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TODO::CHANGE::Guidelines for database transitioning on production environments

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TODO::CHANGE::Guidelines for database transitioning on production environments

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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 take place.

Service Level Agreements (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, it is a document that a service provider delivers to its consumers with minimum quality of service (QoS) metrics.

This work assesses and improves 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 NoSQL one. Our study is validated by case studies.

Keywords: SLA, Database, Migration.

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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 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 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 pragmatic 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 NoSQL¹ 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

¹NoSQL 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*.

a similar 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 transitioning processes could be to map the relational schema into the new kind of document. Some works, such as (LOMBARDO; NITTO; AR-DAGNA, 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 Benchmarking 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 RDBMSs 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 doesn't follow a pragmatic process, bugs may be introduced on the application, rework may be necessary and even data the existing data may be corrupted.

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. An example is given to clarify

how this process can be used:

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 could be its the search speed. i.e: *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* is more sophisticated 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

In this work, the main contributions are:

- Proposition of a set of Guidelines based on SLAs to justify and and guide the transitions from RDBMs to NoSQL DBs;
- A Batch PDF-Tokens matcher, available on (PDFTOKENSMATCHER, 2015);

- 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 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 extensively 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 the next steps that are possible from this work. The references that were used on this work are available after Chapter 5.

2 Bibliographic Review

The goal of this chapter is to explore the main concepts that are related to this work. We begin the section 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 company 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*) (CONNOLLY

D. FOX, 2010).

According to (CONNOLLY 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’s 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.

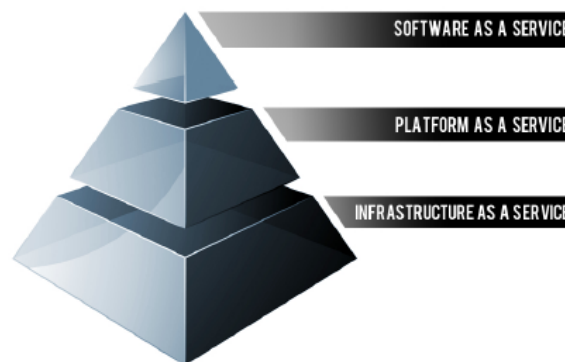


Figura 1: IaaS-PaaS-SaaS Stack (KEPES, 2011).

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.

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 might be found on the PaaS and SaaS layers.

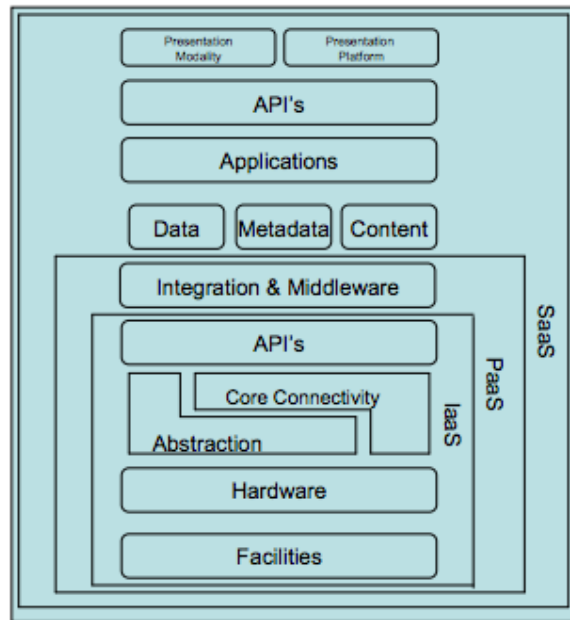


Figure 2: Cloud Reference Model (ALLIANCE, 2009).

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.

