Microsoft

Research Faculty Summit 2018

Systems | Fueling future disruptions

Carnegie Mellon University

MAKE YOUR DATABASE DREAM OF ELECTRIC SHEEP

DESIGNING FOR AUTONOMOUS OPERATION

@andy_pavlo

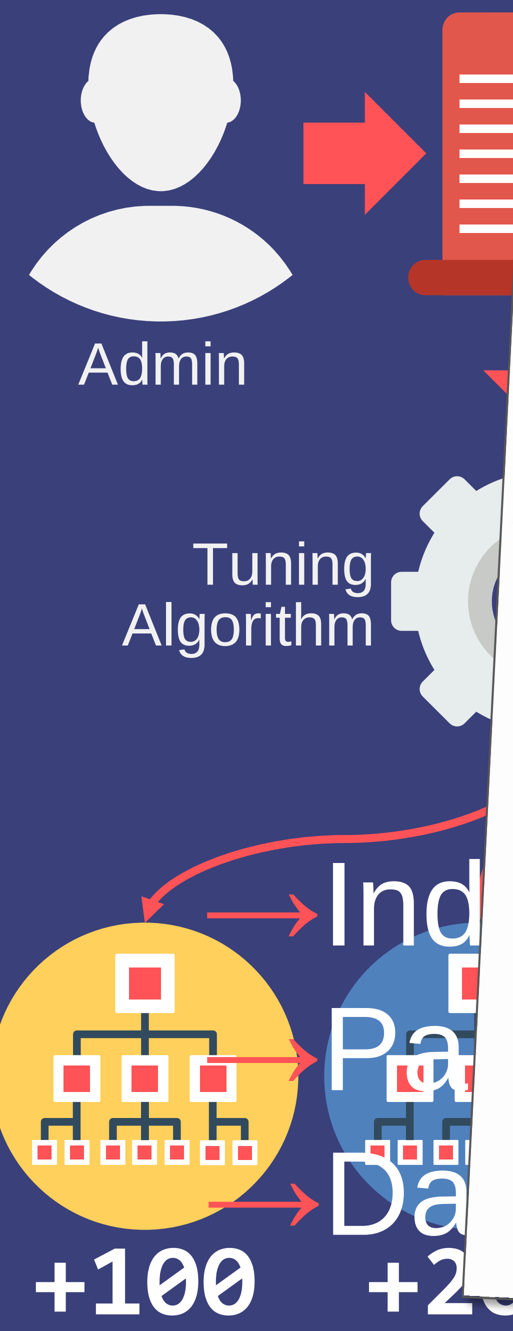
[Image Source]

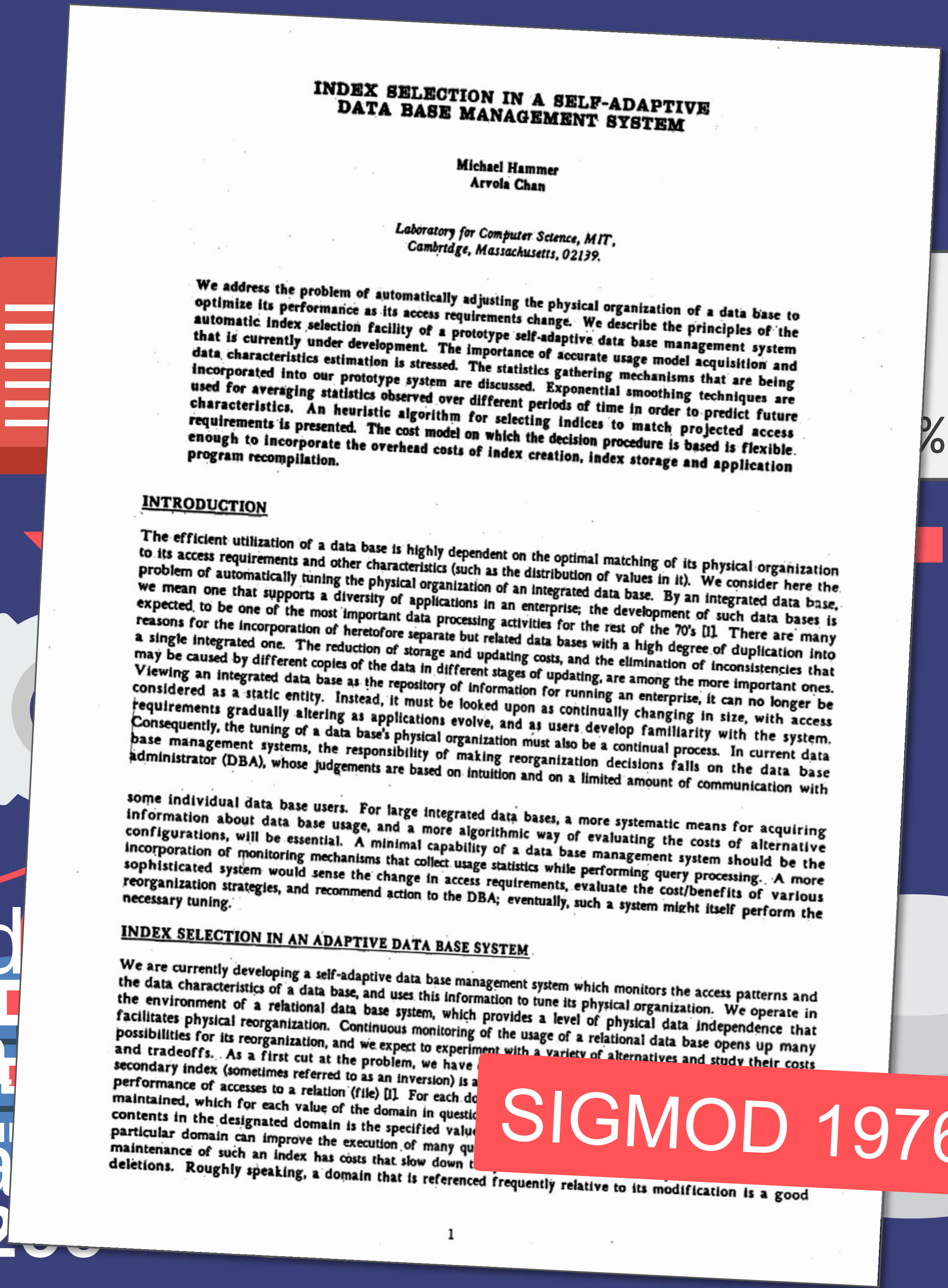
Part #1 – Background

Part #2 – Engineering

Part #3 – Oracle Rant

1970-1990s
Self-Adaptive Databases





INDEX SELECTION IN A SELF-ADAPTIVE DATA BASE MANAGEMENT SYSTEM

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Arvola Chan

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We address the problem of automatically adjusting the physical organization of a data base to optimize its performance as its access requirements change. We describe the principles of the automatic index selection facility of a prototype self-adaptive data base management system that is currently under development. The importance of accurate usage model acquisition and data characteristics estimation is stressed. The statistics gathering mechanisms that are being incorporated into our prototype system are discussed. Exponential smoothing techniques are used for averaging statistics observed over different periods of time in order to predict future characteristics. An heuristic algorithm for selecting indices to match projected access requirements is presented. The cost model on which the decision procedure is based is flexible enough to incorporate the overhead costs of index creation, index storage and application program recompilation.

