Universidade Federal do Rio Grande do Norte
Centro de Ciências Exatas e da Terra
Departmento de Informática e Matemática Aplicada
Programa de Pós-Graduação em Sistemas e Computação
Mestrado Acadêmico em Sistemas e Computação

SLA-Based Guidelines for Database Transitioning

Fabio de Sousa Leal

Natal-RN
Fevereiro de 2016

Fabio de Sousa Leal

SLA-Based Guidelines for Database Transitioning

Dissertação de Mestrado apresentada ao Programa de Pós-Graduação em Sistemas e Computação do Departamento de Informática e Matemática Aplicada da Universidade Federal do Rio Grande do Norte como requisito para a obtenção do grau de Mestre em Sistemas e Computação.

Linha de pesquisa:
Engenharia de Software

Orientador

Martin A. Musicante

PPgSC – Programa de Pós-Graduação em Sistemas e Computação
DIMAp – Departamento de Informática e Matemática Aplicada
CCET – Centro de Ciências Exatas e da Terra
UFRN – Universidade Federal do Rio Grande do Norte

Natal-RN

Fevereiro - 2016

Dissertação de Mestrado sob o título *SLA-Based Guidelines for Database Transitioning* apresentada por Nome completo do autor e aceita pelo Programa de Pós-Graduação em Sistemas e Computação do Departamento de Informática e Matemática Aplicada da Universidade Federal do Rio Grande do Norte, sendo aprovada por todos os membros da banca examinadora abaixo especificada:

Martin A. Musicante
Presidente
DIMAp – Departamento de Informática e Matemática Aplicada
UFRN – Universidade Federal do Rio Grande do Norte

Marcia J. N. Rodrigues Lucena - Professora Adjunta
Examinador
DIMAp – Departamento de Informática e Matemática Aplicada
UFRN – Universidade Federal do Rio Grande do Norte

Genoveva Vargas-Solar - Pesquisadora
Examinador
CNRS - French Council of Scientific Research

Plácido A. Souza Neto - Professor Associado
Examinador
IFRN – Instituto Federal do Rio Grande do Norte

Natal-RN, 26 de Fevereiro de 2016.

SLA-Based Guidelines for Database Transitioning

Author: Fabio de Sousa Leal
Supervisor: Martin A. Musicante

Abstract

Component-based Software Engineering (CBSE) and Service-Oriented Architecture (SOA) became popular ways to develop software over the last years. During the life-cycle of a software system, several components and services can be developed, evolved and replaced. In production environments, the replacement of core components, such as databases, is often a risky and delicate operation, where several factors and stakeholders should be considered.

Service Level Agreement (SLA), according to ITILv3's official glossary, is "an agreement between an IT service provider and a customer. The agreement consists on a set of measurable constraints that a service provider must guarantee to its customers.". In practical terms, SLA is a document that a service provider delivers to its consumers with minimum quality of service (QoS) metrics.

This work is intended to assesses and improve the use of SLAs to guide the transitioning process of databases on production environments. In particular, in this work we propose SLA-Based Guidelines/Process to support migrations from a relational database management system (RDBMS) to a NoSQL one. Our study is validated by case studies.

Keywords: SLA, Database, Migration.

Resumo

Engenharia de Software Baseada em Componentes (CBSE) e Arquitetura Orientada a Serviços (SOA) tornaram-se formas populares de se desenvolver software nos últimos anos. Durante o ciclo de vida de um software, vários componentes e serviços podem ser desenvolvidos, evoluídos e substituídos. Em ambientes de produção, a substituição

de componentes essenciais - como os que envolvem bancos de dados - é uma operação delicada, onde várias restrições e stakeholders devem ser considerados.

Service-Level agreement (acordo de nível de serviço - SLA), de acordo com o glossário oficial da ITIL v3 , é "um acordo entre um provedor de serviço de TI e um cliente. O acordo consiste em um conjunto de restrições mensuráveis que um prestador de serviços deve garantir aos seus clientes.". Em termos práticos, um SLA é um documento que um prestador de serviço oferece aos seus consumidores garantindo níveis mínimos de qualidade de serviço (QoS).

Este trabalho busca avaliar a utilização de SLAs para guiar o processo de transição de bancos de dados em ambientes de produção. Em particular, propomos um conjunto de *guidelines* baseados em SLAs para apoiar decisões migrações de bancos de dados relacionais (RDBMS) para bancos NoSQL. Nosso trabalho é validado por estudos de caso.

Keywords: SLA, Database, Migration.

List of Figures

List of Acronyms

ACID - Atomicity, Consistency, Isolation, Durability

AJAX - Asynchronous JavaScript and XML

API - Application Programming Interface

CAAS - Communication as a Service

CMS - Content Management System

CPU - Central Processing Unit

CRUD - Create Retrieve Update Delete operation

DB - Database

DBAAS - Database as a service

DBMS - Database Management System

FTS - Full-Text Search

GB - Gigabyte

HTTP - Hypertext Transfer Protocol

IAAS - Infrastructure as a service

IT - Information Technology

ITIL - Information Technology Infrastructure Library

JAR - Java Archive

JDBC - Java Database Connectivity

JSON - JavaScript Object Notation

MAAS - Monitoring as a Service

MVP - Minimum-Viable Product)

NOSQL - New SQL (OR Not Only SQL)

ORDB - Object Relational Database

PAAS - Platform as a Service

QOS - Quality of Service

RDBMS - Relational Database

REST - Representational State Transfer

ROFR - Rate of faulty requests

SAAS - Software as a Service

SDK - Software development kit

SLA - Service-Level Agreement

SLO - Service-Level Objective

SM - Systematic Mapping

SOA - Service-oriented Architecture

SQL - Standard Query Language

TPC - Transaction Processing Performance Council H Benchmark

TTM - Time-to-market

UDDI - Universal Description, Discovery, and Integration

UI - User Interface

WS - Web Service

XAAS - Everything as a Service

XML - Extensible Markup Language

Contents

1 Introduction

Cloud computing became a reality over the last years, and many companies are now moving their data-centers to the cloud. A concept that is often linked with cloud computing is Infrastructure as a Service (IaaS): the computational infrastructure of a company can now be seen as a monthly cost instead of a number of different factors. Recently, a number of organizations started to replace their relational databases with hybrid solutions (NoSQL[1] DBs, Search Engines, Object-Relational Databases).

These changes are motivated by (*i*) performance improvements on the overall speed of the applications and (*ii*) inability for a RDBMS to provide the same performance of a hybrid solution given a fixed monthly infrastructure cost.

In this scenario, not always the companies can estimate beforehand the future impact on the performance of their services by making this sort of technological changes (replace RDBMS by another solution).

In a production environment, it is necessary to assure that a database transition will actually bring benefits to the overall performance of the application. To avoid external threats and unknown risks, a database transition must be made in a systematic manner on each step of the transition: from the initial hypothesis to the deployment of the new architecture.

1.1 Problem

The decision to migrate (part of) an application from RDBMSs to NoSQL alternatives, such as Search Engines or Graph Databases, is justified when the alternatives have better performance/manutenability than the classic RDBMSs and the cost to have a similar

[1] NoSQL stands for **Not Only** SQL (QI et al., 2014). Some authors also refer to NoSQL as "Non-SQL", "NoREL" (non relational) or even "New SQL". (NOSQL-ORG, 2015) defines it as being *Next Generation Databases mostly addressing some of the points: being non-relational, distributed, open-source and horizontally scalable.*

performance on the current database architecture is significantly higher.

Several steps are needed in the process of replacing a relational database by a NoSQL alternative. An initial step on the transitioning processes could be to map the relational schema into the new kind of document. Some works, such as (LOMBARDO; NITTO; ARDAGNA, 2012) (ZHU; WANG, 2012) address this sort of problem.

Schema mappings across different technologies are, however, very particular to each application. (BAHL, 2014) shows, for example, how a MySQL schema may be represented on MongoDB and Neo4j (both NoSQL DBs).

The need for a transition may be characterised by showing that the current database infrastructure is breaking some of the requirements of an application, such as the speed of an operation. This may be done by the result of a DB Benchmark or the execution of an automated test, for example.

Several Benckmarking Frameworks, such as TPC-H (COUNCIL, 2008), can be used on this step. Automated tests can make use of testing libraries/frameworks, as jUnit (MASSOL; HUSTED, 2003) and RSpec (CHELIMSKY et al., 2010) or can be implemented from scratch using popular programming languages, such as Java and Python.

Database transitions generally follows non-standardized methods and processes may differ significantly in each application, as revealed on (LEAL; MUSICANTE, 2015).

In this work, we assess how Service-Level Agreements (SLAs) can be used to help the migrations from RDBMSs to NoSQL solutions and propose a set of Guidelines based on SLAs to justify and assess the transitions from RDBMs to NoSQL alternatives.

1.2 Proposed solution

Changing the database layer of an application is a decision that requires ample thinking, extensive analysis of the risks & impacts and a large number of experiments and benchmarks.

If a database transition does not follow a systematic process, bugs may be introduced on the application, rework may be necessary and even semantical changes on data queries may emerge, as different databases may implement the same operation in different ways, as will be revealed on section 3.3.3.1.

In this work we propose a set of guidelines based on Service Level Agreements (SLAs)

to assist the transition of the database layer on applications. Let us now give an example to illustrate our proposal:

1.2.1 Example: Database transitioning on a simple TO-DO list application

Suppose that a simple to-do list application was built on the top of MySQL (RDBMS) with the following features:

- Create, Update, Retrieve and Delete (CRUD) of tasks;
- Search tasks by query string.

An SLA could then be established for this application. One of the objectives of this SLA may be establish a minimum search speed, for instance, it may require that *Every search operation must be executed in less than 2 seconds.*

As the number of tasks on the database grow, users may claim that the speed of task searching has degraded. In fact, this is an expected scenario, as the number of DB records to be analyzed also grows.

The developers of the application could then claim that a database transition might be needed, as a *Search Engine* may be preferred rather than MySQL to perform full-text search features.

From the SLA of the application, we could then build a transitioning process that performs benchmarks with the current technology (MySQL) and the proposed technology (a Search Engine) to verify if a database transition is really needed.

The steps & guidelines proposed by this work are detailed and extensively discussed on Chapter 3

1.3 Contribution

The main contributions of this work are:

- The proposition of a set of Guidelines based on SLAs to justify and and guide the transitions from RDBMs to NoSQL DBs;

- A Systematic mapping study on "Using SLA to guide database transition to NoSQL on the cloud", available on (LEAL; MUSICANTE, 2015);
- Proof of concept for our guidelines in the form of Migration scenarios.

1.4 Related Works

A number of works related to SLA and database transitioning processes are presented and discussed on the Section *"IV. Outcomes"* of the Systematic Mapping available at appendix A.

Another important work related to ours is *"Transitioning from Relational to NoSQL: A Case Study"* (MCPHILLIPS, 2012). In this work, the NoSQL scenario is assessed as an alternative to a relational database. *The research is built around a case study of a bulletin board application that uses a relational database for data storage and evaluate how such an application can be converted to using a NoSQL database.*

As it is built around a single case study, it does not proposes a standardized way of transitioning relational to NoSQL databases, as proposed by our work.

Other relevant works that present challenges and discussions around relational to NoSQL transition are (PADHY; PATRA; SATAPATHY, 2011) and (SCHRAM; ANDERSON, 2012).

1.5 Research Methodology

The first step of our research was to do a broad literature review around the concepts that involved this work, such as Cloud Computing, Service Level Agreements, NoSQL databases, Database Transitions and Systematic Mappings. The results of this literature review are available on Chapter 2.

After that, a systematic mapping was made (LEAL; MUSICANTE, 2015) to answer questions that are relevant to our work. The systematic mapping enabled a clear view of the problem and was the starting point to the proposed solution, discussed on chapter 3.

The development process of the guidelines can be split in three main phases:

1. Find publications and studies about relational to NoSQL transitions

2. Discover common parts that are used in these studies
3. Propose adjustments on the proposed architecture discussed on meetings with the research advisor

A few iterations over these steps were necessary to reach a final solution to the proposed guidelines.

1.6 Structure of this work

On Chapter 2 we present a detailed view on each concept that surround this work and explain how each of these concepts are linked with our work.

On Chapter 3 we detail our problem and the proposed solution.

On Chapter 4 we present how the guidelines defined on Chapter 3 might be used on a RDBMS to NoSQL transition.

On Chapter 5 we present our conclusions and future works. The references that were used on this work are available after Chapter 5.

On Appendix A we presented a systematic mapping that was made in the initial phase of this study and helps to understand the concepts behind this work.

Appendix B presents raw outcomes of the experiments that are detailed on chapter 4.

2 Bibliographic Review

The goal of this chapter is to explore the main concepts that are related to our work. We begin by presenting popular concepts, such as Cloud Computing, *Everything as a Service* strategy, NoSQL and Service Level Agreements. We also explain how each of these concepts are linked with this work.

2.1 Cloud Computing

Technology evolved with big steps over the last decades. Internet is now a pervasive concept and individuals can be connected virtually everywhere on Earth. (ARMBRUST et al., 2009)

Web applications and IT-based processes followed this evolution and today a number of companies rely on software on its production chain. Information Technology can be a competitive advantage of a company, but it **might not** be part of its core business (POWELL; DENT-MICALLEF, 1997). In fact, this is a common scenario on a number of successful companies of the current century, as we might notice.

To avoid losing track of its core business, a number of companies now prefer to outsource (part of) their IT department to other companies (QUINN; DOORLEY; PAQUETTE, 2013). In other words, today it is possible to outsource IT infrastructure, product development and even the entire IT department to other companies.

In the late 60's, former Stanford University professor John McCarthy introduced the concept of time-sharing of computing services in a famous speech on time-sharing systems, as referenced by (RAPP, 2011) and (WIKIPEDIA, 2015). In fact, Prof. McCarthy believed that computer resources would be provided as commodities, like water and electricity.

Several years later, this concept brought to life the notion of *Cloud Computing*, together with new concepts, such as Infrastructure as a Service *(IAAS)*, Platform as a Service *(PAAS)*, Software as a Service *(SAAS)* and Everything as a Service *(XaaS)* (CONNOLY

D. FOX, 2010).

According to (CONNOLY D. FOX, 2010), *Cloud computing refers to both the applications delivered as services over the Internet and the hardware and systems software in the data centers that provide those services.*

(STANOEVSKA-SLABEVA; WOZNIAK, 2009) outlines some of the features of Cloud Computing:

- Cloud Computing is a new computing paradigm.
- The main features of clouds are virtualization and scalability on demand.
- Infrastructure resources (hardware, storage and system software) and applications are provided in X-as-a-Service manner.
- Utility computing and SaaS are delivered in an integrated manner. Computing might be consumed separately.
- Cloud services are consumed either via Web browser or via a defined API.

The "pay as you go" model offered by Cloud providers revolutionized the IT market, enabling companies to consume computing resources that matched its needs. Small companies became more competitive, as there is no more need to build datacentres to scale companies. As professor McCarthy believed, computing resources can now be seen as commodities for a company, just like water and electricity.

2.2 Everything as a Service - XaaS

Service-Oriented Architecture (SOA) defines several concepts of "as-a-service" models. To enumerate a few, it is possible to find mentions to Platform as a Service (PaaS), Infrastructure as a Service (IaaS), Software as a Service (SaaS), Database as a Service (DBaaS), Desktop as a Service (DaaS), Monitoring as a Service (MaaS) and Communication as a Service (CaaS) on the literature.

To summarize all these concepts, a new term arose: Everything as a service (XaaS)(DUAN et al., 2015)(ARMBRUST et al., 2009).

On the context of Cloud Computing, however, three of these concepts are the most relevant, and we define them more precisely:

- Infrastructure as a service (IaaS): It is the most simple kind of "as-a-service" product and is located on the base of the IaaS-PaaS-SaaS Stack (Figure 1). IaaS mostly refers to (Virtual) Machines, Storage Devices, Network Infrastructure and other infrastructural services that are available on Cloud Computing vendors. Some examples of IaaS providers are (EC2, 2015) (RACKSPACE, 2015) and (AZURE, 2015).

- Platform as a Service (PaaS): PaaS refers to the development environments that are available from cloud vendors. PaaSs are composed by a development stack, and generally offer databases, web servers and execution runtime. Examples of PaaSs are (BEANSTALK, 2015), (AZURE, 2015) and (APPENGINE, 2015).

- Software as a Service (SaaS): Software as a Service refers to the applications that run on the cloud: Webmail, CRM, Gaming Platforms, Learning Management Systems, etc. SaaSs, just as IaaSs and PaaSs, generally charge its users a periodic fee. The fee is generally conceived in a pay-as-you-go model, so users get charged in a scalable way.

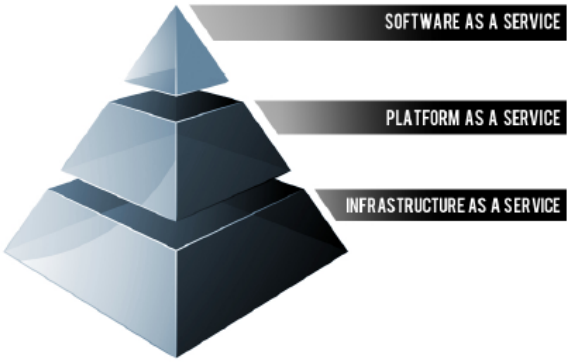


Figure 1: IaaS-PaaS-SaaS Stack (KEPES, 2011).

Since the beginning of the Cloud movement several discussions were held concerning the security of Clouds. (SHINDER, 2010) discusses that the security threats that arise on Cloud Computing are the result of users/enterprise lack of control of the IaaS layer. Not all companies know where their documents/data is physically stored and what are the security instruments that must be used to assure data safety on Cloud environments.

On the base of the pyramid of Figure 1 is located the IaaS - machines, Network Infrastructure and other Simple Services. Above IaaS lies the PaaS layer - It acts as a "middleware" between the SaaS Layer and the IaaS layer, providing the development environments that developers need to deploy applications. On the top of the image is located the SaaS layer.

To have a better understanding of the security concerns on Cloud Computing, a deeper understanding of its architecture is needed. Figure 2 illustrates the reference model for cloud computing (ALLIANCE, 2009).

The IaaS layer is generally composed by five elements: API's, Abstraction, Core Connectivity, Hardware and Facilities. A cloud provider may be vulnerable if a security breach is discovered on its APIs or Abstraction Layer, for example. Another possible vulnerability in cloud providers are outages. In 2014, major cloud providers, such as (EC2, 2015), (AZURE, 2015), (RACKSPACE, 2015) and (APPENGINE, 2015) experienced downtime (PARISEAU; JONES, 2014).

Similar security issues can be found on the PaaS and SaaS layers.

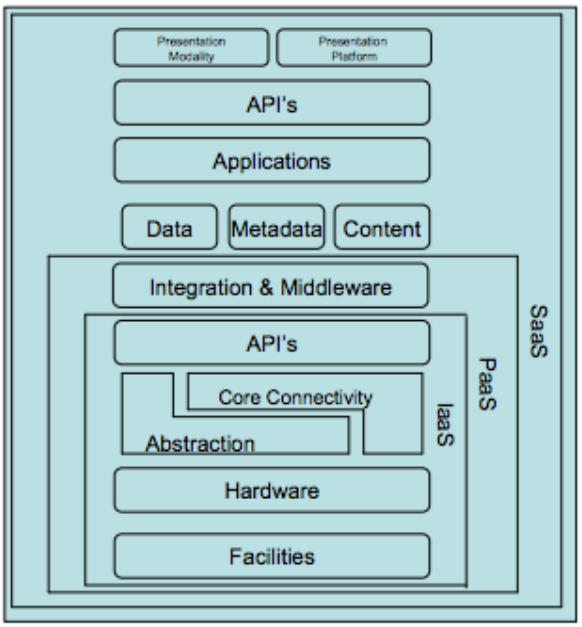


Figure 2: Cloud Reference Model (ALLIANCE, 2009).

2.3 The technological shift

The adoption of cloud solutions is growing fast among organizations (ARMBRUST et al., 2009). Centralized (mostly mainframe) technology is being replaced by distributed and more flexible forms of data storage and processing. This change of paradigm is motivated by the necessity to improve the use of resources, as well as by the increasing velocity in which data is produced.

On the early 90's it was commonplace for every Information Technology (IT) company to have its own Data Center with huge servers and mainframes. IT costs were high,

and high-performance computing was available only for big companies, as data centers required a large physical infrastructure and have high costs for maintenance (ARMBRUST et al., 2009).

The regular way of building a web application was to use a client-server approach, where the server was a powerful (and expensive) machine. At the same time, new players, such as Google or Yahoo, were rising with bigger missions: *"to organize the world's information and make it universally accessible and useful"* (SPECTOR; NORVIG; PETROV, 2012). The popularization of the internet use incentivized new ways of commerce exchange, yielding an explosion in the amount of data produced and exchanged. It was *just* impossible to store the petabytes of daily-generated data in a single server.

From this point on, the community realized the economical convenience of building and maintaining several low-performance servers, instead of a single high-performance one, even if this this requires a change of culture in the administration of the new datacentres. The new approach (scale-out) is also incompatible with the traditional way of building applications (scale-up), that usually were designed to work on a single server and database. Both approaches are represented on Figure 3.

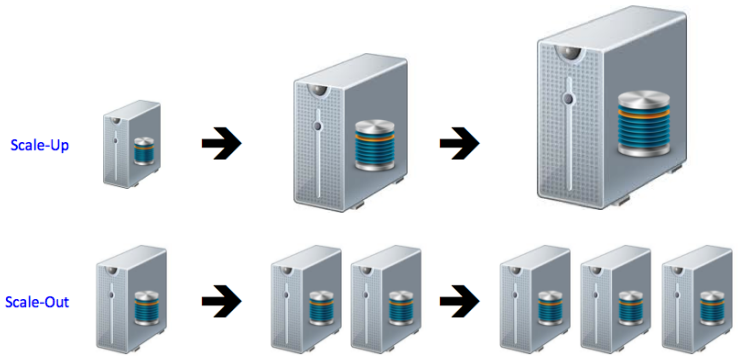


Figure 3: Scale Out vs Scale Up (DHANDALA, 2015).

Several research initiatives were conducted in this area and a common solution was rising: to distribute data storage and processing. Google, Yahoo and other big IT players helped to build open source tools to make this approach possible, like Hadoop (SHVACHKO et al., 2010).

2.4 Data Integration, NoSQL Movement & Polyglot Persistence

Along with the NoSQL (Not only SQL) movement and expansion of Social Networks, new concepts for Database Models became popular, like Document Store, Search Engines, Key-Value store, Wide Column Store, Multi-Model and Graph DBMS (RANKINGCHART, 2015).

New ways to store and retrieve data are in high demand, as Figure 4 suggests. This chart shows trends of popularity growth among categories. As (RANKINGCHART, 2015) explains: *"In order to allow comparisons, the initial value is normalized to 100. For most of the categories the trend starts with January 2013 but search engines and multivalue DBMS are only collected since February 2013 and May 2013."*.

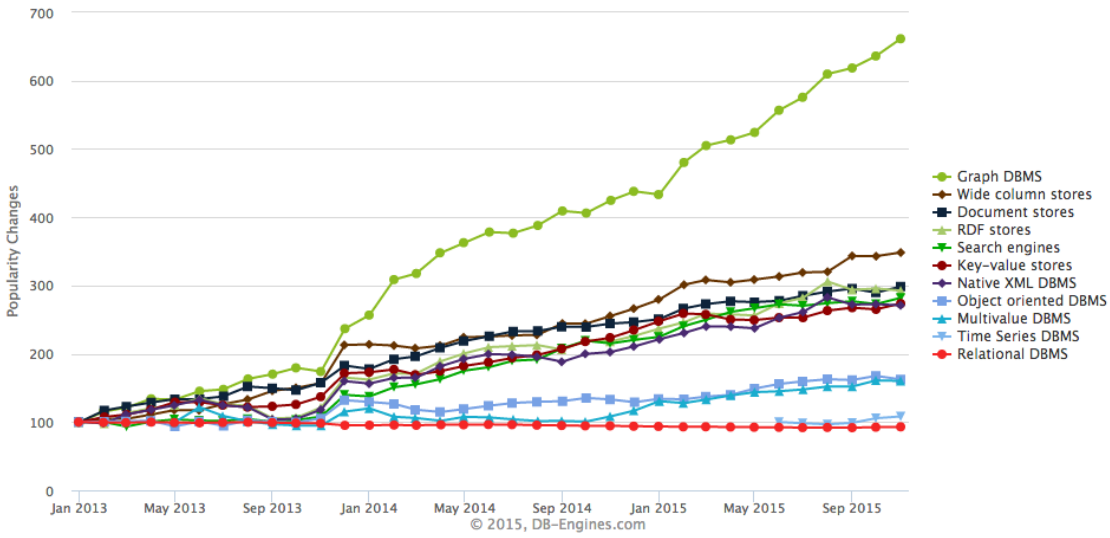


Figure 4: Database Popularity Growth Chart (RANKINGCHART, 2015).

Figure 5 presents the current database popularity by categories. It shows that despite of the NoSQL movement, relational databases are still responsible for more than 80% of the databases used in applications.

Today, instead of having a single Relational Database Management System (DBMS) for the whole application, it is efficient and cost-effective to have several Data Base Engines, one for each type of data that the application handles. This concept is called *Polyglot Persistence* (SADALAGE; FOWLER, 2012). In (RANKING, 2014) a ranking of the most popular DB engines is presented.

As (SOLAR, 2014) illustrates, polyglot persistence is very useful in the context of e-

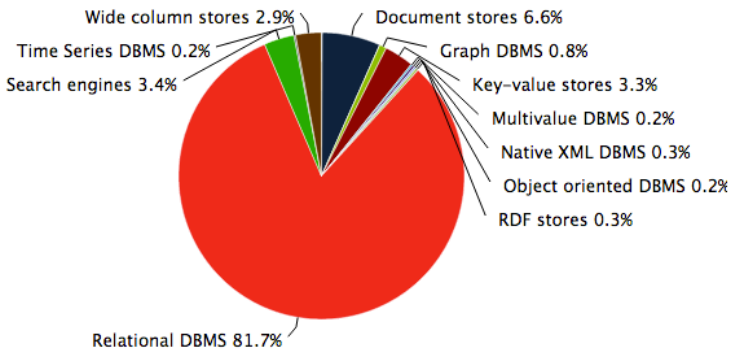


Figure 5: Database Popularity Chart - February/2016 (RANKINGCHART, 2015).

commerce applications that deal with a catalog, user access logs, financial information, shopping carts and purchase transactions, for example.

