuous growth of data, big data management systems need to be able to handle massive amounts of data, including structured, semi-structured, and unstructured data. These data may come from different data sources, including sensors, social media, log files, and so on. Meanwhile, these data may have different formats, data types, and data qualities, requiring big data management systems to have the ability to handle these complex data. In addition, in the evaluation benchmark of big data management systems, the real-time performance and processing speed of data also need to be considered. With the continuous growth of data, big data management systems need to be able to process data in real-time and provide accurate results in a short period of time. This requires big data management systems to have efficient data processing capabilities and optimized algorithms.

2.2 Challenges of Data Security and Privacy Protection

In the challenge of benchmarking big data management systems, data security and privacy protection are two important challenges. Real-world big data workloads exhibit temporal variability, seasonality, and evolving patterns that static benchmarks struggle to capture. Streaming workloads demonstrate burstiness and irregular arrival distributions. Analytical queries often follow power-law distributions with "heavy hitters" and long-tail query patterns. Machine learning pipelines combine iterative computation, model training, and inference phases with distinct resource requirements. Effective benchmarks must capture this dynamism while remaining reproducible and comparable across systems.

2.2.1 Data Security Challenges

The big data management system needs to handle a large amount of sensitive data, including personal identity information, financial data, medical records, etc. The leakage or hacking of this data may cause significant losses to individuals and organizations. Therefore, data security is an important indicator in the evaluation benchmark of big data management systems. The challenges of data security mainly include three aspects: data encryption, access control, data backup, and recovery.

(1) Data encryption:

The big data management system needs to use encryption technology to protect the security of data. Encryption technology can transform data into an unrecognizable form, and only authorized users can decrypt and access the data.

(2) Access control:

The big data management system needs to implement strict access control mechanisms to ensure that only authorized users can access data. The access control mechanism can be implemented through authentication, permission management, and other methods.

(3) Data backup and recovery:

The big data management system needs to implement data backup and recovery mechanisms to prevent data loss or damage. The data backup and recovery mechanism can be achieved through regular data backups, disaster recovery, and other methods.

2.2.2 Privacy Protection Challenges

Big data management systems need to handle a large amount of personal data, so privacy protection is another important indicator in the evaluation benchmark. The challenges of privacy protection mainly include data anonymization, data anonymization, and privacy protocols.

(1) Data desensitization:

The big data management system needs to adopt data anonymization technology to transform sensitive data into an unrecognizable form, in order to protect user privacy.

(2) Data anonymization:

The big data management system needs to adopt data anonymization technology to separate sensitive data such as personal identity information from other data, in order to protect user privacy.

(3) Privacy Policy:

The big data management system needs to implement privacy protocols, clarify the rules and restrictions for the use of user data, in order to protect user privacy.

2.3 Challenges of Data Quality and Consistency

2.3.1 Data Quality Challenges

Big data management systems need to handle massive amounts of data, which may contain a large amount of noise, missing values, outliers, and other data quality issues. These issues may lead to inaccurate and unreliable data analysis results, thereby affecting the correctness of business decisions. Therefore, big data management systems need to have powerful data cleaning and data quality control functions, which can automatically identify and handle data quality issues, ensuring the accuracy and reliability of data.

2.3.2 Data Consistency Challenge

Big data management systems need to handle heterogeneous data from multiple sources, which may come from different data sources, formats, granularities, and so on. In this situation, data consistency becomes an important challenge. If the data is inconsistent, it may lead to errors and uncertainties in business decisions. Therefore, big data management systems need to have powerful data integration and conversion functions, which can integrate heterogeneous data from multiple sources into a consistent dataset, ensuring data consistency and reliability. At the same time, big data management systems also need to support version control and traceability of data, so that problems can be quickly located and resolved when they occur.

2.4 Challenges in Data Processing and Analysis Efficiency

2.4.1 Challenges in Data Processing Efficiency

The challenge of data processing efficiency lies in how to quickly process large amounts of data. A big data management system needs to be able to handle massive amounts of data and complete the data processing in a short period of time. Therefore, the processing speed and efficiency of the system are important indicators for evaluation. At the same time, the efficiency of data processing also needs to consider the quality and accuracy of the data, ensuring that the results of data processing are reliable.