INTRODUCTION

The efficient utilization of a data base is highly dependent on the optimal matching of its physical organization to its access requirements and other characteristics (such as the distribution of values in it). We consider here the problem of automatically tuning the physical organization of an integrated data base. By an integrated data base, we mean one that supports a diversity of applications in an enterprise; the development of such data bases is expected to be one of the most important data processing activities for the rest of the 70's [1]. There are many reasons for the incorporation of heretofore separate but related data bases with a high degree of duplication into a single integrated one. The reduction of storage and updating costs, and the elimination of inconsistencies that may be caused by different copies of the data in different stages of updating, are among the more important ones. Viewing an integrated data base as the repository of information for running an enterprise, it can no longer be considered as a static entity. Instead, it must be looked upon as continually changing in size, with access requirements gradually altering as applications evolve, and as users develop familiarity with the system. Consequently, the tuning of a data base's physical organization must also be a continual process. In current data base management systems, the responsibility of making reorganization decisions falls on the data base administrator (DBA), whose judgements are based on intuition and on a limited amount of communication with

some individual data base users. For large integrated data bases, a more systematic means for acquiring information about data base usage, and a more algorithmic way of evaluating the costs of alternative configurations, will be essential. A minimal capability of a data base management system should be the incorporation of monitoring mechanisms that collect usage statistics while performing query processing. A more sophisticated system would sense the change in access requirements, evaluate the cost/benefits of various reorganization strategies, and recommend action to the DBA; eventually, such a system might itself perform the necessary tuning.

INDEX SELECTION IN AN ADAPTIVE DATA BASE SYSTEM

We are currently developing a self-adaptive data base management system which monitors the access patterns and the data characteristics of a data base, and uses this information to tune its physical organization. We operate in the environment of a relational data base system, which provides a level of physical data independence that facilitates physical reorganization. Continuous monitoring of the usage of a relational data base opens up many possibilities for its reorganization, and we expect to experiment with a variety of alternatives and study their costs and tradeoffs. As a first cut at the problem, we have secondary index (sometimes referred to as an inversion) is a performance of accesses to a relation (file) [1]. For each do maintained, which for each value of the domain in questi contents in the designated domain is the specified valu particular domain can improve the execution of many qu maintenance of such an index has costs that slow down t deletions. Roughly speaking, a domain that is referenced frequently relative to its modification is a good

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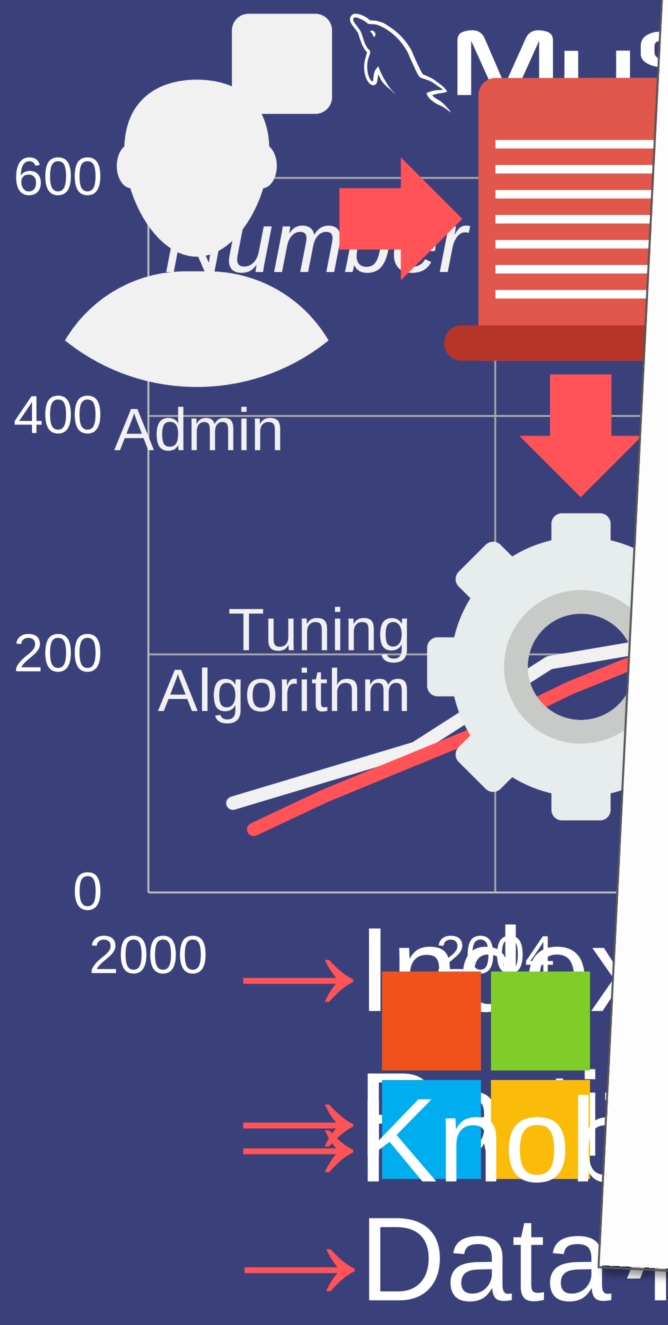
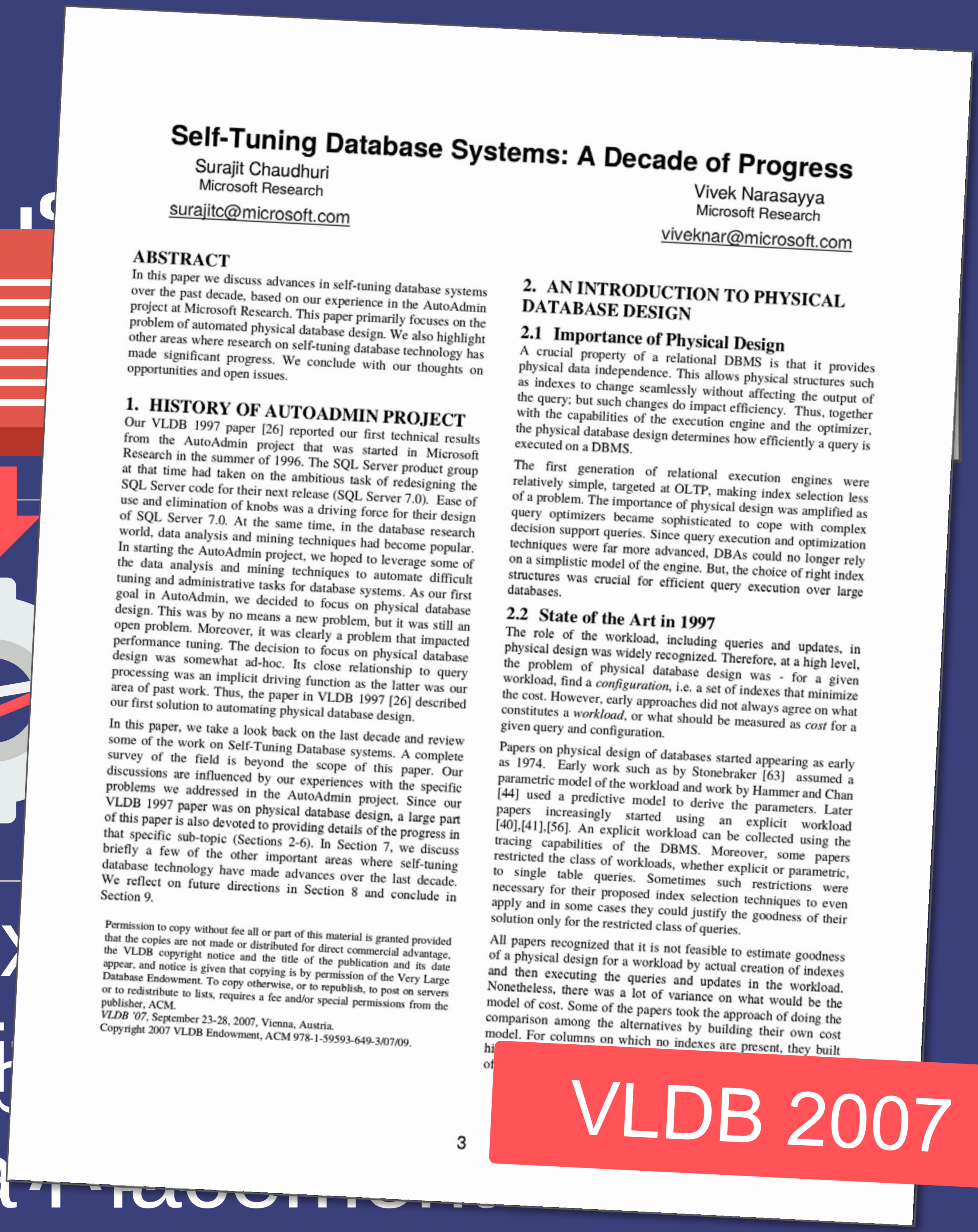
SIGMOD 1976

