

SCHOOL OF COMPUTATION,  
INFORMATION AND TECHNOLOGY —  
INFORMATICS

TECHNISCHE UNIVERSITÄT MÜNCHEN

Master's Thesis in Information Systems

**Visualization and statistical analysis of  
performance measurements of database  
systems**

Julian Macias De La Rosa

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**Visualisierung und statistische  
Aufbereitung von Performance Messungen  
von Datenbanksystemen**

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Submission Date: 20.10.2023

I confirm that this master's thesis is my own work and I have documented all sources and material used.

Munich, 20.10.2023

Julian Macias De La Rosa

## **Acknowledgments**

# **Abstract**

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# **1 Introduction**

Interactive performance visualization is a powerfull skill and plays a vital role for the demonstration of meaningful data insights in the context of performance measurements. Our goal is to use this powerfull skill properly to enable potential optimization possibilities for compiling database systems.

## **1.1 Motivation**

## **1.2 Technical Background**

### **1.2.1 React**

### **1.2.2 Redux**

### **1.2.3 React Sweet State//**

### **1.2.4 Plotly**

### **1.2.5 React-Flow**

### **1.2.6 Material UI**

## **1.3 Existing Visualization of Performance Data of Umbra //PDF**

## **1.4 Research objectives**

## **1.5 Scope and contribution of the thesis**

## **1.6 Thesis structure**

## 2 Related Work

In this chapter, we give an overview about the existing work in the domain of the visualization of database performance profiling. We will investigate the importance of optimizing query executions in database systems and the role of visualizations in identifying potential improvements. As performant measurement and analysis play a crucial role in developing and optimizing database systems, it is essential to examine the state-of-the-art techniques and tools that have been used in this domain. We will also cover a visualization tool closely associated with this thesis, as its key feature is integrated into the Benchy Viewer.

### 2.1 Performance Visualization

Sektion eher in Background **Todo: Was es alles in dieser Domain gibt. Was effektiv ist und wir benutzen. Was wir nicht benutzen mit Begründung.**

### 2.2 Database Performance Profiling

Performance profiling in database systems is crucial for optimizing their execution regarding achieving optimal hardware utilization and query efficiency. Profiling the performance of database systems involves collecting and analyzing various performance metrics during query execution.

Besides profilers presenting results at the instruction and function granularity, a paper on "Profiling Dataflow Systems on Multiple Abstraction Levels" [Bei+21] proposes a solution that tracks the code generation process and aggregates profiling data to higher abstraction levels. This approach helps bridging the semantic gap between low-level profiles and high-level constructs, making it easier for developers to interpret profiling results and identify bottlenecks and hotspots in the system. The paper introduces the concept of Tailored Profiling, which extends the compilation steps to annotate the generated code with metadata. This enables the mapping of profiling results back to desired abstraction levels and provides more understandable profiling data. Building

on the insights from this work, the opportunity arises to create more meaningful visualizations regarding the dataflow in system performance profiling.

An essential concept of this thesis is to build upon the concepts of tailored profiling to gain a deeper understanding of the system's performance and support the location of potential optimization possibilities. Thus, we integrate an intuitive and interactive query plan visualization feature that is able to break down complex queries into their constituent operators and pipelines. We clarify further details about the query plan in section 2.3.1 and in chapter X (Implementation) **Todo: Chapter linking**.

## 2.3 Related visualization tools

This section explores related visualization tools that aid developers analyse their database system queries, with a specific focus on performance visualization. We will go through the Query Plan Difference Visualizer and the Umbra Profiler **Todo: Zitat**, which are both tools, that are strongly related to the Benchy Viewer.

### 2.3.1 Query Plan Difference Visualizer

The efficiency of a database system's query execution relies on the physical execution plan it generates. Given the complexity of finding the best plan, the comparison of query plans both within a single system and across different systems has garnered attention. This comparative analysis aims to gain valuable insights and identify potential optimisation opportunities. Previous efforts in this direction have mainly focused on quantitative metrics, in particular the total cost of the plan.

Query execution plans describe the step-by-step hierarchical sequence of physical operations that a database system uses to process a particular SQL query. The fascinating aspect of this is that identical queries can result in different plans when processed by different database systems. This variability in plan generation can have a significant impact on overall performance.

The Query Plan Difference Visualizer is a web application that compares and visualizes these physical query execution plans from different relational database systems, as shown in Figure 2.1. It is designed for database developers who want to inspect the correlation between variations in query execution speed and the respective query plans. Through enhanced hierarchical differencing algorithms with semantic information about query plans, the tool is able to interactively capture and present the difference between query plans. This is particularly useful for comparing different database systems or different versions of the same system when varying query plans are used

## 2 Related Work



Figure 2.1: Query Plan Difference Visualizer

by the systems under test to process the same query. Furthermore, it provides the flexibility to pick an arbitrary number of systems for which to compare plans and select a metric for evaluating query performance, such as total runtime or compilation time. For the given metric, it directly shows the difference between the baseline system and the better system.

Once a query plan is initialized, the comparative tool provides the option to improve the clarity of the query plan visualization using various configuration settings. For instance, the tool offers a match mode selection, allowing users to capture the tree from, e.g., a top-down or bottom-up matching perspective. With the Expand and Collapse feature, users can collapse entire subtrees and selectively expand specific child nodes, customizing the focus of the visualization and tailoring the area of attention to the most interesting parts of the tree. For query plans containing Directed Acyclic Graph (DAG) edges, such as the Pipeline Breaker Scan operator in Umbra, the tool offers support to include these DAG edges and consider them during the matching process. Additionally, to enable more effective comparisons against systems that generate non-DAG-shaped plans, an option is available to replicate subtrees instead.

