Re-thinking the Performance of Information Processing Systems

Vishal Sikka

SAP AG

3410 Hillview Ave, Palo Alto, CA, 94304, USA

vsikka@sap.com

***Abstract* — Recent advances in hardware and software technologies have enabled us to re-think how we architect databases to meet the demands of today's information systems. However, this makes existing performance evaluation metrics obsolete. In this paper, I describe SAP HANA a novel, powerful database platform that leverages the availability of large main memory and massively parallel processors. Based on this, I propose a new, multi-dimensional performance metric that better reflects the value expected from today's complex information systems.**

I. Introduction

Parts of the physical world that we inhabit are slowly dissolving away. I mean this literally, in that bits are replacing the atoms that make up many of the artefacts around us. Examples of items that have disappeared (or are disappearing) include books, tape recorders, cassettes/CDs, cameras, travel agency offices, retail stores, paper documents, filing cabinets, darkrooms, printing presses, desk phones, cash registers, blackboards, thermostats, and networking equipment. More than a decade ago, Negroponte [1] observed that *"the change from atoms to bits is irrevocable and unstoppable."* In most cases, along with these artefacts, the jobs that manage these artefacts are also disappearing – they have been "dis-intermediated." More and more power and control over the new digital manifestations of these physical artefacts is moving directly to the end-user or the consumer.

This trend is inevitable and has arguably been going on for a long time. The printing press comes to mind as an advance that simultaneously simplified printing and empowered ordinary people to express themselves in print. Given time, technological advances tend to slowly dissolve away the redundant artefacts that limit human experience, and eliminate middle-tiers. Activities tend to become real-time or just-in-time, in that software-driven assembly of artefacts and experiences becomes increasingly possible, within a window of time, during an interaction at an end-point. This observation is especially applicable in enterprise computing. The enterprise landscape is littered with layers upon layers of redundant infrastructure. A natural consequence of this redundancy is high cost and complexity, slow processing of data (usually with batch processing), and end-users being provided data and analyses that are old, slow, and based on aggregates or summaries - not on fresh data that is un-processed. Imagine instead, that we have data stored in one database, where we can both process transactions and analyse the data in "real-time" at the required speed. We do this without incurring the cost of replicating the transactional data in a data warehouse.

In this paper I argue that modern in-memory database technology, such as SAP HANA (from this point onwards referred to as HANA), can enable us to completely rethink information processing: from batch-oriented and workload-specific thinking, to real-time thinking without boundaries, so that business activities can be conducted within a specified window of opportunity. This outcome has always been a desirable one for enterprises and end-users, but has just recently become technically feasible and financially viable. I believe this technology will have a massive impact on enterprises and enterprise computing. However, to fully comprehend and quantify the value of such a technology, we also need to re-think the metrics that define the performance of information processing systems, including databases. I will start with a brief description of HANA, and then introduce some metrics to measure database performance, and finally share some examples and conclusions.

II. A Brief Description Of HANA

HANA is a fully in-memory, parallel, ACID-compliant database [2] that is natively designed to take maximum advantage of large main-memories and massively parallel processing on multi-core CPUs: two key aspects of modern hardware. It can be used without compromise to tackle diverse enterprise workloads – transactional and analytical, structured and unstructured, simple and complex, simultaneously in a single instance. HANA is a realization of Hasso Plattner's idea of a single in-memory columnar database for OLTP and OLAP workloads [3].

HANA is architected with a transactional column store at its heart [4], and is designed ground-up for massively parallel processing, with new data structures and vector-based operators that make set-based operations very efficient. The query interface supports standard SQL and goes beyond it, to support mixed queries on structured or unstructured, historic or planned, and recent or aged data without degradation of performance. Extensions include full-featured text search and planning engines, geographical information processing, and an extensible (or "timeless" [5]) architecture that enables us to add future capabilities such as processing graphs, rule languages and genome processing. HANA's insert-only capability enables arbitrary reconstruction of the sequence of events that put the database in the current state (or time-travel). In addition, HANA is a data management platform that comes equipped with multiple language runtimes, and function libraries for statistics, machine-learning functions, text analytics and linguistic processing, and business functions designed to execute logic in-database.