The notion of polyglot persistence is built upon the observation that the *nature* of each data type is significantly different (i.e: user logs imply high volume of writes on multiple nodes, shopping carts need high availability and user sessions require rapid access for reads and writes).

As computing services started to decentralize, developers started to build applications that depended of several data-sources. By this time the use of Web Services and Service Oriented Architecture (SOA) became more popular (ARMBRUST et al., 2009).

2.5 Transitioning Processes

In 1965 Gordon E. Moore, Intel's co-founder, published a paper stating that the number of components in integrated circuits had doubled every two years, and would continue to do so for the at least another decade (MOORE, 1998). Today, this statement is known as "Moore's Law".

A similar trend is stablished for commercial software. Wirth's law, Gates' law (Microsoft) or Page's law (Google) state that "the speed of software halves every 18 months", compensating Moore's law. (WIRTH, 1995)(BRIN, 2009)

In other words, software components evolve in the opposite direction that hardware evolves. Useful software are usually versioned, updated and patched on a regular basis. As stated by (GLASS, 2001), maintaining software products is not cheap, and generally consumes on average 60% of software costs.

Time-to-market (TTM) is the length of time that takes for from a product being conceived until its available for sale. Minimum-Viable-Product (MVP) is the product with the highest return on investment versus risk (BLANK, 2013). Building a MVP and selling it should be the primary goal of a startup (BLANK, 2013).

The current economy demands faster shipping of software products in order to meet the desired TTM of software products and to deploy MVPs in less time. Cloud computing and Agile Methods made software development and deployment faster, cheaper and easier for a number of companies.

One of the points of the 12 principles of the Agile Manifesto (FOWLER; HIGHSMITH, 2001) is *"Deliver working software frequently, from a couple of weeks to a couple of months, with a preference to the shorter timescale"*.

This need for speed on software delivery has its downsides, however. Decisions must be made by the IT department on a short time schedule, sometimes leaving not enough time to make the best choices on the technologies that should be used on a software product. This and other factors often leads to a software migration, replacement or transitioning scenario. In this scenario (part of) a software is replaced with a more suitable alternative.

In the context of Service-Oriented Architecture this might be seen as the replacement of a Service. In a Multitier architecture scenario this might be seen as the replacement of an entire layer. In fact, basically any component of a **modular** software can be replaced, migrated or upgraded.

Examples of Software migrations are numerous on the industry. To number a few:

- Spotify migrated their user base from Postgres to Cassandra(ALBINSSON BARKAS, 2015)
- Google moved from MySQL to MariaDB (CLARK, 2013)
- Twitter moved from Ruby-On-Rails to Java (GADE, 2011)

Our work focuses specifically on Database Transitioning scenarios. We propose a set of guidelines to justify and guide the transitions from RDBMs to NoSQL databases;

2.6 Systematic Mappings

According to (PETERSEN et al., 2008), "*A software engineering systematic map is a defined method to build a classification scheme and structure a software engineering field of interest.*" Systematic Mapping studies provide a global view of a given research field and identify the quantity, results, and the kinds of researches in this field.

A Systematic mapping study is composed by a number of steps (Figure 6).

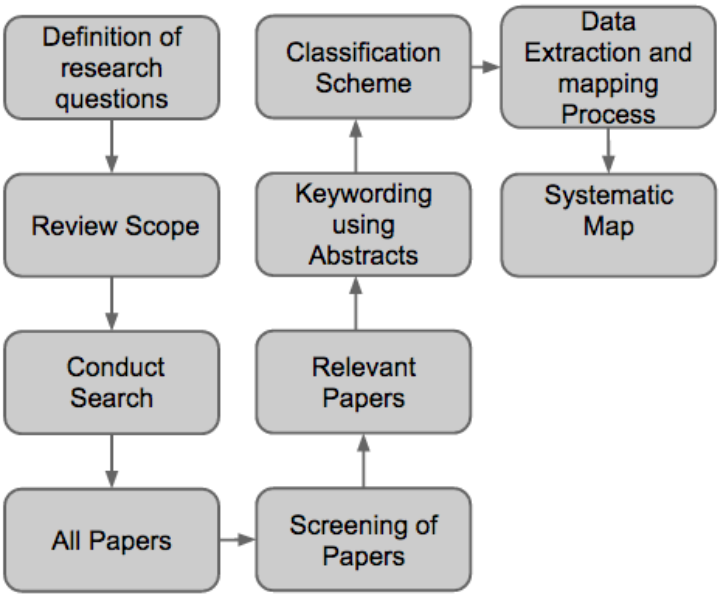


Figure 6: Systematic Mapping Steps (PETERSEN et al., 2008).

On the first step, *Definition of Research question*, the questions that must be answered on the survey are defined. On the *Review Scope* step, researchers target the papers/journal sources that will be taken into consideration on the systematic map. After that, the *Search* step is done using a set of predefined search engines and a body of papers (*All papers*) is retrieved.

After an initial *Screening of the papers*, the *Relevant papers* are chosen according to inclusion and exclusion criteria defined by the research team. At this point, the papers that will participate of the study are selected. The selection is based on the title, abstracts and keywords of each paper (*Keywording using Abstracts*).

After that, a *Classification Scheme* is built, defining different points-of-view (or facets) from which the body of papers will be classified. After matching each paper with the classification schema (*Data Extraction and Mapping Process*), the systematic mapping is performed. In this phase the relationships between the collected data (in the light of the

classification scheme) are used to answer the research questions.

In (LEAL; MUSICANTE, 2015) a Systematic mapping study was developed to investigate the use of Service-Level-Agreements (SLAs) on database-transitioning scenarios and to verify how SLAs can be used in this processes. The results of this study are presented in Section 2.8.

2.7 Service Level Agreements (SLAs)

In the field of Law, a contract (or agreement) is generally a written document concerning any point of interest between two parties, each of whom intends to create legal obligations between them. In business environments, contracts are highly necessary to avoid unpleasant situations between a provider and a consumer.

In the context of service provisioning, it is common to refer to contracts (or agreements) as "Service-Level agreements" (SLA's), as the name suggests.

According to *ITILv3's* official glossary (AXELOS, 2012), a Service Level Agreement (SLA) is "*an agreement between an IT service provider and a customer. A service level agreement describes the IT service, documents service level targets, and specifies the responsibilities of the IT service provider and the customer.*"

The agreement consists on a set of measurable constraints that a service provider must guarantee to its customers. In practical terms, it is a document that a service provider delivers to its consumers with minimum quality of service (QoS) metrics. If the service is delivered with a lower QoS than is promised on the SLA, consumers may be refunded or earn benefits that were accorded beforehand.

In the next subsection we present the life-cycle of an SLA, explaining in details each step of it.

2.7.1 The Life-Cycle of an SLA

The Life-cycle of an SLA consists on six steps, as presented on Figure 7. Each step is explained in the following subsections.

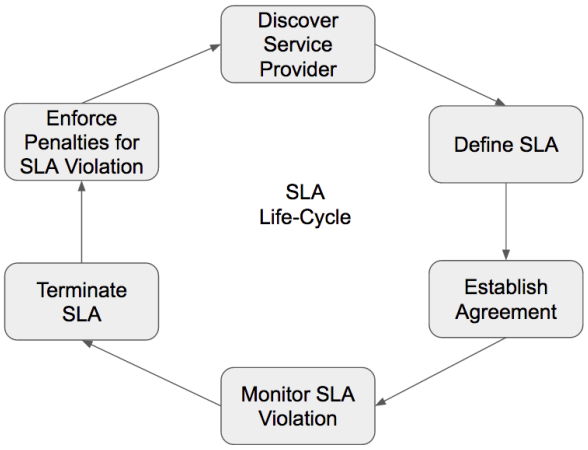


Figure 7: SLA Life-cycle (WU; BUYYA, 2012).

2.7.1.1 Discover Service Provider

On the first step *(Discover Service Provider)*, a consumer tipically discovers several service providers that may fulfill its needs on a specific scenario. On the domain of Web Services, *Universal Description, Discovery, and Integration* (UDDI) can be used to retrieve a list of web services that might be used to achieve a goal, for example.

In a Cloud Computing scenario, it is possible to buy computing services from a number of providers, and a cloud-service broker could be used to retrieve a list of available providers. This scenario is very common in cloud computing auctions (SHI et al., 2015), a new concept that arised with cloud computing and was made possible by companies like Hetzner.com, a company that hosts regular auctions of its computing resources.

2.7.1.2 Define SLA

The second step of the SLA life-cycle *(To Define SLA)* is when an SLA is proposed by the provider. Several works, such as (KOUKI et al., 2014) and (KOUKI; LEDOUX, 2012) address the issue of specifying an SLA. WS-Agreement (ANDRIEUX et al., 2005) and WSLA (NEPAL; ZIC; CHEN, 2008) are very important works on this area. As it is presented on (LEAL; MUSICANTE, 2015), there are several ways to specify SLA, but none of them are considered a de-facto standard.

(LEAL; MUSICANTE, 2015) also shows that there are several ways to represent an SLA. To enumarate a few, it is possible to represent an SLA as a *i) a natural-language document*, and *ii) an ontology automated test suite (unit tests, integration tests)*.

2.7.1.3 Establish Agreement

As stated on the beginning of this secttion, an SLA is a contract between a provider and a consumer. The points of interest of this contract are known as *Service-Level Objectives* (SLOs).

According to (STURM; MORRIS; JANDER, 2000), SLOs must respect a series of features. They must be *Attainable*, *Repeatable*, *Measurable*, *Understandable*, *Meaningful*, *Controllable*, *Affordable* and *Mutually acceptable*.

Each SLA may explicitly define the "hardness" of its SLOs in terms of time. In other words, an SLA can specify what is the fault tolerance rate of each of its SLOs.

An example can be given to clarify this concept: Two telecommunication companies may have different SLAs regarding the uptime of their services given a fixed period of time. **Company A** may assure that their uptime is 99.9% of the time under the period of a year, and **Company B** may assure that their uptime is 99.99%.

In this scenario, it is said that the SLA of Company B is "harder" than the SLA of Company A. Figure 8 compares the Availability SLO defined in SLAs of some popular cloud services.

After chosing the service and defining the SLOs, SLA might be established between a consumer and the provider - the third step of th SLA life-cycle.

2.7.1.4 Monitor SLA violation

The fourth step *(Monitor SLA violation)* is one of the most important on the SLA life-cycle. It is in this step where the consumer protects himself against unfulfilled SLOs.

Several frameworks and processes might be used to measure and monitor SLA violation. As SLAs do not present a standard way for representation, it is also difficult to find a standardized way to monitor SLA violation.

(RANA et al., 2008) presents three "monitoring-models" for SLA violation:

- *All-or-nothing*: In a all-or-nothing situation, **all** the SLOs must be satisfied to guarantee that the SLA is still valid.
- *Partial*: In a partial scenario, the SLA specifies what are the SLOs that may not be broken, and declares rules less important SLOs.

Service Level Objective: Availability

Compose.io

Promised SLA	Penalty
< 99.98%	Discount: 20%

Locaweb.com

Promised SLA	Penalty
99,0% to 99,4%	Discount: 5%
95,0% to 98,9%	Discount: 10%
90,0% to 94,9%	Discount: 20%
< 89.9%	Discount: 30%

Amazon RDS

Promised SLA	Penalty
99,95% to 99,0%	Discount: 10%
< 99,0%	Discount: 20%

Figure 8: Service Level Objective: Availability on Cloud Services (LOCAWEBSLA, 2015)(COMPOSE.IO, 2015)(AMAZONRDS, 2015).

- *Wheighted Partial*: In a wheighted partial scenario, the consumer and provider specify thresholds that must be met for specific SLOs. If the service quality drops below a threshold, a penalty can be applied.

In the context of Web Apps it is also possible to monitor SLA violations with the help of web applications, such as (DATADOG, 2014), (APPSEE, 2014) and (NEWRELIC, 2014). These tools offer graphical dashboards and alerts when SLAs defined by the software team are violated. The tools are able to monitor the three layers of a web application: front-end, business logic and databases. AJAX calls, plugins and server daemons are used to monitor each part of the web stack.

2.7.1.5 Terminate SLA

An important question of the life-cycle of a SLA (fith step) is *when* the termination of an SLA is needed. If the termination is due to an SLA violation, it is important to know what party broke the SLA and what are the consequences for the parts.

These situations must be explicitly declared in the initial SLA to avoid unpleasant situations between the provider and the consumer in the future.

2.7.1.6 Enforce Penalties for SLA violation

The sixth step *(Enforce penalties for SLA violation)* can be performed if the penalties that were previously defined are being hit in a regular basis or if both parties of the SLA agree. Several works, as (LEE et al., 2010) propose penalty models/processes for SLA violations. These processes can be analyzed and used by the SLA parties.

2.8 Our Systematic Mapping

To provide us a better understanding over the use of SLAs in component / service migrations, we have performed a Systematic Mapping study to assess the use of SLAs in database transition scenarios, specifically on migrations from relational databases with NoSQL ones.

This study is available on Appendix A.

2.8.1 Identified problems

As a result, we have analyzed over 70 publications closely related to the use of SLAs in migration scenarios. The study revealed a number of interesting outcomes, and we emphasize two of them below:

- No publication was found addressing the problem of measuring the overall improvements after a database transition. Several benchmarking frameworks, such as TPC-H, TPC-DS and YCSB were identified (MOUSSA, 2013) during our survey, though. These benchmarking frameworks could be a good starting point to develop new tools and specialized frameworks to solve this problem and might be used in our study to validate that a migration was successful.

- (SAKR; LIU, 2012), (ZHAO; SAKR; LIU, 2013), (KLEMS; BERMBACH; WEINERT, 2012) and (XIONG et al., 2011) propose SLA-centric/User-Centric solutions to monitor the performance of web applications. All these solutions are technology-agnostic and could be used to monitor the performance improvements promised by a database transitioning process. Industry experts also pointed out that there are some services,

such as New Relic (NEWRELIC, 2014), Appsee (APPSEE, 2014) and Datadog (DATADOG, 2014) that provide SLA-monitoring tools for web apps.

The systematic mapping revealed no open source solution to monitor Application SLAs in a user-centered view (application level).

3 The Guidelines

In this section we detail the problem that we analyze in this study.

3.1 Problem Breakdown

For a long time the industry developed applications storing data on relational databases. Graph databases, Search Engines, Document stores, Wide Column Store and other types of database systems emerged over the last years as a demand of the industry.

New categories and types of database systems are capable of processing and accessing data in new ways that relational DBs do not support. In other words, for some application, using relational databases may not be the best fit.

When developing an application, it is not always possible to use the technology that is most suited to the application use cases and requirements. This situation is due to a number of reasons. In an Agile project, for example, not always the team knows all use-cases and application requirements at once; as the Agile Manifesto states: "Welcome changing requirements, even late in development. Agile processes harness change for the customer's competitive advantage." (FOWLER; HIGHSMITH, 2001).

Furthermore, using different databases on the early releases of a software product may add unnecessary complexity to the code base and might become an overengineering problem over time.

The fact that some applications are built not knowing beforehand all the requirements, use-cases and expected workload on production environments - *(**how much** will it scale?)* - can lead to database transitioning scenarios.

Applications that work with more than one database type are popular at the present time, as (SADALAGE; FOWLER, 2012) reveals. Some companies, as Instaclustr (INSTACLUSTR, 2014) and (ELASTIC, 2015a), emerged over the last years to provide support and

consultancy to database transitioning scenarios.

There are other cases, also, where an application is developed using an existing database technology, as MySQL, and a number of improvements are made on it, leading to the rise of new databases. Twitter FlockDB (FLOCKDB, 2014), a distributed & fault-tolerant graph database, emerged in these conditions.

3.2 Database transitions in the industry

Database transitioning processes are not easy and straightforward tasks, depending on the size of the application. A number of steps is required when performing database transitions, as revealed on Section 1.

On the other side, a structured process is not always followed when switching databases on production environments. (LEAL; MUSICANTE, 2015) revealed, for instance, that database transition scenarios on the industry usually follow non-standardized methods and that they may differ significantly among applications. This situation may lead to losses, rework and a hard to maintain codebase.

There are some industry reports, as the ones from Coursera, a leading Education Technology company with over 10 million users (WIKIPEDIA-COURSERA, 2014), where more than one database transitions were made in a brief period of time.

Frank Chen, member of Coursera's engineering team, enlightened the reasons why Coursera replaced part of its database technology from MongoDB (NoSQL DB) to MySQL (Relational DB) (HAO, 2014b) .

In other post (HAO, 2014c), Chen also reveals that part of the new MySQL architecture was migrated in a second step to Cassandra (NoSQL DB). A blog post from Coursera's Engineering team confirms and discusses more about the transition from MySQL to Cassandra (COURSERATECH, 2014).

Analyzing all the conditions evidenced on this section, a problem to our study was defined: How can a database transition be made in a systematic manner? What are the steps and pitfalls to be avoided in relational to NoSQL transitions?

3.3 Proposed solution

When an application or website grows, a good strategy is to isolate the application server and database server in two distinct machines, as (ELLINGWOOD, 2014) suggests. If a machine shares its resources among Web Servers, DB Servers and other applications, for example, a high CPU load on the web server side may impact the performance of the Database, downgrading its performance.

In this work we propose a set of steps to guide the transition from relational databases to NoSQL ones. The suggested guidelines make use of a set of Service Level Agreements (SLAs) to guide the whole process.

These guidelines are represented on Figure 9 and will be discussed along this chapter. The figure presents a "waterfall" approach of the guidelines, as the steps must be executed one after the other. The relevant outcomes of each step are also represented.

The arrow that connects the last step to the first shows that this process can also be considered during the software life-cycle, as a continuous process. The arrow that connects steps 5 and 6 to step 2 shows that SLA renegotiations are possible if any issues are found when meeting the desired SLAs (budget, technical or physical limitations, for instance. On section 4.2.6.1 an example of SLA renegotiation is presented.

The guidelines proposed in this work assume that the database server is isolated on its own machine.

3.3.1 List application operations that are performed at database-level

A database transition can be motivated by a number of reasons, as budget, lack of support from the community and performance issues. Migrations scenarios motivated by performance issues are the focus of this study, as other reasons might be very specific to each application / transition scenario.

Performance issues might be caused by database growth or by new application requirements. The first step in a transition scenario is, then, to identify *which* are the application operations or requirements that are driving the transition.

To identify these operations, it is necessary to explicitly enumerate the application operations that are performed at database level. To illustrate the process of enumerating

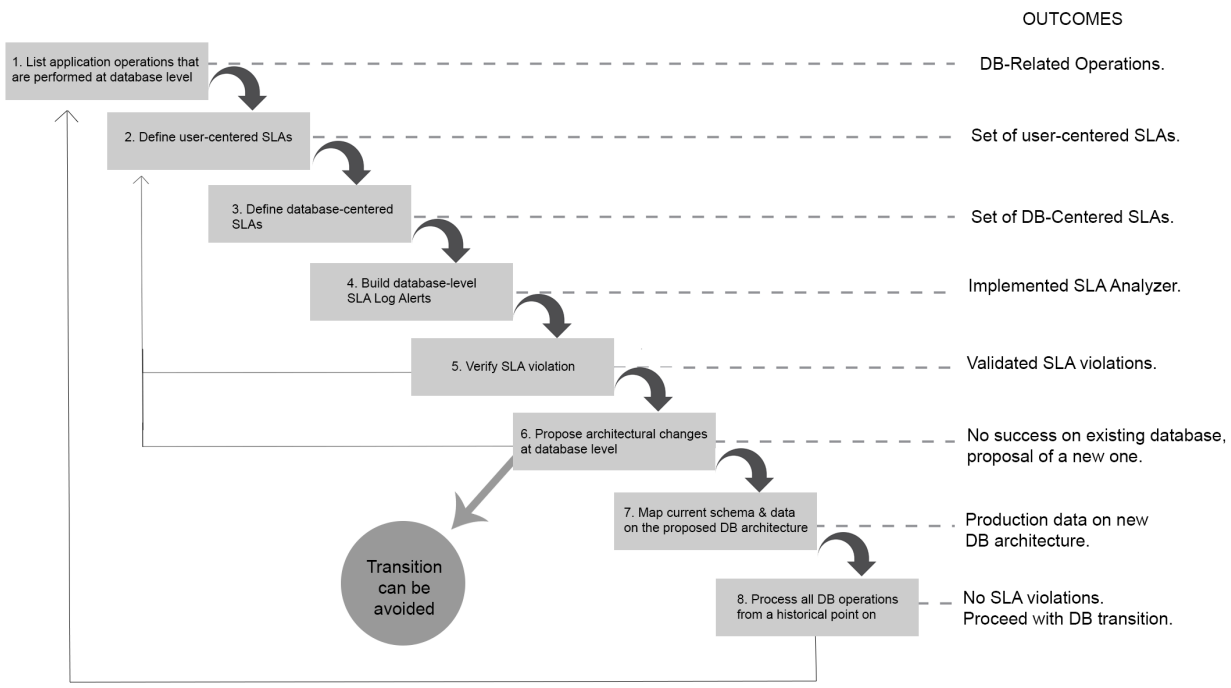


Figure 9: Relational to NoSQL Steps.

these operations, consider the following application examples [1]:

A retail business-intelligence application: A retail business-intelligence application can be used by large retail corporations and supermarket chains. Some use-cases that perform database-level operations on this kind of applications may be:

- To process consumer purchases;
- To clusterize customers by their consumption profiles;
- To export summarized reports of transactions that happened last week;

Social Networks: A social network is a category of applications where users generally may befriend / follow other users, publish posts and share their own content. On this kind of applications. Some use-cases that perform database-level operations are:

- Follow or befriend another user;
- Publish posts;
- List user timeline;

[1] These examples are given to provide a better understanding of how this step can be done in different applications, and are not continued on the next sections of this chapter.

3.3.2 Define user-centered SLAs

For each database operation enumerated on the previous step, a **user-centered** wheighted-partial SLA is defined with the stakeholders of the application. For these SLAs, two thresholds must be explicitly defined for each operation: an ***ideal threshold*** and a ***tolerable threshold***.

Ideal threshold is the performance level that is expected by application users. The ***tolerable threshold*** is a threshold where users can still use the application, but the user experience with the application is downgraded.

When the ***tolerable threshold*** is broken, user experience is dramatically affected and (part of) the application may not be operational for its users.

An example of user-centered SLA is given in the context of the retail business-intelligence application previously defined:

- **Process consumer purchase (Store credit card transaction on my Data Warehouse**

  Ideal Threshold: up to 1 seconds;

  Tolerable threshold: up to 1 minute;

  In other words, the user expects a purchase to be processed in one second. If it takes up to 60 seconds, the application can still be used, despite it may affect user's experience. If a purchase takes more than 60 seconds to be processed, users may get really frustrated and long lines may be expected on the cashier.

- **Export summarized report of transactions that happened last week (Retrieve and perform aggregation operations on selected records)**

  Ideal Threshold: up to 24 hours;

  Tolerable threshold: up to 72 hours;

In other words, the app user expects that a summarized report of last week's transactions is made available in up to 24 hours. If the exported report takes more than 3 days (72h) to be generated, the application is not useful to the user anymore, as the business strategy might be severely affected by application performance.

The ***SLA Delta Factor*** between the ***Ideal Threshold*** and ***Tolerable Threshold*** is defined as the number of ***Ideal thresholds*** that can fit inside ***Tolerable threshold***.

From this concept, we can define the ***SLA Delta Factor*** for the operations defined above:

- **Process consumer purchase (Store credit card transaction on my Data Warehouse)**

  Ideal Threshold: up to 1 seconds;

  Tolerable threshold: up to 1 minute;

  SLA Delta Factor: 6.000% (60x)

- **Export summarized report of transactions that happened last week (Retrieve and perform aggregation operations on selected records)**

  Ideal Threshold: up to 24 hours;

  Tolerable threshold: up to 72 hours;

  SLA Delta Factor: 300% (3x)

The **SLA delta** is always equals to or greater than 100% by definition, and will be used as a parameter on the next steps of the proposed guidelines.

As stated previously, the **ideal threshold** and **tolerable threshold** should be defined in conjunction with the application stakeholders as quantifiable metrics. The **SLA Delta** can be obtained as the division: **tolerable threshold** / **ideal threshold**.

On Figure 10 it is possible to graphically visualize the concepts of **Ideal Threshold**, **Tolerable Threshold** and **SLA Delta**.

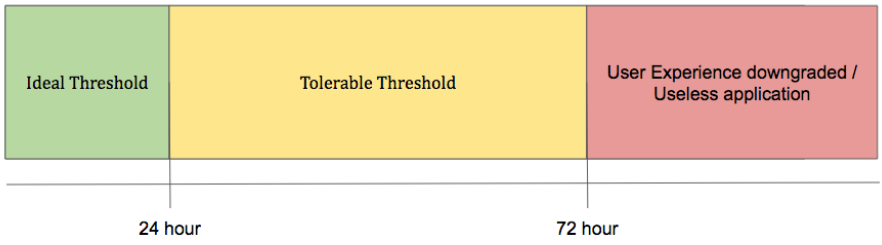


Figure 10: SLA Thresholds - 3x SLA Delta factor.

As we will be targeting performance issues at database level, **ideal threshold**, **tolerable threshold** and **SLA delta** can generally be defined in terms of time, as shown on the examples above.

In fact, *time* is the main metric when benchmarking databases, as presented on (ENDPOINT, 2015) - operations/sec and latency.

Other quantifiable metrics and Key Performance Indicators (KPIs), as *client processed workload* and *client CPU and memory usage* can also be used as metrics to the thresholds, however.

3.3.3 Define database-centered-SLAs

On a multitier architecture, databases are generally the last layer to be reached on a user operation. Several other steps are necessary to process a user request, as field validations, security filters and business logic.

From the user-centered SLAs defined on the previous step, another set of SLAs should be proposed on this step, now at database level. These SLAs are called ***database-centered-SLAs*** in our guidelines and are derived from the ***user-centered SLAs***.

By definition, ***database-centered-SLAs*** should be "harder" than the user-centered SLAs, as other operations are needed in the process of processing a user request. A ***database-centered SLA*** specifies the Quality-of-Service (QoS) that is expected from the database service while processing an operation.

Database-centered-SLAs should only be defined for the operations that perform transactions at database-level. The same concepts that were defined for ***user-centered SLAs (Ideal Threshold, Tolerable Threshold and SLA Delta)*** are valid for ***database-centered SLAs***.