Database developers often find value in comparing query plans, particularly when

they have thoroughly examined different results using quantitative metrics. Therefore, we decided to integrate the Query Plan Difference Visualizer with its core features of comparing query plans. In addition to visualizing quantitative metrics from different database systems within the Benchy Viewer, the incorporation of the Query Plan Difference Visualizer with its capabilities will further enhance our objective of simplifying the detection of performance bottlenecks in query execution and optimizing database systems.

Hence, the Query Plan Difference Visualizer is strongly related to this thesis and we will dive deeper into the integration of the comparative tool in Chapter X. ***Todo: Chapter linking***

### 2.3.2 Umbra Profiler

The Umbra Profiler is a tool that enables in-depth analysis for identifying bottlenecks in query execution processes of the database system Umbra.

It is integrated with a backend application for preparing extensive profiling data and offers multiple perspectives, including a runtime dashboard, a memory dashboard, and an instruction dashboard, each depicting distinct information, as illustrated in Figure 2.2.



Figure 2.2: Umbra-Profiler: A tool for analyzing and profiling Umbra’s compiling queries. From left-to-right: runtime dashboard, memory dashboard, and instruction dashboard.

The runtime dashboard is the default view that appears after providing recorded hardware samples of a query execution. It offers an initial overview of the query execution structure, allowing users to analyze the activity of specific processor events, operators, and pipelines over time. Abnormalities in execution, such as resource-intensive operations, can be identified, aided by visualizations including key performance indicators, activity histograms, bar charts, query plans, sunburst charts, and swim lanes.

The memory behavior dashboard focuses on memory access patterns in query execution. It offers memory heatmaps for each operator, showing either absolute memory accesses or sequential memory address differences.

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## 2 Related Work

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The instruction Dashboard facilitates detailed analysis of query execution using Umbra Intermediate Representation (UIR) **Zitat** instructions. It allows comparison of UIR instructions with query plans to identify performance problems based on costs and occurrences.

Similar to the Benchy Viewer, the goal is to support database engineers in optimizing query execution by providing an interactive user interface, enabling an effective in-depth analysis process.

The Umbra Profiler is designed based on the innovative Tailored Profiling approach [Bei+21], where the connection between query plans and compiled code is maintained. This technique was previously unaddressed by standard profilers and is now used in both the Umbra Profiler and the Benchy Viewer.

However, unlike the Benchy Viewer, the Umbra Profiler is focused to operate exclusively with the database system Umbra. In contrast, the Benchy Viewer has the versatility to function with multiple database systems or multiple instances of a single database system.

In broad terms, the Umbra Profiler is primarily designed for in-depth analysis of query performance within a single database system, while the Benchy Viewer is oriented towards its comparative function, enabling the comparison of queries executed by different instances. This comparative approach is the main essence of the concept of the Benchy Viewer, which aims to enhance the understanding of differences between database instances.

An effective scenario that synergizes the Benchy Viewer and the Umbra Profiler would involve identifying intriguing queries using the Benchy Viewer and subsequently conducting comprehensive analyses using the Umbra Profiler.

# 3 Theoretical Foundations

In this chapter, we investigate the theoretical foundations by examining database performance measurements and in the next step describing used datasets and the data structure.

We will start by discussing the characteristics of database systems and elaborate on the significance of performance measurements in this context. Additionally, we will outline the common performance metrics, that play a central role in the evaluation of performance analysis.

For clarifying used datasets and the data structure, we commence by describing the utilized performance data, followed by giving an overview of the structure of the Benchy Viewer's input file containing the performance measurements. Moreover, the data preparation for this input file will be explained.

## 3.1 Database Systems and Performance Measurements

Performance measurement and analysis are fundamental in the realm of database systems. They offer valuable insights into system behavior, helping to pinpoint bottlenecks and optimization opportunities. This process is crucial not only for evaluating one's own system but also for making meaningful comparisons with other systems. Visualisations play a pivotal role in understanding performance data and are often used to convey complex findings effectively. To interpret performance data effectively, we begin by understanding the characteristics and core traits of a Database System.

### 3.1.1 Characteristics of Database Systems

Database systems are complex structures that manage and store vast amounts of data efficiently, involving interrelated factors that must be finely tuned to ensure optimal performance.

One of the fundamental functions of a database system is query processing. A query is essentially a request for specific information from the database. This involves receiving and then executing that query. The process includes tasks like parsing, optimization,

and execution.

Queries go through two main phases: compilation and execution. **Figure mit Compilation und Execution** During compilation, the query is transformed into an execution plan. This plan outlines the steps the system should take to retrieve the requested data. In the execution phase, the system follows this plan to fetch the data.

Query plans are roadmaps that guide how a database executes queries, with operators as specialized components responsible for specific actions. Operators, like selection and join operators, perform data operations during query execution, such as filtering and combining data. Optimizing query plans is vital for database efficiency, with query optimizers selecting the best plan considering factors like data distribution and hardware capabilities.

Query processing can be time-consuming due to various challenges. For instance, complex queries, large datasets, and suboptimal query plans can lead to slow performance. Identifying and overcoming these challenges is essential for improving system efficiency.

Understanding these characteristics is key to understanding the complexity of database performance. Challenges such as optimising query plans and dealing with large data sets are common, and manual assessment is often impractical.

The need for objective metrics is therefore obvious, making performance measurements essential for targeted optimisations. Due to the complexity of these metrics, visualisation techniques are invaluable for easier interpretation and analysis.

In the next section, we will explore the important role of performance measurements and their visualisation in improving database efficiency.