Inside HANA, search is used as the starting point for everything – we simply search for the answer set to any query (for example, by finding all possible objects which contain a specific company name). The column-store mechanism allows for new dictionary and vector-based data structures that result in substantial (5X-20X) data compression, making set-based operations on large data sets extremely efficient. Finally, with HANA, data partitioning is done dynamically, in-memory, utilizing all cores in a multi-core processor for each query, with no limit to the scalability. With all these capabilities in place, on a Sandy Bridge[1] processor, HANA achieves speeds in excess of 3B integer scans/second/core, and more than 12M aggregations/second/core, giving us an unprecedented ability to directly relate system performance to business outcomes.

Altogether, HANA is built on a functional base that is different from current DBMS technology. The main advantage of the new functional base is that query processing in HANA becomes much closer to the original mathematical formulation of a business question. A lot of dead weight is now removed from query processing - no time is wasted on data access and data manipulation in a conventional sense. As a result, the distance (i.e. the volume of computation) between the raw data set and the business becomes much smaller.

The consequent benefits of these technological advances in database architecture are multi-fold. One of the most important benefits of this is the collapse of the software layers, especially the application and data management layers. A data layer designed using these principles is capable of going far beyond traditional database systems, resulting in more advanced features, capabilities and services. It is much more than the traditional relational SQL engine. Indeed, traditional measures like those defined by TPC [6] are not capable of measuring the capabilities of such a system.

In the next section, I propose a more comprehensive framework for measuring these benefits, and the business value generated by implementing such a system.

III. The Value Of A New Database Architecture

An early adopter of the HANA technology is leading a food and beverage company in China (see Section V[B]). At this company, an operational report on the calculation of transportation costs used to route trucks carrying their product to various destinations used to take more than 25 hours to run. On HANA it runs in ~700ms – which is a performance improvement of more than 100,000 times. Presently, around 20 customers of SAP have implemented business scenarios in HANA that operate at least 10,000 times faster than their previous implementations of the same scenario on a traditional RDBMS. These results prompt us to ponder the significance of performance improvements of this magnitude. What is the business value these improvements deliver? What are the underlying governing dynamics of the performance, and cost of information systems that enable and support our decisions?

I believe that value in decision-making results from our ability to *efficiently* take *important decisions* within their *relevant time-window*. Let us look at the economics and the engineering that underlie this. Basic economics tells us that:

$$Value = \frac{Derived\ Benefit}{Incurred\ Cost}$$

The benefits offered by a data-processing system depend on several of its abilities. Here, I propose five distinct and orthogonal dimensions that make up the benefits and costs. To perform highly, an information processing system needs to maximize the boundaries of each one of these dimensions: (1) going deep, (2) and going broad, (3) in real-time, (4) within a given window of opportunity and (5) without pre-processing of data. Let us examine each of these dimensions next.

A. Going Deep

This dimension relates to the benefit of allowing unrestricted query complexity. Does the system enable us to go deep into the kinds of questions we can ask? Does it enable us to ask a large variety of questions, simple and complex, even questions that we have not fully articulated in advance and need to iteratively arrive at after exploring the relevant data? Modern data analysis scenarios increasingly involve complex questions and sophisticated, mathematical, treatment of data, e.g. recursive scans thru data for parts explosion, configurations, market-basket analysis, iterative scans of data for classification and segmentation. A system that enables us to ask a large variety of questions is, obviously, more beneficial than one that doesn't.

B. Going Broad

This dimension relates benefit of allowing unrestricted data volume and variety. Does the system enable us to ask our questions to a large corpus of heterogeneous data? Can we use as many different types of data as our question needs? Performance limitations of existing data processing systems, limit us to operate on data that is pre-aggregated, summarized, or on its subsets, to fit into their performance windows.

In a related observation, researchers from Google [7] said *"…but invariably, simple models and a lot of data trump more elaborate models based on less data."* Adam Thier, an expert on business planning at SAP recently put it a different way: *"They [the reports] don't tell enough of a story to act on. The statistical reductions smooth out the curves – and this kills our decision-making. We want to find the exceptions. To do this we need much larger chunks of data."*

C. In Real-Time

This dimension relates to the benefit of including the most recent data into the analysis. Can we pose our questions to data that are recent, preferably real-time? How do we

[1] Codename for a particular 32nm family of processors from Intel®

minimize the distance between the raw data and the business that is relevant to it?

D. Within a Given Window of Opportunity

This dimension relates to benefit of response time. Are we able to get our answers rapidly? In most cases, the human mind works best when responses to questions come within a 1 second window [8], enabling us to interact with a system in one train of thought and arrive at a conclusion iteratively. When it comes to getting answers to important questions, speed matters. When we detect actionable events and circumstances, time to respond is often critical, as actions are typically taken within a window of opportunity, at a point of interaction where a business activity is taking place, e.g. determining inventory availability, or price or cost feasibility, while a customer is on the line.