2.4.2 Challenges in Data Analysis Efficiency

The challenge of data analysis efficiency lies in how to quickly analyze large amounts of data. Big data management systems need to be able to analyze massive amounts of data, extract valuable information and insights to support decision-making and business development. Therefore, the analysis speed and efficiency of the system are also important indicators for evaluation. At the same time, the efficiency of data analysis also needs to consider the accuracy and reliability of the analysis, ensuring that the analysis results are credible.

2.5 Challenges of Data Visualization and Interactivity

2.5.1 Data Visualization Challenge

A big data management system needs to be able to process massive amounts of data and transform them into visual charts that are easy to understand and analyze. This requires the system to have efficient data processing and visualization techniques, which can quickly generate various types of charts and visualization effects, while ensuring the accuracy and reliability of the data.

2.5.2 Interactive Challenge

Big data management systems need to provide flexible interactive features that allow users to freely explore and analyze data. This requires the system to have efficient data query and filtering techniques, be able to quickly respond to user operations, and provide multiple interaction methods such as drag and drop, zooming, filtering, etc.

3. RESEARCH PROGRESS ON EVALUATION BENCHMARKS FOR BIG DATA MANAGEMENT SYSTEMS

The evaluation methods for big data management systems can be divided into the following categories based on benchmark requirements: dataset based evaluation methods, task-based evaluation methods, performance metric based evaluation methods, and user experience based evaluation methods. Based on the nature and requirements of benchmarking, evaluation methods for Big Data Management Systems (BDMS) can be systematically classified into four principal categories. Each category addresses distinct evaluation objectives, technical dimensions, and user perspectives, providing a structured framework for comprehensive system assessment. Dataset-based approaches utilize standardized or representative datasets to evaluate system performance under controlled conditions. These benchmarks employ both synthetic datasets (e.g., TPC-DS, TPC-H) designed to model specific data distributions and real-world datasets that capture authentic complexities.

3.1 Dataset based evaluation method

The research progress of dataset based evaluation methods mainly focuses on the following aspects:

(1) Dataset selection:

Choosing the appropriate dataset is the key to evaluating big data management systems. Researchers typically choose representative and diverse datasets to ensure the accuracy and reliability of evaluation results.

(2) Dataset generation:

To better evaluate the performance of big data management systems, researchers can use dataset generation tools to generate different types of datasets. These datasets can simulate real-world data to better evaluate system performance.

(3) Dataset analysis:

Another key aspect of evaluating a big data management system is analyzing the dataset. Researchers can use different analysis tools to analyze the features and properties of the dataset in order to better evaluate the performance of the system.

(4) Dataset evaluation metrics:

Another key to evaluating big data management systems is to choose appropriate evaluation metrics. Researchers can use different metrics to evaluate the performance of the system, such as response time, throughput, concurrency performance, etc.

(5) Dataset sharing:

In order to promote the research on benchmark evaluation of big data management systems, researchers can share the datasets and evaluation results they use. This helps other researchers better understand and compare the performance of different systems.

3.2 Task based evaluation method

At present, task-based evaluation methods have been widely applied and researched. Typical research progress mainly includes TPC-DS benchmark, BigBench benchmark, TPC-H benchmark, and YCSB benchmark. Task-based evaluation emphasizes specific computational operations and workload patterns rather than particular datasets.

3.2.1 TPC-DS benchmark

The TPC-DS benchmark is a task-based evaluation method primarily used to assess the performance of data warehouse systems. This benchmark includes 99 query tasks, covering various query types and complexities in data warehouse systems. By performing these query tasks, the query performance, load balancing performance, data loading performance, and other indicators of the data warehouse system can be evaluated.

3.2.2 BigBench benchmark

BigBench benchmark is a task-based evaluation method primarily used to assess the performance of big data management systems. This benchmark includes 30 query tasks, covering various query types and complexities in big data management systems. By performing these query tasks, the query performance, data loading performance, data processing performance, and other indicators of the big data management system can be evaluated.

3.2.3 TPC-H benchmark

The TPC-H benchmark is a task-based evaluation method primarily used to assess the performance of relational database systems. This benchmark includes 22 query tasks, covering various query types and complexities in relational database systems. By performing these query tasks, the query performance, load balancing performance, data loading performance, and other indicators of relational database systems can be evaluated.