### 3.1.2 Importance of Performance Measurements

Database systems are the core of a wide range of applications. Consequently, their performance matters not just in terms of user-friendliness and reliability, but also in terms of efficiency. Performance measurements play a central role in this context.

One of the key advantages of performance measurements lies in their capacity to assist in optimization efforts. By quantifying performance in a series of metrics, database developers can pinpoint precisely where bottlenecks occur, whether it is in the compilation phase, the query plan, data retrieval, or any other component of the database system. This focused approach minimizes the trial and error often involved in performance tuning and directs resources toward the most impactful modifications.

Furthermore, bottlenecks and areas with room for improvement are often not obvious. With the aid of performance measurements, these elements come into sharp focus. Measurements can reveal, for example, if the system's weak point lies in query com-

pilation or if the query plan needs to be optimized. Understanding and interpreting the findings correctly is crucial for making informed decisions on where to prioritize improvement efforts.

Another fundamental aspect is scalability. In a world where data is continuously growing, the scalability of a database system becomes a certain priority, because data volumes continue to grow. Performance measurements can identify the limitations of a system as it scales, revealing performance degradation points before they become critical bottlenecks. This approach is not only applied to solve current needs of data volume, but is also contributing to the system's scalability for the future.

Referring back to the introduction's implication, the complexity of performance metrics can often be overwhelming. Visualisation techniques become invaluable tools in this context. By translating numerical data into graphical elements, these visualisations can illuminate patterns and trends that could otherwise be easily overlooked, offering an intuitive and interactive way to understand the performance bottlenecks and operational nuances.

In summary, performance measurements are essential in the effective management and optimization of complex database systems. With these basic principles in mind, the next section examines common performance metrics for evaluating database systems, which serve as the quantitative backbone for the analyses and visualisations discussed here.

### 3.1.3 Common Performance Metrics

Understanding the importance of performance measurements in database systems necessitates a deeper dive into the specific metrics that help analyse various aspects of performance. This section explores effective metrics and how they are used within this domain, which indicates the desired functionalities of the Benchy Viewer in terms of interaction and visualisation.

In the paper "Bringing Compiling Databases to RISC Architectures" [Gru+23] the compilation performance of the dominant x86-64 server architecture is contrasted with the new introduced code generator designed for AArch64-based systems. This is interesting for the Benchy Viewer as it conducts a comparative analysis of different perspectives in terms of performance, leveraging specific performance metrics that are also visually represented.

The paper utilizes both quantitative and subjective performance metrics when addressing the query compilation strategy. However, for the scope of our visualisation, we focus on the quantitative metrics. Relying on quantitative metrics allows for clear, objective visualisation that can represent performance differences, whereas subjective metrics

does not offer the same level of clarity and consistency in a visual representation. Here one of the most central metrics is the throughput, a key metric in databases, measures the number of processed tuples per second and is a primary optimization target. In the context of compiling databases, throughput is primarily influenced by the quality of the generated machine code for queries.

Another fundamental metric is the latency, which is the time needed for generating and compiling query code before execution, with lower latency being particularly important for real-time transactional systems.

With these two metrics, the paper shows an intuitive and clear overview of how different database instances perform on the TPC-H benchmark, as demonstrated in Figure 3.1.

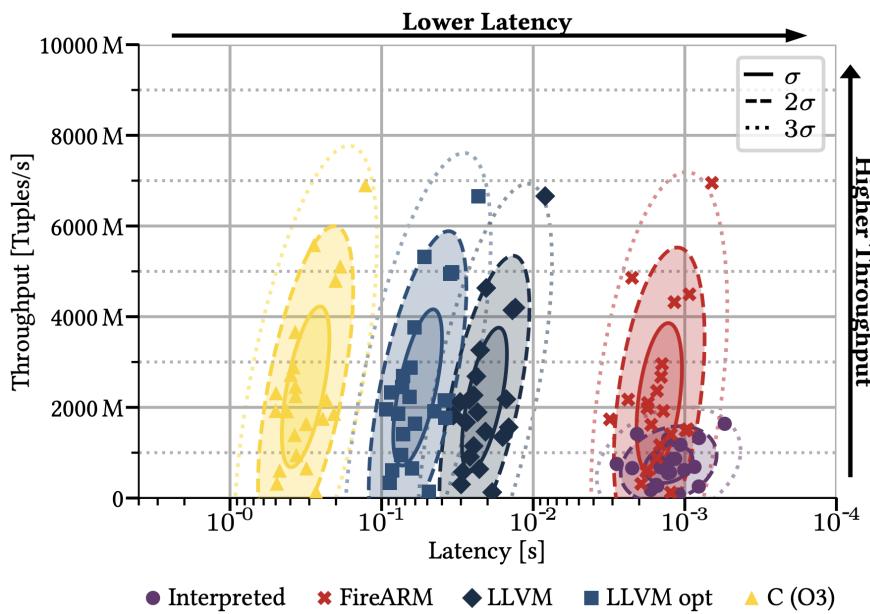


Figure 3.1: Visualisation example of compile-time and throughput of different query-compilation strategies running the TPC-H benchmark [Gru+23].

The visualisation presents a scatter plot that groups query results into clusters, with each cluster representing a database instance by a distinct color. The Y-axis displays the throughput in tuples per second, while the X-axis shows the latency in seconds, which is a descending value from left to right. Additionally, arrowed labels point to the preferred values: higher values on the Y-axis and lower on the X-axis. Thus, top-right-corner values represent optimal performance, allowing viewers to quickly identify well-performing database instances as well as the performance differences

between instances.