E. Without Pre-processing of Data

This dimension relates to the cost of data preparation. Are we able to ask our questions on actual fine-grained data, without pre-aggregation into summaries that someone else created, that restrict our ability to ask questions, or limit them to the scope of the aggregation? Does the system require tuning by experts before we can pose our questions to it? Does it require us to send our question to experts who are the ones that interact with the system on our behalf?

A system that achieves high performance on all 5 of these dimensions would result in very high value in our decision-making ability. Traditional enterprise systems existing today make compromises on each of these dimensions due to fundamental technological or architectural limitations. However, this means that we don't get the answers we seek, and we don't get them fast enough, don't get them to the level of detail necessary, or on up-to-date information. This has, of course, been our goal with HANA.

With this basic framework in place for measuring the value of an information processing system such as HANA, I will next define these key dimensions more quantitatively, and propose a value-metric.

IV. Quantifying The Dimensions of Value

Shannon, in his seminal work on the theory of communication [9], showed that information is a physical quantity, and can be measured as such. He proposed a way to measure information quantitatively using information entropy, which was subsequently proved to be fully equivalent to ordinary entropy from thermodynamics [10]. In other words, information is not just an abstract notion, but can be converted to heat, can perform work, needs a physical carrier, and is governed by principles that apply to physical artifacts. Can we use this notion to measure the performance of an information processing system, i.e. to assess how well equipped we are to make decisions based on information?

From basic physics, we have:

$$Speed = \frac{Distance}{Time}$$

I propose a simple framework, derived from this classical equation of speed, to assess the performance and the value of a data-processing system like HANA. We can measure performance of an information system in this manner, as a ratio of a question's "information distance" from its answer, and the amount of time involved in obtaining the answer, as follows:

$$Performance = \frac{Amount\ of\ Information\ Processed}{Answer\ Propagation\ Time}$$

Performance is the analogue of *Speed* from the prior equation. The two variables in this equation are themselves constituted from the five more basic constructs defined earlier in this paper. Below, I describe an approach in order to quantify the five dimensions using concrete, real-world measurements.

A. Query Complexity

This is the computational complexity of a query. Generally speaking, a simple query (e.g. a table scan), of course, takes less time to run on a given amount of data than a more complex query (e.g. percentile calculation). Query complexity is a measure of the "distance" between a question and its answer, and could be measured in a basic unit of query operations. In computer science, we measure algorithmic complexity in well-defined complexity classes, but in information processing systems, it would be beneficial to have straightforward ways of measuring query complexity. In the past database systems have used QPH (Queries per Hour) as a unit to measure throughput [11], occasionally normalized by database size and hardware cost, but not normalized by the complexity of the query. We need a basic unit of query complexity, somewhat analogous to flops or BTUs. I propose QOPS (Query Operations per Second), where a query operation is a basic unit of work performed by a system in processing a query on an atomic unit of data (e.g. a single record that is the subject of the query in a sequence of basic fetch, compare, store operations).

B. Data Size

This is the amount of data, based on the number of records and the number of columns. It is important to limit data size to only the data, and all the data, required for the query's computation.

C. Data Detail

In general, the more fine-grained and detailed the data is, the better our ability to make decisions and find the necessary information from it. This would be measured in amount of data (e.g. number of available bytes).

D. Data Diversity

This refers to the individual types of data (e.g. integers, text etc.) and whether these reside in one system or multiple systems. Having multiple types of data and their processing engines within one system improves the overall efficiency of an information system in a non-linear manner. This would be measured as a type dependant complexity factor on the data size.

E. Query Execution Time

This refers to the response time of the system to produce and possibly display the results of the query to the consumer, including any query/system optimization. This is measured in units of time (e.g. seconds)

F. Data Preparation Time

This refers to the time it took, since the query relevant events took place, for the information about them to make their way to the system from where the query response is calculated. This can include the time it takes to build up indices, cubes, any intermediate structures and representations that data processing systems can use, time to replicate data, etc. This should also be measured in units of time (e.g. seconds).

Based on the fields described above, we can calculate the variables of the performance equation as follows:

Amount of Information Processed =
f(Query Complexity, Data Size, Data Diversity)

and,

Answer Propagation Time =
g(Query Response Time, Data Preparation Time)

In the basic case I propose that *f* is ordinary multiplication and *g* is ordinary addition.