1990-2000s
Self-Tuning Databases





Self-Tuning Database Systems: A Decade of Progress

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ABSTRACT

In this paper we discuss advances in self-tuning database systems over the past decade, based on our experience in the AutoAdmin project at Microsoft Research. This paper primarily focuses on the problem of automated physical database design. We also highlight other areas where research on self-tuning database technology has made significant progress. We conclude with our thoughts on opportunities and open issues.

1. HISTORY OF AUTOADMIN PROJECT

Our VLDB 1997 paper [26] reported our first technical results from the AutoAdmin project that was started in Microsoft Research in the summer of 1996. The SQL Server product group at that time had taken on the ambitious task of redesigning the SQL Server code for their next release (SQL Server 7.0). Ease of use and elimination of knobs was a driving force for their design of SQL Server 7.0. At the same time, in the database research world, data analysis and mining techniques had become popular. In starting the AutoAdmin project, we hoped to leverage some of the data analysis and mining techniques to automate difficult tuning and administrative tasks for database systems. As our first goal in AutoAdmin, we decided to focus on physical database design. This was by no means a new problem, but it was still an open problem. Moreover, it was clearly a problem that impacted performance tuning. The decision to focus on physical database design was somewhat ad-hoc. Its close relationship to query processing was an implicit driving function as the latter was our area of past work. Thus, the paper in VLDB 1997 [26] described our first solution to automating physical database design.

In this paper, we take a look back on the last decade and review some of the work on Self-Tuning Database systems. A complete survey of the field is beyond the scope of this paper. Our discussions are influenced by our experiences with the specific problems we addressed in the AutoAdmin project. Since our VLDB 1997 paper was on physical database design, a large part of this paper is also devoted to providing details of the progress in that specific sub-topic (Sections 2-6). In Section 7, we discuss briefly a few of the other important areas where self-tuning database technology have made advances over the last decade. We reflect on future directions in Section 8 and conclude in Section 9.

VLDB '07, September 23-28, 2007, Vienna, Austria.

2. AN INTRODUCTION TO PHYSICAL DATABASE DESIGN

2.1 Importance of Physical Design

A crucial property of a relational DBMS is that it provides physical data independence. This allows physical structures such as indexes to change seamlessly without affecting the output of the query; but such changes do impact efficiency. Thus, together with the capabilities of the execution engine and the optimizer, the physical database design determines how efficiently a query is executed on a DBMS.

The first generation of relational execution engines were relatively simple, targeted at OLTP, making index selection less of a problem. The importance of physical design was amplified as query optimizers became sophisticated to cope with complex decision support queries. Since query execution and optimization techniques were far more advanced, DBAs could no longer rely on a simplistic model of the engine. But, the choice of right index structures was crucial for efficient query execution over large databases.

2.2 State of the Art in 1997

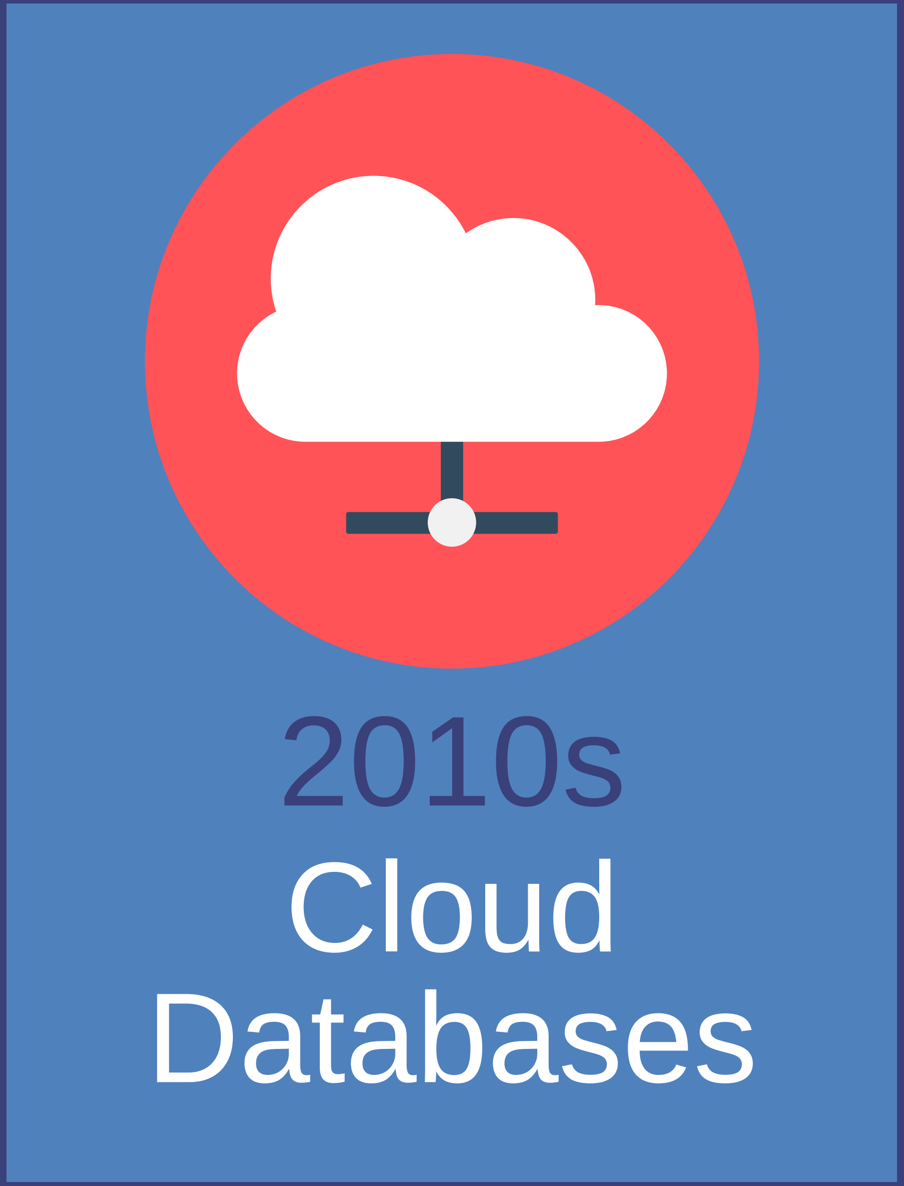
The role of the workload, including queries and updates, in physical design was widely recognized. Therefore, at a high level, the problem of physical database design was - for a given workload, find a *configuration*, i.e. a set of indexes that minimize the cost. However, early approaches did not always agree on what constitutes a *workload*, or what should be measured as *cost* for a given query and configuration.