In this illustration, the system highlighted in red is notable for its low latency and high throughput. Conversely, the system marked in yellow has the poorest latency performance. The instance in purple also stands out, boasting the lowest latency, but it lags behind in terms of throughput.

In the context of performance metrics, the Benchy Viewer should be capable of visualizing the key differences between instances in an intuitive and effective way.

Besides grouping the query results into clusters, with each cluster representing a database instance, it would also be beneficial to have the flexibility to choose a specific metric for this categorization. For instance, if a database developer is primarily concerned with the metrics of execution time and throughput, they should have the option to shape the data visualisation based on these metrics.

Up next, we'll explore the dataset that is consumed by the Benchy Viewer to offer all the data and performance metrics within the analytical visualisations. We'll detail the data structure and how the data is prepared to get in this shape.

## 3.2 Used Datasets and Data Structure

In this section, we talk about the dataset that is consumed by the Benchy Viewer to create meaningful performance visualisations.

At first, we explore the diverse metrics encompassed within the dataset. For each metric, we provide a concise definition and rationalize its significance within the Benchy Viewer framework. Subsequently, we offer an outline of the input file's structure, where we explain how database systems are mapped to the executed queries and the corresponding metric data. Finally, we describe all the steps required within the data preparation process, where raw data is transformed into the previously specified format.

### 3.2.1 Description of the Utilized Performance Data

In this section, we take a closer look at the performance data which is utilized by the Benchy Viewer. These data contain various metrics that give us insights into how our database system is performing: total time (compilation, execution), cycles, instructions, L1 data cache misses, LLC (Last-Level Cache) misses, branch misses, DTLB (Data Translation Lookaside Buffer) misses, tasks, instructions per cycle (IPC), CPU frequency (GHz), and scalability metrics.

**Total time** represents the combined time taken for both query compilation and query execution. It's a critical measure of how efficiently queries are processed. Lower total times are desired, indicating faster query processing.

**Compilation** is the preparation for the execution phase where source code, written in a high-level language, is converted into a lower-level representation. Producing highly-optimized code in this stage can significantly enhance the speed and efficiency of program execution.

**Execution** refers to the phase after the compilation phase where the compiled code is executed on a CPU. It involves the actual processing of instructions and data to perform the tasks specified by the program. The execution phase is of vital significance as it directly measures how efficiently a program or task runs on the hardware.

**Instructions** count the number of individual machine-level instructions during the execution of a program or a specific operation and helps assessing the efficiency of code execution. A high instruction count indicates that the program is performing a large number of computations, which impacts CPU utilization and overall performance. Well-optimized code tends to have a lower instruction count for the same computational tasks. While instruction count provides valuable information about code complexity, it does not capture the complete performance picture. For a more comprehensive understanding, it should be considered alongside metrics such as cycle counts and IPC (Instructions Per Cycle).

**Cycles** refer to the number of clock cycles executed during the test by a CPU. It measures the raw computational effort involved and can indicate the CPU's workload. Lower cycle counts indicate more efficient code execution, while higher counts suggest greater computational complexity or inefficiencies. While cycles provide valuable information about computational effort, they do not give a complete picture of overall system performance. Other metrics, such as instructions per cycle (IPC), may be necessary to better understand the performance landscape.

**IPC (Instructions Per Cycle)** is a performance metric that measures the average number of instructions during a single clock cycle. A higher IPC value indicates that the CPU is executing more instructions per clock cycle, which suggests better performance. Well-optimized code and algorithms tend to have higher IPC values.

**L1D-Misses (Level 1 Data Cache Misses)** are a performance metric that counts the number of times a CPU requested data from its Level 1 Data Cache but was unable to find the required data there. Instead, the CPU had to retrieve the data from a higher-level cache or main memory. The number of L1D-Misses is significant because it reflects how efficiently the CPU's cache hierarchy is operating. High L1D-Miss rates

suggest that the CPU frequently needs to access data from slower memory levels, resulting in increased latency and potentially impacting overall system performance. Lower L1D-Miss rates generally indicate more efficient cache utilization and can result in improved execution performance.

**LLC-Misses (Last-Level Cache Misses)** are a performance metric that counts the number of times a CPU failed to find requested data in its last-level cache. Instead, it had to retrieve the data from a slower memory hierarchy level, such as a higher-level cache or main memory. The number of LLC-Misses is significant because it indicates how effectively the CPU's last-level cache is utilized. Similar to L1D-Misses high LLC-Miss rates suggest that frequently accessed data is not readily available in the cache, leading to increased memory access latency and potential performance bottlenecks. Lower LLC-Miss rates generally indicate more efficient cache utilization and can lead to better overall execution performance.

**Branch-Misses**, often referred to as "branch mispredictions," are a performance metric that counts the number of times a CPU incorrectly predicts the outcome of a branch instruction. Branch instructions are conditional statements (e.g., if-else or loops) in code that determine the program's flow based on a condition. A branch miss occurs when the CPU's branch predictor guesses incorrectly about the branch's outcome and, as a result, has to discard or re-execute some instructions. Therefore, high Branch-Miss rates can indicate inefficiencies in the code execution, as mispredicted branches can lead to the execution of unnecessary instructions and decreased overall performance. Several factors influence Branch-Miss rates, including the complexity of code logic, the CPU's branch prediction algorithms, and the effectiveness of compiler optimizations. Other metrics, such as instruction count, cycle count, and cache utilization, should be also considered to obtain a comprehensive view of performance.