An example of ***database-centered SLA*** is given for the operations that were enumerated on the the previous step:

- **Store credit card transaction on my Data Warehouse** ***(process consumer purchase)***

  Ideal Threshold: up to 0.2 seconds;

  Tolerable threshold: up to 8 seconds;

  SLA Delta factor: 4.000% (40x)

- **Retrieve and perform aggregation operations on selected records** ***(export summarized report of transactions that happened last week)***

  Ideal Threshold: up to 10 hours;

Tolerable threshold: up to 20 hours;

SLA Delta factor: 200% (2x)

3.3.3.1 Types of Metrics

As stated on the previous section, other types of ***measurable*** metrics can also be used as thresholds to the SLAs. Consider the problem of checking if two objects overlap on a spatial Database, for example. The objects presented on Figure 11 can be represented as rows and coordinates in DBs that support spatial functions.

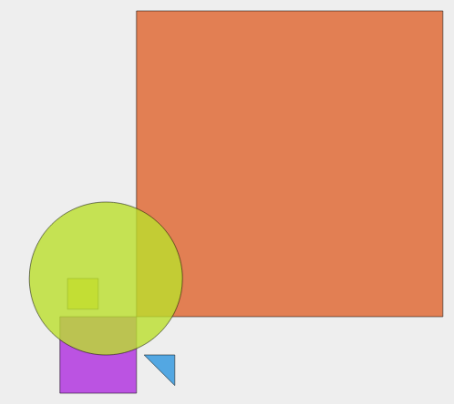


Figure 11: Representation - object overlapping (STACKOVERFLOW, 2015).

DBs that support spatial objects implement functions that can check if the squares of Figure 11 are completely inside of the circle - function *ST_Contains* in MySQL, can be used to perform this query (STACKOVERFLOW, 2015), for example.

To simplify computing and give faster results, some databases, as Oracle, may add a error tolerance factor to spatial queries (ORACLE, 2015). Other Databases can even simplify too much the way that it checks if a point is within a polygon, resulting in error-prone scenarios.

MySQL, for example, uses the Minimum Bounding Rectangle (MBR) strategy to check if a point is within an irregular polygon. The city of Natal - Brazil is represented on Figure 12 as a irregular polygon (as it is). MySQL's MBR strategy reduces the problem of checking if a point is within this irregular shape to the problem of checking if the point is within the minimum-bounding rectangle (the whole figure, in this case), which gives a big error margin.

In this scenario, **the number of wrong results of each query** when performing a spatial query calculation is also a metric that can be used as a parameter on the SLA

Figure 12: Natal - Brazil - Minimum-Bounding Rectangle (GMAPS/NATAL, 2015).

thresholds. Server-related metrics, as consumed CPU and memory can also be used as metrics on the SLA thresholds.

3.3.4 Build database-level SLA log alerts

After defining ***user-centered*** and ***database-centered SLAs***, application architects must define a rate of requests that can be executed within the tolerable-threshold level for each operation.

This ***rate of faulty requests (ROFR)*** is necessary to avoid unnecessary alerts caused by infrastructural instability, inherently present on cloud providers, as Figure 8 presents.

3.3.4.1 Defining a Rate of Faulty Requests (ROFR)

The ***rate of faulty requests*** is used in our guidelines to alert application developers that some operations are not being executed with the desired QOS.

With a defined *ROFR*, it is possible to build a log / application analyzer that will track if any database operations are breaking the tolerable threshold, or if the rate of faulty requests is above expected.

If the ***ROFR*** exceeds the expected level or if a request exceeds the tolerable threshold, an alert should be sent to the Database administrators and maintainers of the application, indicating that an SLA violation was found and that further analysis is needed. This alert can be sent using regular alerting systems, as Email, SMS and push notifications.

Log analyzers and alerts can be implemented within the source code of the application or using external services, such as (LOGSTASH, 2015), (PAPERTRAIL, 2015) and (NEWRELIC, 2014).

Once an alert is sent, it should contain the timestamp of the moment when the SLA violation was detected and even the process list of what was being executed on the database at that time.

The ROFR can be derived from the cloud provider availability SLA, as shown on Figure 8, but should also consider the importance of each operation for the application. We propose that an acceptable ROFR for *important* operations should be not higher than 5% - this way we assume that the 95th percentil of the requests will be running at an ideal level.

The software team should, at this point, define a rate of faulty requests for the examples given above:

- **Store credit card transaction on my Data Warehouse**

  Ideal Threshold: up to 0.2 seconds;

  Tolerable threshold: up to 8 seconds;

  SLA Delta: 4.000% (40x)

  ROFR: 10%

- **Retrieve and perform aggregation operations on selected records**

  Ideal Threshold: up to 10 hours;

  Tolerable threshold: up to 20 hours;

  SLA Delta: 200% (2x)

  ROFR: 30%

In other words, if more than 10% of the "Store credit card transactions on my Warehouse" are performed on a **Tolerable threshold** level, an alert is fired. If any transaction of this kind lasts more than 8 seconds, another alert is also fired.

In the second case, if up to 30% of the transactions are processed within the tolerable threshold, no alert is fired. If any transaction lasts more than 20 hours to be executed, one alert is fired.

3.3.5 Verify SLA violation

When an SLA violation alert is received, it is necessary to know what caused it.

Failures might be possible at machine-level or on the infrastructure that hosts the database server. Hardware issues, network problems and cyber attacks are some factors that may downgrade database performance.

Extensive and detailed work from application developers might be needed to detect the real cause behind an SLA violation, and the source of each violation is very singular for each application.

Another possible point of failure is the application itself. The mean number of operations per second may have increased, resulting in a downgraded performance of the database; A new feature might be demanding more DB resources and bugs might end up performing faulty requests on the database.

3.3.5.1 Further Analysis

SLA violation alerts contain the exact timestamp of when the violation ocurred, as well as the database process list that was active on the moment of the violation.

Popular relational databases, as MySQL, Oracle and Postgresql implement a feature called *point-in-time recovery* (MYSQLRECOVERY, 2015) (ORACLERECOVERY, 2015) (POSTGRESRECOVERY, 2015). This feature allows a DB to be dumped and restored to a specific point in time.

As the alert contains the timestamp of when the SLA violation was triggered, it is possible to clone the relational database and restore it to the exact time before the SLA violation was triggered. In this cloned environment it is possible to investigate in detail what caused the SLA Violation.

If everything is working properly (no issues were found on the database server and on the application), two actions are possible: relax SLA thresholds or propose changes on the current DB Architecture;

3.3.6 Propose architectural changes on database-level

Not always it is necessary to replace the database to address a performance problem. SQL tunning, denormalizing tables and creating indexes are some ways to improve the performance of applications that use relational databases.

Another option to address performance problems on relational databases would be to scale-up the current DB, buying more powerful hardware. This scenario is not covered by this work, as budget is always a finite resource on companies.

If the SLA remains broken after the architectural changes have been performed on the current DB infrastructure, a NoSQL strategy might be recommended. In this case, a new Database Model (Graph DBs, Document Stores, Key-value stores, etc.) and technology (Neo4j, MongoDB, Couchbase) might be chosen.

Several works, as (HAN et al., 2011) and (LEAVITT, 2010) present overviews of NoSQL databases. A good starting point to choose which category of NoSQL Database is the best fit for an application is the CAP theorem (SADALAGE, 2014), presented on Figure 13.

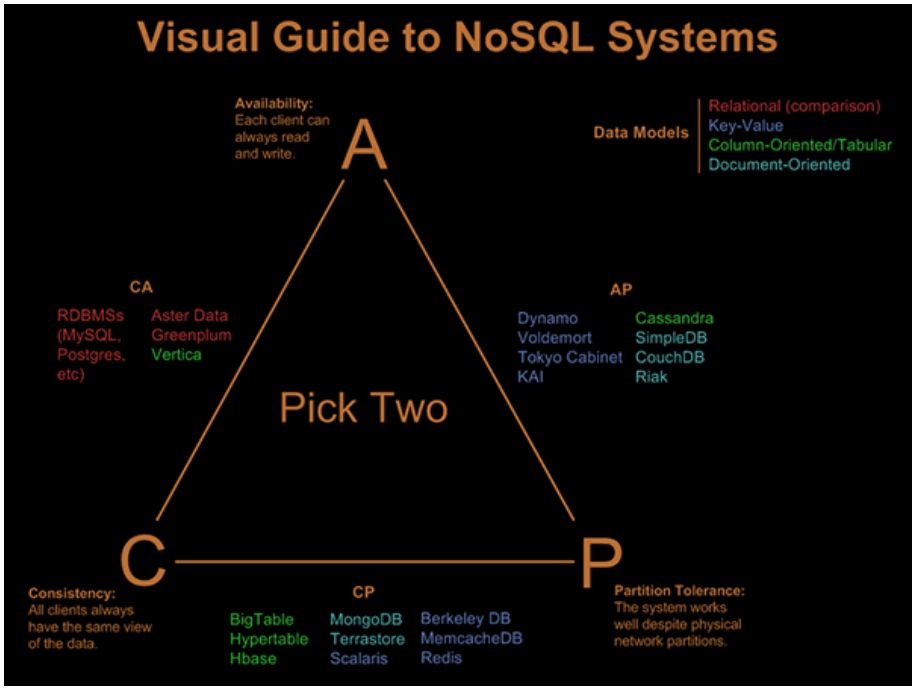


Figure 13: CAP Theorem (HAO, 2014a).

The CAP Theorem states that that it is possible to have two from the three capabilities in a database:

- Consistency (all nodes see the same data at any point of time);

- Availability (a guarantee that every request receives a response about whether it was successful or failed)
- Partition tolerance (the system continues to operate despite arbitrary message loss or failure of part of the system)

Relational databases have consistency and availability, resulting in a scale up strategy, presented on Figure 3.

3.3.7 Map current schema & data on the proposed DB architecture

After choosing the new NoSQL database, it is necessary to map the table's rows and relationships into the concepts of the chosen NoSQL technology. Despite the fact that some NoSQL DBs are schemaless, defining a schema and building indexes help to leverage the perfomance of NoSQL DBs.

To compare the performance of RDBMS vs NoSQL on a specific scenario, the same data should be present on both databases. A Dump & Restore procedure should be done at this point. i.e: The data should be dumped from the RDBMS and imported on the proposed NoSQL architecture.

The process of mapping (part of) the relational database entities into the new NoSQL schema is very unique to each application and the chosen NoSQL technology. This is a wide topic and not a subject of this work. (BAHL, 2014) shows, for example, how the models of an application might be mapped between different relational & NoSQL technologies.

Once the new DB architecture is restored with the production data, it is possible to compare the results of the proposed architecture and the old architecture, which is done on the next step.

Over the last sections we have defined thresholds for operations on a Business Intelligence application. The relational database that stores application data on this kind application should have several entities, as users, products and commercial transactions. Each of these entities have their own tables, and tables are connected from relationships.

On a NoSQL architecture, all these entities and relationships could be combined on a single JSON document, as presented on listing 3.1.

Listing 3.1: BI application commercial transaction represented as a single document.

```
{
"id": 12089367123
"user": 12908376123,
"items": [{"id": 01,"category":"food","name":"rice"}, {"id": 21,
   "category":"drinks","name":"soda"}]
}
```

Special Case

When the chosen NoSQL architecture is not able to deliver the same results to the query that is done with the relational DB and post-processing is necessary within the source code of applications, the time that the code spends post-processing the DB results should also be taken in consideration as the "total time spent on database".

3.3.8 Process all DB operations from a historical point

In this step it is possible to compare the performance of the relational database and the proposed NoSQL architecture. From this point, the following elements should exist as outcomes from the previous steps:

- A production relational database;
- A clone from relational database;
- The proposed NoSQL technology & data model;
- The same data should be available on the cloned database and on the proposed NoSQL database;
- Logs of the relational database;
- One or more SLA violations;

In a scenario where the relational database will be completely replaced by a NoSQL alternative, it should be possible to execute the same operations on the relational DB and on the proposed NoSQL alternative in any given point in time.

Some DB transitioning processes, however, are performed using a *polyglot persistance* strategy, where an application has several databases. In this case, only some of the application entities will be present on the NoSQL model, and the application data layer will

be composed by two or more databases. In this case, only a subset of operations can be executed on the NoSQL side.

A question that may arise at this point is *"What should be the starting-point to compare requests between the relational and NoSQL databases looking for SLA violations?"*

The most complete strategy would be to restore the relational database to the oldest point in time recorded by the logs and to perform all operations from that point on, to the point where the SLA violation was triggered. By doing so, it is possible to even discover SLA violations that do not exist in the relational architecture and that may arise on the NoSQL architecture.

There are some cases, however, where the volume of data transactions is too large to go back to the oldest point in history. In these cases, a good strategy could be to retrieve all processes that were executing immediately before the SLA violation was fired and go to the point in time when the first of this processes started.

For the examples given on the previous sections, an alarm would be triggered when the database lasts more than 20 hours to generate a report. When this situation happens, the admins should check the meaningful operations that were running immediately before the alarm is triggered and start to execute the requests in a chronological sequence.

3.3.9 Transitioning Recommendations

If the proposed NoSQL architecture is able to handle production operations without triggering SLA violations, this is a good sign that the NoSQL might be able to handle the production load.

Transitioning a production database is not an easy or straightforward task. It is necessary to change the source code of applications and also to change some of the automated tests. Some bugs may be revealed during the process.

Software engineers and database dministrators should assess the impacts of changing database entities and build a transition roadmap considering the following steps:

1. Choose entities to be transitioned: as stated previously, it is not necessary to change all database entities at once. If SLA violations are being triggered only for some entities, replacing these entities in a NoSQL architecture can solve the problem.

2. Change source code, tests and documentation: Changing the database results in

changes on the source code of application and possibly make changes on tests and documentation. This should be done as a second step in a transition process.

3. Parallelize production calls to both databases: A good practice on database transitioning is to run both storage solutions during a period of time. This means that the relational database is still used as a master storage and the NoSQL is used as a secondary storage. Doing so, a production request should be handled in parallel, but the results of the operations on the secondary database are ignored.

4. Perform integrity checks and SLA verifications: At this point it is possible to check if the production requests are correctly being handled by the NoSQL DB. No further SLA violations should be fired at this point.

5. Change for a small user base: A small user base can be used to make sure that no other issues will arise from the database transition. These users will have the results from the secondary (NoSQL) database as a result.

6. Change for all users: After a small user base is tested and no SLA violations were found, the transition can be performed for all production users. In this point, (part of) the relational database can be deprecated.

If the engineers decide not to transition the database at once, it is possible to perform these steps in a cycled, incremental manner. i.e: it is possible to transition the entities where SLA violations are being intensively fired at first and then perform other transitioning cycles. In this way, the negative impacts of a database transition are amortized.

4 Validation

To validate our guidelines, we searched for open-source tools that could possibly require database transitions. As stated on Section 1, a database migration is justified when the alternatives have better performance/manutenability than the classic RDBMSs and/or the cost to have a similar performance on the relational database architecture is significantly higher.

This condition (assessing the need for a database transition) is, then, only verifiable on production or simulated environments. Wordpress(WORDPRESS, 2015), world's most popular Content Management System (CMS) (BUILTWITH.COM, 2015), can be used to illustrate this problem.

Wordpress is built on the top of relational databases, such as PostgreSQL and MySQL. So, to justify a database transition on a wordpress-based application, we must *(i)* have access to a deployed and active version of the CMS or *(ii)* build a simulated environment and load it with posts, pages, comments and other entities that are present on a regular wordpress website.

Having access to the production version of a heavily used tool, such as Wordpress, is not easy, as the owner of the CMS must give access to sensible information of its database, users and posts.

Other open source tools were considered on this phase of the research, such as Redmine (REDMINE, 2015) and Moodle (MOODLE, 2015), but the same problem that emerged trying to accessing sensible information of Wordpress environments was found on these tools.

Besides that, famous open source tools usually have a large user-base. This results in a large support from the community towards the development of the software. With that, if a database transition from RDBMs to NoSQL is needed, it possibly have plugins/addons from the community, as (PARIS, 2015).

Facing this access restrictions to popular open-source projects, to validate the Guide-

lines proposed on the previous chapter, we have built scenarios that can be easily mapped to real-world applications.

The application proposed on section 4.1 is used to illustrate our case studies.

4.1 Assessing database transition on a social media monitoring application

To validate the guidelines presented on Chapter 3 we have modeled *the core database schema* of a social media monitoring application. Some examples of industry platforms of this kind are (SPROUTSOCIAL, 2015), (MENTION, 2015) and (BUZZMONITOR, 2015).

This category of applications are capable of searching and storing posts from social media platforms, as Twitter and Facebook. On the setup of a new account, users usually define a boolean query of the terms that they want to monitor and the platform begins to monitor *Application Program Interfaces* (APIs) from social networks, searching publications that match the boolean query.

4.1.1 Application Requirements and use cases

From a user perspective, this kind of application might be used to search for relevant topics across social media posts, to be aware of public opinion about brands (brand awareness) or to assess market for a product, for example.

From a software engineering perspective, some use-cases of this application could be:

1. **Create, retrieve, update and delete (CRUD) user account** - Users are able to create, modify and delete their account from the application.
2. **CRUD users' terms to monitor** - Users are able to edit the terms that they want to monitor across social networks.
3. **Retrieve posts by ids** - Given a set of post ids, the user is able to visualize them on the user interface (UI).
4. **Classify posts (add/tags tags)** - N tags (subjects) can be added or removed from a set of posts.
5. **Filter captured posts by filters** - Some possible filters are:

- Boolean Query: Search posts that mention a boolean query string. *i.e: (Brazil AND Neymar) OR (Orlando AND Kaka)*
- Date: Search posts that were published within a date range. For example: posts from 2015/01/01 to 2015/02/01.
- Tags: Search posts that match a tag query. i.e: posts about "Soccer Player" and "High Salary".

Other possible features and use-cases of this kind of applications are not listed to enable a deeper view of the scenarios that are presented on the next sections.

4.1.2 Application Architecture

Building applications like this one brings some challenges and decisions to software architects and engineers. As the scope of the project grows, it can be a wise decision to split the application in various sub-applications (or components).

Moreover, it is quite costly to manage the whole application from a single code base. The source code needs to handle users registration, query several API's and automatically analyze the sentiment of posts using Natural Language Processing techniques, for example.

Each of these components may have several other sub-components, or microservices. A microservice architecture brings some benefits to the application, such as maintainability, reuse and simplicity of deployment. A microservice that automatically detects the language from a given a string, for example, can be built and used in all components that need to accomplish this task.

Components or service-oriented architecture are useful as they enable using different technologies for distinct purposes. Just as in polyglot persistence, the idea is to use the best technology for each task.

Several sub applications could be proposed and created to work with each social network that is supported by the application. For instance, one service/component might be able to handle all the content related to *Facebook*, other component may be responsible for *Twitter* and another one for *Pinterest*-related features.

On Figure 14 we illustrate a component-based architecture for the proposed application.

Five main components can be extracted from the proposed architecture:

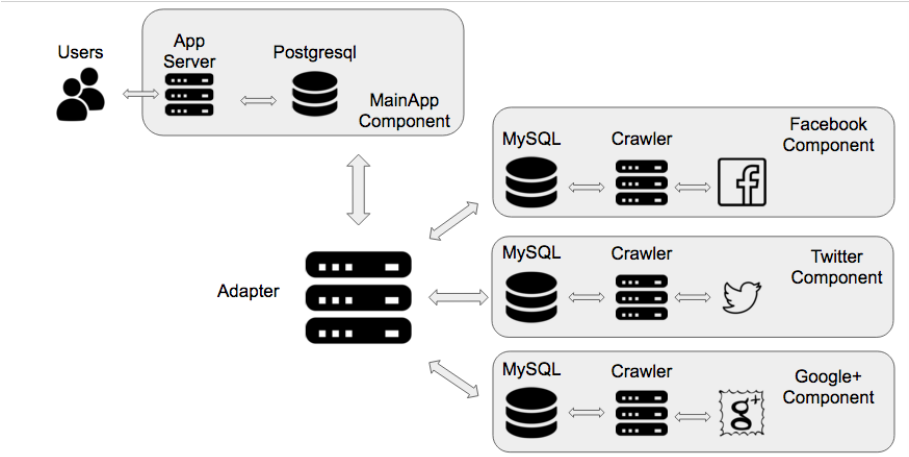


Figure 14: Proposed architecture - Social Media monitoring app.

- **MainApp Component**: This component can be seen as a web application where users can create their account, manage their social profiles, edit the terms that they want to monitor and where the user-interface is presented. A web framework, such as Ruby on Rails or Django can be used to build this component.

- **Twitter, Google Plus and Facebook Components**: These components are responsible to provide the necessary communication between the MainApp component and Social Networks. The strategy to build a component for each social network was assumed as different social networks have distinct APIs, with different entities and distinct communication patterns.

  In other words, *Facebook* may release its API through a HTTP REST perspective, while *Twitter* may release Software Development Kits (SDKs) to a restrict set of programming languages (Gems for Ruby, JARs for Java, for example) and Google plus may release its API through the SOAP protocol, making XML the standard way to handle data on its scenario.

- **Adapter Component**: The adapter component is responsible to integrate and to act as an interface between the different schemas that compose the data layer from other components (Facebook, twitter and Google Plus).

As presented on Figure 14, the architecture of the proposed application relies a Polyglot Persistence strategy. Two distinct databases are used on the app: Postgresql and MySQL. On real-world scenarios, this situation might be caused, for instance, by legacy code or by internal decisions of application architects.

4.1.3 When application grows, problems may arise

Once the application is released, it is desirable that no performance issues are found. Operations executed by application users should be , theoretically, at a acceptable performance level.

In the Facebook component, for example, it is expected to have no performance issues with tens to hundreds of rows stored on the MySQL database. However, worldwide events, as the Soccer World Cup, or national elections, may start to be suddenly monitored, bringing an unusual workload to the components.

In these cases, or when the application starts to keep track of millions or billions of data records, application performance and user experience may be dramatically affected if the engineering team have not performed satisfactory load and stress tests.

Following this scenario, after some months since application release, the number of records on MySQL databases from the three social-networks components may have grown exponentially. A simple query that checked if a column contains a substring would now need to analyze millions of posts instead of hundreds. As the number of posts to be analyzed grows, the query time may also grow.

4.1.4 Does the application need other databases?

On the scenario described on section 4.1.3, application users may start to complain that the application is taking too long to process their requests. This situation ends up slowing the overall performance of the users, as an action that should be processed within seconds starts taking minutes to be finish.

User complains about performance, however, may be related to a number of different factors. To number a few: the business logic might be taking too long to execute, the number of records in the database may have grown in an unexpected way, the database architecture might not be the best choice to handle application data and failures on network or server hardware may exist.

Given this scenario, we will focus our analysis on the components that are responsible for storing the posts on MySQL databases. More precisely, our study will be focused on the Facebook component, to present a clearer definition of the problem.

A possible complain from the application users' is that the application is getting slower

month after month to filter, process and present the posts on the user interface (UI).

It is expected that the number of posts grow month after month. In this case, the search speed slows down as the number of posts in the database grows, and application developers and DBAs may use this fact as a hint to start searching for the real cause of the problem.

This way, the engineering team from the Facebook component might have a strong intuition that the cause of the slowness is on the data layer (MySQL). Engineers may also have an intuition that it is a specific kind of SQL query that is taking too long to execute, consuming too much CPU & memory resources. The team may also suggest that a NoSQL technology could be a better fit for the use case that is performing below users' expectation.

In this case, the guidelines proposed on the previous chapter are a good fit, as they are useful to verify if any problems/bottlenecks exist on the database side and to check if a NoSQL architecture could be a better fit to the scenario.

4.1.5 The application setup: Server

In this section we detail the server technical specifications that were used to host the data layer of the application that we presented on the previous section. We have selected a **T2.SMALL** instance from (EC2, 2015) to host it, as it is a general purpose and low-price instance. T2.SMALL instances feature the following configuration:

- High Frequency Intel Xeon Processors with Turbo up to 3.3GHz Burstable CPU, governed by CPU Credits, and consistent baseline performance
- 1 vCPU
- 12 CPU Credits/hour
- 2 GB RAM

4.1.6 The application setup: Software

The following software configuration was installed on the servers:

- Operating System: Ubuntu 14.04.2 LTS (GNU/Linux 3.13.0-48-generic x86_64)

- Secure Shell
- MySQL Version: 14.14 Distrib 5.5.44, for debian-linux-gnu (x86_64) using readline 6.3

4.1.7 The application setup: Data

To retrieve the data that is used on the scenarios, we have developed a web crawler that gathers posts from Facebook and store them on our MySQL database. The data was captured from public posts on popular Fan Pages.

A total number of 3.332.534 posts were captured and the Dump file with these posts is available on (LEAL, 2015a).

4.1.8 The application setup: Database schema

The first database schema was built with the intention of being optimized to production environments, and building **de**-normalized schemas help to leverage application performance, as revealed by (SANDERS; SHIN, 2001).

On Figure 15 it is possible to view all the columns that compose the **Posts** table. All post entities, like *message* (content of the post), *link* and *number of likes* are present on this table.

Figure 15 reveals that "tags" is a text field on the posts table. By internal convention from the engineering team, a post tag can be represented by a string with a defined format: *#**username_ tagname**#*.

A *tags* cell might store several tags for a single post. Listing 4.1 gives the representation of a tags cell with multiple tags within:

Listing 4.1: Tag field standard format

```
1 #username1_tag1##username2_tag1##username3_tag1
```

When the user adds a tag to a given post, the "tags" field is concatenated with the given tag. A SQL UPDATE that represents this situation is shown on listing 4.2.

Listing 4.2: Update Tag - SQL

```
UPDATE post set tags=concat(tags, '#username3_tag1#') WHERE id=1;
```

Column	Type
id	bigint(30)
post_id	bigint(20) unsigned
comment_id	bigint(20) unsigned
comment_reply_id	bigint(20) unsigned
fan_page	tinyint(1)
collected_from	enum('POSTS','FAN_PAGE','GROUP')
created_time	datetime
updated_time	datetime
message	text
type	varchar(20)
link	text
name	varchar(250)
caption	varchar(150)
description	text
picture	text
source	text
mood	float(3,2)
icon	varchar(250)
likes	int(11)
comments	int(11)
page_id	bigint(20) unsigned
group_id	bigint(20) unsigned
page_url	varchar(400)
author_id	bigint(20) unsigned
author_name	varchar(150)
author_gender	char(1)
upload	tinyint(1)
in_reply_to	bigint(20)
tags	text
replied_element_id	varchar(70)
replies	smallint(6) unsigned
shares	int(11)
term	text
archived_by_user	text
archived	tinyint(1)
location	varchar(100)

Figure 15: Posts table.

To remove a tag, a "replace" operator can be used, as shown on listing

Listing 4.3: Remove Tag - SQL

```
UPDATE post SET tags= REPLACE(tags, '#username3_tag1#', '') WHERE id=1;
```

The decision to store the tags in a field instead of storing it on another database was taken to avoid JOINS between several tables when searching for posts that have a set of tags.