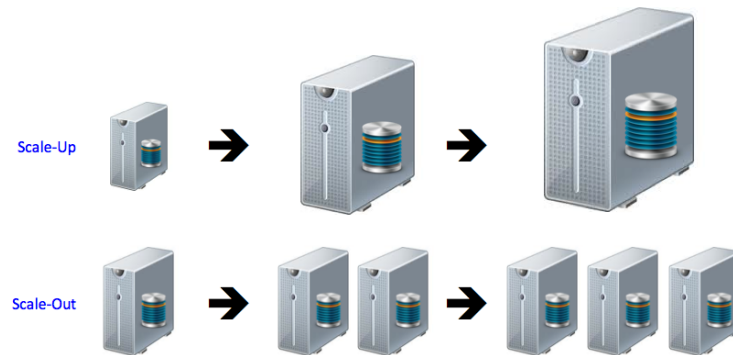


Figura 3: Scale Out vs Scale Up.(DHANDALA, 2015)

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 were in high demand, as Figure 4 suggests. This chart shows trend of the DB categories' popularity. 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.*

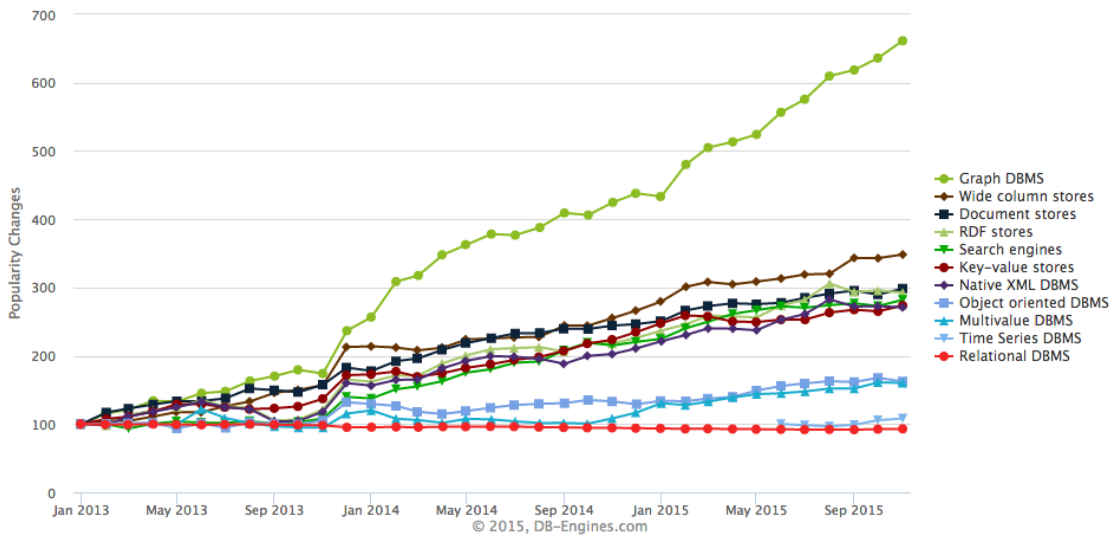


Figure 4: Database Popularity Chart (RANKINGCHART, 2015).

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-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 established 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 as well as 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 module 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 5).

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*).

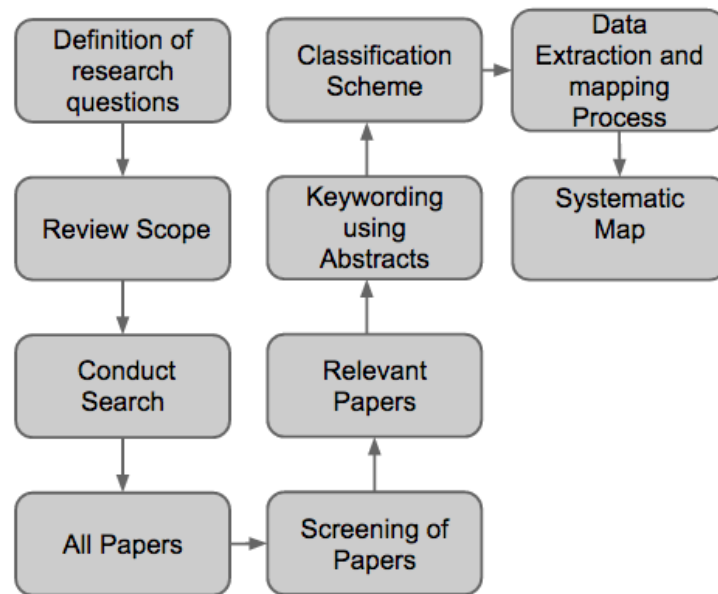


Figura 5: Systematic Mapping Steps (PETERSEN et al., 2008).