**DTLB-Misses (Data Translation Lookaside Buffer Misses)** are the number of times a CPU requested data from memory, and during this request, it also needed to fetch or translate the virtual memory address to its corresponding physical memory address, but couldn't find the translation in the Data Translation Lookaside Buffer (DTLB). Instead, it had to consult a more extensive translation structure, such as the page table in memory, to perform the translation. The number of DTLB-Misses is significant because it indicates how effectively the CPU's DTLB, which is responsible for accelerating memory address translation, is functioning. High DTLB-Miss rates suggest that the translation process is less efficient, leading to increased memory access latency.

**Tasks** refer to concurrent units of work or threads that a computer system or application is managing or executing simultaneously. These tasks may represent various processes, threads, or parallel workloads. The number of tasks and their management is significant

because it reflects the system's concurrency and workload handling capacity. They help assess how well a system scales with increased workloads and concurrent tasks.

**CPUs** are defined by the number of cores utilized by the system. A higher number of CPUs implies a higher degree of concurrent computing, potentially leading to executing the given query in a more efficient manner. However, the effectiveness of parallel processing also depends on factors like architecture, clock speed, and the specific nature of the computing tasks.

**GHz (Gigahertz)** is a unit of measurement used to quantify the clock speed or frequency of a CPU or other electronic components within a computer system. Specifically, it represents one billion cycles per second. In computing, it is primarily used to describe the operating frequency of a CPU. The GHz metric is significant because it reflects how quickly a CPU can process instructions and perform calculations. Higher GHz values generally indicate faster processing speeds, which can lead to quicker execution of tasks and improved system performance.

**Scale**, in the context of performance analysis for databases, refers to the size of the dataset. It quantifies the system's ability to handle increasing amounts of data and workload. Scale is often measured in terms of data volume, storage capacity, or concurrent user connections. Scale-related metrics are essential for benchmarking and comparing different database systems, hardware configurations, or software designs. They help assess how systems perform as data or workload sizes increase and enable informed decisions regarding system scalability.

In this section, we have provided a comprehensive overview of the performance metrics that will be employed in our system. The next section will detail how we format and organize our performance data for analysis.

### 3.2.2 Structure of the Input File with Performance Measurements

One step preceding the utilization of the Benchy Viewer is the provision of the benchmark data, which will be later used to generate the performance visualisations. In this section, we give an overview about the structure of the input file for the Benchy Viewer.

When submitting data to the Benchy Viewer, only one CSV file is needed to be uploaded to the system. This CSV file contains the benchmark data of all the participating database systems.

The structure of the input file, as depicted in Figure 3.2, is well-defined. It contains the entries of the respective database systems, with each query being associated with a database system. For example, when comparing TPC-H benchmark data, each database

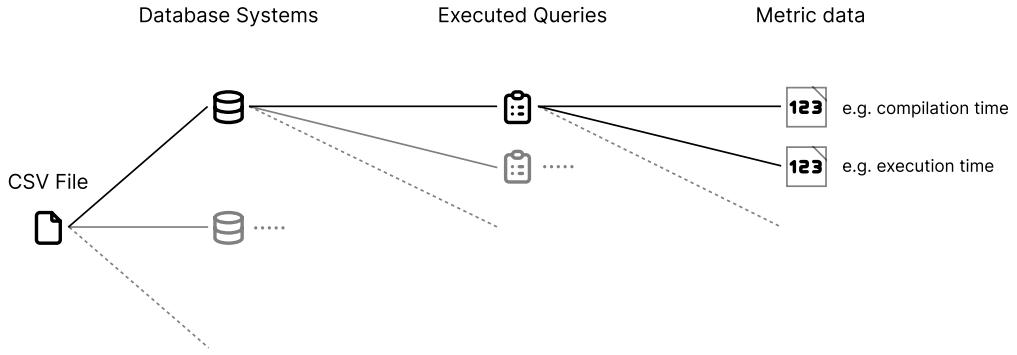


Figure 3.2: CSV structure of the input data for the Benchy Viewer

should comprise data for all 22 TPC-H queries. Each individual query contains data for multiple metrics, which were defined in the previous section such as compilation time, execution time, cycles, instructions, etc.

Moreover, the system accommodates the use of multiple instances of a single database system. Within a database system entry, there is an attribute that allows the specification of the system's particular version. Besides, comparing different systems, this feature enables the comparison of different configurations within one system.

The queries contain metric data which are expressed in specific units or data types. Time-related metrics, such as total, compilation, and execution times, are measured in milliseconds, offering insights into the temporal aspects of query processing.

Hardware-related metrics, including cycles, instructions, cache misses, and more, are provided as integer values, reflecting various hardware-level details. Task-related metrics are also presented as integers, helping to assess task-specific performance. IPC metrics are in floating-point numbers, offering a nuanced perspective on instruction efficiency. CPU-related metrics are integers, while frequency-related metrics are in gigahertz (GHz), providing information about CPU clock speeds.

Next up is the "Data Preparation" section, where we'll dive into the necessary steps for formatting and structuring our data to make it compatible with the Benchy Viewer.

### **3.2.3 Data Preparation**

Prozess, wie man die Daten von einem Testdurchlauf bekommt und davon ein CSV erstellt -> Max fragen

# 4 Implementation

## Chapter Introduction

### 4.1 Concept: Features and Interaction Capabilities of the App

In this section, we explore the expected features and capabilities crucial for our objectives and the necessary interaction capabilities from an end user's perspective.

We start with the visualisation capabilities of the benchmark data, where the goal is to easily identify performance bottlenecks. This involves pinpointing interesting queries with distinct performances for subsequent in-depth analysis.