4.2 Using the guidelines

As shown on chapter 3, the guidelines proposed on this work are useful to assess and guide database transitions in production-ready or simulated environments. We may use the guidelines to assess if a database migration to NoSQL is really needed or if the problem

can be solved by improving the current DB architecture or if it is not even located on the data layer.

Throughout this section we use the guidelines in a step-by-step strategy, as shown on chapter 3, to motivate and guide a database transition on the application proposed on the previous sections of this chapter.

As stated previously on 4.1.4, we want to check if the MySQL Database from Facebook Component needs to be transitioned, given the users are experiencing a degraded QoS in some parts of the application.

4.2.1 List application operations that are performed on database-level

According to the guidelines, the first step in a scenario where a database transition is being considered is to *List application operations that are performed on database level.* As the focus of our study is the Facebook component, operations from other components, as "CRUD user account" and "CRUD terms to monitor" should not be considered at this point.

Thus, from the requirements presented on section 4.1.1, we identify that the operations that are related to the Facebook Component are **"Retrieve posts by ids"**, **"Classify posts (add tags)"** and **"Filter captured posts by filters"**. These are the operations that could possibly demand a transitioning process on the data layer of the component.

4.2.2 Define user-centered SLAs

Section 3.3.2 reveals that for each operation listed on the previous step, a set of SLAs should be proposed. This way, from interviews and surveys with application stakeholders, a network of SLAs could be proposed to the three operations that are subject to our study:

- **Retrieve posts by ids**:
  - Ideal threshold: 3 seconds
  - Tolerable threshold: 10 seconds
  - SLA Delta Factor: 3.3X
- **Classify posts (add/remove tags)**:

  - Ideal threshold: 1.5 second
  - Tolerable threshold: 3 second
  - SLA Delta Factor: 2x

- **Filter captured posts by filters**:
  - Ideal threshold: 3 seconds
  - Tolerable threshold: 10 seconds
  - SLA Delta Factor: 3.3x

4.2.3 Define database-centered SLAs

As shown on previous sections, users and other application stakeholders are capable of identifying SLAs to the use cases of the application. On the other hand, the application engineers are responsible for defining a set of SLAs that work at database level.

These SLAs should be *stronger* than the SLAs defined by the users, as several other actions are also necessary to accomplish a single use-case. In the context of a web application, for example, authentication tokens, filters, business logic and network delays are some of the factors that affect the execution time of a use case.

In this way, a set of Database-oriented SLAs could be defined to the three proposed use-cases:

- **Retrieve posts by id**:
  - Ideal threshold: 1.0 seconds
  - Tolerable threshold: 4 seconds
  - SLA Delta Factor: 4x
  - ROFR: 30%
- **Classify posts (add/remove tags)**:
  - Ideal threshold: 0.5 second
  - Tolerable threshold: 2 second
  - SLA Delta Factor: 4x
  - ROFR: 30%

- **Filter captured posts by filters**:
  - Ideal threshold: 2 seconds
  - Tolerable threshold: 6 seconds
  - SLA Delta Factor: 3x
  - ROFR: 15%

Thus, from the "Filter posts captured by filters" use case, it can be said that a request to filter posts at database level should take up to two seconds to assure that users will not face any performance issues caused by Database-related problems. If the query takes longer than six seconds to execute, users can get really frustrated about the slowness of the tool and this may have a big negative impact on the Quality of Service.

This SLA also reveals that there should be no problems if up to 15 % of the requests are executed between two and six seconds. These outlier data points may be caused by expected instabilities on cloud providers.

4.2.4 Build database-level SLA log alerts

Parts of the application proposed on this chapter were implemented to assess the use of the proposed guidelines. In a real-world scenario, the alerting system could be built within the source code of the application. Other services, such as New Relic, might also be used for this purpose.

It's also worth mentioning that the SLA checkers are only useful if database queries and processes are actually being executed by the users. In a simulated environment, like this one, user requests can be simulated by load test tools, as JMeter, or can be created programmatically from scratch.

In our case study we proposed and programmatically built scenarios that simulate, at the same time, the requests that are sent by users and part of the source code that analyzes SLA conditions and sends alerts if any SLAs are broken.

Through the implemented scenarios it is possible to identify if are there any cases where the proposed SLAs are not being fulfilled and consequently if application users may find any degraded QoS caused by database-level problems.

Three scenarios - one for each operation - were built to assess wether the SLAs for each operation are being met or not.

On the following subsections we detail how each scenario was implemented and discuss the motivation to migrate from the relational architecture to a NoSQL strategy on the proposed application.

4.2.4.1 Retrieve posts by id

The first operation to be checked is to retrieve a set of posts, given their ids. This operation could be originated from a screen that presents a list of posts to the users, where they are able to check for details on each post, for example.

At database level, this operation can be seen as a simple SQL query, as revealed on listing 4.4.

Listing 4.4: SQL Query - Retrieve posts by ids

```
1 SELECT * FROM posts WHERE id IN (1,2,41,13,12903, ... ,435,31)
```

On the previous step, we have defined that a database-level SLA for the *"Retrieve posts by id"* operation is composed by:

- Ideal threshold: 1.0 seconds
- Tolerable threshold: 4 seconds
- SLA Delta Factor: 4x
- ROFR: 30%

To verify if the QoS of this operation is below expected, a test environment was setup according to the following steps:

1. For each dataset size on the list [3, 30, 300, 3000, 30000, 300000, 3000000]:
2. Retrieve a random number of posts between 50 and 100. These posts are the ones that would be presented to the users;
3. Wait for a random time between 30 to 300 milliseconds, to reproduce real-world scenario and avoid query flood on the database at once;
4. Repeat steps 2 and 3 for 30 times for each dataset size.

```java
public class Ex01 {
    public static void main(String[] args) {
        int[] datasetSizeArray = {3,30,300,3000,30000,300000,3000000};
        int numQueriesPerExperiment = 30;

        for (int datasize:datasetSizeArray) {
            for (int j = 0; j < numQueriesPerExperiment; j++) {
                int amountOfPostsToRetrieve = Util.generateRandomNumbers(50, 100, 1)[0];
                RunnableDemo R1 = new RunnableDemo(datasize, amountOfPostsToRetrieve);
                R1.start();
                try {
                    int randomTimeToSleep= Util.generateRandomNumbers(30, 300, 1)[0];
                    Thread.sleep(randomTimeToSleep);
                } catch (InterruptedException e) {
                    // TODO Auto-generated catch block
                    e.printStackTrace();
                }
            }
        }
    }
}
```

Figure 16: Experiment Setup.

```java
public void run() {
    try {
        Class.forName("com.mysql.jdbc.Driver");
        Connection con = DriverManager.getConnection(
                "jdbc:mysql://54.186.38.180:3306/mestrado", "root",
                "mestrado");

        Statement st = con.createStatement();
        String idList = Util.getIdList(amountOfPostsToRetrieve, datasetSize);
        String query = ("SELECT * FROM post_all_pages_portugal_globo_pt WHERE id < " + datasetSize +  " AND id IN " + idList);
        long startTime = System.currentTimeMillis();
        ResultSet result = st.executeQuery(query);
        long estimatedTime = System.currentTimeMillis() - startTime;
        System.out.println((datasetSize+ "," + estimatedTime));
        addExecutionToArray(estimatedTime);
        con.close();

    } catch (ClassNotFoundException ex) {
        System.out.println("Driver not found");
    } catch (SQLException ex2) {
        ex2.printStackTrace();
    }
}
```

Figure 17: Main Thread - Run Method.

Figures 16 and 17 present the Java implementation of the given algorithm. [1]

Figure 18 presents how the SLA checkers were implemented in Java programming language. As revealed on Chapter 3, alerts are triggered when any query exceeds the tolerable threshold or when the ROFR is above the desired level. We have also defined that a minimum number of 10 operations should be executed before any alert is sent, to avoid unnecessary alerts from unusual situations at the first time that a query is run.

Figure 19 shows the execution time in milliseconds for the first scenario. On the chart, each line represents a dataset size, where 30 SELECT queries are sent to the MySQL database and the response time is registered on each query.

The query time in small datasets (from 3 to 300.000) is "near-zero" milliseconds, as the chart presents. So, multiplying the dataset size by a 10x factor has almost no impact on the query performance for small datasets. When iterating over 3KK rows (indexed as

[1] This algorithm was run from the database server that host the database to assure that the measured time woud not be affected by network or other hardware-related delays.

```
43      static int idealThreshold = 1000; // 1 sec
44      static int tolerableThreshold = 4000; // 4 sec
45      static float max_rofr = 0.30f; // 30%
46
47      static void addExecutionToArray(long executionTime) {
48          synchronized (executionArray) {
49              executionArray.add(executionTime);
50          }
51          checkSLAisBroken();
52      }
53
54      static void checkSLAisBroken() {
55          ArrayList<Long> executionsAboveIdealTheshold = new ArrayList<Long>();
56          synchronized (executionsAboveIdealTheshold) {
57              for (Long executionTime : executionArray) {
58                  if (executionTime > idealThreshold) {
59                      executionsAboveIdealTheshold.add(executionTime);
60                  }
61                  if (executionTime > tolerableThreshold) {
62                      System.err.println("Execution time over tolerable Threshold - ALERT");
63                  }
64              }
65              if ((executionsAboveIdealTheshold.size() / executionArray.size()) > max_rofr
66                      && executionArray.size() > 10) {
67                  System.err.println("ROFR Exceeded - ALERT");
68              }
69          }
70      }
71
```

Figure 18: SLA Checkers.

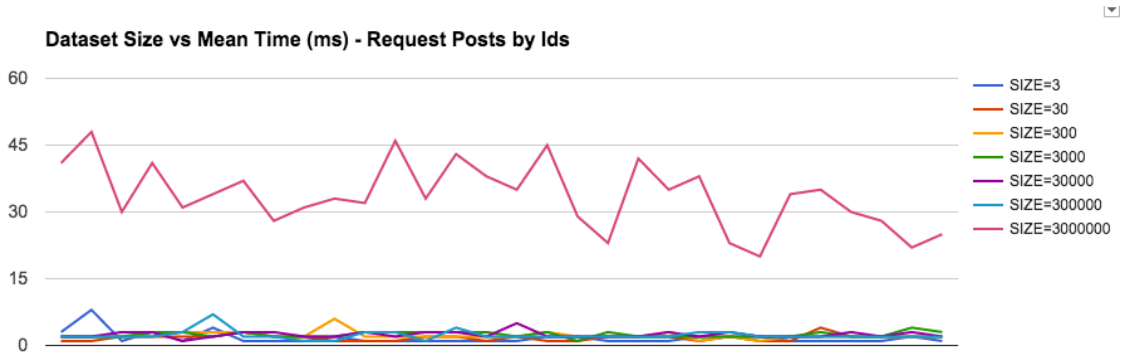


Figure 19: First Scenario - Retrieve post by ids.

a b-tree, as *id* are primary key on this table), however, a "gap" emerges, representing the amount of time that is needed to search over 3KK nodes on the *id* index.

As the ideal threshold to this operation states that all operations must be executed in up to 1000 milliseconds (a second), we can assure that the data layer is not a bottleneck to the users on this kind of operation. It is worth mentioning that over 200 queries were executed on this scenario, and not a single query was over 1/10 of the desired ideal threshold.

On the Appendix B.1 it is possible to visualize the raw data extracted from this scenario.

4.2.4.2 Classify posts (add/remove tags)

The operation of classifying posts is used when a user wants to add or remove a set of tags from a set of posts. Posts may be updated using their ids or using other tags as references. In other words, it is possible to add or remove a tag from posts that have already been tagged with other tags. In practical terms, the user may want to add a "SPECIAL_CUSTOMER" tag to posts that have already been tagged as "FAMOUS_PEOPLE" or "RICH_PEOPLE", for example.

Section 4.1.8 presents how tags may be added or removed from posts in the proposed database schema. Listings 4.2 and 4.3 present a detailed view on how these operations can be performed.

On the previous section we have defined that a database-level SLA for the *"Classify posts (add/remove tags)"* operation. It is composed by:

- Ideal threshold: 0.5 second
- Tolerable threshold: 2 second
- SLA Delta Factor: 4x
- ROFR: 30%

To verify if the QoS of this operation is below expected, a test environment was setup according to the following steps

1. For each dataset size on the list [3, 30, 300, 3000, 30000, 300000, 3000000]:
2. Randomly generate a number of tags between 1 and 4;
3. Execute SQL UPDATEs to add one more tag to posts that already have one of the tags generated on step 2.[2]
4. Wait for a random time between 30 to 300 milliseconds, to reproduce real-world scenario and avoid query flooding on the database at once.
5. Start another thread of the same type until a total number of 30 threads are run per dataset size.

[2]If four tags are generated, for example, the SQL statement has the following format: *"UPDATE posts set tags=concat(tags, #username9_tag4#) WHERE tags LIKE #username6_tag3# OR tags LIKE #username0_tag7# OR tags LIKE #username0_tag2# OR tags LIKE #username0_tag8#"*

The Java implementation of the proposed environment is presented on Figures 20 and 21. The SLA checker for this scenario is very similar to the one that was presented for the first scenario (Retrieve a list of posts by ids) - Figure 18.

```
154 public class Ex02 {
155     public static void main(String[] args) {
156         int[] datasetSizeArray = {3, 30, 300, 3000,30000,300000,3000000};
157         int numQueriesPerExperiment = 30;
158 
159         for (int datasize:datasetSizeArray) {
160             for (int j = 0; j < numQueriesPerExperiment; j++) {
161                 Util2 u = new Util2();
162                 int amountOfTags = u.generateRandomNumbers(1, 4, 1)[0];
163                 RunnableDemo2 R1 = new RunnableDemo2(datasize, amountOfTags,u);
164                 R1.start();
165                 try {
166                     int randomTimeToSleep = u.generateRandomNumbers(30, 300, 1)[0];
167                     Thread.sleep(randomTimeToSleep);
168                 } catch (InterruptedException e) {
169                     e.printStackTrace();
170                 }
171             }
172         }
173     }
174 }
```

Figure 20: Second Scenario - Add or Remove tags.

```
120     public void run() {
121         try {
122             Class.forName("com.mysql.jdbc.Driver");
123             Connection con = DriverManager.getConnection(
124                     "jdbc:mysql://54.186.38.180:3306/mestrado", "root",
125                     "mestrado");
126 
127             Statement st = con.createStatement();
128             String queryType;
129             queryType = getQueryType01(amountOfTags); // Option 01
130 //          queryType = getQueryType02(amountOfTags); // Option 02
131             long startTime = System.currentTimeMillis();
132             st.executeUpdate(queryType);
133             long estimatedTime = System.currentTimeMillis() - startTime;
134             System.out.println(datasetSize + " , "+ estimatedTime + " , \"" + queryType+ "\"");
135             addExecutionToArray(estimatedTime);
136             con.close();
137 
138         } catch (ClassNotFoundException ex) {
139             System.out.println("Driver not found");
140         } catch (SQLException ex2) {
141             ex2.printStackTrace();
142         }
143     }
```

Figure 21: Edit Tags - Run method.

Finding a broken SLA

The chart displayed on Figure 22 shows how the execution time changes (in milliseconds) for this operation between query sizes. Appendix B.2 presents the data output from this scenario.

As presented on the chart, no tolerable threshold is broken or ROFR is exceeded on the datasets from 3 to 30.000 posts. The SLA is eventually broken when querying the datasets sizes are over 300.000 posts. In production environments, this means that the application would work fine on a small scale, but would get sluggish as the database grows.

Big datasets, as the ones over 300.000 posts, present a linearity on the chart - the scale growth between 300K posts and 3KK posts is linear (10x). That is caused by the jobs that are being queued and can only be processed after a previous job finished. Figure 23 shows how job queueing is viewed from MySQL's processlist.

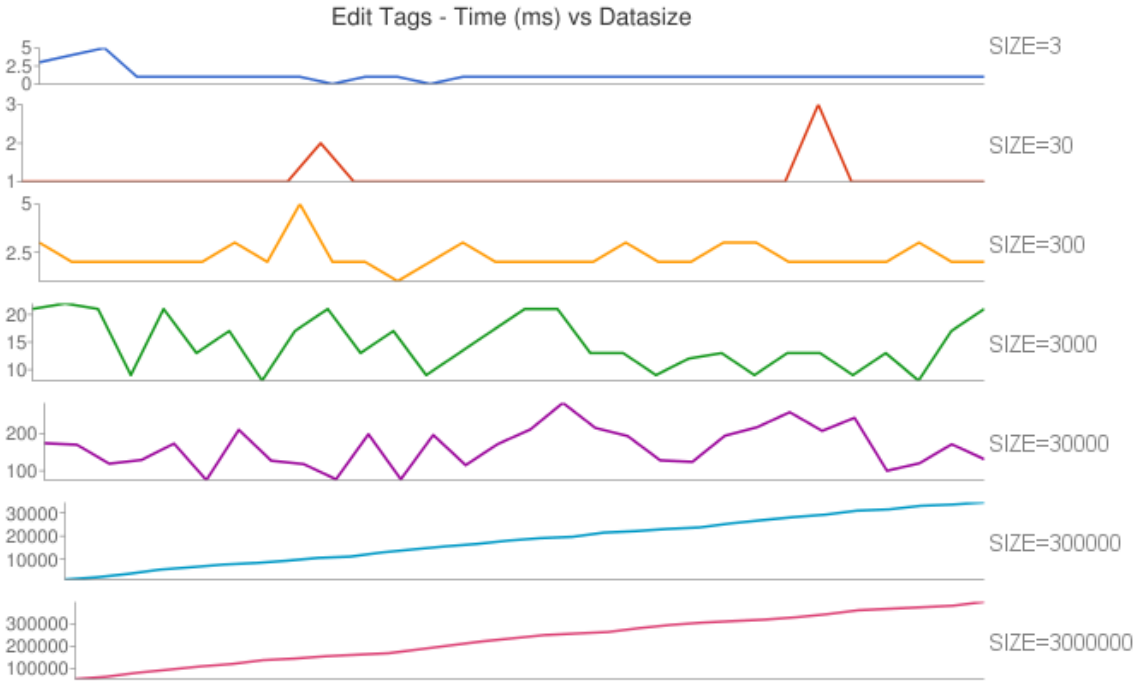
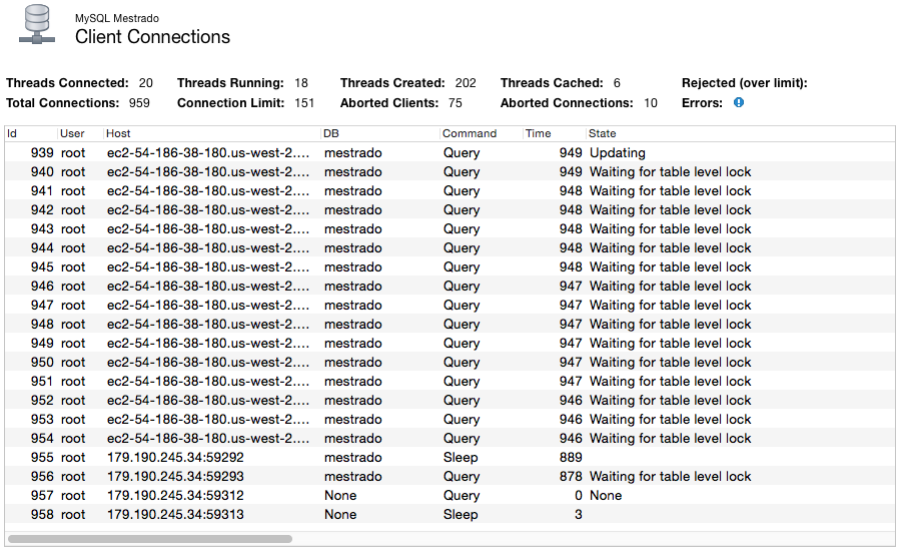


Figure 22: Edit Tags - Dataset Sizes vs Time (ms).



MySQL Mestrado
Client Connections

Threads Connected: 20 **Threads Running:** 18 **Threads Created:** 202 **Threads Cached:** 6 **Rejected (over limit):**
Total Connections: 959 **Connection Limit:** 151 **Aborted Clients:** 75 **Aborted Connections:** 10 **Errors:**

Id	User	Host	DB	Command	Time	State
939	root	ec2-54-186-38-180.us-west-2....	mestrado	Query	949	Updating
940	root	ec2-54-186-38-180.us-west-2....	mestrado	Query	949	Waiting for table level lock
941	root	ec2-54-186-38-180.us-west-2....	mestrado	Query	948	Waiting for table level lock
942	root	ec2-54-186-38-180.us-west-2....	mestrado	Query	948	Waiting for table level lock
943	root	ec2-54-186-38-180.us-west-2....	mestrado	Query	948	Waiting for table level lock
944	root	ec2-54-186-38-180.us-west-2....	mestrado	Query	948	Waiting for table level lock
945	root	ec2-54-186-38-180.us-west-2....	mestrado	Query	948	Waiting for table level lock
946	root	ec2-54-186-38-180.us-west-2....	mestrado	Query	947	Waiting for table level lock
947	root	ec2-54-186-38-180.us-west-2....	mestrado	Query	947	Waiting for table level lock
948	root	ec2-54-186-38-180.us-west-2....	mestrado	Query	947	Waiting for table level lock
949	root	ec2-54-186-38-180.us-west-2....	mestrado	Query	947	Waiting for table level lock
950	root	ec2-54-186-38-180.us-west-2....	mestrado	Query	947	Waiting for table level lock
951	root	ec2-54-186-38-180.us-west-2....	mestrado	Query	947	Waiting for table level lock
952	root	ec2-54-186-38-180.us-west-2....	mestrado	Query	946	Waiting for table level lock
953	root	ec2-54-186-38-180.us-west-2....	mestrado	Query	946	Waiting for table level lock
954	root	ec2-54-186-38-180.us-west-2....	mestrado	Query	946	Waiting for table level lock
955	root	179.190.245.34:59292	mestrado	Sleep	889	
956	root	179.190.245.34:59293	mestrado	Query	878	Waiting for table level lock
957	root	179.190.245.34:59312	None	Query	0	None
958	root	179.190.245.34:59313	None	Sleep	3	

Figure 23: MySLQ Job Queueing.

At this point, we have a broken SLA for the operation.

4.2.4.3 Filter captured posts by filters

The operation of *filtering captured posts by filters* is used when a user wants to visualize only a set of posts that match a defined criteria. Some possible filters are: Sentiment (Positive, Negative and Neutral) - represented on the table as *mood* (a float from 0 to 1,

representing the result of a sentiment classifier), *Boolean Query* (words that are mentioned on the post) and Starting Date. *Tags* could also be used as filters at this point, as the previous section suggests.

Filtering posts at a database level can be represented by a simple SQL query, as illustrated on Listing 4.5.

Listing 4.5: Filter posts query - Example

```
SELECT * from post WHERE mood>0.0 AND created_time > 2015-5-3 AND created_time
    < 2015-7-15 AND message like '%ruim%'
```

On the previous sections we have also defined that a database-level SLA for the *"Filter captured posts by filters"* operation. It is composed by:

- Ideal threshold: 2 seconds
- Tolerable threshold: 6 seconds
- SLA Delta Factor: 4x
- ROFR: 15%

To verify if the QoS of this operation is below expected, a test environment was setup according to the following steps

1. For each dataset size on the list [3, 30, 300, 3000, 30000, 300000, 3000000]:
2. Randomly generate a set of filters for date, sentiment (mood) and a Boolean Query;
3. Execute SQL SELECTs to retrieve the posts that match the boolean query.
4. Wait for a random time between 30 to 300 milliseconds, to reproduce real-world scenario and avoid query flooding on the database at once.
5. Start another thread of the same type until a total number of 30 threads are run per dataset size.

Finding a broken SLA: Figure 24 presents how the execution time changes (in milliseconds) for this operation between query sizes. In our implemented scenario, we could also find that there's no noticeable difference between querying random generated ascii-chars and words that actually exist on the posts or on the dictionary.

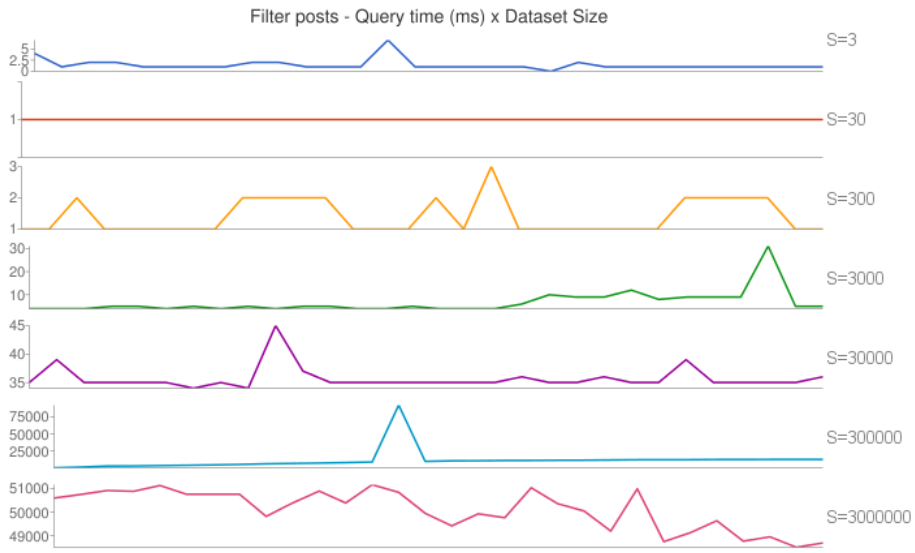


Figure 24: Filter captured posts by filters - Dataset Sizes vs Time (ms).

As presented on Figure 24, the SLA for this operation is broken in the same dataset sizes where the operation *Classify posts (add/remove tags) broke, as the numbers on the left represent the time in milliseconds that took for an operation be executed.*

At this point, we also have a broken SLA for this operation.

4.2.5 Verify SLA violation

SLA Violations were found on the *Classify posts (add/remove tags)* and *Filter captured posts by filters* operations.

To find the reason *why* SLA violations were being triggered in these cases, we started by reading performance-related MySQL guides, running EXPLAIN queries and analyzing table columns to check if any improvements could be done on this side.

4.2.5.1 Classify posts (add/remove tags)

For this operation, it was clear that the UPDATE was taking too long because it had to scroll over several records to *i) find posts that matched the desired tag query* and *i) perform a row-by-row update.*

MySQL documentation presents other options to perform Full Text Searches rather than using the "LIKE" clause. Particularly, a "MATCH AGAINST" clause can be used instead of a "LIKE" clause to search for tags in this step, as the "tags" column is stored as plain text.