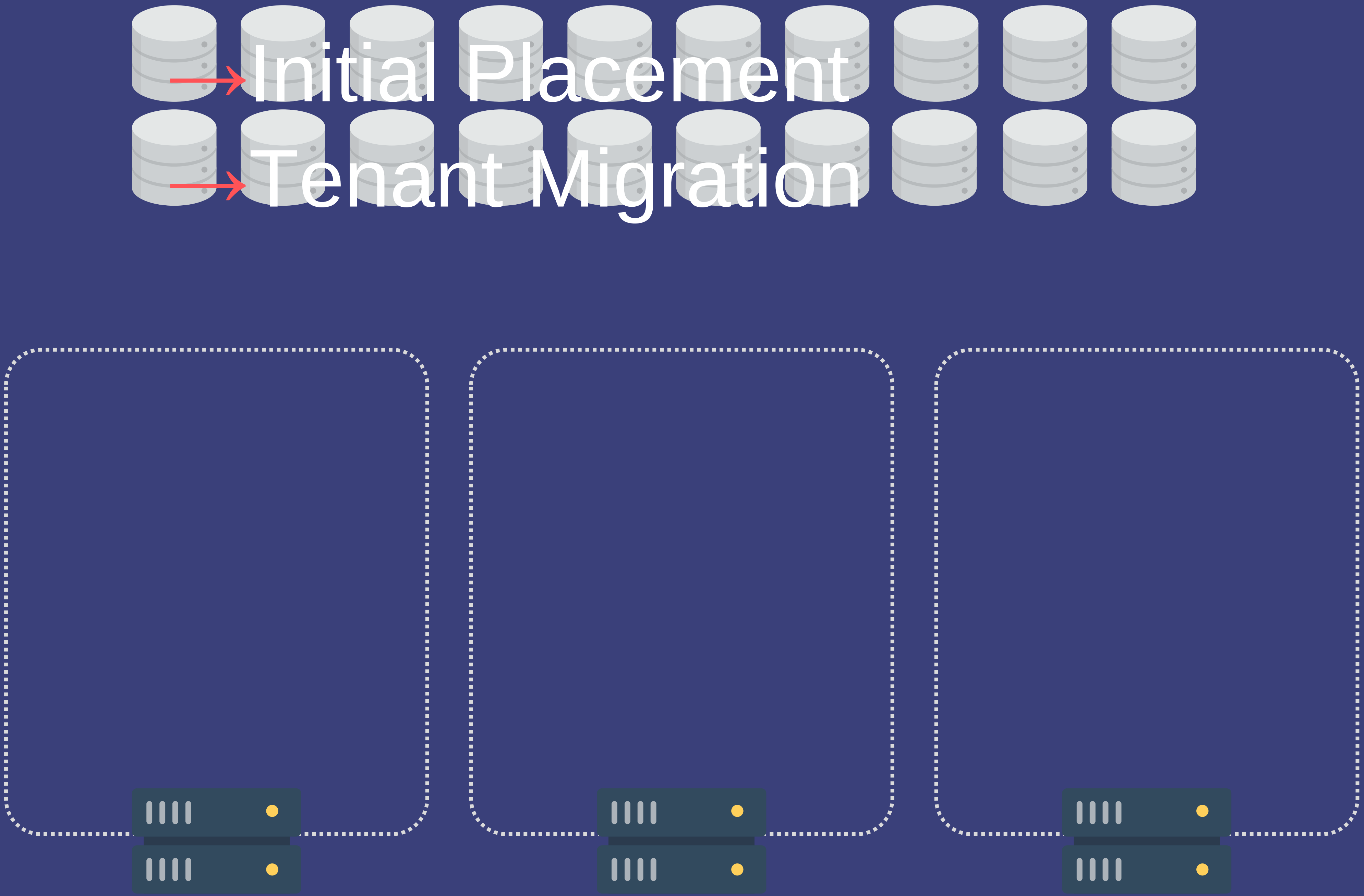
Papers on physical design of databases started appearing as early as 1974. Early work such as by Stonebraker [63] assumed a parametric model of the workload and work by Hammer and Chan [44] used a predictive model to derive the parameters. Later papers increasingly started using an explicit workload [40],[41],[56]. An explicit workload can be collected using the tracing capabilities of the DBMS. Moreover, some papers restricted the class of workloads, whether explicit or parametric, to single table queries. Sometimes such restrictions were necessary for their proposed index selection techniques to even apply and in some cases they could justify the goodness of their solution only for the restricted class of queries.

All papers recognized that it is not feasible to estimate goodness of a physical design for a workload by actual creation of indexes and then executing the queries and updates in the workload. Nonetheless, there was a lot of variance on what would be the model of cost. Some of the papers took the approach of doing the comparison among the alternatives by building their own cost model. For columns on which no indexes are present, they built

3

VLDB 2007


2010s
Cloud
Databases

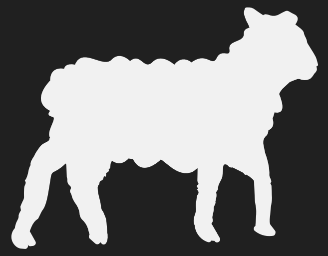

→Initial Placement
→Tenant Migration

Why is this Previous Work Insufficient?

Problem #1
Human Judgements

Problem #2
Reactionary Measures

Problem #3
No Transfer Learning



What is Different this Time?