For deeper analysing and achieving a profound understanding of diverse performance results within queries, the application should support a focus on individual queries. Users should be able to view the performance of a single query from various perspectives, providing a comprehensive image. Comparative analysis across queries from different database systems or even the same database but with different configurations is also essential.

Then, we examine the requirements for a suitable dashboard that contains the main part of the performance visualisations. Multiple views are necessary to construct a complete understanding of the current point of interest. The optimal structure of these views may vary depending on the point of interest. The flexibility of a drag-and-drop solution for structuring views allows users to tailor the overview according to their specific interests.

Finally, we examine the capability of the system to facilitate collaboration and knowledge sharing. The application should enable the saving and sharing of potential findings. This involves saving the interface configuration of the analysis for sharing with other users. Recipients should be able to upload the received configuration, gaining access to the same data and visualisation structure for collaborative exploration.

### 4.1.1 Visualising Benchmark Data

Visualising Benchmark Data includes multiple aspects. It involves the import of the actual data, where a proper way of importing the data should be provided. We also cover the utilized plots and charts for the data visualization. In addition to visualisation, we offer a comprehensive table view of the data.

#### Import of Performance Data

The first step working with the Benchy Viewer is to import a file containing the performance data which should be visualised. The file needs to follow the format introduced in Section 3.2.2. Figure 4.1 summarizes the import of the input file in a process diagram.

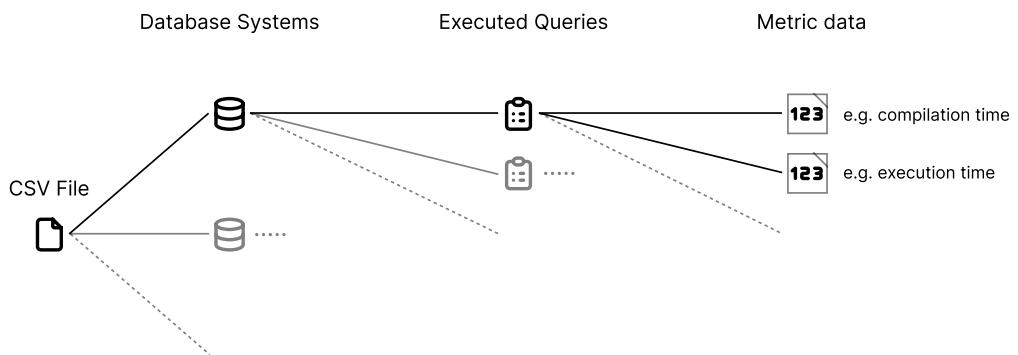


Figure 4.1: Import process of input data

Chart beschreiben.

#### Charts and Plots

We aim to offer a dashboard containing multiple data views. To prevent UI clutter, a universal legend of database system instances is suitable, eliminating the necessity to display a legend in every chart. In the legend depicted in Figure 4.2 all database systems included in the benchmark data are presented as coloured toggles, allowing users to activate or deactivate their appearance in the visualisation.

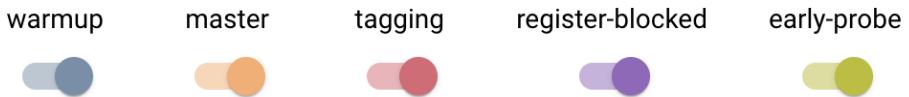


Figure 4.2: Global legend of all database systems contained in the imported performance data.

The preceding visualization solution [Referenz auf PDF](#) shows essential benchmark visualisations, offering both a comprehensive overview of all queries and a detailed examination of each individual query.

It commences with a comparative analysis of each query using a bar chart. Similar to Figure 4.3, this chart displays queries from various database systems on the X-Axis, with the total time presented on the Y-Axis.

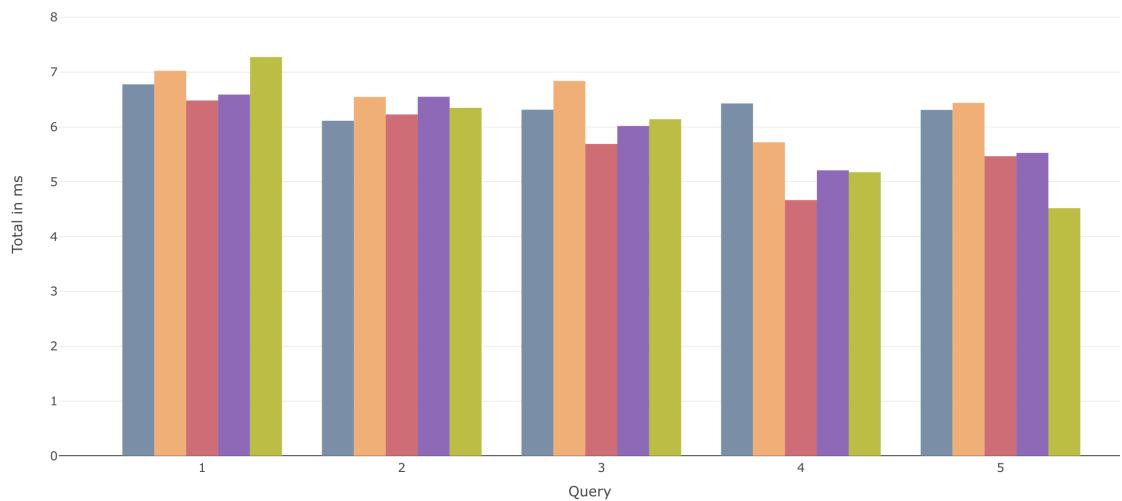


Figure 4.3: Bar chart visualises the totals time in ms of different queries.