Listing 4.6 shows how the two queries differ from each other and (S.OVERFLOW-MYSQL, 2015) presents some advantages in using MATCH AGAINST instead of LIKE.

Listing 4.6: A new operator - MATCH AGAINST

```
UPDATE post set tags = "#user1_tag2#" where tags LIKE "#user1_tag1#" -- old
    sentence
UPDATE post set tags = "#user1_tag2#" where MATCH(tags) against ("#user1_tag1#"
    IN BOOLEAN MODE) -- new sentence
```

Our DB schema was built using InnoDB Engine, native database engine for MySQL. InnoDB, however, does not support the MATCH AGAINST operator / Full Text Search features (MYSQL, 2015), so we had to migrate the posts table engine to MyISAM to try the MATCH AGAINST operator. With only 3 million posts stored on our database, the migration lasted around 12 minutes. Migrating a cluster with hundreds of millions of rows in production seems to be a challenging problem.

MyISAM also has major downsides, however, as revealed by MySQL's documentation:

- No foreign keys and cascading deletes/updates

- No transactional integrity (ACID compliance)
- No rollback abilities
- Row limit of 4,284,867,296 rows
- Maximum of 64 indexes per row

After running the same scenario with the MATCH AGAINST operator, the database SLA was still not being met. As advised by (S.OVERFLOW-MYSQL, 2015), this solution quickly becomes unusable for hundreds of rows.

This way, the literature review proceeded and a possible solution was emerging: to change data format. On the next section we present how changing the data format for tags helped to solve the problem.

4.2.5.2 Filter captured posts by filters

The issue found on the *Filter captured posts by filters* operation was similar to the one found on *Classify posts*. Indexes were added to the *created_at* and *mood* columns, and a EXPLAIN query showed that the bottleneck of the operation was to perform a full-text search across several records.

When the filters were wide, a full table scan was still needed. To ease understanding, on section 4.2.6.2 we present how using the MATCH AGAINST operator together with FULLTEXT indexes *apparently* solved the performance issues of this operation.

4.2.6 Propose architectural changes at database-level

On the last section, a set of improvements were made to the posts table, but some operation SLAs remained broken. On this section we discuss how changes on the app/-database infrastructure could help to fix the broken SLAs.

4.2.6.1 Changes on tags structure

To solve the problem of adding/removing tags to a set of posts that already contain other set of tags, we have proposed a separate table to store tags information.

Figure 25 shows the elements that compose a *tag* record. Each tag has a unique ID - *idtags*, a *post_id* (foreign key to the post table), a *tag_user* (the username of the user

who has tagged this post) and *tag_name*, the subject of this post.

The tags table is also denormalized, as *tag_user* and *tag_name* are entities that could be represented on separate tables on a normalized schema.

Column	Type
idtags	int(11)
post_id	bigint(30)
tag_user	varchar(45)
tag_name	varchar(45)

Figure 25: Tags table.

Indexes were added to the *post_id*, *tag_user* and *tag_name* columns. With the proposed table structure, adding and removing tags from a set of posts that have other tags needed new query fomats, as presented on listing 4.7.

Listing 4.7: New SQL queries to add and remove tags

```
INSERT INTO tags (post_id, tag_user,tag_name) SELECT t.post_id, "newTagUser",
    "newTagName" from tags t where (t.tag_user= "user1" and t.tag_name="tag1")
    OR (t.tag_user="user2" and t.tag_name="tag2") -- Create tags

DELETE FROM tags where (tag_user="user1" AND tag_name="tag1") --Remove Tags
```

The time to create tags in big datasets was, however, still very high, and a set of composed indexes were created on this table. Figure 26 presents all database indexes that were created on the table. Indexes composed by *post_id*, *tag_name* and *tag_user* were essential to leverage performance on the operations.

To add tags to posts that already have a set of tags, two actions are necessary: i - *To find* the posts that already have the tags and ii - *to actually write* the tags on the DB. These two steps are also the same for tags removal.

The tags table performance dramatically improved - and made possible - *to find* posts that already have a set of tags, as presented on Figure 27.

It is still not possible, however, to say that the SLA is being respected, as the SLA makes no restriction about how many tags may be added or removed in a single operation. As any Database server has a limited number of operations that it is capable of processing in a period of time (ops/sec), it is not possible to say that a single server will be able to handle the insertion of an infinite amount of tags.

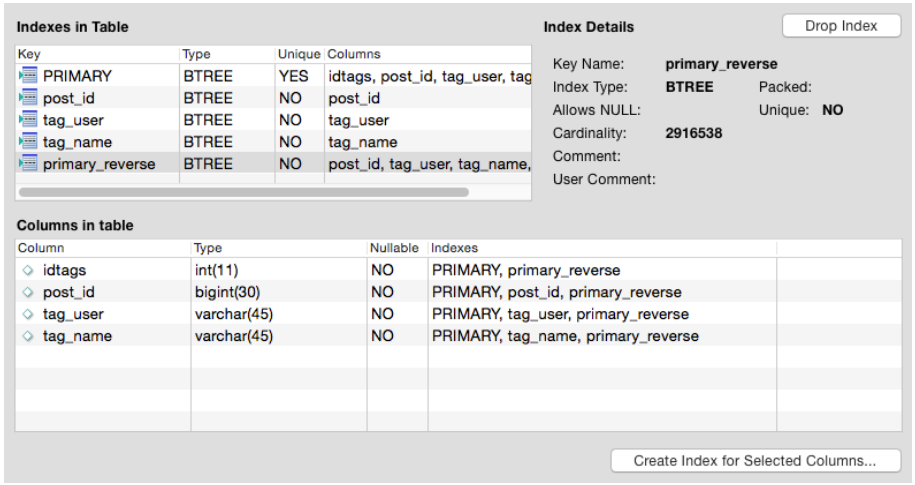


Figure 26: Tags table Indexes.

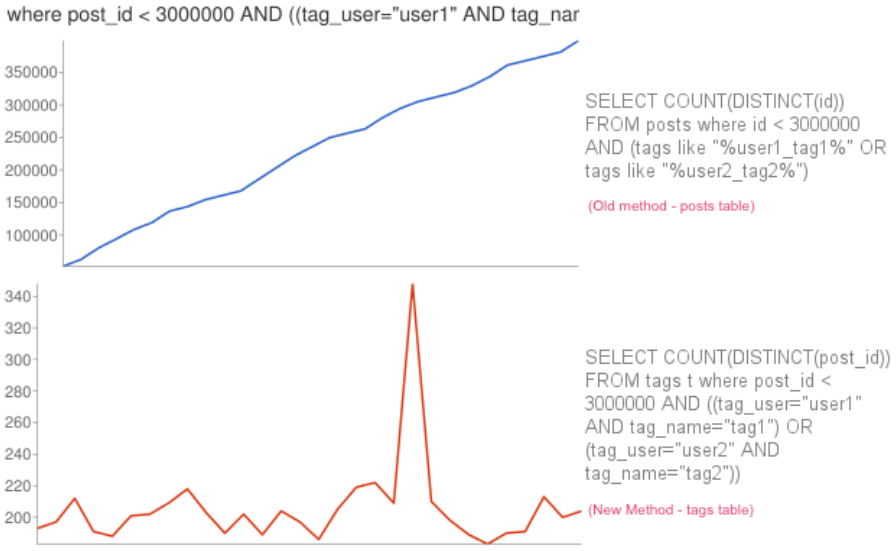


Figure 27: Retrieve posts to be modified - (on Tags table / MyISAM) vs Retrieve posts to be modified (on posts table / InnoDB) - 3 million posts dataset.

This may evidence that either the SLA needs to be renegotiated with stakeholders or that further work is still needed. If the renegotiation is possible, users may agree to specify this SLA in terms of the number of tags that can be added/removed per second. For instance, users may agree that 10.000 tags/second is a satisfiable level.

If the SLA can't be renegotiated, a possible strategy is to setup a MySQL cluster with sharding enabled, as (MYSQL-SHARDING, 2015) suggests. This way, a single operation can be handled in multiple servers at once, and the accorded SLA can eventually be met by adding computing resources.

4.2.6.2 Changing the way Fulltext Search is done on the app

The last operation that remained with a broken SLA is *Filter captured posts by filters*, as explained on section 4.2.4.3.

Several modifications were made on MySQL's configuration on this table since the first query was proposed:

- **Switched table engine**: The table engine of posts table was switched from InnoDB to MyISAM. This enabled the construction of Full Text Search Indexes on this table.
- **Created FTS Indexes**: FTS indexes were created on the fields that store user-generated text (*message*, *caption*).
- **Created Regular Indexes (BTrees)**: Other indexes were added to the other searchable fields - *mood* and *created_time*)

This way, the query format for this operation changed from the one presented on Listing 4.5 to the one presented on Listing 4.8. The chart presented on Figure 28 reveals how the use of a Full Text Search index *apparently* solved the problem of alerts being triggered for this operation.

Listing 4.8: New filter posts query format

```
SELECT * from post_all_pages_portugal_globo_pt WHERE mood=0.1 AND created_time
    > 2013-5-24 AND MATCH (message) AGAINST ('booleanSearchString' IN BOOLEAN
    MODE)
```

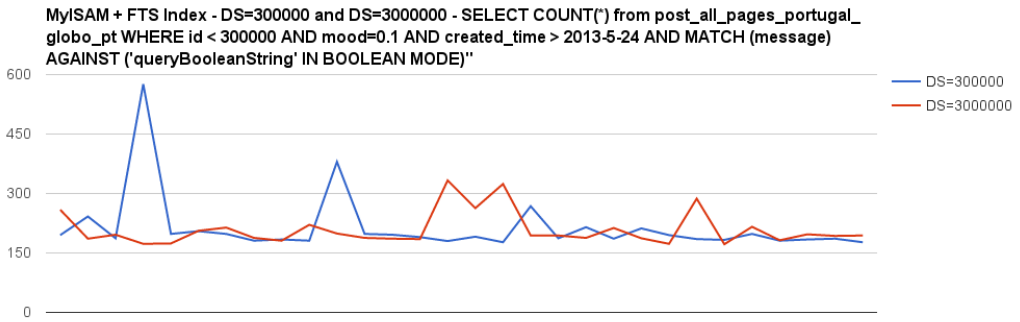


Figure 28: Searching on posts table - New Format: MyISAM and FTS Index.

InnoDB vs MyISAM

Using MyISAM and a FTS index in MySQL have its downsides, however. As shown on section 4.2.5.1, major features of relational DBs, as *transactional integrity (ACID compliance)* and *foreign keys / cascading deletes*, are lost when using MyISAM engine instead of InnoDB.

Table locks on MyISAM are also a huge problem, as pointed out by (SCOUTENGINEERING, 2015) (while a table is being updated, no other changes to that table can be performed). If the application needed to assure integrity of transactions, for example, engineers would have to do it by their own.

Another possible option is to have two databases - a master (where the updates and ACID compliance operations are done) and a slave (where search operations are done). This approach enables to have all the benefits from InnoDB and MyISAM at the same time. As a downside, however, all the problems of data replication in a master-slave database architecture arise to be handled by the application engineers.

Is MySQL *really* for search?

Using MATCH AGAINST operator in MyISAM tables have another big downside: the support for **stemming**.

Stemming, in search, "*describes the process for reducing inflected (or sometimes derived) words to their word stem, base or root form - generally a written word form*" (STEMMING/WIKI, 2015). A stemming algorithm reduces the words "playing", "played", and "player" to the root word, "play". "argue", "argued", "argues", "arguing", and "argus" correspond to the stem "argu" (a stem is not itself a word or root) but "argument" and "arguments" are related to the stem "argument" (STEMMING/WIKI, 2015).

When a user searches for "lay" using the LIKE operator, MySQL will return all the posts that contain "lay" as a substring. i.e: posts that mention "play", "lay" and "laying" will come as results, which is not what the user expects. On the other hand, when the users search for "lay" using the MATCH AGAINST operator, it will only return posts that exactly mention "lay", excluding posts that mention "lays" or "layed". Both results are not what users expect when using popular search tools, like Google.com.

Tickets reffering to the support of stemming were open in 2010 on MySQL's development roadmap (DICTIONARY/MYSQL, 2010) (STEMMING/MYSQL, 2010). Despite being flagged as "very high priority" tasks, they still remain un-assigned for more than 6 years, and even when the support for this operation is eventually released, it will only provide support to the english language.

Possible alternatives to support stemming operations on MySQL would be *i) to build stemming functions on the top of MySQL from the ground up* or *ii) to use external plugins, like (UDMSTEMMER, 2007) and (UDFSTEMMER, 2009)*. Using external plugins has major downsides, as projects may be discontinued - the last commit on both cited plugins are from 2007 and 2009, respectively, and there's no community support around these technologies.

Adding support to stemming functions in a database may become a big task, and besides query complexity, it's hard to compete with the performance of a dedicated search engine.

A search engine is needed

Apache Solr, Lucene, Amazon Cloudsearch and Elasticsearch are **Search Engines** that provide fulltext-search and Stemming as main features.

After performing extensive literature review, discussing in popular technical forums and analyzing benchmarks (STACKOVERFLOWELASTIC, 2015) (SOLRVSELASTICSEARCH, 2015) (QUORAELASTIC, 2015), Elasticsearch (a.k.a. Elastic) seemed to be a good alternative to the problem that the application struggled with MySQL.

On the next section we discuss a new data model to the posts and show how Elasticsearch enabled a *Filter captured posts by filters* operation that runs on a SLA-acceptable level and gives the results that users expect.

4.2.7 Map current schema & data on the proposed DB architecture

On the last section we discussed how a search engine can help to make the *Filter captured posts by filters* operation run on an acceptable SLA level and deliver the results that users expect from a search operation.

In this section we detail how using Elasticsearch in a polyglot-persistence approach helped to solve the problems that were found while handling search operations on MySQL.

A new data model

A new data model should be proposed once the new database technology is chosen. As Elasticsearch stores data as JSON documents, the same structure of a post post row on the relational schema was transformed into a valid JSON document.

Listing 4.9 shows how a post row is represented as a JSON document on Elasticsearch indexes. Tags information is stored both as a text field and as an indexed JSON element.

Listing 4.9: Post representation - JSON document


```
{
   "id": 732632,
   "post_id": 731899886918573,
   "comment_id": 732001700241725,
   "comment_reply_id": 0,
   "fan_page": null,
   "collected_from": "FAN_PAGE",
   "created_time": "2015-06-23T16:51:38.000Z",
   "updated_time": null,
   "message": "Permito-me acreditar mais no cidadao comum do que na
      autoridade em questao! E isto sera crime? Vamos ver...",
   "type": null,
   "link": null,
   "name": null,
   "caption": null,
   "description": null,
   "picture": null,
   "source": null,
   "mood": 1,
   "icon": null,
   "likes": 12,
   "comments": null,
   "page_id": 144632798978621,
   "group_id": null,
   "page_url": null,
   "author_id": 1131060413576410,
   "author_name": "Nuno Miranda",
   "author_gender": "n",
   "upload": 1,
   "in_reply_to": null,
   "tags": "[{\"name\": \"Adela\", \"user\": \"The\"}, {\"name\":
```

```
    \"Adele\", \"user\": \"functions\"}, {\"name\": \"Adell\",
    \"user\": \"this\"}, {\"name\": \"Agripina\", \"user\":
    \"instantiate\"}, {\"name\": \"Adelia\", \"user\": \"each\"}, {
    \"name\": \"Adena\", \"user\": \"You\"}]",
  "replied_element_id": null,
  "replies": 0,
  "shares": 0,
  "term": null,
  "archived_by_user": null,
  "archived": 1,
  "location": null,
  "tag": [
     {
        "tag_name": "The",
        "tag_user": "Adela"
     },
     {
        "tag_name": "functions",
        "tag_user": "Adele"
     },
     {
        "tag_name": "this",
        "tag_user": "Adell"
     },
     {
        "tag_name": "instantiate",
        "tag_user": "Agripina"
     },
     {
        "tag_name": "each",
        "tag_user": "Adelia"
     },
     {
        "tag_name": "You",
        "tag_user": "Adena"
```

```
        }
    ]
}
```

A new server with the same configurations of the one listed on section 4.1.5 was provisioned and Elasticsearch version 1.7.2 was installed.

The portuguese Language Analyzer (ELASTICSEARCH/LANGUAGEANALYZERS, 2015) for Elasticsearch was also activated to enable stemming and querying user-expected results on portuguese language.

To dump the data from MySQL and import to Elasticsearch, a Python script was made (LEAL, 2015b). However, loading data was taking too long as the script didn't paralellize the bulk insert queries on Elasticsearch and database connection kept dropping. To overcome this issue, an open-source project that connects Elasticsearch to MySQL via JDBC and imports data (JPRANTE, 2015) was used.

The mapping from the relational tables to the elasticsearch indexes was done using the transform query presented on Figure 29.

```
# Updated Mapping - with searchable tags

bin=/home/ubuntu/river/elasticsearch-jdbc-1.7.2.1/bin
lib=/home/ubuntu/river/elasticsearch-jdbc-1.7.2.1/lib

echo '{
    "type" : "jdbc",
    "jdbc" : {
        "url" : "jdbc:mysql://54.186.38.180:3306/mestrado",
        "user" : "root",
        "password" : "mestrado",
        "sql": "select \"mestrado\" as \"_index\", post_all_pages_portugal_globo_pt.id as
        \"_id\", post_all_pages_portugal_globo_pt.*, tags.tag_name as \"tag[tag_name]\",
        tags.tag_user as \"tag[tag_user]\" from post_all_pages_portugal_globo_pt left join
        tags on post_all_pages_portugal_globo_pt.id = tags.post_id order by _id",
        "index" : "mestrado"
    }

}' | java \
       -cp "${lib}/*" \
       -Dlog4j.configurationFile=${bin}/log4j2.xml \
       org.xbib.tools.Runner \
       org.xbib.tools.JDBCImporter
```

Figure 29: Mapping - MySQL to ES.

Once the Elasticsearch index was built and the data was successfully imported, the next step of the guidelines should be executed (to process DB operations from a historical point).

4.2.8 Process all DB operations from a historical point on

On this step we should execute all operations that were triggering SLA exceptions from the application logs. As this case study built scenarios that represent application logs, the corresponding action would be to run the same operations on the proposed architecture.

As shown on previous sections, all three operations *(Retrieve posts by id)*, *Classify posts (add/remove tags)* and *Filter captured posts by filters* satisfied the proposed SLAs when database-level improvements were performed.

In this way, what needs to be done in this step is to verify if the Elasticsearch architecture enables *Filtering captured posts by filters* without triggering any SLA exceptions.

Elasticsearch vs MySQL

Figures 30, 31 and 32 respectively present the performance of the three operations using the proposed Elasticsearch architecture instead of MySQL. Only the bigger dataset sizes (300K and 3KK) were considered in this execution scenarios.

Figure 30 shows that the operation *Retrieve posts by id* runs at an acceptable level (max = 45ms), similar to the scenario presented on figure 19, that presents the same operation being executed on the top of MySQL.

Figure 31 also reveals that the operation of searching/updating tags, run at an acceptable level, similar to the threshold seen on Figure 27.

The execution of *Filter posts* operation, represented by Figure 32, shows that the Elasticsearch architecture was able to process the Full Text Search at least 3x faster than the proposed MySQL architecture, represented on Figure 28. All queries run below a 30ms threshold, showing that it has better performance than MySQL for FTS purposes.

In other words, no SLA violations were triggered when performing the operations on the new architecture, built on the top of Elasticsearch.

Changes on query language

SQL, as the name suggests, stands for ***Standard*** *Query Language*. This way, a number of relational databases rely on a **standard** syntax to implement their language, despite some small syntactic differences can be observed across different technologies.

NoSQL DBs, as Elasticsearch, can implement their own domain specific language (DSL), adding one more barrier to the onboarding of developers that are used to relational

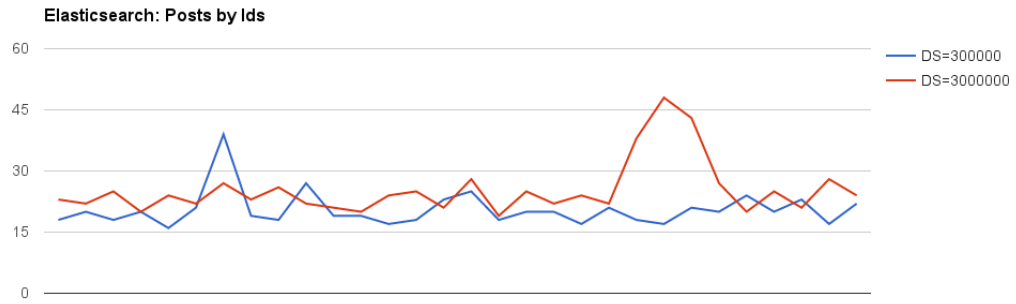


Figure 30: Elasticsearch architecture: Retrieve posts by Id.

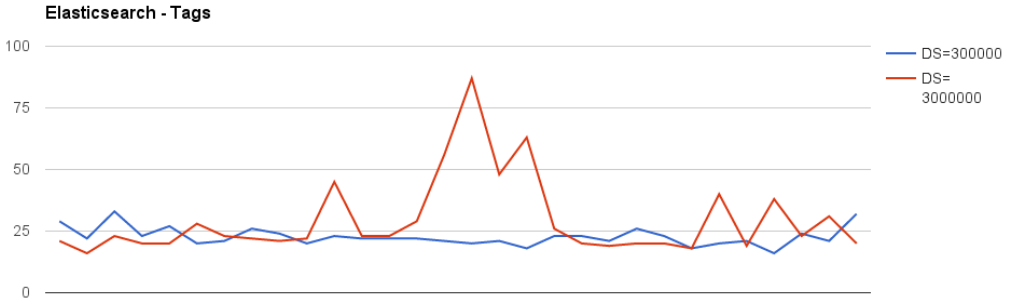


Figure 31: Elasticsearch architecture: Update by tags.

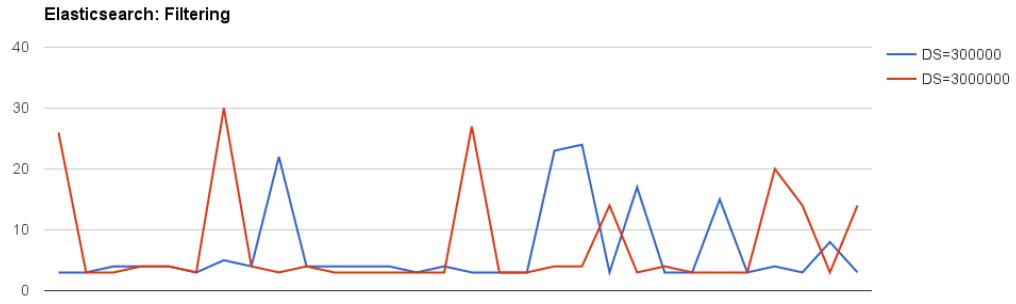


Figure 32: Elasticsearch architecture: Filter posts.

technologies.

Figures 33, 34 and 35 show how the three operations can be performed using Elasticsearch's Query Language instead of SQL.

Concepts as *filters*, *bool*, *must*, *match* and *range*, essential to understand Elasticsearch DSL, are explained on the documentation, available at (ELASTIC, 2015d).

A *SELECT * FROM posts WHERE id IN (175184, 149550)* can be translated to Elasticsearch as a HTTP Request (ES offers a restful API) with the payload presented on Figure 33.

The payload to find the posts that match a set of tags is represented on Figure 34 instead of what is shown on listing 4.7.

To perform the Filter posts operation, instead of performing the SQL query shown on Listing 4.8, the payload presented on Figure 35 should be sent to Elasticsearch.

```
GET /index/_search?pretty
{
  "query": {
    "bool": {
      "should": [
        {
          "match": {
            "id": 175894
          }
        },
        {
          "match": {
            "id": 149550
          }
        }
      ]
    }
  }
}
```

Figure 33: Elasticsearch query: get posts by ids.

```
GET - Tags
GET /index/_search?pretty
{
    "query": {
        "bool": {
            "must": [
                { "match": {"tag.tag_name": "and"}},
                { "match": {"tag.tag_user" : " Abraham "}}
            ]
        }
    }
}
```

Figure 34: Elasticsearch query: Posts with tags.

4.2.9 What else elasticsearch enables?

Besides being able to execute the three operations at a desired QoS, adding a Elasticsearch to the stack of the application enables a number of features that are *technically possible* to have with MySQL, but have poor performance when compared to other NoSQL solutions, as search engines.

An interesting report to have in a social-media monitoring application is a “word cloud”. In the context of the Facebook component, a word cloud shows the count of terms

```
GET - Filters
GET /index/_search?pretty
{
   "query": {
      "bool": {
         "must": [
            {
               "match": {
                  "message": "departamento"
               }
            },
            {
               "match": {
                  "mood": 0
               }
            },
            {
               "range": {
                  "created_time": {
                     "gte": "2013-03-05T00:00:00.000"
                  }
               }
            }
         ]
      }
   }
```

Figure 35: Elasticsearch query: Filter posts by filters.

from the “message" field. (SPLITTER, 2015a) and (SPLITTER, 2015b) discuss a method of building a word counting system with MySQL. The process relies in having a second table where each word from each “message” is inserted and then a COUNT (DISTINCT()) query is performed.

In the worst case of the proposed scenarios, 3.000.000 posts would have to be analyzed. If the *message* field contains 21 words on average, a word count in this scenario represents a total of 630.00.000 (3.000.000 x 21) INSERTS in a separate table just to count the words. A stored procedure that makes use of this approach is available on (SPLITTER, 2015b).

Other way to perform word count using MySQL is to retrieve the posts from the database and perform a programmatic count using parallel processes in several machines, but this approach would also require a high amount of extra effort, as handling with network conditions and woud require extremely high network throughput to deliver results within seconds.

Concepts as *bucketing*, *in-memory-processing*, *aggregations* and *term-vectors* make the *word-frequency count* job much easier (and nearly-instant (ELASTIC, 2015f)) when performed by Search Engines, as Lucene and Elasticsearch, as discussed on (SPLITTER, 2015b) and fully explained in (ELASTIC, 2015f).

Elasticsearch aggregations and filters enable statistics to be delivered in near-realtime even when handling massive datasets (ELASTIC, 2015f). This has some other downsides,

however. Many of the elasticsearch operations are made at memory level, instead of in-disk. This implies that elasticsearch clusters need high amounts of memory, and applications that rely on elasticsearch must constantly monitor the cluster health to add resources or perform modifications on the documents mappings. Elasticsearch's API to handle with cluster health is available on (ELASTIC, 2015c).