It is somewhat simpler to quantify the factors that influence the cost of a data-processing system. These include the cost of setting up and making data available to the system (including the system costs as well as the necessary administrative costs), and the cost of operating the system (including all its sub-systems, and its connectivity to other systems etc.).

With the quantification of performance and cost as described above, the measurement of business value of the new database architecture as described in Section III easily follows.

V. Examples

Below are some representative examples of how this approach has been applied to several productive implementations of HANA. The application of this framework to measure performance and value of specific systems is an early and ongoing effort at SAP in collaboration with other organizations. We aim to further refine and expand these results towards a measurable quantitative performance metric.

A. Multinational Construction Conglomerate Based in Asia

As all the projects at this company are CapEx-oriented (material, infrastructure), they need to be monitored closely and constantly to maximize the margins for individual projects. A key report is the project valuation report, which is meant to calculate the following KPIs: Planned Progress against Actual Progress, Actual Cost and Accrued Cost, Cost to Complete the Project, Actual Revenue and Billed Revenue.

Query Complexity:	Medium(Join & Scan intensive)
Data Diversity:	5 (Int, Float, Char, Date, Time)
Data Size:	Existing: 2 GB, HANA: ~400 MB
Query Exec. Time:	Existing: 15 hours HANA: 4.8 sec
Data Prep. Time:	Existing: 15 hours (creating data cubes) HANA: 0 (no data prep.)

B. Food and Beverage Company in China

Transportation cost occupies a large part of its total operational cost. After the end of each month, they need to evaluate and allocate all the transportation cost of last month to every product, and to know which batches of products incur the most.

Query Complexity:	High (Route Optimization)
Data Diversity:	3 (Char, Dec, Time)
Data Size:	Existing: 565MB, HANA: 129MB
Query Exec. Time:	Existing: ~ 25 hours HANA: 0.7 sec
Data Prep. Time:	0 (no data prep.)

C. Financial Services Company in China

The investment managers at this company explore the best investment model in the Chinese stock market through multi-dimension interaction. There are over 2000 stocks in Chinese markets since 1991, and the stock selection strategy is complex. Even for the most recent 4 years (assuming the observation / holding periods ranging from 1 - 400 days, and the number of stocks in the portfolio ranging from 5 to 15), there are over 200M calculations for each optimization.

Query Complexity:	High (Clustering, 10k ops/row)
Data Diversity:	3 (Char, Int, Double)
Data Size:	Existing: 50MB
Query Exec. Time:	Existing: ~ 42 hours HANA: 15 sec
Data Prep. Time:	0 (no data prep.)

D. Leading Bank in Asia

The senior management of the company receives a comprehensive report of KPIs across business lines. This monthly performance report is published across the management hierarchy at the bank. This is the basis to review the past month's performance across the zones and to plan the strategy and action plan for the current month. The 2.5M records that are the basis for the report come from multiple systems, and the review takes about a week.

Query Complexity:	Medium (Join & Scan Intensive, 10 ops)
Data Diversity:	5 (Int, Float, Char, Date, Time)
Data Size:	Existing: 163 GB HANA: ~ 63 MB
Query Exec. Time:	Existing: 2 hours HANA: 15m 44 sec
Data Prep. Time:	Existing: 3 days HANA: 15m

The significant performance improvement achieved in these cases is a combination of a very complex query on a large, fine-grained, data set, and on real-time data. A combination of this sort results in extreme gain in performance while maintaining a very low marginal cost, resulting in a very substantial value gain to the business. Enterprise derive extreme value from systems like HANA in cases where, on real-time or near-real-time data, there is a need to run valuable, yet complex queries, on large data sets. When we add text data to the mix, and include scenarios where questions aren't known in advance, the value becomes that much greater.

VI. Conclusion

Modern hardware and in-memory technology advances have enabled a new powerful architecture for databases and information processing. This enables us to rethink information processing in enterprise systems: from batch-oriented and workload-specific thinking, to real-time thinking without boundaries, so that business activities can be conducted within a specified window of opportunity, instead of being constrained by system performance. HANA is such a system, now in productive use at hundreds of companies. These large advances necessitate a re-thinking of how we measure performance of these systems. In this paper, I have proposed some comprehensive ways of measuring performance and business value for this new generation of information processing systems.

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