Bar plots stand out as a versatile visualization method, particularly when tasked with presenting the performance metrics of multiple queries. Their inherent clarity, with the length of each bar directly corresponding to a specific performance metric such as compilation time or execution time, makes them well-suited for diverse scenarios.

The straightforward visual comparison they offer is a notable strength. With each query distinctly represented by a separate bar, variations in performance become immediately apparent.

This quality proves especially valuable for our objective of identifying outliers, as these exceptional values are easily noticeable.

To facilitate a quick and clear overview of all queries, violin charts are employed. These charts not only provide an initial glimpse of the overall system performance but also offer distribution insights, including the shape and density of the data. They can also be combined with box plots to get a concise summary of the distribution of the results, displaying key statistics such as the median and quartiles.

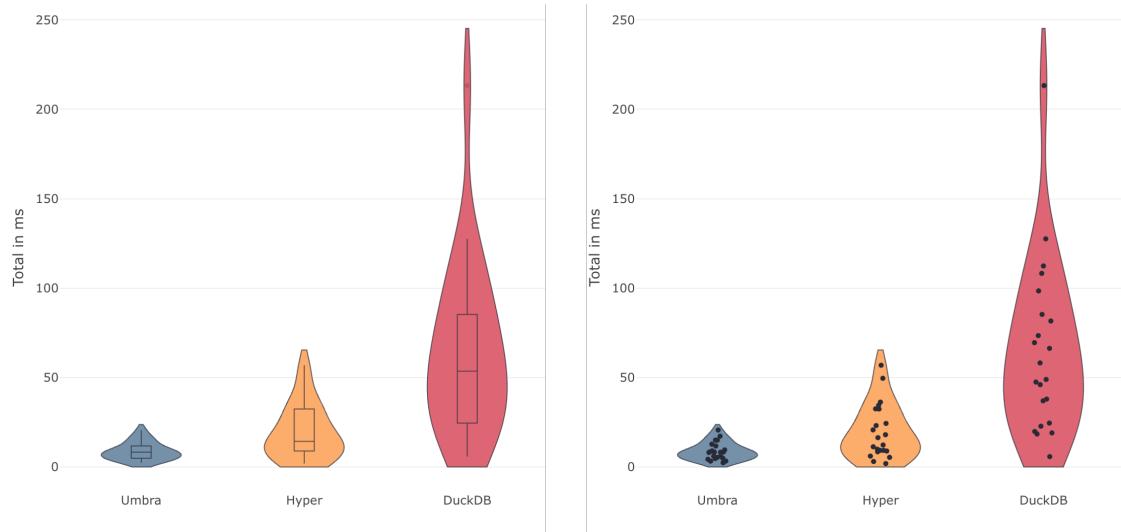


Figure 4.4: Violin charts visualise the totals time in ms of different queries. The left variant contains a box plot and the right variant contains all data points.

Within the Benchy Viewer violin plots that contain data points, as shown in Figure 4.4 on the right side, additionally allow you to hover over a data point. This action highlights the corresponding query in the violins of the other database systems. We will explore this hover feature further in 4.1.1.

In the context of providing a clear and comparative understanding of how different systems perform relative to a chosen baseline, the metrics maximum slowdown and maximum speedup become crucial. They offer a comprehensive view of the range of performance variations. Maximum slowdown indicates the worst-case scenario of reduced performance, while maximum speedup highlights the most significant improvement achieved.

**Slowdown** indicates how much slower a specific system is compared to the baseline system. It is calculated as the ratio of the time taken by the system under consideration

to the time taken by the baseline system. A slowdown value greater than 1 implies that the system is slower than the baseline. For example, a slowdown of 1.5 means the system is 1.5 times slower than the baseline.

Identifying slowdowns is crucial for pinpointing areas of inefficiency or performance bottlenecks in a system. It helps in understanding where improvements are needed.

**Speedup**, on the other hand, quantifies how much faster a specific system is compared to the baseline system. It is calculated similarly to slowdown but in the reverse manner. A speedup value greater than 1 implies that the system is faster than the baseline. For example, a speedup of 2 means the system is twice as fast as the baseline.

Knowing the speedup is essential to highlight improvements. It indicates the effectiveness of optimizations or enhancements made to the system compared to the baseline.

The Benchy Viewer employs tables to showcase the maximum slowdown and maximum speedup, visualized in Figure 4.5, where the maximum slowdown is displayed on the left side and the maximum speedup on the right side using Umbra as the baseline system. The use of cell colors in the table serves as an effective visual indicator of performance outliers. Intensity in color corresponds to the extent of the outlier, offering a rapid understanding of the range and distribution between these extreme values. This color-coded representation aids users in identifying and assessing the significance of performance variations across different systems.

Maximum slow-down for Umbra			
Query	Umbra	Hyper	DuckDB
19	15.03 ms <b>1x</b>	6.11 ms <b>0.41x</b>	48.95 ms <b>3.26x</b>
6	2.37 ms <b>1x</b>	1.93 ms <b>0.81x</b>	5.79 ms <b>2.44x</b>
14	3.28 ms <b>1x</b>	3.08 ms <b>0.94x</b>	19.85 ms <b>6.05x</b>
1	8.44 ms <b>1x</b>	18.04 ms <b>2.14x</b>	46.05 ms <b>5.46x</b>
2	5.37 ms <b>1x</b>	34.51 ms <b>6.42x</b>	37.98 ms <b>7.07x</b>

Maximum speed-up for Umbra			
Query	Umbra	Hyper	DuckDB
4	3.32 ms <b>1x</b>	9.30 ms <b>2.80x</b>	85.31 ms <b>25.70x</b>
20	4.69 ms <b>1x</b>	9.95 ms <b>2.12x</b>	108.26 ms <b>23.10x</b>
21	12.77 ms <b>1x</b>	20.75 ms <b>1.63x</b>	213.26 ms <b>16.70x</b>
10	8.35 ms <b>1x</b>	32.52 ms <b>3.89x</b>	112.42 ms <b>13.46x</b>
22	6.01 ms <b>1x</b>	8.52 ms <b>1.42x</b>	73.46 ms <b>12.23x</b>

Figure 4.5: Tables showcase the maximum slowdown and the maximum speedup using color intensity to indicate performance outliers.