Several other operations that are simplified by Elasticsearch instead of using MySQL can be named:

1. **FTS support in several languages:** Performing full-text search in 32 different languages is natively supported by Elasticsearch (ELASTICSEARCH/LANGUAGEANALYZERS, 2015).

2. **"Did you mean?" feature:** Operations that suggest corrections to user typos are simplified by using the search term suggester feature on elasticsearch(ELASTIC, 2015e)

3. **Deep paging feature:** On the proposed application architecture (Figure 14), each social network component has its own data storage (MySQL DB). When a user queries for a string term on the interface, it's expected that the application presents the posts (from whatever social network they are from) that match the selected criteria paginated in bulks of n posts. This way, the Adapter component has to perform pagination across multiple data repositories (i.e: Twitter component, Facebook component, Youtube component).

   Supposing that each page that is presented has 10 posts, when a user queries for the last 10 posts, for example, the application has to execute an algorithm that joins the first 10 posts of all databases in a single view. Sorting and paging posts on multiple data repositories are a problematic task, as revealed by (ELASTIC, 2015b).

   To understand why deep paging is problematic, suppose that the proposed application has 5 distinct social network components. When the user requests the first page of results (results 1 to 10), each component produces its own top 10 results and returns them to the adapter component, which then sorts all 50 results in order to select the overall top 10.

   Now, the user asks for page 1.000 (results 10.001 to 10.010). Everything works in the same way except that each social network component has to produce its top 10.010 results. The adapter component then sorts through all 50.050 results and discards

50.040 of them. That's why, in a distributed system, the cost of sorting results grows exponentially the deeper the page is (ELASTIC, 2015b).

Leaving the pagination task to be done by Elasticsearch removes a potentially problematic business logic from the Adapter component, making the application more maintainable and simple.

4.2.10 Case study conclusions

On this chapter we have analyzed how the proposed guidelines can help a software team to assess and execute database-level migrations, transitioning (part of an application) from relational databases to NoSQL architectures.

All operations that were listed on the initial steps of the case study could be performed by the relational database (MySQL), although a series of database-level improvements were needed.

In a real application it is necessary to analyze the trade-off of *i) making a series of database/source-code improvements to meet the desired QoS* or *ii) adding a new/replacing the database layer of an application.* In some scenarios, improving too much the current database architecture and source code can often lead to hard-to-maintain applications, as related by (SCOUTENGINEERING, 2015).

Adding support to multiple databases on an application can help to improve QoS and accelerate application development, but can also be an unnecessary move, as revealed by the sections of this chapter. Each application needs to be extensively analyzed before proposing database-level transitions on production environments.

One of the main outcomes of the study is to show that *not always* it is necessary to completely switch the data layer from relational databases to NoSQL. As the previous sections proved, architectural changes at relational databases can be made to have similar performance to NoSQL databases in certain scenarios.

In some scenarios, however, using a NoSQL architecture (as Elasticsearch in the context of this app) can help to leverage user experience, QoS and accelerate application development.

Transition recommendations (Learned Lessons)

Database transitions, as any refactoring in software projects, should be test-oriented to assure that not only the transitions will bring better QoS, but will also not change the

way that the application works.

Even in tested tests, it's not advisable to completely replace a database at once, as un-tested scenario behaviors may change between databases. In a complete transition scenario, parts of the application can be progressively switched between the data layers to assure that application users will not experience a major fault.

It's also highly advisable to *verify* if the proposed migration will be able to successfully handle the real workload before using a migrated scenario in production. In other words, it's recommended to run both storage solutions for a while, handling production requests in parallel, ignoring the results of the proposed architecture, to verify that it will be able to successfully handle the workload once the environment is completely transitioned.

It's also advisable to re-visit the recommendations presented on section 3.3.9 when transitioning a real application. These recommendations were extracted from a set of industry reports from migration scenarios, such as (ALBINSSON BARKAS, 2015), (COURSERATECH, 2014) and (SCOUTENGINEERING, 2015) and are also part of the proposed guidelines.

5 Conclusions

On this chapter we summarize how this research was developed and present its outcomes. The phases of the work were extensively detailed over the chapters of this document and are briefly summarized on this chapter.

We started our work by searching studies that are related to SLA and database transitions. A systematic mapping study (LEAL; MUSICANTE, 2015) was developed to answer questions like *"What are the reasons to change from RDBMSs to NoSQL solutions?"*, *" How can we measure the overall improvements promised by this change?"*, *"How can SLAs be used to guide database transitioning processes from RDBMSs to NoSQL databases in cloud-based apps?"*.

As outcomes of the systematic mapping, it was found out that there is a lack of consensus and standards on how database transitions from relational DBs to NoSQL should be done, as no formal process or guidelines have been found on the literature.

Chapter 2 discusses some of the concepts that are related with the solution proposed to the problems found on the systematic mapping. Concepts as *Polyglot Persistence* and *Service Level Agreements*, essential to the understanding of the proposed solution, are revealed on that chapter.

On chapter 3 we discussed the outcomes of our systematic mapping and present extra findings that were discovered on further literature review from industry reports about database transitions in production environments.

On the same chapter, on section 3.3, we propose a set of SLA-based guidelines that can be used to assess and guide database transitions from relational databases to NoSQL databases. The guidelines follow a systematic approach and are validated on Chapter 4 by a case study.

At a first moment, the validation phase searched popular open source tools where a transition might be needed, but the scope of this kind of transition became too large for

the context of this work. To validate the guidelines, the core prototype of a social-media-monitoring application was built and presented on chapter 4. This chapter reveals that despite some relational databases have incorporated a number of features from NoSQL technologies over the last years, sometimes even losing basic relational ACID properties, the use of a NoSQL database together with a relational database is recommended in some scenarios.

5.1 Contribution

The main contributions that emerged as results of this research are:

1. A Systematic Mapping study about database transitions published on an international conference. (LEAL; MUSICANTE, 2015)(Qualis/CC:B1)
2. Development of manpower able to work with database transition scenarios from relational databases to NoSQL environments. As NoSQL is a relatively recent concept, not many professionals are experienced with database transitioning scenarios to these technologies;
3. A set of guidelines to guide and assess database transitions from relational to NoSQL databases;
4. The core architecture, based on *polyglot persistence* approach, of a social-media monitoring application. The proposed architecture enables rich user-experience features, such as suggested queries and query stemming in multiple languages, operations that are hard to be implemented in a relational-only scenario;
5. A set of Java-implemented load test scenarios that can be adapted to assess the QoS of applications.

5.2 Future Works

From the results of this research, the following future works can be proposed:

1. Transition of (part of) a production-ready application with a large user base making use of the proposed guidelines;

2. Assess the performance of applications after database transitions have been performed. Verify if the guidelines were able to anticipate problems that may not be found if the guidelines weren't used;

3. Assess the usability of the proposed guidelines by software teams;

4. Write publications about the proposed guidelines in international conferences about databases, NoSLQ and Quality of Service;

5. Extend the proposed guidelines to enable other types of transitions in software. Assess the use of a SLA-oriented and user-oriented strategy to perform migrations of software components and services.

6. A study around the categories of problems that NoSQL databases help to solve: The case study presented on this work shows how some problems related to *text searching* on relational DBs can be solved with NoSQL DBs. The idea of the study is to explore and analyze categories of problems that NoSQL can solve better than relational DBs (Geo Spatial problems, Graph problems, Image problems, etc.)

References

ALBINSSON BARKAS, K. M. S. V. W. Blog, *Switching user database on a running system*. 2015. `https://labs.spotify.com/2015/06/23/user-database-switch/`.

ALLIANCE, C. S. *Security Guidance for Critical Areas of Focus in Cloud Computing*. [S.l.]: Cloud Security Alliance, 2009.

AMAZONRDS. *SLA for Cloud Services*. 2015. [Online; accessed 22-November-2015]. Disponível em: <https://aws.amazon.com/pt/rds/sla/>.

ANDRIEUX, A. et al. *Web Services Agreement Specification (WS-Agreement)*. [S.l.], set. 2005. Disponível em: <http://www.ggf.org/Public_Comment_Docs/Documents/Oct-2005/WS-AgreementSpecificationDraft050920.pdf>.

APPENGINE, G. *Google App Engine*. 2015. [Online; accessed 22-November-2015]. Disponível em: <https://cloud.google.com/appengine/docs>.

APPSEE. 2014. `https://www.appsee.com/`.

ARMBRUST, M. et al. *M.: Above the clouds: A Berkeley view of cloud computing*. [S.l.], 2009.

AXELOS. *Best Management Practice portfolio: common glossary of terms and definitions*. out. 2012. Disponível em: <http://www.axelos.com/gempdf/Axelos_Common_Glossary_2013.pdf>.

AZURE, M. *Azure*. 2015. [Online; accessed 22-November-2015]. Disponível em: <https://azure.microsoft.com>.

BAHL, S. Mysql vs neo4j vs mongodb an application centric comparison. 2014.

BEANSTALK, A. E. *Amazon Elastic Beanstalk*. 2015. [Online; accessed 22-November-2015]. Disponível em: <https://aws.amazon.com/pt/documentation/elastic-beanstalk/>.

BLANK, S. *The four steps to the epiphany*. [S.l.]: K&S Ranch, 2013.

BRIN, S. *Breaking Page's Law*. 2009. Disponível em: <https://www.youtube.com/watch?v=4kty5YNOaaw>.

BUILTWITH.COM. *CMS Ranking - 2015*. 2015. [Online; accessed 22-November-2015]. Disponível em: <http://trends.builtwith.com/cms>.

BUZZMONITOR. *Buzzmonitor*. 2015. [Online; accessed 22-November-2015]. Disponível em: <http://getbuzzmonitor.com>.

CHELIMSKY, D. et al. *The RSpec book: Behaviour driven development with Rspec, Cucumber, and friends*. [S.l.]: Pragmatic Bookshelf, 2010.

CLARK, J. Blog, *Google swaps out MySQL, moves to MariaDB*. 2013. `http://www.theregister.co.uk/2013/09/12/google_mariadb_mysql_migration/`.

COMPOSE.IO. *SLA for Cloud Services*. 2015. [Online; accessed 22-November-2015]. Disponível em: <https://docs.compose.io/enhanced/sla.html>.

CONNOLY D. FOX, A. e. a. *A View of Cloud Computing*. April 2010. [Online; posted 01-April-2010]. Disponível em: <"http://delivery.acm.org/10.1145/1730000/1721672/p50-armbrust.pdf">.

COUNCIL, T. P. P. Tpc-h benchmark specification. *Published at http://www. tcp. org/hspec. html*, 2008.

COURSERATECH. *Coursera's Adoption of Cassandra*. 2014. [Online; accessed 22-November-2015]. Disponível em: <https://tech.coursera.org/blog/2014/09/23/courseras-adoption-of-cassandra/>.

DATADOG. 2014. `https://www.datadoghq.com/`.

DHANDALA, N. *3 signs that you might need to move to NoSQL*. 2015. [Online; accessed 22-November-2015]. Disponível em: <http://cbblog.azurewebsites.net/3-signs-that-you-might-need-to-move-to-nosql/>.

DICTIONARY/MYSQL. *WL#2428: Dictionary for fulltext*. 2010. [Online; accessed 22-November-2015]. Disponível em: <https://dev.mysql.com/worklog/task/?id=2428>.

DUAN, Y. et al. Everything as a service (xaas) on the cloud: Origins, current and future trends. In: *Cloud Computing (CLOUD), 2015 IEEE 8th International Conference on*. [S.l.: s.n.], 2015. p. 621–628.

EC2, A. *Amazon EC2*. 2015. [Online; accessed 22-November-2015]. Disponível em: <http://aws.amazon.com/en/ec2/>.

ELASTIC. *Elastic*. 2015. [Online; accessed 22-November-2015]. Disponível em: <https://elastic.co>.

ELASTIC. *Elasticsearch - Deep Paging*. 2015. [Online; accessed 22-November-2015]. Disponível em: <https://www.elastic.co/guide/en/elasticsearch/guide/current/pagination.html>.

ELASTIC. *ElasticSearch Cluster Health API*. 2015. [Online; accessed 22-November-2015]. Disponível em: <https://www.elastic.co/guide/en/elasticsearch/reference/current/cluster-health.html>.

ELASTIC. *Elasticsearch Filters - Documentation*. 2015. [Online; accessed 22-November-2015]. Disponível em: <https://www.elastic.co/guide/en/elasticsearch/reference/2.0/query-dsl.html>.

ELASTIC. *ElasticSearch Term Suggester*. 2015. [Online; accessed 22-November-2015]. Disponível em: <https://www.elastic.co/guide/en/elasticsearch/reference/2.0/search-suggesters-term.html>.

ELASTIC. *ElasticSearch Term Vectors API*. 2015. [Online; accessed 22-November-2015]. Disponível em: <https://www.elastic.co/guide/en/elasticsearch/reference/2.0/docs-termvectors.html>.

ELASTICSEARCH/LANGUAGEANALYZERS. *Language Analyzers*. 2015. [Online; accessed 22-November-2015]. Disponível em: <https://www.elastic.co/guide/en/elasticsearch/reference/1.4/analysis-lang-analyzer.html>.

ELLINGWOOD, J. *How To Set Up a Remote Database to Optimize Site Performance with MySQL*. 2014. [Online; accessed 22-November-2015]. Disponível em: <https://www.digitalocean.com/community/tutorials/how-to-set-up-a-remote-database-to-optimize-site-performance-with-mysql>.

ENDPOINT. *Benchmarking Top NoSQL Databases*. 2015. [Online; accessed 22-November-2015]. Disponível em: <http://www.datastax.com/wp-content/themes/datastax-2014-08/files/NoSQL_Benchmarks_EndPoint.pdf>.

FLOCKDB, T. *Twitter FlockDB*. 2014. [Online; accessed 22-November-2015]. Disponível em: <https://github.com/twitter/flockdb>.

FOWLER, M.; HIGHSMITH, J. The agile manifesto. *Software Development*, [San Francisco, CA: Miller Freeman, Inc., 1993-, v. 9, n. 8, p. 28–35, 2001.

GADE, K. Blog, *Twitter Search is Now 3x Faster*. 2011. `https://blog.twitter.com/2011/twitter-search-now-3x-faster`.

GLASS, R. Frequently forgotten fundamental facts about software engineering. *Software, IEEE*, v. 18, n. 3, p. 112–111, May 2001. ISSN 0740-7459.

GMAPS/NATAL. *Google Maps - Natal, Brazil*. 2015. [Online; accessed 22-November-2015]. Disponível em: <https://www.google.com.br/maps/place/Natal+-+State+of+Rio+Grande+do+Norte/@-5.8019484,-35.2923622,12z/data=!3m1!4b1!4m2!3m1!1s0x7b2fffe144c508b:0xe0bbded8ff561818>.

HAN, J. et al. Survey on nosql database. In: *Pervasive Computing and Applications (ICPCA), 2011 6th International Conference on*. [S.l.: s.n.], 2011. p. 363–366.

HAO, H. *Learning Python - Databases Chapter*. 2014. [Online; accessed 22-November-2015]. Disponível em: <http://learning-python.readthedocs.org/en/latest/chapter16/README.html>.

HAO, H. *Quora question: How do I migrate data from a MongoDB to MySQL database? Can it be done in a real-time scenario? What are the pros and cons for each migration? Which one do you advice? What is your experience? Any reference DB expert who can do it?* 2014. [Online; accessed 22-November-2015]. Disponível

em: <https://www.quora.com/How-do-I-migrate-data-from-a-MongoDB-to-MySQL-database-Can-it-be-done-in-a-real-time-scenario-What-are-the-pros-and-cons-for-each-migration-Which-one-do-you-advice-What-is-your-experience-Any-reference-DB-expert-who-can-do-it>.

HAO, H. *Quora question: Why has Coursera migrated from MongoDB to MySQL?* 2014. [Online; accessed 22-November-2015]. Disponível em: <https://www.quora.com/Why-has-Coursera-migrated-from-MongoDB-to-MySQL>.

INSTACLUSTR. *Instaclustr Inc.* 2014. [Online; accessed 22-November-2015]. Disponível em: <https://www.instaclustr.com/>.

JPRANTE. *Elastic JDBC.* 2015. [Online; accessed 22-November-2015]. Disponível em: <https://github.com/jprante/elasticsearch-jdbc>.

KEPES, B. Understanding the cloud computing stack. *Rackspace White Paper*, 2011.

KLEMS, M.; BERMBACH, D.; WEINERT, R. A runtime quality measurement framework for cloud database service systems. In: *Quality of Information and Communications Technology (QUATIC), 2012 Eighth International Conference on the.* [S.l.: s.n.], 2012. p. 38–46.

KOUKI, Y.; LEDOUX, T. CSLA : a Language for improving Cloud SLA Management. In: *International Conference on Cloud Computing and Services Science, CLOSER 2012.* Porto, Portugal: [s.n.], 2012. p. 586–591. Disponível em: <https://hal.archives-ouvertes.fr/hal-00675077>.

KOUKI, Y. et al. A language support for cloud elasticity management. In: *Cluster, Cloud and Grid Computing (CCGrid), 2014 14th IEEE/ACM International Symposium on.* [S.l.: s.n.], 2014. p. 206–215.

LEAL, F. *Posts Dump.* 2015. [Online; accessed 22-November-2015]. Disponível em: <hhttps://www.dropbox.com/s/nb08sl9m5b6459x/dump.tar.bz2?dl=0>.

LEAL, F. *Python to Elasticsearch importer.* 2015. [Online; accessed 22-November-2015]. Disponível em: <https://github.com/fabiosl/ufrn-masters-research/blob/master/exp01/python-mysql-to-es-importer/importer.py>.

LEAL, F.; MUSICANTE, M. A. Using sla to guide database transition to nosql on the cloud: a systematic mapping study. In: *12th ACS/IEEE International Conference on Computer Systems and Applications. USA: IEEE, 2015.* [S.l.: s.n.], 2015.

LEAVITT, N. Will nosql databases live up to their promise? *Computer*, v. 43, n. 2, p. 12–14, Feb 2010. ISSN 0018-9162.

LEE, Y. C. et al. Profit-driven service request scheduling in clouds. In: *Proceedings of the 2010 10th IEEE/ACM International Conference on Cluster, Cloud and Grid Computing.* Washington, DC, USA: IEEE Computer Society, 2010. (CCGRID '10), p. 15–24. ISBN 978-0-7695-4039-9. Disponível em: <http://dx.doi.org/10.1109/CCGRID.2010.83>.

LOCAWEBSLA. *SLA for Cloud services.* 2015. [Online; accessed 22-November-2015]. Disponível em: <http://wiki.locaweb.com.br/pt-br/SLA_nos_planos_compartilhados>.

LOGSTASH. *Logstash*. 2015. [Online; accessed 22-November-2015]. Disponível em: <https://www.elastic.co/products/logstash>.

LOMBARDO, S.; NITTO, E. D.; ARDAGNA, D. Issues in handling complex data structures with nosql databases. In: IEEE. *Symbolic and Numeric Algorithms for Scientific Computing (SYNASC), 2012 14th International Symposium on*. [S.l.], 2012. p. 443–448.

MASSOL, V.; HUSTED, T. *Junit in action*. [S.l.]: Manning Publications Co., 2003.

MCPHILLIPS, J. *Transitioning from Relational to NoSQL: A Case Study*. [S.l.]: Regis University, 2012.

MENTION. *Mention*. 2015. [Online; accessed 22-November-2015]. Disponível em: <http://mention.com>.

MOODLE. *Moodle - Course Management System*. 2015. [Online; accessed 22-November-2015]. Disponível em: <https://moodle.org/>.

MOORE, G. Cramming more components onto integrated circuits. *Proceedings of the IEEE*, v. 86, n. 1, p. 82–85, Jan 1998. ISSN 0018-9219.

MOUSSA, R. Benchmarking data warehouse systems in the cloud. In: *Computer Systems and Applications (AICCSA), 2013 ACS International Conference on*. [S.l.: s.n.], 2013. p. 1–8. ISSN 2161-5322.

MYSQL. *MySQL*. 2015. [Online; accessed 22-November-2015]. Disponível em: <https://dev.mysql.com/doc/refman/5.5/en/fulltext-restrictions.html>.

MYSQL-SHARDING. *MySQL - Scaling*. 2015. [Online; accessed 22-November-2015]. Disponível em: <https://www.mysql.com/products/cluster/scalability.html>.

MYSQLRECOVERY. *7.5 Point-in-Time (Incremental) Recovery Using the Binary Log*. 2015. [Online; accessed 22-November-2015]. Disponível em: <http://dev.mysql.com/doc/refman/5.7/en/point-in-time-recovery.html>.

NEPAL, S.; ZIC, J.; CHEN, S. Wsla+: Web service level agreement language for collaborations. In: *Services Computing, 2008. SCC '08. IEEE International Conference on*. [S.l.: s.n.], 2008. v. 2, p. 485–488.

NEWRELIC. 2014. `http://newrelic.com`.

NOSQL-ORG. *NoSQL-ORG*. 2015. [Online; accessed 22-November-2015]. Disponível em: <http://nosql-database.org>.

ORACLE. *Oracle - Tolerance*. 2015. [Online; accessed 22-November-2015]. Disponível em: <http://docs.oracle.com/cd/B28359_01/appdev.111/b28400/sdo_intro.htm>.

ORACLERECOVERY. *Performing Database Point-In-Time Recovery*. 2015. [Online; accessed 22-November-2015]. Disponível em: <https://docs.oracle.com/cd/B19306_01/backup.102/b14192/flashptr006.htm>.

PADHY, R. P.; PATRA, M. R.; SATAPATHY, S. C. Rdbms to nosql: Reviewing some next-generation non-relational databases. *International Journal of Advanced Engineering Science and Technologies*, v. 11, n. 1, p. 15–30, 2011.

PAPERTRAIL. *Papertrail App*. 2015. [Online; accessed 22-November-2015]. Disponível em: <https://papertrailapp.com/>.

PARIS, H. *Fantastic Elasticsearch plugin for Wordpress*. 2015. [Online; accessed 22-November-2015]. Disponível em: <https://wordpress.org/plugins/fantastic-elasticsearch/>.

PARISEAU, B.; JONES, T. *Cloud outage audit 2014 reveals AWS on top, Azure down*. 2014. [Online; accessed 22-November-2015]. Disponível em: <http://searchcloudcomputing.techtarget.com/news/2240237323/Cloud-outage-audit-2014-reveals-AWS-on-top-Azure-down>.

PETERSEN, K. et al. Systematic mapping studies in software engineering. In: *Proceedings of the 12th International Conference on Evaluation and Assessment in Software Engineering*. Swinton, UK, UK: British Computer Society, 2008. (EASE'08), p. 68–77. Disponível em: <http://dl.acm.org/citation.cfm?id=2227115.2227123>.

POSTGRESRECOVERY. *Continuous Archiving and Point-in-Time Recovery (PITR)*. 2015. [Online; accessed 22-November-2015]. Disponível em: <http://www.postgresql.org/docs/9.1/static/continuous-archiving.html>.

POWELL, T. C.; DENT-MICALLEF, A. Information technology as competitive advantage: The role of human, business, and technology resources. *Strategic management journal*, v. 18, n. 5, p. 375–405, 1997.

QI, M. et al. Big data management in digital forensics. In: *Computational Science and Engineering (CSE), 2014 IEEE 17th International Conference on*. [S.l.: s.n.], 2014. p. 238–243.

QUINN, J.; DOORLEY, T.; PAQUETTE, P. Technology in services: rethinking strategic focus. *Sloan Management Review, Win-ter1990QuinnWinterSloan Management Review1990*, 2013.

QUORAELASTIC. *Quora - Differences between Elastic, Solr and SolrCloud*. 2015. [Online; accessed 22-November-2015]. Disponível em: <https://www.quora.com/What-are-the-main-differences-between-ElasticSearch-Apache-Solr-and-SolrCloud>.

RACKSPACE. *Rackspace*. 2015. [Online; accessed 22-November-2015]. Disponível em: <https://www.rackspace.com/>.

RANA, O. et al. Managing violations in service level agreements. In: *Grid Middleware and Services*. Springer US, 2008. p. 349–358. ISBN 978-0-387-78445-8. Disponível em: <http://dx.doi.org/10.1007/978-0-387-78446-5_23>.

RANKING, D. *DB Engines Ranking*. maio 2014. Disponível em: <http://db-engines.com/en/ranking>.

RANKINGCHART. *DB Engines RankingChart*. 2015. Disponível em: <http://db-engines.com/en/ranking_categories>.

RAPP, B. Blog, *Goodbye, John McCarthy*. 2011. `http://cavewall.jaguardesignstudio.com/2011/10/24/goodbye-john-mccarthy/`.

REDMINE. *Redmine Project Management Software*. 2015. [Online; accessed 22-November-2015]. Disponível em: <http://www.redmine.org/>.

SADALAGE, P. *NoSQL Databases: An Overview*. 2014. [Online; accessed 22-November-2015]. Disponível em: <https://www.thoughtworks.com/insights/blog/nosql-databases-overview>.

SADALAGE, P. J.; FOWLER, M. *NoSQL distilled: a brief guide to the emerging world of polyglot persistence*. [S.l.]: Pearson Education, 2012.

SAKR, S.; LIU, A. Sla-based and consumer-centric dynamic provisioning for cloud databases. In: *Cloud Computing (CLOUD), 2012 IEEE 5th International Conference on*. [S.l.: s.n.], 2012. p. 360–367. ISSN 2159-6182.

SANDERS, G.; SHIN, S. Denormalization effects on performance of rdbms. In: *System Sciences, 2001. Proceedings of the 34th Annual Hawaii International Conference on*. [S.l.: s.n.], 2001. p. 9 pp.–.

SCHRAM, A.; ANDERSON, K. M. Mysql to nosql: Data modeling challenges in supporting scalability. In: *Proceedings of the 3rd Annual Conference on Systems, Programming, and Applications: Software for Humanity*. New York, NY, USA: ACM, 2012. (SPLASH '12), p. 191–202. ISBN 978-1-4503-1563-0. Disponível em: <http://doi.acm.org/10.1145/2384716.2384773>.

SCOUTENGINEERING. *FROM MYSQL FULL-TEXT SEARCH TO ELASTICSEARCH*. 2015. [Online; accessed 22-November-2015]. Disponível em: <http://blog.scoutapp.com/articles/2014/12/19/from-mysql-full-text-search-to-elasticsearch>.

SHI, W. et al. An online auction framework for dynamic resource provisioning in cloud computing. *Networking, IEEE/ACM Transactions on*, PP, n. 99, p. 1–1, 2015. ISSN 1063-6692.

SHINDER, D. Security in the cloud: Trustworthy enough for your business? *http://bit.ly/1jhbnkC*, v. 11, 2010. Disponível em: <http://bit.ly/1jhbnkC>.