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 le-*

vel 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 6. Each step is explained in the following subsections.

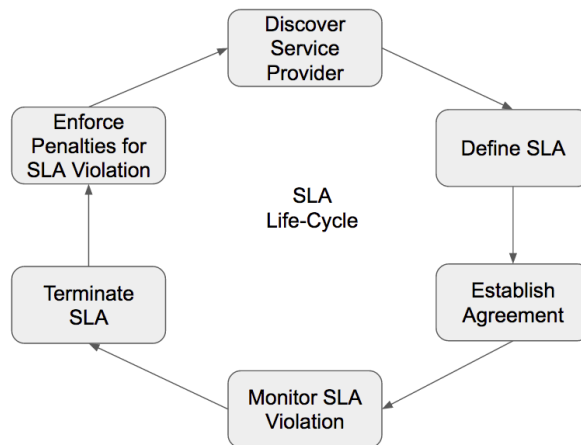


Figura 6: SLA Life-cycle (WU; BUYYA, 2012)

2.7.1.1 Discover Service Provider

On the first step (*Discover Service Provider*), a consumer typically discovers several service providers that may fulfill his 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 an 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 enumerate 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 section, 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 7 compares the Availability SLO defined in SLAs of some popular

cloud services.

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%

Figura 7: Service Level Objective: Availability on Cloud Services (LOCAWEBSLA, 2015)(COMPOSE.IO, 2015)(AMAZONRDS, 2015)

After choosing the service and defining the SLOs, an SLA might be established between a consumer and the provider - the third step of the 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.
- *Weighted 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 violation with the help of web applications, such as (DATADOG, 2014), (APPSEE, 2014) and (NEWRELIC, 2014).

2.7.1.5 Terminate SLA

An important question of the life-cycle of a SLA (fifth 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 Problem

In this section we detail the problem that we tackle in this study. A good understanding of the previous sections and of the systematic mapping available in (LEAL; MUSCANTE, 2015) is required.

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 several 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?*) - often leads to database transitioning scenarios.

In fact, applications that work with more than one database type are popular at

the present time, as (SADALAGE; FOWLER, 2012) reveals. Some companies, as Instaclustr (INSTACLUSTER, 2014) and (ELASTIC, 2015), emerged in order 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.

3.1.1 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 transitioning migrating databases on production environments. (LEAL; MUSICANTE, 2015) revealed, for instance, that database transition scenarios on the industry follow non-standardized methods and that they may vary 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 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 pragmatic manner? What are the steps and pitfalls to be avoided in relational to NoSQL transitions?

3.2 Proposed solution

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 8.