The tables are organized based on the resulting ratio.

In the maximum slowdown tables, the arrangement is ascending, placing the slowest queries of the baseline system compared to the faster alternative system at the top.

Conversely, in maximum speedup tables, the sorting is descending, presenting the fastest queries of the baseline system compared to the alternative system at the forefront. This sorting strategy provides a logical structure to quickly identify and compare

performance differences in either scenario.

Scatter plot is also used for displaying the speedup and slowdown

**Hover Feature**

**Data Viewer**

**4.1.2 Deeper Inspection and Comparison of selected Queries**

Query Plan DBs aktivieren/ deaktivieren

**4.1.3 Flexible Interface Hub**

**Drag and Drop**

DnD Sektionen und Dnd Charts

**Chart Configurations**

- Metrics auswählen - table und scatter: speed-up/ slow-down - Scale: Linear/ Log/ Throuput - Violin: scatter und boxplot

#### **4.1.4 Saving and Sharing the Application State**

### **4.2 Design**

#### **4.2.1 User Interface**

#### **4.2.2 Page Structure and Navigation**

### **4.3 Data Structure**

#### **4.3.1 Overall Project Structure**

#### **4.3.2 Input File and Benchmark Data**

#### **4.3.3 Plot Options**

#### **4.3.4 Visualisation Arrangement Data Structure**

#### **4.3.5 Query Plan**

Visualisation Parameters

Query Plan Data Structure

### **4.4 Integration of Plotly-React for Data Visualization**

#### **4.4.1 Types of Plots and Charts**

#### **4.4.2 Hover Feature**

#### **4.4.3 Selected Query Feature**

### **4.5 Integration of semantic-diff-tool**

#### **4.5.1 Business Logic**

#### **4.5.2 Settings**

#### **4.5.3 UI**

## **5 Discussion**

### **5.1 Evaluation of Achievement of Objectives**

### **5.2 Critical Reflection on the App Development**

#### **5.2.1 Challenges/ Technical Limitations (Performance limits)**

#### **5.2.2 Design Choices and Trade-offs**

#### **5.2.3 User Feedback and Iterative Development**

#### **5.2.4 Comparison with Existing Solutions**

#### **5.2.5 Potentials and Future Improvements**

## **6 Conclusion**

**6.1 Summary of Results**

**6.2 Future Developments and Enhancements**

**6.3 Final Remarks (Summary of Key Findings/ Contribution to the field)**

# 7 Example

## 7.1 Section

Citation test [Lam94].

Acronyms must be added in `main.tex` and are referenced using macros. The first occurrence is automatically replaced with the long version of the acronym, while all subsequent usages use the abbreviation.

E.g. `\ac{TUM}`, `\ac{TUM}` ⇒ Technical University of Munich (TUM), TUM

For more details, see the documentation of the `acronym` package<sup>1</sup>.

### 7.1.1 Subsection

See Table 7.1, Figure 7.1, Figure 7.2, Figure 7.3.

Table 7.1: An example for a simple table.

A	B	C	D
1	2	1	2
2	3	2	3

---

<sup>1</sup><https://ctan.org/pkg/acronym>

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## 7 Example

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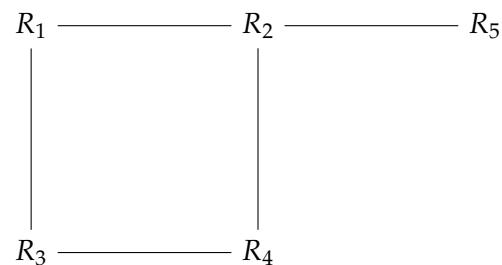


Figure 7.1: An example for a simple drawing.

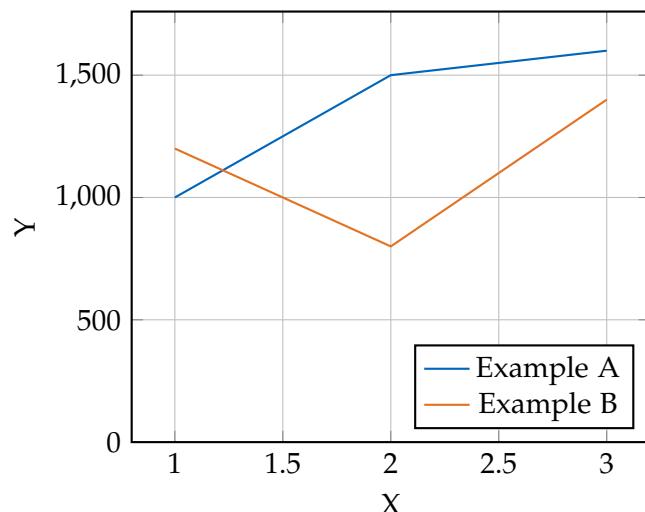


Figure 7.2: An example for a simple plot.

```
SELECT * FROM tbl WHERE tbl.str = "str"
```

Figure 7.3: An example for a source code listing.

# **Abbreviations**

**TUM** Technical University of Munich

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