SHVACHKO, K. et al. The hadoop distributed file system. In: *Mass Storage Systems and Technologies (MSST), 2010 IEEE 26th Symposium on*. [S.l.: s.n.], 2010. p. 1–10.

SOLAR, G. V. *Addressing data management on the cloud: tackling the big data challenges*. maio 2014. Disponível em: <http://ceur-ws.org/Vol-1087/keynote4.pdf>.

SOLRVSELASTICSEARCH. *Solr. vs Elasticsearch*. 2015. [Online; accessed 22-November-2015]. Disponível em: <http://solr-vs-elasticsearch.com/>.

S.OVERFLOW-MYSQL. *Stackoverflow - LIKE or MATCH AGAINST*. 2015. [Online; accessed 22-November-2015]. Disponível em: <http://stackoverflow.com/questions/792875/which-sql-query-is-better-match-against-or-like>.

SPECTOR, A.; NORVIG, P.; PETROV, S. Google's hybrid approach to research. *Commun. ACM*, ACM, New York, NY, USA, v. 55, n. 7, p. 34–37, jul. 2012. ISSN 0001-0782. Disponível em: <http://doi.acm.org/10.1145/2209249.2209262>.

SPLITTER. *MySQL String splitter*. 2015. [Online; accessed 22-November-2015]. Disponível em: <http://www.tero.co.uk/scripts/mysql.php>.

SPLITTER. *MySQL String splitter - Stored Procedure*. 2015. [Online; accessed 22-November-2015]. Disponível em: <http://stackoverflow.com/questions/5649711/mysql-count-amount-of-times-the-words-occur-in-a-column>.

SPROUTSOCIAL. *SproutSocial*. 2015. [Online; accessed 22-November-2015]. Disponível em: <http://sproutsocial.com>.

STACKOVERFLOW. *How can I handle MySQL polygon overlap queries?* 2015. [Online; accessed 22-November-2015]. Disponível em: <http://stackoverflow.com/questions/29642159/how-can-i-handle-mysql-polygon-overlap-queries>.

STACKOVERFLOWELASTIC. *Stack Overflow - Solr. vs Elasticsearch*. 2015. [Online; accessed 22-November-2015]. Disponível em: <http://stackoverflow.com/questions/10213009/solr-vs-elasticsearch>.

STANOEVSKA-SLABEVA, K.; WOZNIAK, T. *Grid Basics*. [S.l.]: In: Stanoevska-Slabeva, K., Wozniak, T., and Ristol, S., Grid and Cloud Computing A Business Perspective on Technology and Applications, 2009.

STEMMING/MYSQL. *WL#2423: Stemming for full-text*. 2010. [Online; accessed 22-November-2015]. Disponível em: <https://dev.mysql.com/worklog/task/?id=2423>.

STEMMING/WIKI. *Stemming*. 2015. [Online; accessed 22-November-2015]. Disponível em: <https://en.wikipedia.org/wiki/Stemming>.

STURM, R.; MORRIS, W.; JANDER, M. {Foundations of Service Level Management}. Sams publishing, 2000.

UDFSTEMMER. *MySQL UDF Repository*. 2009. [Online; accessed 22-November-2015]. Disponível em: <https://github.com/mysqludf/lib_mysqludf_stem#readme>.

UDMSTEMMER. *MySQL fulltext parser plugin*. 2007. [Online; accessed 22-November-2015]. Disponível em: <http://www.mnogosearch.org/doc/msearch-udmstemmer.html>.

WIKIPEDIA. *John McCarthy (computer scientist)*. 2015. [Online; accessed 22-November-2015]. Disponível em: <https://en.wikipedia.org/wiki/John_McCarthy_(computer_scientist)>.

WIKIPEDIA-COURSERA. *Coursera - Wikipedia*. 2014. [Online; accessed 22-November-2015]. Disponível em: <https://en.wikipedia.org/wiki/Coursera>.

WIRTH, N. A plea for lean software. *Computer*, v. 28, n. 2, p. 64–68, fev. 1995.

WORDPRESS. *Wordpress CMS*. 2015. [Online; accessed 22-November-2015]. Disponível em: <http://wordpress.com>.

WU, L.; BUYYA, R. Service level agreement (sla) in utility computing systems. *IGI Global*, 2012.

XIONG, P. et al. Activesla: A profit-oriented admission control framework for database-as-a-service providers. In: *Proceedings of the 2Nd ACM Symposium on Cloud Computing*. New York, NY, USA: ACM, 2011. (SOCC '11), p. 15:1–15:14. ISBN 978-1-4503-0976-9. Disponível em: <http://doi.acm.org/10.1145/2038916.2038931>.

ZHAO, L.; SAKR, S.; LIU, A. A framework for consumer-centric sla management of cloud-hosted databases. *Services Computing, IEEE Transactions on*, PP, n. 99, p. 1–1, 2013. ISSN 1939-1374.

ZHU, J.; WANG, A. Data modeling for big data. *CA, Beijing*, CA Technologies, 2012. Disponível em: <http://www.ca.com/us/ /media/files/articles/ca-technology-exchange/data-modeling-for-big-data-zhu-wang.aspx>.

APPENDIX A – Systematic Mapping

Using SLA to guide database transition to NoSQL on the cloud: a systematic mapping study

Fabio Leal and Martin A. Musicante
Computer Science Department, Federal University of Rio Grande do Norte, Natal, Brazil
Email: sousaleal.fabio@gmail.com, mam@dimap.ufrn.br

***Abstract*—Cloud computing became a reality, and many companies are now moving their data-centers to the cloud. A concept that is often linked with cloud computing is Infrastructure as a Service (IaaS): the computational infrastructure of a company can now be seen as a monthly cost instead of a number of different factors. Recently, a large number of organizations started to replace their relational databases with hybrid solutions (NoSQL DBs, Search Engines, ORDBs). These changes are motivated by (*i*) performance improvements on the overall performance of the applications and (*ii*) inability to a RDBMS to provide the same performance of a hybrid solution given a fixed monthly infrastructure cost. However, not always the companies can exactly measure beforehand the future impact on the performance on their services by making this sort of technological changes (replace RDBMS by another solution). The goal of this systematic mapping study is to investigate the use of Service-Level-Agreements (SLAs) on database-transitioning scenarios and to verify how SLAs can be used in this processes.**

Keywords*—*Transition to Cloud, NoSQL, Systematic Mapping.

I. Introduction

The adoption of cloud solutions is growing fast among organizations [1]. Centralized (mostly mainframe) technology is being replaced by distributed and more flexible forms of data storage and processing. This change of paradigm is motivated by the necessity to improve the use of resources, as well as by the increasing velocity in which data is produced.

In this scenario, transitions must take into account the quality of the service delivered by the new solutions. The notion of Service-Level-Agreement (SLA) [2] may be used as a parameter in this context. SLAs are widely used to to provide service thresholds between clients and providers and are present in almost every service contract over the internet.

SLAs or OLAs - Operational Level agreements, are particularly useful to guide the process of choosing the most convenient service from a pool of service providers.

In this paper, we survey the use of SLA on database-transitioning scenarios, trying to investigate how they might be used to help the execution of this process. Our study is performed using the systematic mapping [3] technique: A set of papers is retrieved from the most popular bibliography repositories; this set is then filtered according to predefined parameters and finally, the analysis of the remaining papers is guided by a small number of research questions.

This work was partly funded by CNPq (Brazil, PDE-201118/2014-9, PQ-305619/2012-8, INCT-INES-573964/2008-4), CAPES/CNRS (Brazil/France, SticAmSud 052/14) and CAPES/ANII (Brazil/Uruguay, Capes-UdelaR 021/10).

This paper is organized as follows: Section II presents some of the concepts that are related to the transition from a traditional setting to a cloud-aware one. Section III presents our research questions and each step of our survey. The outcomes of our Systematic Mapping study can be seen on Section IV.

II. The Technological Shift

On the early 90's it was commonplace for every Information Technology (IT) company to have its own Data Center with huge servers and mainframes. IT costs were high, and high-performance computing was available only for big companies, as data centers required a large physical infrastructure and have high costs for maintenance [4].

The regular way of building a web application was to use a client-server approach, where the server was a powerful (and expensive) machine. At the same time, new players, such as Google or Yahoo, were rising with bigger missions: *"to organize the world's information and make it universally accessible and useful"* [5]. The popularization of the internet use new ways of commerce exchange, yielding an explosion in the amount of data produced and exchanged. It was *just* impossible to store the petabytes of daily-generated data in a single server.

From this point on, the community realized the economical convenience of building and maintaining several low-performance servers, instead of a single high-performance one, even if this this requires a change of culture in the administration of the new datacentres. The new approach is also incompatible with the traditional way of building applications, that usually were designed to work on a single server and database.

Several research initiatives were conducted in this area and a common solution was rising: to distribute data storage and processing. Google, Yahoo and other big IT players helped to build open source tools to make this approach possible, like Hadoop [6].

This revolution brought to life the notion of *Cloud Computing*, together with new concepts, such as Infrastructure as a Service *(IAAS)*, Platform as a Service *(PAAS)* and Software as a Service *(SAAS)* [7]. According to [7], *Cloud computing refers to both the applications delivered as services over the Internet and the hardware and systems software in the data centers that provide those services.*

Data Integration & Polyglot Persistence: On the last years, the number of Data Base (DB) Engines grew like never before [8]. Along with the NoSQL (Not only SQL) movement

and expansion of Social Networks, new concepts for Database Models appeared, like Document Store, Search Engines, Key-Value store, Wide Column Store, Multi-Model and Graph DBMS. In [8] a ranking of the most popular DB engines is presented.

Today, instead of having a single Relational Database Management System (DBMS) for the whole application, it is efficient and cost-effective to have several Data Base Engines, one for each type of data that the application handles. This concept is called *Polyglot Persistence* [9].

As [10] illustrates, polyglot persistence is very useful in the context of e-commerce applications that deal with a catalog, user access logs, financial information, shopping carts and purchase transactions, for example. The notion of polyglot persistence is built upon the observation that the *nature* of each data type is significantly different (i.e: user logs imply high volume of writes on multiple nodes, shopping carts need high availability and user sessions require rapid access for reads and writes).

As computing services started to decentralize, developers started to build applications that depended of several data-sources. By this time the use of Web Services and Service Oriented Architecture (SOA) became more popular [4].

Service Level Agreements (SLAs): According to *ITILv3's* official glossary [11], a Service Level Agreement (SLA) is "*an agreement between an IT service provider and a customer. A service level agreement describes the IT service, documents service level targets, and specifies the responsibilities of the IT service provider and the customer.*"

The agreement consists on a set of measurable constraints that a service provider must guarantee to its customers. In practical terms, it is a document that a service provider delivers to its consumers with minimum quality of service (QoS) metrics. If the service is delivered with a lower QoS than is promised on the SLA, consumers may be refunded or earn benefits that were accorded beforehand.

Systematic Mappings: According to [3], "*A software engineering systematic map is a defined method to build a classification scheme and structure a software engineering field of interest.*" Systematic Mapping studies provide a global view of a given research field and identify the quantity, results, and the kinds of researches in this field.

A Systematic map is composed by a number of steps (Figure 1).

On the first step, "Definition of Research question", the questions that must be answered on the survey are defined. On the "Review Scope" step, researchers target the papers/journal sources that will be taken into consideration on the systematic map. After that, the "Search" step is done using a set of predefined search engines and a body of papers ("All papers") is retrieved. After an initial "Screening of the papers", the "Relevant papers" are chosen according to inclusion and exclusion criteria defined by the research team. At this point, the papers that will participate of the study are selected. The selection is based on the title, abstracts and keywords of each paper ("Keywording using Abstracts"). After that, a "Classification Scheme" is built, defining different points-of-view (or facets) from which the body of papers will be classified. After matching each paper with the classification schema ("Data Extraction and Mapping Process"), the systematic mapping is performed. In this phase the relationships between the collected data (in the light of the classification scheme) are used to answer the research questions.

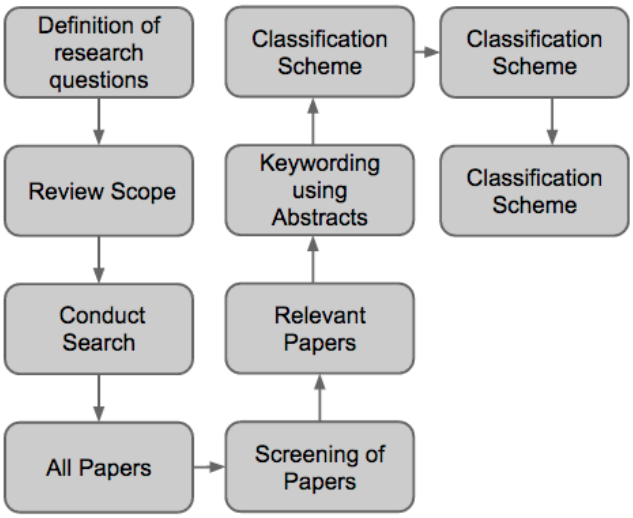


Fig. 1. Systematic Mapping Steps [3].

In the next section we build a systematic mapping to evaluate the use of SLA in database transition scenarios, from relational database management systems to NoSQL.

III. A Systematic Mapping

In this section we develop our systematic mapping, in the way described in section II.

We start by defining our research scope and by pointing out the questions to be answered by the end of the survey (Section III-A), followed by the selection of keywords that composed the search string (Section III-B). The other steps of the systematic mapping procedure follow.

After that, we defined a classification schema and classified the relevant papers. These steps (screening of papers to classification scheme) were not linear as shown on Figure 1. We had to iterate on the screened papers a few times to find the ideal classification schema to our systematic map.

A. Definition of the research questions

As we wanted to investigate the way in which SLAs has been used in database transitioning processes, we proposed three main research questions and two associated questions, as follows:

RQ1) What are the reasons to change from RDBMSs to NoSQL solutions? This question is about *why* technological changes are needed on Information Systems and what is the *motivation* behind them.

AQ1.1) What are the pros and cons to migrate from RDBMSs to NoSQL solutions? This question is particularly

important, as we also want to *point out the down sides* of DB migrations.

AQ1.2) How can we measure the overall improvements promised by this change? After a migration is performed, it is also important to *measure the benefits* of this migration, and this question evidences this point.

RQ2) How can SLAs be used to guide database transitioning processes from RDBMSs to NoSQL databases in cloud-based apps? This is one of the main questions of our study, as we want to evidence the state-of-art on the use of SLAs in migration scenarios.

RQ3) Is there a standard representation of SLAs in cloud services? We also try to search for standards on the representation of SLAs to verify if future works can be done under this field.

These are relevant questions for our survey as our focus is to determine how SLAs can be used in Database migrations scenarios. Our questions are intended to cover *why* it is good to migrate from RDBMSs to a NoSQL solution and *how* we can do it. In the end of our survey we also reveal what are the most popular technologies related to migrations.

B. Definition of keywords

Our research scope can be splitted in three main categories:

1) Databases: As we wanted to investigate RDBMS to NoSQL transitions, we defined that a representative query string for this category would be

NoSQL AND (rdbms OR relational)

2) Migration: A number of terms terms were oftenly linked with database migration and transition scenarios. Most of them, however, are consistently represented by the radicals "migr" and "transit". Thus the representative search string for this category is defined by:

migr OR transit**

3) Service level agreements: Service Level Agreements can also be represented by its acronym (SLA). A search string for this category is defined as

"Service Level Agreement" OR SLA

As we defined the three main categories of interest, what we wanted to survey is their conjunction. In this way, the final search string can be represented as:

(migr OR transit*) AND (NoSQL AND (rdbms OR relational)) AND (SLA OR "Service Level agreement")*

C. Conduct Search for Primary Studies (All Papers)

The next step of our systematic map was to identify relevant publishers. We surveyed academia experts and initially chose five main sources: **Springer, ACM, Sciencedirect, IEEE and Elsevier**. All of these publishers have relevant publications about databases and Service Level Agreements, as they index publications from reputable international conferences & journals.

Each of these publishers had their own search engine, however some inconsistent results were obtained when querying some of them directly. For instance, on one occasion IEEE search engine returned 0 results to the query string "*changes AND database AND nosql AND sla*". When we searched the same query on Google Scholar filtering *only IEEE publications* we found **90** results. We supposed that this erratic behavior is due to network traffic conditions. In order to mitigate the risks of having different results for the same query on different search engines, we used Google Scholar as a meta-search engine. It is important to mention that the use of Google Scholar made it possible to enlarge our search space. Our scope is not limited to the list of publishers identified above; these publishers represent only the minimal coverage of the literature in this systematic map.

During this step, we also noticed that 2009 would be the starting year of our survey, since this was the year when the term NoSQL was reintroduced to the community, by Johan Oskarsson (Last.fm) [12].

D. Search Strategy

Google Scholar returned 74 results for our search string. We have also manually included other particularly relevant publications that were picked from selected sources, such as [13], a master thesis about Relational Database Schema Migration to NoSQL.

These publications were either not published by the selected publishers or were not indexed by Google Scholar.

Our search strategy was composed by the following steps:

Step 1 - Basic Search: Search publications from 2009 to 2015 that matched the query string and add other relevant publications manually. This step was performed from 01 April 2015 to 11 April 2015 and returned 80 publications.

Step 2 - Dump the retrieved results on a spreadsheet. This spreadsheet is publicly available on [14].

Step 3 - Screening for keywords in of title and abstract: On the spreadsheet each publication has title, abstract, year and referenced URL. Title and abstract were considered on the initial screening. On this step we discarded publications that are notably not related to the topic of our study.

Step 4 - Apply inclusion/exclusion criteria: The inclusion/exclusion criteria are shown below. We first applied the inclusion criteria over the selected works, and then exclusion criteria removed the out of scope publications. Only papers clearly not relevant for the purposes of the study were removed. The publications that were considered on this study are marked on the spreadsheet with a green background.

1) Inclusion Criteria:
   - The publication is about a migration from RDBMS to a NoSQL technology;
   - The main focus of the publication is on RDBMs or NoSQL systems;
   - The publication makes use or references a SLA.

2) Exclusion Criteria
   - Non-English written publications;
   - Access-restriction to the original publication (could not access the source of the publication);
   - Non-technical publications;
   - The work is about migrations within the same database DBMS;
   - The work is not related to databases or SLAs.
   - The work is related to databases but no comparison is made between two technologies.

A total of 35 publications were selected after this phase.

Step 5 - Fast Reading of the papers: We've performed a fast read of all publications that were not excluded on the previous step. This helped us to classify each paper accurately. This step is extensively detailed on the next section.

E. Classification of the Papers

We classified each selected publication in three facets: **Contribution Type**, **Technologies used** and **SLA representation**.

1) **Contribution type**: On the initial screening of papers we have defined 5 main types of contribution to our study. Other systematic mapping studies, such as [15] and [16] use a similar classification schema for contribution type.
   - Benchmark
   - Migration Experience Report
   - Bibliographical Review
   - Tool
   - Framework / Process

   When a migration of databases is described in a publication, we also classify specific data to answer the questions of this study: Source and Target technology of the migration, motivation to migrate and "Uses SLA or other artifact to validate the migration?";
2) **Technologies used**: To classify and rank the technologies mentioned on each paper we have developed a *"Batch-PDF-Tokens-Matcher"*. This tool matches a list of strings against a list of PDF files. The tool was made open-source and is publicly available on [17]. In our case, we wanted to find the most cited technologies on relevant publications. As it was not possible to include all database types on this category, we chose to match only the 250 most-popular databases, ranked and made publicly available by [8].
3) **SLA representation**: One of the questions that our study wanted to answer was RQ3 (Is there a standard representation of SLAs in cloud services?). There are several ways to represent an SLA, and we clusterized some of these ways. It is also possible that no information is given about SLA representation on the publication, so we added two subcategories to this facet: "No SLA is used" and "Missing information".
   - Tool/Code/Database records
   - Language
   - Missing Information
   - No SLA is used

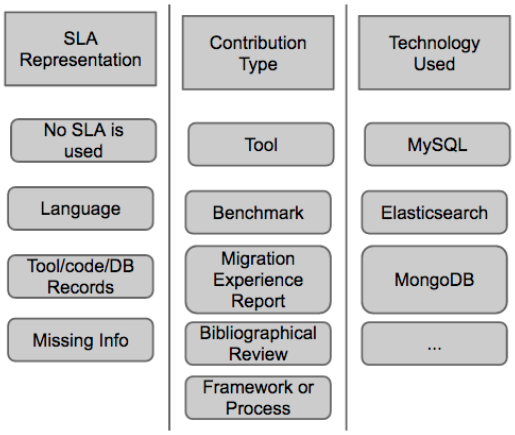


Fig. 2. Classification scheme for selected publications.

A graphical representation of our classification schema is detailed on Figure 2. We have listed only a subset of the several technology types that were found on the review.

IV. Outcomes

As mentioned in Section III-D, 74 publications were found matching our query string on IEEE, Elsevier, ACM, Springer and Sciencedirect using Google Scholar as a meta-search engine. We have manually added other 5 publications to our study. These publications were either not published by the selected publishers or were not indexed by Google Scholar.

35 out of the total of 79 publications were selected, after the screening of abstract and analysis of the inclusion/exclusion criteria[1].

The considered publications are: [18] [2] [19] [20] [21] [22] [23] [24] [25] [26] [27] [28] [21] [29] [30] [31] [32] [33] [34] [35] [36] [37] [38] [39] [40] [41] [42] [43] [44] [45] [46] [47] [48] [1] [49].

The results are given in two steps: *Frequency Analysis between relevant criteria* and *Answers to research questions*.

A. Frequency Analysis between relevant criteria

Each analysis is presented below and is followed by a brief interpretation of the result.

- Publications by year: The publications by year table - Figure 3 - shows us that 2013 was the year when most of the publications were made on this research area. As we have just reached the middle of 2015 it is expected that not many publications are indexed on the search engines on this year.
- Frequency - Publication type vs Years: An interesting pattern can be found on the table Publication Type vs Years (Figure 4); "Migrations Experience Reports" were the main type of publication that our study aimed to discover, but only 3 publications of this type were found on our systematic map.

[1] A column in our spreadsheet [14] contains the justification for the rejection of each discarded publication.

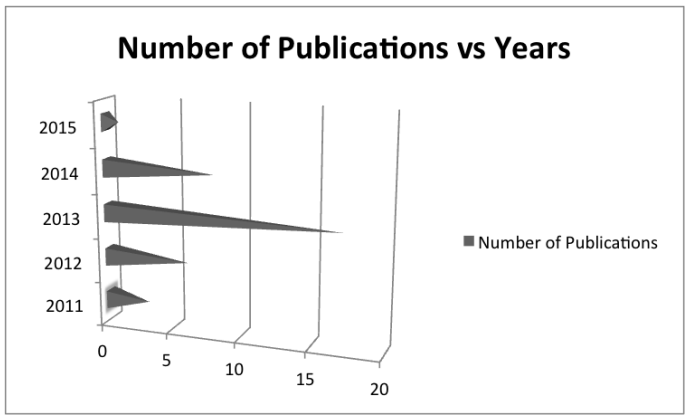


Fig. 3. Publications by year.

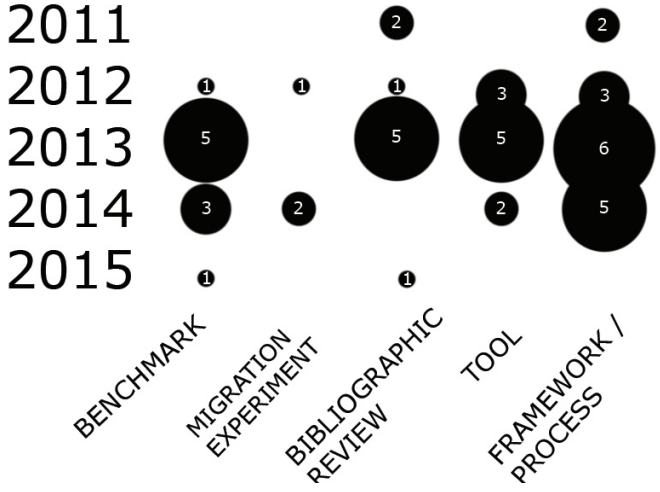


Fig. 4. Frequency - Publication type vs Years.

- Publications by country: Figure 5 shows that USA, Australia and Romania were responsible for almost 50% of the total selected publications. The other half of publications were distributed among other 16 countries, proving that the research area is not being developed by a single research group.

- Popular Technologies: Figure 6 shows that Cassandra, MongoDB and MySQL were the most-cited databases on the papers that we analyzed. This chart can be used as a starting point to propose new works in the area of database migration. The full count of each technology is available on [50].

- SLA Representation: 29% of the publications didn't make any use of SLAs. Another big part - 32% - didn't even mention how the SLA is represented internally. 3 publications propose or use DSLs (Domain Specific Languages) to represent SLAs. This evidences a clear absence of standards when defining/using SLAs. The full table is presented on Figure 7. [50].

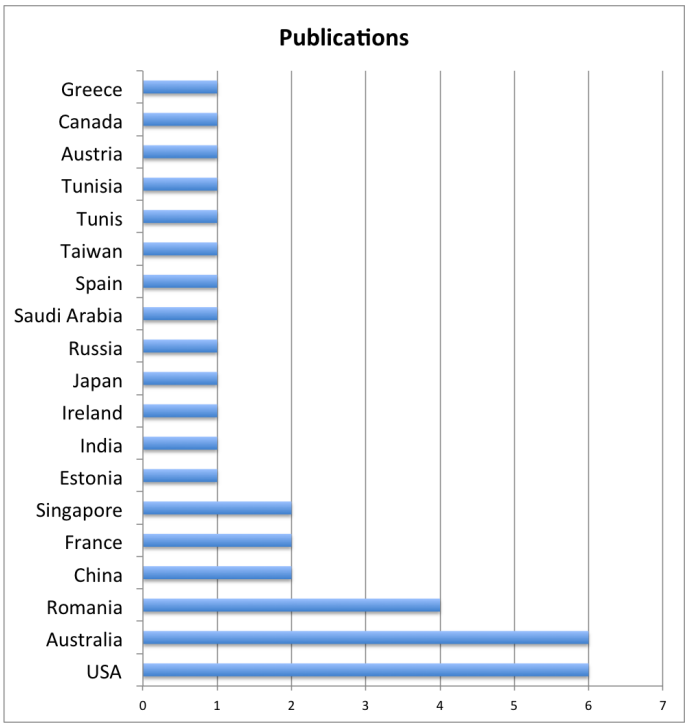


Fig. 5. Publications by country.