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

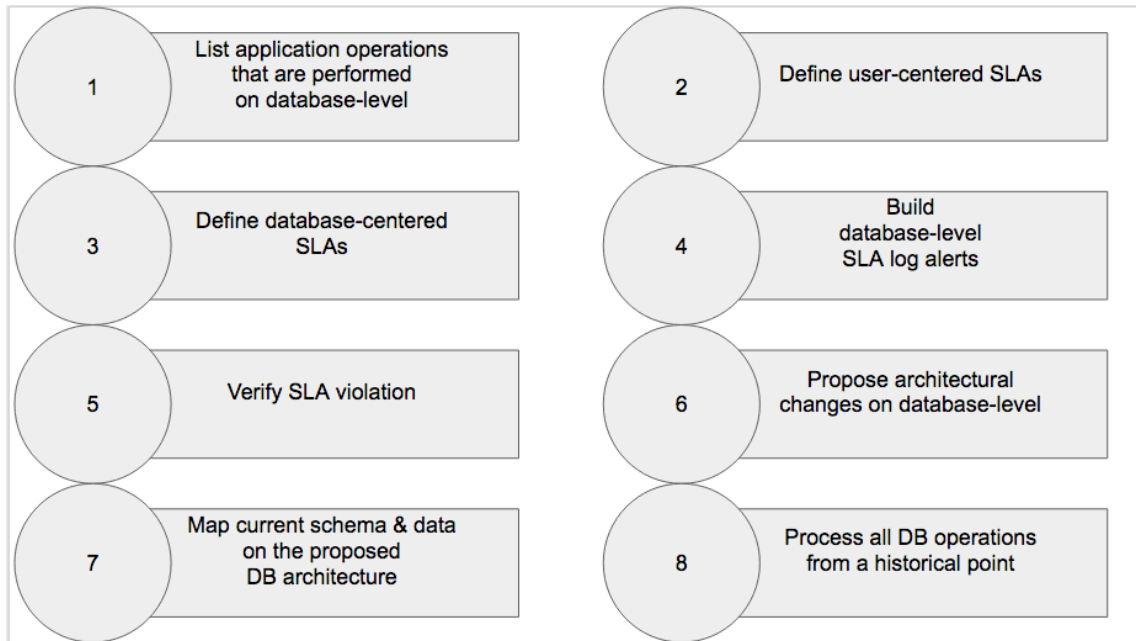


Figure 8: Relational to NoSQL Steps.

3.2.1 List application operations that are performed on 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 require-

ments. 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 on database level. To illustrate the process of enumerating these operations, consider the following application examples:

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;

3.2.2 Define user-centered SLAs

For each database operation enumerated on the previous step, a **user-centered** weighted-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 to illustrate this concept:

- **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* between the *Ideal Threshold* and *Tolerable Threshold* is defined as the number of *Ideal SLAs* that can fit inside *Tolerable SLA*. From this concept, we can define the *SLA Delta* 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: 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: 300% (3x)

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

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

As we will be targeting performance issues at database level, **ideal threshold**, **tolerable threshold** and **SLA delta** can generally be seen as a time-related metrics, as it is shown on the examples above.

In fact, *time* is the main metric when benchmarking databases, as presented on (END-POINT, 2015) - operations/sec and latency. Other quantifiable metrics and Key Performance Indicators (KPIs), as *processed workload* and *client CPU / memory usage* can also be used as metrics to the thresholds, however. I.E: it is also possible to define thresholds related to the client CPU usage, for example.

On Figure 9 it is possible to graphically visualize the concepts of **Ideal Threshold**, **Tolerable Threshold** and **SLA Delta**.

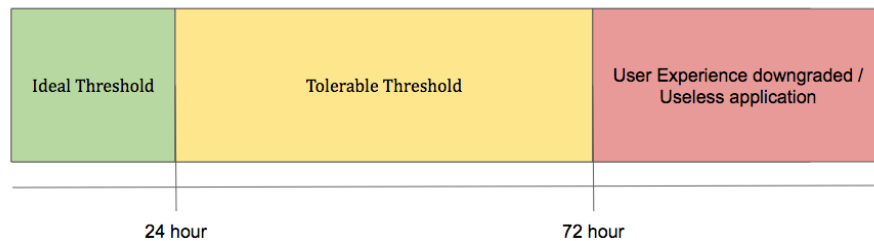


Figura 9: SLA Thresholds - 3x SLA Delta.

3.2.3 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 on database level. These SLAs are called *database-centered-SLAs* in our guidelines and are proposed 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:** 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:** 200% (2x)

3.2.4 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 on 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 7 presents.

3.2.4.1 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 New Relic, Papertrail and Logstash.

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

It is possible to 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.