OtterTune

Existing Systems

Peloton

New System

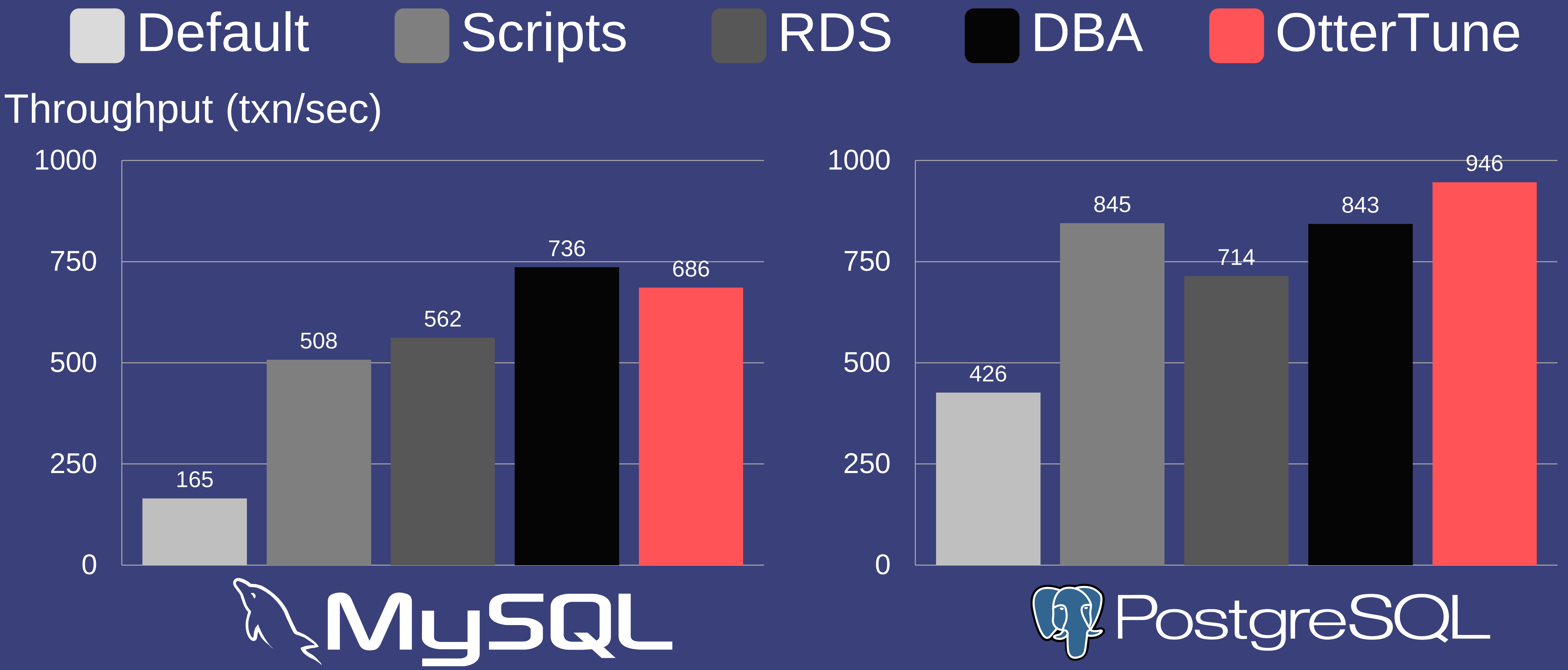
Database Tuning-as-a-Service

→ Automatically generate DBMS knob configurations.

→ Reuse data from previous tuning sessions.

OtterTune

ottertune.cs.cmu.edu



AUTOMATIC DATABASE MANAGEMENT SYSTEM TUNING THROUGH LARGE-SCALE MACHINE LEARNING
SIGMOD 2017

Peloton

pelotondb.io

Self-Driving Database System

→ In-memory DBMS with integrated planning framework.

→ Designed for autonomous operations.

Design Considerations for Autonomous Operation

Configuration Knobs

Internal Metrics

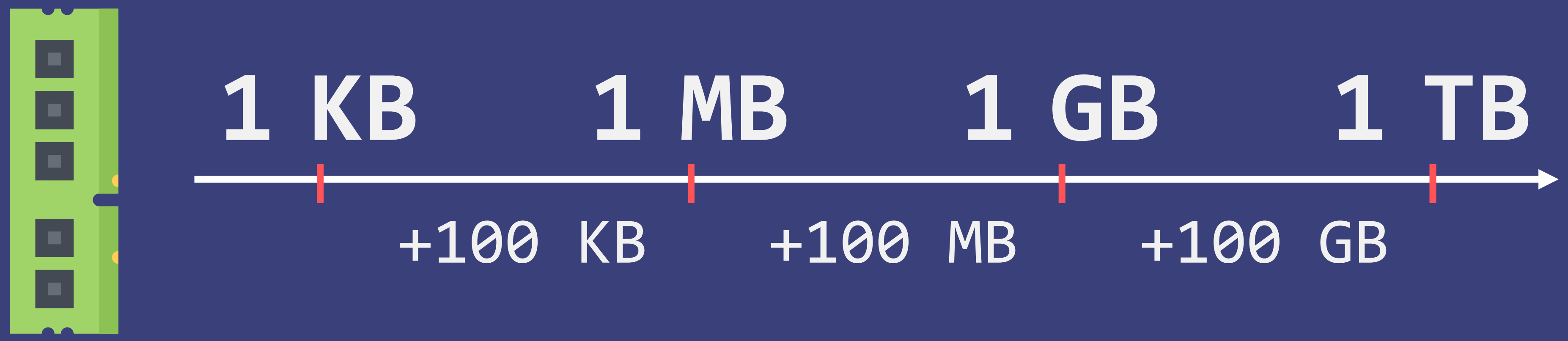
Action Engineering

Anything that requires a human value judgement should be marked as off-limits to autonomous components.

- *File Paths / Network Info*
- *Durability / Isolation Levels*
- *Hardware Usage*
- *Recovery Time*

The autonomous components need hints about how to change a knob.

- *Min/max ranges.*
- *Separate knobs to enable/disable a feature.*
- *Non-uniform deltas.*



If the DBMS has sub-components that are tunable, then it must expose separate metrics for those components.

Bad Example: RocksDB

RocksDB Column Family Knobs

```
rocksdb_override_cf_options=\
    cf_link_pk={prefix_extractor=capped:20}
```

Global Metrics

Column Family Metrics

```
mysql> SHOW GLOBAL STATUS;
+-----------------------------------+-----------+
| METRIC_NAME                       | VALUE     |
+-----------------------------------+-----------+
| ABORTED_CLIENTS                   | 0         |
•••
| ROCKSDB_BLOCK_CACHE_BYTES_READ    | 295700537 |
| ROCKSDB_BLOCK_CACHE_BYTES_WRITE   | 709562185 |
| ROCKSDB_BLOCK_CACHE_DATA_HIT      | 64184     |
| ROCKSDB_BLOCK_CACHE_DATA_MISS     | 1001083   |
| ROCKSDB_BYTES_READ                | 5573794   |
| ROCKSDB_BYTES_WRITTEN             | 5817440   |
| ROCKSDB_FLUSH_WRITE_BYTES         | 2906847   |
•••
| UPTIME_SINCE_FLUSH_STATUS         | 5996      |
+-----------------------------------+-----------+
```

```
STAT;
------------+
 VALUE      |
------------
 1          |
 21672      |
 21672      |
 0          |
 0          |
 18         |
 0          |
 0          |
 2          |
------------+
```

