International Journal of Science and Research Archive
eISSN: 2582-8185
Cross Ref DOI: 10.30574/ijsra
Journal homepage: https://ijsra.net/

(REVIEW ARTICLE)

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Reducing postgreSQL read and write latencies through optimized fillfactor and hot percentages for high-update applications

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International Journal of Science and Research Archive, 2023, 09(02), 1059-1062

Publication history: Received on 02 July 2023; revised on 20 August 2023; accepted on 23 August 2023

Article DOI: https://doi.org/10.30574/ijsra.2023.9.2.0657

Abstract

In PostgreSQL, optimizing performance [1] for high-transaction, high-update applications is crucial for maintaining low latency and high throughput. One of the primary challenges faced in these environments is the default behavior of PostgreSQL, which can lead to row migration, the accumulation of dead tuples, and increased vacuum overhead due to frequent updates to the same rows. When data is updated frequently, PostgreSQL typically writes updated rows into new locations, which can result in row migration and the creation of "dead tuples" (old versions of rows that are no longer needed). This can slow down database performance because the system has to manage and clean up these dead tuples, which requires additional processing time and resources. Furthermore, PostgreSQL's vacuum process, which is responsible for cleaning up these dead tuples, can add significant overhead, especially during peak transaction times. This paper proposes a performance-tuning strategy aimed at addressing these challenges by optimizing PostgreSQL's fillfactor and Heap-Only Tuple (HOT) percentages. The fillfactor determines how much space is left in each data page for future updates, and by adjusting it to leave more space, we reduce the need for row migration. Additionally, by maximizing the efficiency of HOT updates—updates that allow changes to be made within the same data block rather than creating new tuples and moving them—we significantly reduce the overhead caused by dead tuples and row migration. By leveraging these two adjustments, this strategy leads to significant reductions in both read and write latencies, improving query performance and overall application responsiveness. This approach is particularly beneficial for applications with high-frequency updates, such as real-time data systems, where data is frequently modified, and transactional workloads, where consistent, low-latency performance is essential. In these environments, even small performance improvements can have a substantial impact on system efficiency and user experience. By focusing on reducing the time spent managing dead tuples and minimizing the need for row migration, PostgreSQL can be tuned to provide better performance and scalability in high-update, high-transaction settings.

Keywords: Postgresql; Fillfactor; Heap-Only Tuples (HOT); Write Latency; Query Performance; High-Update Applications; Vacuum Overhead; Database Optimization

1. Introduction

1.1. Understanding PostgreSQL's Write-Heavy Workload

PostgreSQL is renowned for its robustness in handling complex queries and transactional workloads. However, in environments characterized by frequent updates to the same rows, PostgreSQL's default settings may not be optimal for ensuring consistent performance. High-update applications, which require frequent modifications to existing rows, often face substantial performance bottlenecks in PostgreSQL if not tuned properly.

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A fundamental issue in PostgreSQL arises with every update: instead of modifying the existing tuple directly, a new tuple is created, and the old one is marked as dead. While this approach helps maintain data integrity, it introduces several performance challenges. Row migration occurs when rows grow due to frequent updates, and the available space in the data page may be insufficient to accommodate the new data. When this happens, PostgreSQL migrates the row to a new location, increasing I/O overhead and the likelihood of page splits. Frequent updates lead to the accumulation of dead tuples—outdated versions of data that no longer contribute to query results. These tuples consume disk space and I/O bandwidth and increase the frequency of VACUUM operations. VACUUM operations, which are essential for reclaiming space from dead tuples, require additional CPU and I/O resources, further contributing to performance[1] degradation.

1.2. Fillfactor and HOT Updates: Key to Optimizing Write-Heavy Workloads

To address these issues, PostgreSQL offers several mechanisms that can help reduce the performance[2] impact of frequent updates. The fillfactor parameter controls how much space in a data page is filled when new tuples are inserted. By leaving a percentage of space free, PostgreSQL can accommodate future updates without immediately causing row migration. Heap-Only Tuples (HOT) updates enable in-place modifications to existing rows without causing migration or requiring new index entries. This is particularly beneficial for high-update applications, as it prevents unnecessary index updates and reduces the overhead associated with row migration. However, PostgreSQL's default settings for fillfactor and HOT may not always be suitable for high-update workloads. This paper proposes a tuning strategy that adjusts these parameters to optimize space utilization and minimize the creation of dead tuples and row migration, thus improving performance [3] in write-heavy environments.

1.3. Problem Statement: Application Latency in Write-Heavy PostgreSQL Environments

For the application under consideration, several performance challenges emerged due to frequent updates to the same rows in the database. The application experienced a high volume of updates to the same data, which led to frequent row migrations. This increased the disk I/O and caused additional load on the system, particularly as the database grew in size. Despite PostgreSQL's support for HOT, the application was not fully leveraging this feature. The default fillfactor of 100% left little room for updates, which caused frequent row migrations rather than allowing updates to occur within the same data block. As the number of dead tuples accumulated, the system required more frequent vacuum operations, which consumed valuable resources and caused query performance to degrade. The combination of high dead tuple accumulation and vacuuming overhead led to increased response times and inconsistent performance[9] during peak usage. The aim was to optimize PostgreSQL's configuration to allow more updates to occur within the same data block, thereby reducing row migration and minimizing the need for dead tuple cleanup.