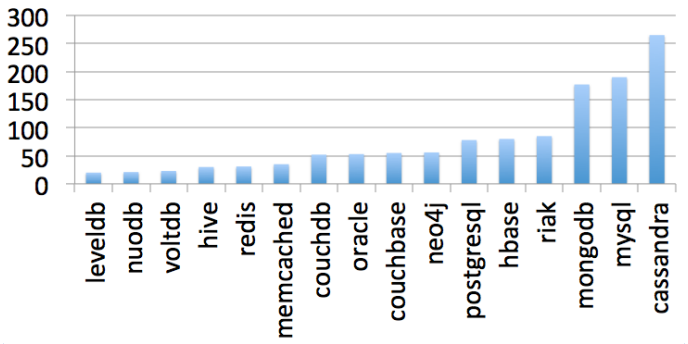


Fig. 6. Most-cited database technologies.

B. Answers to research questions

In this mapping study we have surveyed the state of the art in transitions from RDBMSs to NoSQL databases. We created a rigorous protocol which analyzed 79 publications to answer the research questions that we identified previously. We may consider the answer to these questions as the main outcome of this paper. The answers are summarized below:

RQ1-What are the reasons to change from RDBMSs to NoSQL solutions? and **AQ1.2**-What are the pros and cons to migrate from RDBMSs to NoSQL solutions? investigate the motivation of a database transition. We found a number of reasons to migrate from a relational database to a NoSQL/Hybrid model. As the migration is most of the time motivated by the benefits of these models, the answers to the questions RQ1 and AQ1.2 are presented together.

The publications that reference the benefits and disadvantages of NoSQL / Hybrid solutions were [46] [47] and [48].

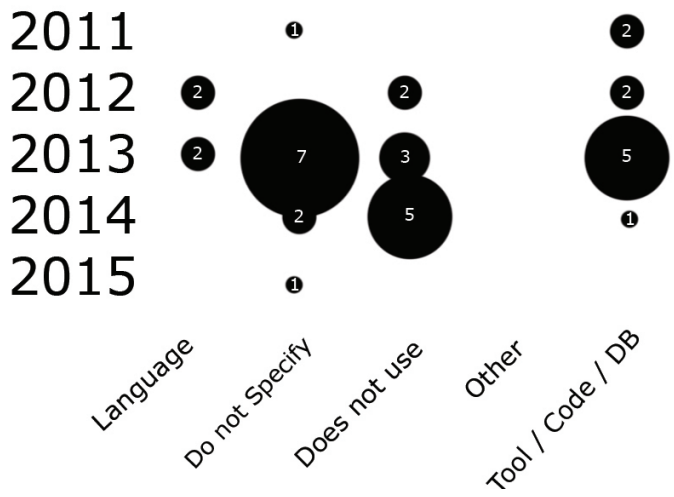


Fig. 7. SLAs representation.

Benefits::

- Segments of the data to be read and processed in parallel using a MapReduce framework, such as Hadoop;
- Schema-less data model;
- Support for large files;
- Scalability - relational databases tend to "Scale up", which is opposed to the "Scale horizontally" strategy used by hybrid solutions;

Disadvantages::

- A big disadvantage on moving from a RDBMS to a NoSQL/Hybrid solution is the need for changes on the data models of the application. Several publications address this problem, such as [46] [51] and [52]
- Another disadvantage of NoSQL and Hybrid solutions is the fact that these concepts are relatively new. As we mentioned previously, the term NoSQL was used to reference these types of databases for the first time in 2009 [12]. The relational model has been in use for more than 30 years;As it is a new concept, it is particularly hard to find developers with a large experience in NoSQL databases.

AQ1.2-How can we measure the overall improvements promised by this change?

No publication was found addressing the problem of measuring the overall improvements after a database transition. In fact, as it is shown on IV-A, there are few publications with the "Migration Experience Report" type.

Several benchmarking frameworks, such as TPC-H, TPC-DS and YCSB were identified [21] during our survey, though. These benchmarking frameworks could be a good starting point to develop new tools and specialized frameworks to solve this problem. This seems to be a promising research theme for future works.

RQ2-How can SLAs be used to guide database transitioning processes from RDBMSs to NoSQL databases in cloud-based apps?

A number of works were found relating SLAs with Quality of Service (QoS) and Quality of Experience (QoE). Several publications, such as [22], [53] and [54] propose a SLA-centric approach to monitor and control the performance of cloud-based apps. [2], [19], [55] and [36] propose SLA-centric/User-Centric solutions to monitor the performance of web applications. All these solutions are technology-agnostic and could be used to monitor the performance improvements promised by a database transitioning process.

The question RQ2 was subject of discussion with industry experts and it was found out that there are some services, such as New Relic [56], Appsee [57] and Datadog [58] that provide SLA-monitoring tools for web apps.

RQ3-Is there a standard representation of SLAs in cloud services?

The selected publications did not present a standardized and common representation for SLAs. In fact, 32% of the selected publications did not even mention how the SLA was represented. 29% represented the SLAs as tables/documents stored on databases without any sla-oriented guidelines. This evidences a clear absence of standards when defining/using SLAs.

[1] proposes SYBL: *An Extensible Language for Controlling Elasticity in Cloud Applications. SYBL allows specifying in detail elasticity monitoring, constraints, and strategies at different levels of cloud applications, including the whole application, application component, and within application component code.* In other words, SYBL can also be seen as a language to specify SLAs in cloud environments.

Specifically related to SLAs on Cloud Services, [49] and [59] propose CSLA (Cloud Service Level Agreement): a language for Cloud Elasticity Management. CSLA features concepts related to SLAs on Cloud service, as QoS/functionality degradation and penalty models. These features are very useful, as it allows providers to express contracts with fines and penalties.

Some other initiatives that tried to define the mechanisms by which Webservice SLAs are established are WS-Agreement [60] and WSLA [61]. Also, [62] presents a framework for managing the mappings of the Low-level resource Metrics to High-level SLAs (LoM2HiS framework).

It is worth to notice that future works on standardizing the representations of SLAs are needed.

V. Conclusions

By analyzing the charts and the answers to the research questions we can conclude that the research area of this mapping study is still not mature.

There is a lack of consensus and standards on this research area, as no official guidelines for migrating from a relational database to a NoSQL/Hybrid database were found. It was also not found a standard way to represent and create SLAs. These

two points seems to be promising research topics and will be covered on future works.

REFERENCES

[1] G. Copil, D. Moldovan, H.-L. Truong, and S. Dustdar, "Sybl: An extensible language for controlling elasticity in cloud applications," in *Cluster, Cloud and Grid Computing (CCGrid), 2013 13th IEEE/ACM International Symposium on*, May 2013, pp. 112–119.

[2] S. Sakr and A. Liu, "Sla-based and consumer-centric dynamic provisioning for cloud databases," in *Cloud Computing (CLOUD), 2012 IEEE 5th International Conference on*, June 2012, pp. 360–367.

[3] K. Petersen, R. Feldt, S. Mujtaba, and M. Mattsson, "Systematic mapping studies in software engineering," in *Proceedings of the 12th International Conference on Evaluation and Assessment in Software Engineering*, ser. EASE'08. Swinton, UK, UK: British Computer Society, 2008, pp. 68–77. [Online]. Available: http://dl.acm.org/citation.cfm?id=2227115.2227123

[4] A. Fox, R. Griffith, A. Joseph, R. Katz, A. Konwinski, G. Lee, D. Patterson, A. Rabkin, and I. Stoica, "Above the clouds: A berkeley view of cloud computing," Tech. Rep., 2009.

[5] A. Spector, P. Norvig, and S. Petrov, "Google's hybrid approach to research," *Commun. ACM*, vol. 55, no. 7, pp. 34–37, Jul. 2012. [Online]. Available: http://doi.acm.org/10.1145/2209249.2209262

[6] K. Shvachko, H. Kuang, S. Radia, and R. Chansler, "The hadoop distributed file system," in *Mass Storage Systems and Technologies (MSST), 2010 IEEE 26th Symposium on*, May 2010, pp. 1–10.

[7] A. e. a. CONNOLY, D. FOX, "A view of cloud computing - http://delivery.acm.org/10.1145/1730000/1721672/p50-armbrust.pdf," April 2010, [Online; posted 01-April-2010].

[8] "Db engines ranking," http://db-engines.com/en/ranking, Accessed: 2014-05-01.

[9] P. J. Sadalage and M. Fowler, *NoSQL distilled: a brief guide to the emerging world of polyglot persistence*. Pearson Education, 2012.

[10] G. V. Solar, "Addressing data management on the cloud: tackling the big data challenges," May 2014. [Online]. Available: http://db-engines.com/en/ranking

[11] Axelos, "Best management practice portfolio: common glossary of terms and definitions," Oct. 2012. [Online]. Available: http://www.axelos.com/gempdf/Axelos_Common_Glossary_2013.pdf

[12] E. Evans, "Eric evans blog - nosql," http://blog.sym-link.com/2009/05/12/nosql_2009.html, Accessed: 2014-05-01.

[13] R. Lamllari, "Extending a methodology for migration of the database layer to the cloud considering relational database schema migration to nosql," Master's thesis, University of Stuttgart, 2013.

[14] F. Leal, "Systematic mapping spreadsheet," https://docs.google.com/spreadsheets/d/1N3DboEqthdiKG3VDMKlqyjFdHC3pxrN1XtXtNoNrhX8, Accessed: 2015-05-01.

[15] A. Tahir and S. Macdonell, "A systematic mapping study on dynamic metrics and software quality," in *Software Maintenance (ICSM), 2012 28th IEEE International Conference on*, Sept 2012, pp. 326–335.

[16] D. Ameller, X. Burgus, O. Collell, D. Costal, X. Franch, and M. P. Papazoglou, "Development of service-oriented architectures using model-driven development: A mapping study," *Information and Software Technology*, vol. 62, no. 0, pp. 42 – 66, 2015. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S0950584915000361

[17] F. Leal, "Fabio leal - pdf tokens matcher," https://github.com/fabiosl/pdf-tokens-finder, Accessed: 2015-05-01.

[18] C.-W. Huang, W.-H. Hu, C.-C. Shih, B.-T. Lin, and C.-W. Cheng, "The improvement of auto-scaling mechanism for distributed database - a case study for mongodb," in *Network Operations and Management Symposium (APNOMS), 2013 15th Asia-Pacific*, Sept 2013, pp. 1–3.

[19] L. Zhao, S. Sakr, and A. Liu, "A framework for consumer-centric sla management of cloud-hosted databases," *Services Computing, IEEE Transactions on*, vol. PP, no. 99, pp. 1–1, 2013.

[20] Z. Zheng, J. Zhu, and M. Lyu, "Service-generated big data and big data-as-a-service: An overview," in *Big Data (BigData Congress), 2013 IEEE International Congress on*, June 2013, pp. 403–410.

[21] R. Moussa, "Benchmarking data warehouse systems in the cloud," in *Computer Systems and Applications (AICCSA), 2013 ACS International Conference on*, May 2013, pp. 1–8.

[22] P. Xiong, "Dynamic management of resources and workloads for rdbms in cloud: A control-theoretic approach," in *Proceedings of the on SIGMOD/PODS 2012 PhD Symposium*, ser. PhD '12. New York, NY, USA: ACM, 2012, pp. 63–68. [Online]. Available: http://doi.acm.org/10.1145/2213598.2213614

[23] E. Alomari, A. Barnawi, and S. Sakr, "Cdport: A framework of data portability in cloud platforms," in *Proceedings of the 16th International Conference on Information Integration and Web-based Applications & Services*, ser. iiWAS '14. New York, NY, USA: ACM, 2014, pp. 126–133. [Online]. Available: http://doi.acm.org/10.1145/2684200.2684324

[24] C. Pahl and H. Xiong, "Migration to paas clouds - migration process and architectural concerns," in *Maintenance and Evolution of Service-Oriented and Cloud-Based Systems (MESOCA), 2013 IEEE 7th International Symposium on the*, Sept 2013, pp. 86–91.

[25] L. Zhao, S. Sakr, and A. Liu, "Application-managed replication controller for cloud-hosted databases," in *Cloud Computing (CLOUD), 2012 IEEE 5th International Conference on*, June 2012, pp. 922–929.

[26] S. Sakr, "Cloud-hosted databases: technologies, challenges and opportunities," *Cluster Computing*, vol. 17, no. 2, pp. 487–502, 2014. [Online]. Available: http://dx.doi.org/10.1007/s10586-013-0290-7

[27] S. Sakr and A. Liu, "Is your cloud-hosted database truly elastic?" in *Services (SERVICES), 2013 IEEE Ninth World Congress on*, June 2013, pp. 444–447.

[28] V. Andrikopoulos, T. Binz, F. Leymann, and S. Strauch, "How to adapt applications for the cloud environment," *Computing*, vol. 95, no. 6, pp. 493–535, 2013. [Online]. Available: http://dx.doi.org/10.1007/s00607-012-0248-2

[29] E. Boytsov, "Designing and development of an imitation model of a multitenant database cluster," *Automatic Control and Computer Sciences*, vol. 48, no. 7, pp. 437–444, 2014. [Online]. Available: http://dx.doi.org/10.3103/S0146411614070049

[30] B. Sodhi and T. Prabhakar, "Assessing suitability of cloud oriented platforms for application development," in *Software Architecture (WICSA), 2011 9th Working IEEE/IFIP Conference on*, June 2011, pp. 328–335.

[31] D. Petcu, G. Macariu, S. Panica, and C. Crciun, "Portable cloud applicationsfrom theory to practice," *Future Generation Computer Systems*, vol. 29, no. 6, pp. 1417 – 1430, 2013, including Special sections: High Performance Computing in the Cloud & Resource Discovery Mechanisms for {P2P} Systems. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S0167739X12000210

[32] G. Giannikis, D. Makreshanski, G. Alonso, and D. Kossmann, "Workload optimization using shareddb," in *Proceedings of the 2013 ACM SIGMOD International Conference on Management of Data*, ser. SIGMOD '13. New York, NY, USA: ACM, 2013, pp. 1045–1048. [Online]. Available: http://doi.acm.org/10.1145/2463676.2463678

[33] K. Grolinger, W. Higashino, A. Tiwari, and M. Capretz, "Data management in cloud environments: Nosql and newsql data stores," *Journal of Cloud Computing: Advances, Systems and Applications*, vol. 2, no. 1, p. 22, 2013. [Online]. Available: http://www.journalofcloudcomputing.com/content/2/1/22

[34] A. Copie, T.-F. Fortis, V. Munteanu, and V. Negru, "Service datastores in cloud governance," in *Parallel and Distributed Processing with Applications (ISPA), 2012 IEEE 10th International Symposium on*, July 2012, pp. 473–478.

[35] A. Copie, T.-F. Fortis, and V. Munteanu, "Determining the performance of the databases in the context of cloud governance," in *P2P, Parallel, Grid, Cloud and Internet Computing (3PGCIC), 2013 Eighth International Conference on*, Oct 2013, pp. 227–234.

[36] P. Xiong, Y. Chi, S. Zhu, J. Tatemura, C. Pu, and H. HacigümüŞ, "Activesla: A profit-oriented admission control framework for database-as-a-service providers," in *Proceedings of the 2Nd ACM Symposium on Cloud Computing*, ser. SOCC '11. New York, NY, USA: ACM, 2011, pp. 15:1–15:14. [Online]. Available: http://doi.acm.org/10.1145/2038916.2038931

[37] S. Srirama and A. Ostovar, "Optimal resource provisioning for scaling enterprise applications on the cloud," in *Cloud Computing Technology*

and Science (CloudCom), 2014 IEEE 6th International Conference on, Dec 2014, pp. 262–271.

[38] M. Dayarathna and T. Suzumura, "Towards scalable distributed graph database engine for hybrid clouds," in *Data-Intensive Computing in the Clouds (DataCloud), 2014 5th International Workshop on*, Nov 2014, pp. 1–8.

[39] L. Qiao, K. Surlaker, S. Das, T. Quiggle, B. Schulman, B. Ghosh, A. Curtis, O. Seeliger, Z. Zhang, A. Auradar, C. Beaver, G. Brandt, M. Gandhi, K. Gopalakrishna, W. Ip, S. Jgadish, S. Lu, A. Pachev, A. Ramesh, A. Sebastian, R. Shanbhag, S. Subramaniam, Y. Sun, S. Topiwala, C. Tran, J. Westerman, and D. Zhang, "On brewing fresh espresso: Linkedin's distributed data serving platform," in *Proceedings of the 2013 ACM SIGMOD International Conference on Management of Data*, ser. SIGMOD '13. New York, NY, USA: ACM, 2013, pp. 1135–1146. [Online]. Available: http://doi.acm.org/10.1145/2463676.2465298

[40] S. Sakr, A. Liu, D. Batista, and M. Alomari, "A survey of large scale data management approaches in cloud environments," *Communications Surveys Tutorials, IEEE*, vol. 13, no. 3, pp. 311–336, Third 2011.

[41] J. Montes, A. Snchez, B. Memishi, M. S. Prez, and G. Antoniu, "Gmone: A complete approach to cloud monitoring," *Future Generation Computer Systems*, vol. 29, no. 8, pp. 2026 – 2040, 2013, including Special sections: Advanced Cloud Monitoring Systems & The fourth {IEEE} International Conference on e-Science 2011 e-Science Applications and Tools & Cluster, Grid, and Cloud Computing. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S0167739X13000496

[42] A. J. Elmore, S. Das, A. Pucher, D. Agrawal, A. El Abbadi, and X. Yan, "Characterizing tenant behavior for placement and crisis mitigation in multitenant dbmss," in *Proceedings of the 2013 ACM SIGMOD International Conference on Management of Data*, ser. SIGMOD '13. New York, NY, USA: ACM, 2013, pp. 517–528. [Online]. Available: http://doi.acm.org/10.1145/2463676.2465308

[43] M. Dayarathna and T. Suzumura, "Graph database benchmarking on cloud environments with xgdbench," *Automated Software Engineering*, vol. 21, no. 4, pp. 509–533, 2014. [Online]. Available: http://dx.doi.org/10.1007/s10515-013-0138-7

[44] H. Hu, Y. Wen, T.-S. Chua, and X. Li, "Toward scalable systems for big data analytics: A technology tutorial," *Access, IEEE*, vol. 2, pp. 652–687, 2014.

[45] D. Shue and M. J. Freedman, "From application requests to virtual iops: Provisioned key-value storage with libra," in *Proceedings of the Ninth European Conference on Computer Systems*, ser. EuroSys '14. New York, NY, USA: ACM, 2014, pp. 17:1–17:14. [Online]. Available: http://doi.acm.org/10.1145/2592798.2592823

[46] A. Schram and K. M. Anderson, "Mysql to nosql: Data modeling challenges in supporting scalability," in *Proceedings of the 3rd Annual Conference on Systems, Programming, and Applications: Software for Humanity*, ser. SPLASH '12. New York, NY, USA: ACM, 2012, pp. 191–202. [Online]. Available: http://doi.acm.org/10.1145/2384716.2384773

[47] C. BĂZĂR, C. S. IOSIF *et al.*, "The transition from rdbms to nosql. a comparative analysis of three popular non-relational solutions: Cassandra, mongodb and couchbase," *Database Systems Journal*, vol. 5, no. 2, pp. 49–59, 2014.

[48] A. Gomez, R. Ouanouki, A. April, and A. Abran, "Building an experiment baseline in migration process from sql databases to column oriented no-sql databases," *J Inform Tech Softw Eng*, vol. 4, no. 137, p. 2, 2014.

[49] Y. Kouki, F. de Oliveira, S. Dupont, and T. Ledoux, "A language support for cloud elasticity management," in *Cluster, Cloud and Grid Computing (CCGrid), 2014 14th IEEE/ACM International Symposium on*, May 2014, pp. 206–215.

[50] "Full db json," https://gist.github.com/fabiosl/18b5e826c9daebda5165, Accessed: 2015-04-21.

[51] R. Cattell, "Scalable sql and nosql data stores," *SIGMOD Rec.*, vol. 39, no. 4, pp. 12–27, May 2011. [Online]. Available: http://doi.acm.org/10.1145/1978915.1978919

[52] C. Mohan, "History repeats itself: Sensible and nonsensql aspects of the nosql hoopla," in *Proceedings of the 16th International Conference on Extending Database Technology*, ser. EDBT '13. New York, NY, USA: ACM, 2013, pp. 11–16. [Online]. Available: http://doi.acm.org/10.1145/2452376.2452378

[53] I. Konstantinou, E. Angelou, D. Tsoumakos, C. Boumpouka, N. Koziris, and S. Sioutas, "Tiramola: Elastic nosql provisioning through a cloud management platform," in *Proceedings of the 2012 ACM SIGMOD International Conference on Management of Data*, ser. SIGMOD '12. New York, NY, USA: ACM, 2012, pp. 725–728. [Online]. Available: http://doi.acm.org/10.1145/2213836.2213943

[54] M. Klems, D. Bermbach, and R. Weinert, "A runtime quality measurement framework for cloud database service systems," in *Proceedings of the 2012 Eighth International Conference on the Quality of Information and Communications Technology*, ser. QUATIC '12. Washington, DC, USA: IEEE Computer Society, 2012, pp. 38–46. [Online]. Available: http://dx.doi.org/10.1109/QUATIC.2012.17

[55] ——, "A runtime quality measurement framework for cloud database service systems," in *Quality of Information and Communications Technology (QUATIC), 2012 Eighth International Conference on the*, Sept 2012, pp. 38–46.

[56] "New relic," http://newrelic.com, Accessed: 2014-05-01.

[57] "Appsee," https://www.appsee.com/, Accessed: 2014-05-01.

[58] "Datadog," https://www.datadoghq.com/, Accessed: 2014-05-01.

[59] Y. Kouki and T. Ledoux, "CSLA : a Language for improving Cloud SLA Management," in *International Conference on Cloud Computing and Services Science, CLOSER 2012*, Porto, Portugal, Apr. 2012, pp. 586–591. [Online]. Available: https://hal.archives-ouvertes.fr/hal-00675077

[60] A. Andrieux, K. Czajkowski, A. Dan, K. Keahey, H. Ludwig, T. Nakata, J. Pruyne, J. Rofrano, S. Tuecke, and M. Xu, "Web Services Agreement Specification (WS-Agreement)," Global Grid Forum, Grid Resource Allocation Agreement Protocol (GRAAP) WG, Tech. Rep., Sep. 2005.

[61] S. Nepal, J. Zic, and S. Chen, "Wsla+: Web service level agreement language for collaborations," in *Services Computing, 2008. SCC '08. IEEE International Conference on*, vol. 2, July 2008, pp. 485–488.

[62] V. Emeakaroha, I. Brandic, M. Maurer, and S. Dustdar, "Low level metrics to high level slas - lom2his framework: Bridging the gap between monitored metrics and sla parameters in cloud environments," in *High Performance Computing and Simulation (HPCS), 2010 International Conference on*, June 2010, pp. 48–54.

APPENDIX B – Execution Reports

B.1 Retrieve Posts by Ids

SIZE=3	SIZE=30	SIZE=300	SIZE=3000	SIZE=30000	SIZE=300000	SIZE=3000000
3	1	2	2	2	2	41
8	1	2	2	2	2	48
1	2	2	2	3	2	30
3	2	2	3	3	2	41
1	2	3	3	1	3	31
4	2	3	2	2	7	34
1	3	3	3	3	2	37
1	2	2	2	3	2	28
1	2	2	2	2	1	31
2	1	6	2	2	1	33
1	1	2	3	3	3	32
1	1	2	3	2	3	46
1	2	2	3	3	1	33
1	2	2	3	3	4	43
1	1	2	3	2	2	38
1	2	2	2	5	2	35
2	1	3	3	2	2	45
2	1	2	1	2	2	29
1	2	2	3	2	2	23
1	2	2	2	2	2	42
1	2	3	2	3	2	35
2	1	1	2	2	3	38
2	2	2	2	3	3	23
2	1	1	2	2	2	20
1	1	2	2	2	2	34
1	4	2	3	2	2	35

```
1  2  2  2  3  2  30
1  2  2  2  2  2  28
2  2  2  4  3  2  22
1  2  2  3  2  2  25
```

B.2 Add or Remove Tags

```
SIZE=3  SIZE=30 SIZE=300 SIZE=3000 SIZE=30000 SIZE=300000 SIZE=3000000
3  1  3  21 174  1233  52051
4  1  2  22 170  2192  62520
5  1  2  21 119  3686  80271
1  1  2  9  129  5523  94348
1  1  2  21 173  6571  108677
1  1  2  13 75 7702 119326
1  1  3  17 210  8350  137024
1  1  2  8  127  9352  143877
1  1  5  17 118  10579 154422
0  2  2  21 77 11116 161416
1  1  2  13 198  12932 167972
1  1  1  17 77 14265 185872
0  1  2  9  196  15543 203654
1  1  3  13 115  16591 221417
1  1  2  17 172  18047 235689
1  1  2  21 211  19081 249869
1  1  2  21 282  19643 256755
1  1  2  13 215  21467 263449
1  1  3  13 193  22121 280995
1  1  2  9  128  23055 295092
1  1  2  12 124  23681 305504
1  1  3  13 194  25436 312420
1  1  3  9  217  26836 319072
1  1  2  13 257  28182 329616
1  3  2  13 207  29215 343534
1  1  2  9  242  30941 361365
1  1  2  13 100  31504 368016
1  1  3  8  120  33025 374778
```

```
1  1  2  17 171   33568 381543
1  1  2  21 131   34504 399029
```

B.3 Filter posts by filters

```
S=3   S=30  S=300 S=3000  S=30000 S=300000 S=3000000
4  1  1  4  35 704   50603
1  1  1  4  39 1730  50754
2  1  2  4  35 3201  50921
2  1  1  5  35 3395  50889
1  1  1  5  35 3886  51134
1  1  1  4  35 4409  50760
1  1  1  5  34 4903  50762
1  1  1  4  35 5554  50761
2  1  2  5  34 6509  49824
2  1  2  4  45 7012  50393
1  1  2  5  37 7535  50900
1  1  2  5  35 8240  50393
1  1  1  4  35 9071  51168
7  1  1  4  35 91963 50844
1  1  1  5  35 10003 49957
1  1  2  4  35 10817 49423
1  1  1  4  35 10987 49933
1  1  3  4  35 11311 49771
1  1  1  6  36 11400 51038
0  1  1  10 35 11624 50361
2  1  1  9  35 11744 50048
1  1  1  9  36 12083 49203
1  1  1  12 35 12339 50994
1  1  1  8  35 12374 48754
1  1  2  9  39 12411 49135
1  1  2  9  35 12756 49639
1  1  2  9  35 12716 48775
1  1  2  31 35 12871 48959
1  1  1  5  35 12826 48516
1  1  1  5  36 12937 48698
```