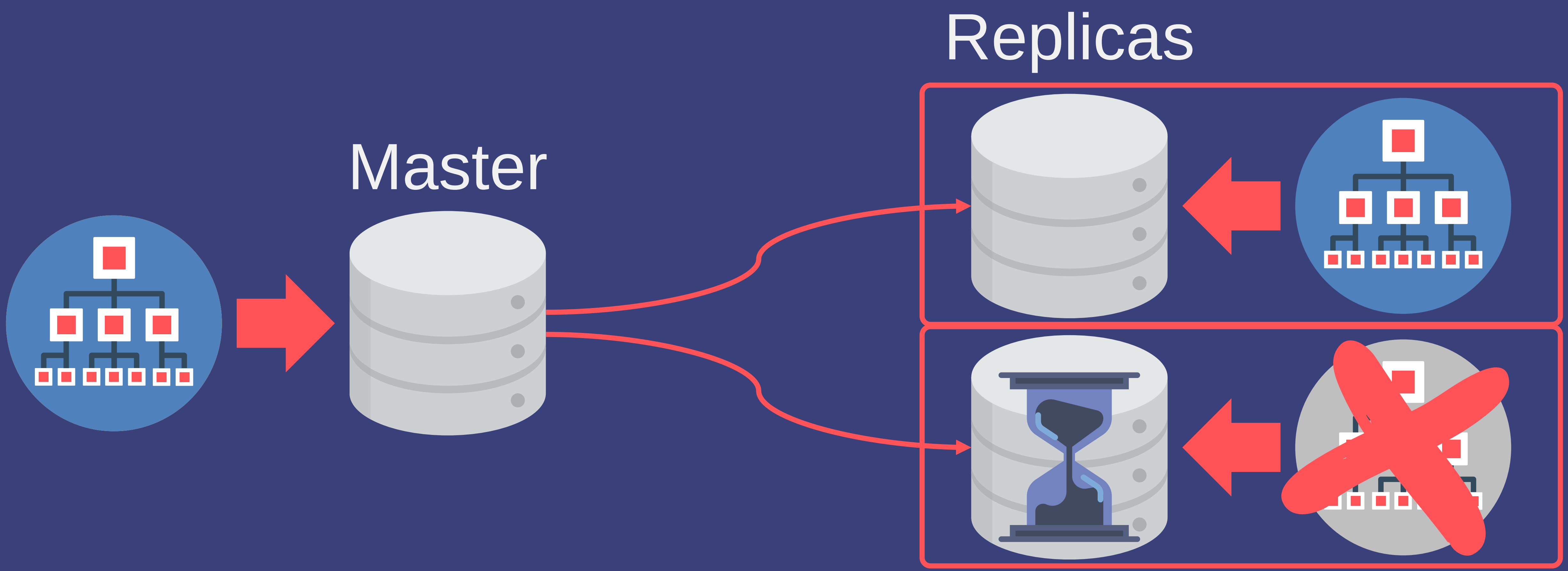
ssing:
Reads
Writes

Aggregated
Metrics

No action should ever require the DBMS to restart in order for it to take affect.

The commercial systems are much better than this than the open-source systems.

Allow replica configurations to diverge from each other.



What About Oracle's Self-Driving DBMS?

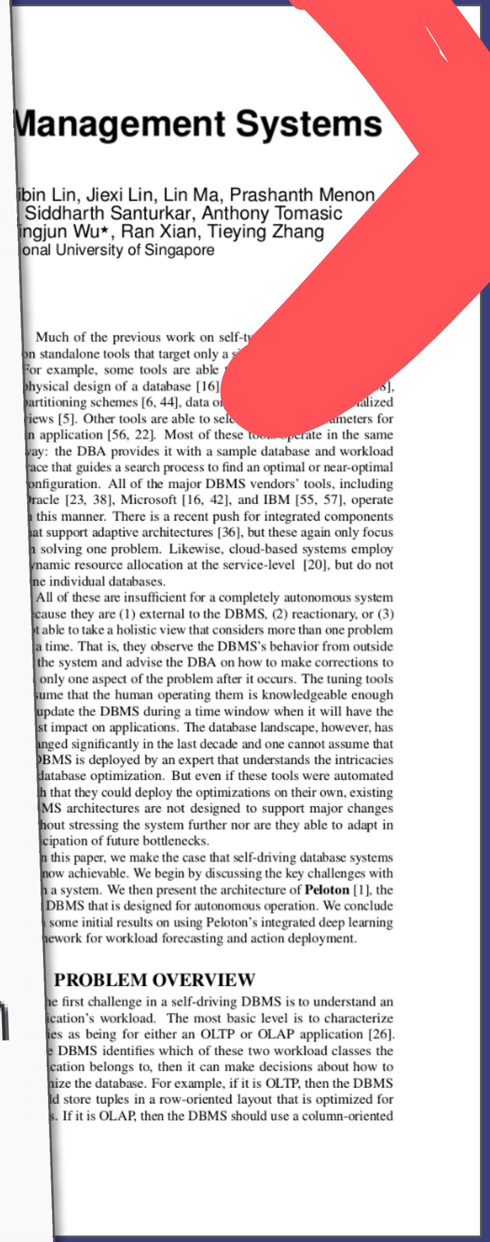
Self-Driving DBMS?

From: Andy Pavlo <pavlo@cs.cmu.edu>
To: Larry Ellison <larry.ellison@oracle.com>
Date: 9/15/17 11:17 PM

LE - I saw your announcement about Oracle putting out the "self-driving" DBMS. What's up with that? You know that my squad been working on our self-driving DBMS for the last two years:

http://pelotondb.io

How can you do this to me after all that we've been through together? This is like that time we were together in Guatemala back in 1999. Do you remember when you asked me whether I had a spare condom? I gave my last one to you and then I found out the next night that you



2017

True autonomous DBMSs are achievable in the next decade.

You should think about how each new feature can be controlled by a machine.