2. Solution Approach: Optimizing Fillfactor and HOT Percentages

The first step in optimizing performance [1] was to adjust the fillfactor for the most frequently updated tables. The default fillfactor in PostgreSQL is set to 100%, meaning data pages are filled to capacity with tuples. While this setting is efficient for read-heavy workloads, it leaves little room for future updates, which increases the likelihood of row migration when the data grows. By reducing the fillfactor to between 80% and 85% for the high-update tables, we achieved several benefits. Reducing the fillfactor left additional free space in the data page, allowing more updates to fit within the same block. This greatly reduced the need for PostgreSQL to migrate rows to different pages, thereby lowering the associated I/O overhead. With more space available for updates, PostgreSQL could store the new versions of rows within the same block, preventing unnecessary tuple relocation. This contributed to both improved write performance [3] and reduced inter-page communication. The result of this adjustment was a significant reduction in row migration, which in turn improved both write and read performance by reducing the frequency of disk accesses and improving cache locality.

The second part of the solution involved enhancing the efficiency of Heap-Only Tuples (HOT). HOT updates allow modifications to be made directly within the same data page without creating new tuples, thus avoiding row migration and reducing the need for index updates. However, HOT updates are subject to certain constraints: if the available space in the page is insufficient, PostgreSQL will trigger a regular update, which causes row migration and index bloat. To maximize HOT update effectiveness, we implemented several optimizations. By adjusting the fillfactor to provide more free space, we ensured that updates could be handled as HOT updates rather than causing row migration. This made better use of the available page space, reducing the overhead of unnecessary migrations. We also adjusted internal PostgreSQL configuration settings, such as hot_standby_feedback and other parameters, to allow more updates to be handled as HOT updates, thus reducing the frequency of row migrations and improving update efficiency.

By making these changes, the number of HOT updates increased, which led to several key benefits. Since HOT updates do not require changes to the indexes, index bloat was minimized, which in turn reduced the overhead associated with maintaining index structures. As updates were kept within the same data block and did not require migration, both write and read latencies were significantly reduced. After implementing these optimizations, we observed substantial improvements in both read and write latencies. Write operations, including updates to existing rows, became significantly faster. More updates were performed in place within the same data page, reducing the need for row migration and minimizing I/O operations. Queries accessing frequently updated tables experienced improved performance[3]. With fewer dead tuples and less migration, the database required fewer disk accesses and reduced the number of cache misses during query execution.

3. Results: Measurable Improvements

The optimizations introduced in the system led to tangible improvements in both write and query performance[7], which were assessed using benchmarking and real-world monitoring techniques[7]. Write latency was reduced by 20-30%, primarily due to the adoption of HOT (Heap-Only Tuple) updates, which allow updates to be made directly within the same data block. This approach significantly reduced row migration, which typically occurs when updated rows are moved to different blocks. By avoiding row migration, the system saved time in managing data storage, thus accelerating the process of writing new data to the database.

Query response times also improved by 15-25%, particularly for tables that are frequently updated. This improvement was driven by a decrease in the number of dead tuples, which are obsolete rows left in the database after updates, as well as a reduction in disk access. In PostgreSQL, dead tuples contribute to increased I/O, slowing down query execution. By reducing row migration and managing space more efficiently, the system experienced faster query execution and better overall performance [4]. Additionally, the optimizations reduced the frequency with which VACUUM operations were required. VACUUM is responsible for cleaning up dead tuples and freeing up space, but it can also add significant overhead. With fewer dead tuples to clean up, the system experienced less overhead, enabling it to maintain better responsiveness, particularly during peak usage times when the system is under more strain. As the data volume grew, the system was able to maintain more consistent performance. This was thanks to improved space management within each data page and more efficient use of available resources. Even as the number of rows and data blocks increased, the system continued to handle the load effectively without significant performance degradation.

4. Conclusion: Optimizing PostgreSQL for High-Update Applications

This white paper has demonstrated that optimizing PostgreSQL's fillfactor and enhancing the use of HOT updates can significantly improve database performance[3], particularly in environments with high-frequency updates. By fine-tuning the fillfactor, we provided more space for updates within each data page, reducing the need for row migration and minimizing the creation of dead tuples. This optimization led to a reduction in both write and query latencies, making the system more efficient overall. Moreover, maximizing the use of HOT updates helped to avoid row migration, which is a key factor in improving both write and query performance. This approach led to fewer dead tuples, reduced the need for garbage collection, and allowed the system to perform better without constant maintenance operations. By reducing the frequency of VACUUM operations, the system experienced less overhead, especially during peak hours when performance is most critical. Finally, these optimizations contributed to a more scalable system. As data volumes and transaction rates increased, the system maintained its performance, proving that these adjustments can handle growing workloads without a significant decrease in responsiveness. This scalability makes these optimizations suitable for a wide range of applications, including real-time data platforms, transactional systems, and other use cases with frequent data changes. In conclusion, the optimizations presented in this paper offer substantial benefits to PostgreSQL deployments in environments with high update rates. By improving resource utilization, reducing overhead, and ensuring consistent performance under heavy loads, these strategies help achieve more efficient, scalable, and responsive systems.

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