3.2.4 YCSB Benchmark

The YCSB benchmark is a task-based evaluation method primarily used to assess the performance of NoSQL database systems. This benchmark includes 6 operational tasks, covering various types and complexities of operations in NoSQL database systems. By performing these operational tasks, the read and write performance, load balancing performance, data consistency, and other indicators of NoSQL database systems can be evaluated [4].

4. FUTURE RESEARCH DIRECTIONS FOR EVALUATION BENCHMARKS OF BIG DATA MANAGEMENT SYSTEMS

Modern evaluation frameworks increasingly combine these methods to create holistic assessment approaches. Hybrid benchmarks incorporate standardized datasets with representative task suites, measure multiple performance metrics simultaneously, and incorporate usability assessments. This integrated perspective recognizes that comprehensive system evaluation requires consideration of both technical capabilities and practical usability factors. The selection and weighting of these evaluation methods depend on specific benchmarking objectives, ranging from pure performance comparison to comprehensive suitability assessment for particular application contexts. Future benchmark development should maintain flexibility across these categories while establishing standardized methodologies within each approach.

4.1 Research on Multidimensional Evaluation Methods

In the evaluation of big data management systems, single indicator evaluation is no longer sufficient to meet practical needs, and multidimensional evaluation methods need to be studied. Multi dimensional evaluation methods can evaluate big data management systems from different perspectives, including performance, reliability, scalability, security, and other aspects. For example, the performance of the system can be evaluated by assessing

indicators such as throughput, latency, and concurrency; The reliability of a system can be evaluated by assessing its fault tolerance, recoverability, and other indicators [5].

4.2 Development of evaluation standards for big data management systems

The formulation of evaluation standards for big data management systems is the foundation of evaluation work. At present, some evaluation criteria have been proposed, such as TPC-DS, TPC-H, etc. However, there are still some issues with these standards, such as insufficient coverage and unrealistic evaluation scenarios. Therefore, further research and development of more comprehensive and authentic evaluation criteria are needed to better assess the performance and reliability of big data management systems.

4.3 Development of evaluation tools for big data management systems

Evaluation tools are important means of conducting evaluations. At present, some evaluation tools have been developed, such as TATP, YCSB, etc. However,
These tools still have some issues, such as not supporting enough database types and not having enough diverse evaluation scenarios. Therefore, further research and development of more comprehensive and rich evaluation tools are needed to better assess the performance and reliability of big data management systems.

4.4 Visualization and interpretation of evaluation results for big data management systems

The visualization and interpretation of evaluation results are important aspects of evaluation work. Through visualization and explanation, evaluation results can be presented more intuitively, helping users better understand the performance and reliability of the system. Therefore, further research and development are needed to develop more intuitive and understandable tools for visualizing and interpreting evaluation results, in order to better serve users.

Taking TATP and YCSB as examples, they are currently popular big data management system evaluation tools. TATP is mainly used to evaluate big data management systems in the field of mobile communication, including data processing, data storage, data queries, and other aspects; YCSB is mainly used to evaluate distributed database systems, including NoSQL databases, relational databases, etc. These tools have their unique evaluation scenarios and metrics, which can help users better assess the performance and reliability of the system. However, they also have some issues, such as not having enough supported database types and not having enough diverse evaluation scenarios. Therefore, further research and development of more comprehensive and rich evaluation tools are needed to better serve users.

5. CONCLUSION

In summary, with the continuous development of big data technology, the requirements for evaluation benchmarks are also constantly increasing, including data scale, data types, data diversity, data processing speed, and other aspects. At the same time, the design of evaluation benchmarks also needs to consider the needs of practical application scenarios, such as data security, data privacy, and other issues. In terms of research progress, we have found that many excellent evaluation benchmarks for big data management systems have emerged, such as TPC-DS, TPC-H, BigBench, etc. These benchmarks can not only evaluate the performance of the system, but also help users choose the system that best suits their needs. In addition, some new evaluation benchmarks are constantly emerging, such as TATP, YCSB, etc., which will further promote the development of big data management systems. In short, the challenges and research progress of benchmark evaluation for big data management systems are a constantly evolving field. We believe that in future research, more excellent evaluation benchmarks will emerge, providing a more comprehensive and accurate assessment for the development of big data management systems.

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