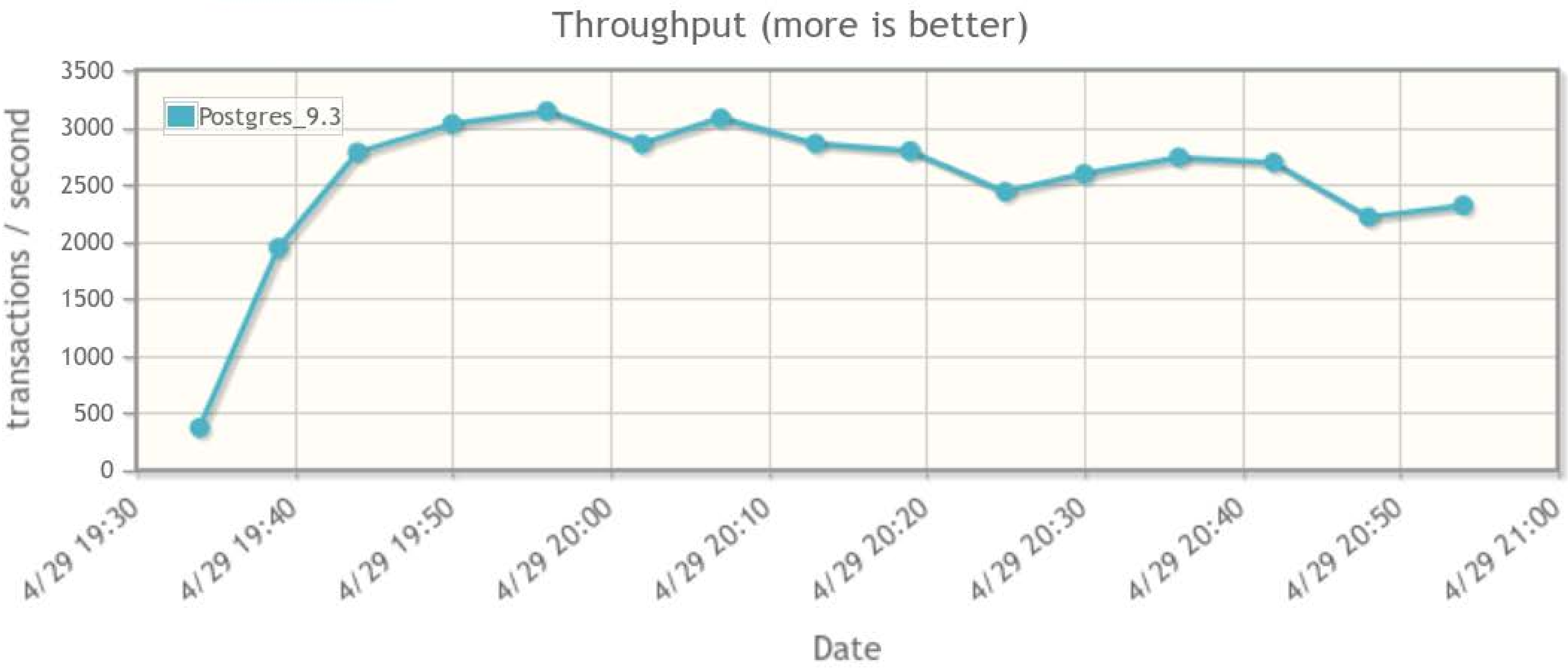
EN

@andy_pavlo

D

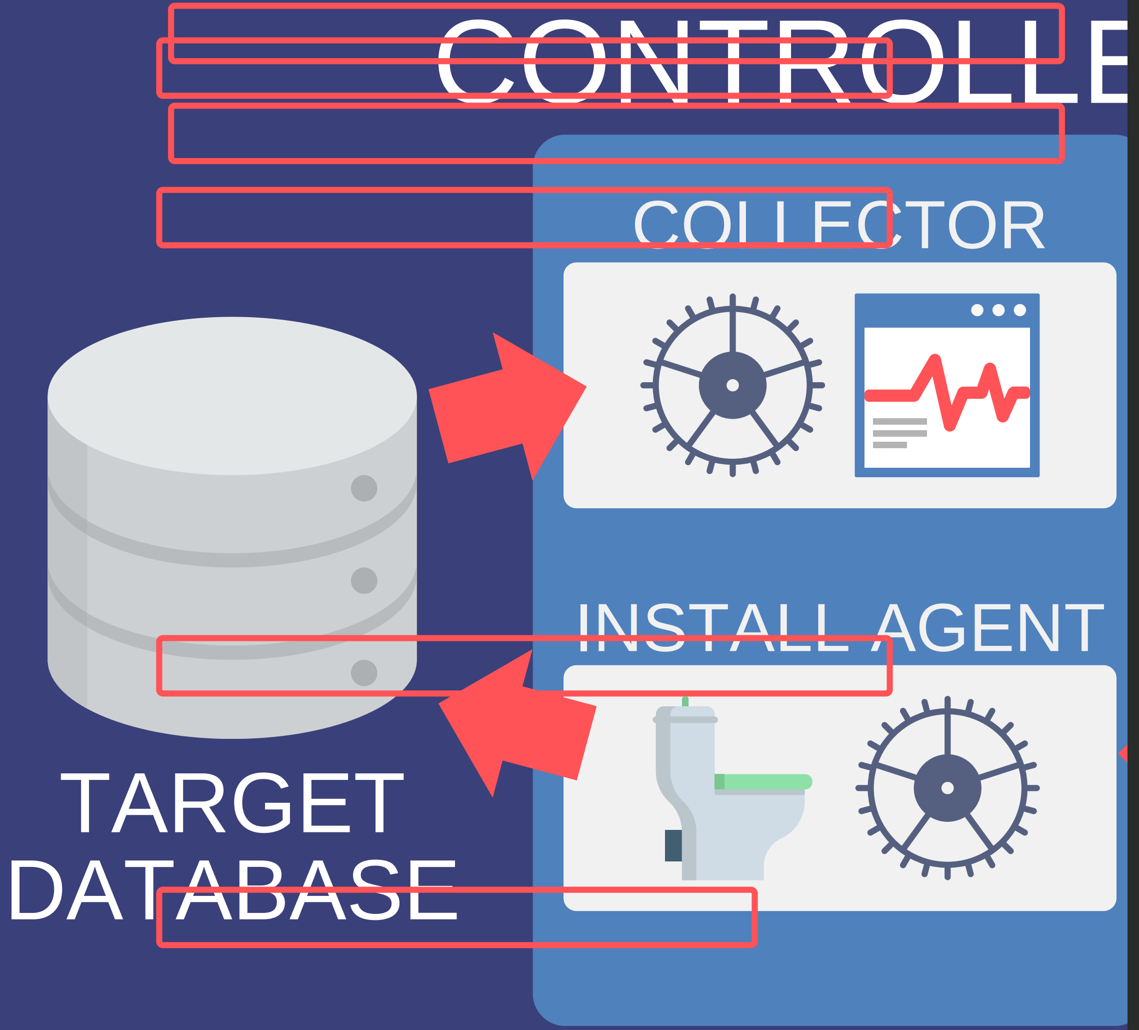
Show the last 100 results

Eq



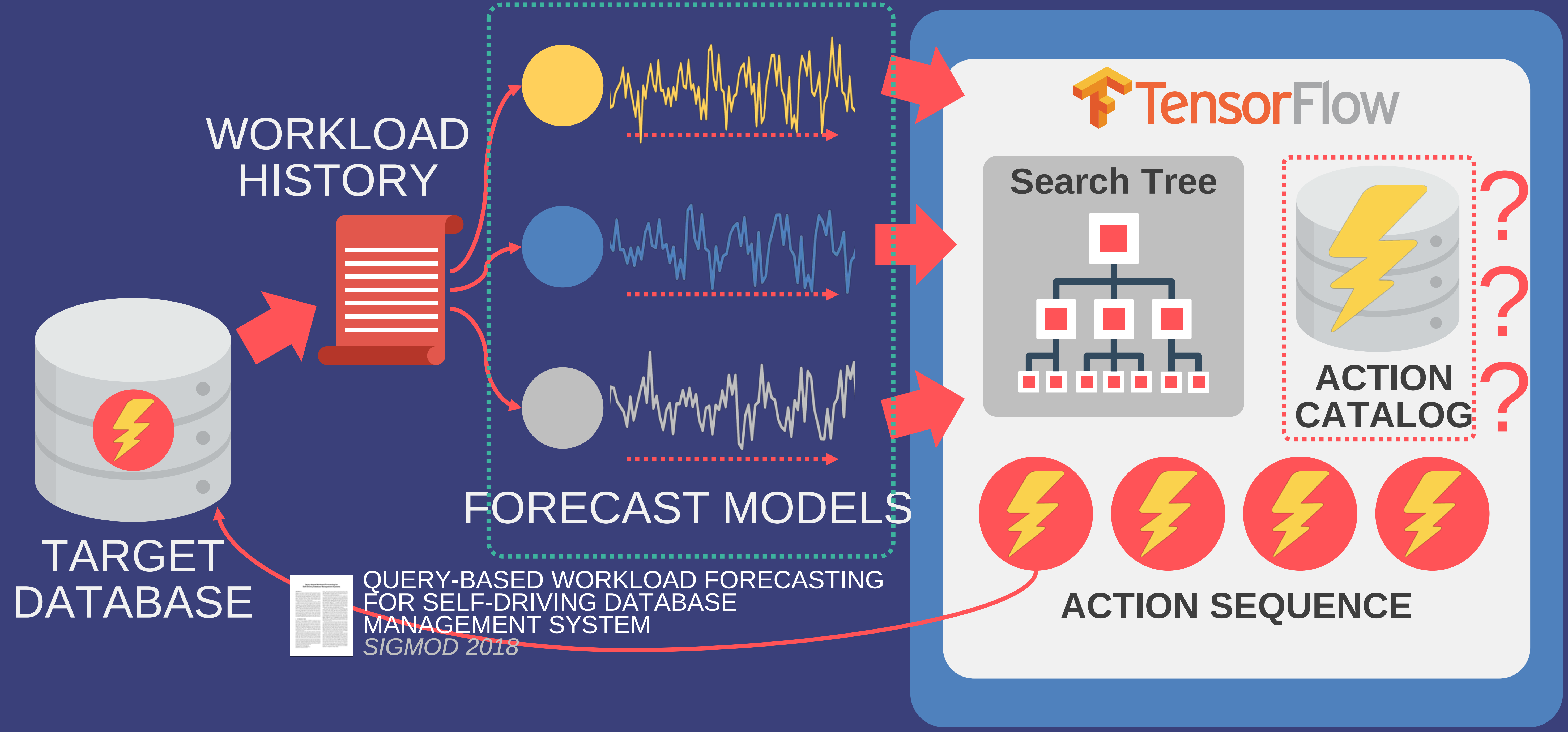
l

l_fsync




```
mysql> SHOW GLOBAL STATUS;
+--------------------------------------+------------+
| METRIC_NAME                          | VALUE      |
+--------------------------------------+------------+
| ABORTED_CLIENTS                      | 0          |
| ABORTED_CONNECTS                     | 0          |
•••
| INNODB_BUFFER_POOL_BYTES_DATA        | 129499136  |
| INNODB_BUFFER_POOL_BYTES_DIRTY       | 76070912   |
| INNODB_BUFFER_POOL_PAGES_DATA        | 7904       |
| INNODB_BUFFER_POOL_PAGES_DIRTY       | 4643       |
| INNODB_BUFFER_POOL_PAGES_FLUSHED     | 25246      |
| INNODB_BUFFER_POOL_PAGES_FREE        | 0          |
| INNODB_BUFFER_POOL_PAGES_MISC        | 288        |
| INNODB_BUFFER_POOL_PAGES_TOTAL       | 8192       |
| INNODB_BUFFER_POOL_READS             | 15327      |
| INNODB_BUFFER_POOL_READ_AHEAD        | 0          |
| INNODB_BUFFER_POOL_READ_AHEAD_EVICT  | 0          |
| INNODB_BUFFER_POOL_READ_AHEAD_RND    | 0          |
| INNODB_BUFFER_POOL_READ_REQUESTS     | 2604302    |
| INNODB_BUFFER_POOL_WAIT_FREE         | 0          |
| INNODB_BUFFER_POOL_WRITE_REQUESTS    | 562763     |
| INNODB_DATA_FSYNCS                   | 2836       |
| INNODB_DATA_PENDING_FSYNCS           | 1          |
| INNODB_DATA_WRITES                   | 28026      |
•••
| UPTIME                               | 5996       |
| UPTIME_SINCE_FLUSH_STATUS            | 5996       |
+--------------------------------------+------------+
```

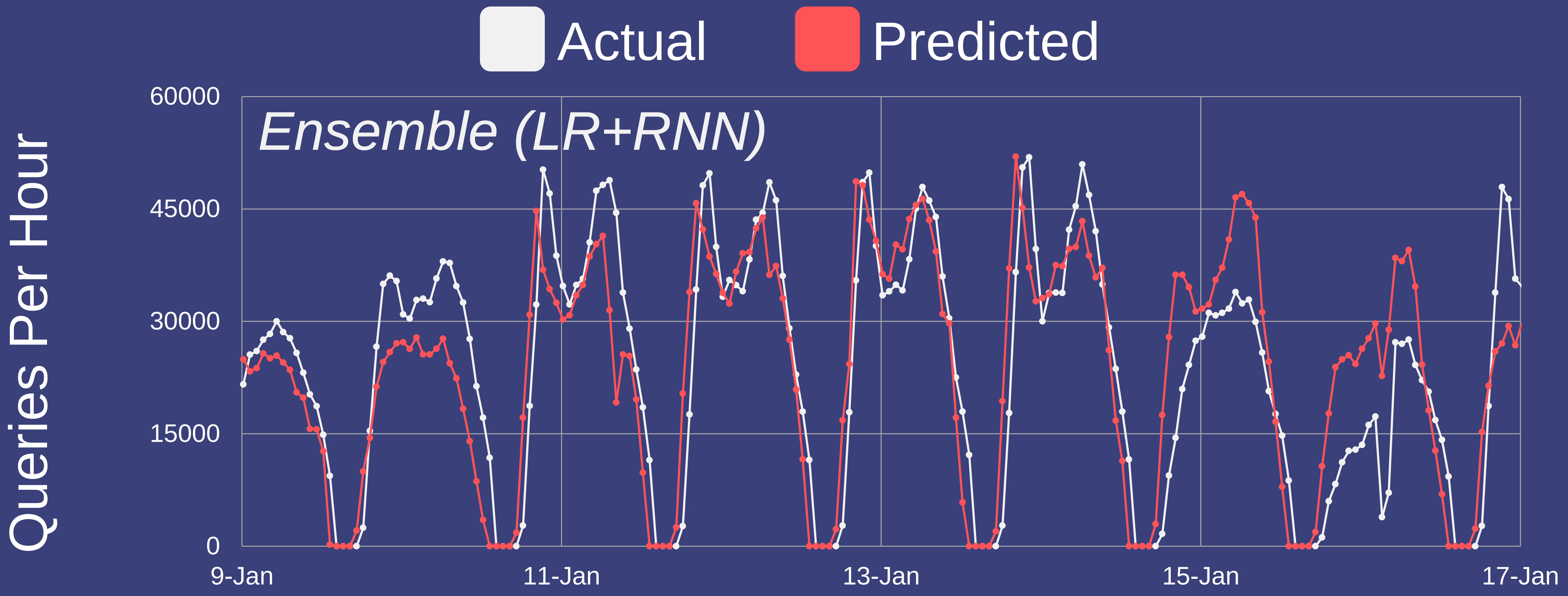
"THE BRAIN"



QUERY-BASED WORKLOAD FORECASTING FOR SELF-DRIVING DATABASE MANAGEMENT SYSTEM
SIGMOD 2018

PELOTON

BUS TRACKING APP WITH ONE-HOUR HORIZON



QUERY-BASED WORKLOAD FORECASTING FOR SELF-DRIVING DATABASE MANAGEMENT SYSTEM

SIGMOD 2018

Provide a notification callback to indicate when an action starts and when it completes.

Harder for changes that can be used before the action completes.

Thank you!

Microsoft