3.2.5 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.

3.2.5.1 Further Analysis

SLA violation alerts contain the exact timestamp of when the violation occurred, 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;

3.2.6 Propose architectural changes on database-level

Not always it is necessary to replace the database to address a performance problem. SQL tuning, 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 10.

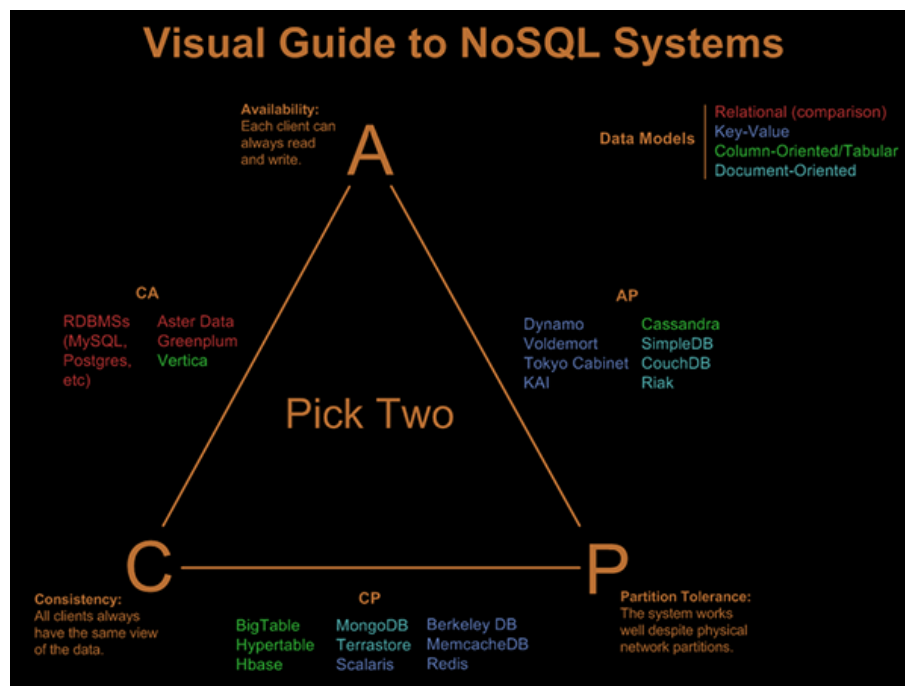


Figura 10: CAP Theorem.(HAO, 2014a)

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.

3.2.7 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 performance 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 a Business Intelligence application example. If this application relies on relational databases, it 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 strategy, 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.

```

1 {
2   "id": 12089367123
3   "user": 12908376123,
4   "items": [{"id": 01, "category": "food", "name": "rice"}, {"id": 21,
5               "category": "drinks", "name": "soda"}]

```

3.2.8 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 persistence* 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 relational database to the oldest point in time where the logs enable and to perform all operations from that point to the point where the SLA violation was triggered. By doing so, it is possible to eventually 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 this 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.

From 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.

3.2.9 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 and straightforward task, however. It is necessary to change the source code of applications, eventually change some tests and some bugs may be arise during the process.

Software engineers and database administrators 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 in 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 eventually 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. This 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 in once, it is possible to perform these steps in a cycled 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. This way, the negative impacts of a database transition is amortized.

3.3 Work Phases - TODO: Continue from here

To provide a better understanding of our work, we splitted the research in six main phases:

Each of these phases is composed by a number of steps, described below:

1. Phase 1 - Identification of Case Studies & SLAs
 - (a) Step 1.1 - Scenario identification / Implementation: On this step we will search for open source projects and real-world scenarios where a Relational Database bottleneck has been identified. If the scope of these scenarios become too large, we will implement our own scenarios;
 - (b) Step 1.2 - Identification of broken SLAs: We need to identify that the a set a constraints (i.e: execution time of a query) is not being met by the current architecture;

Tabela 1: Work Phases.

Phase	Title	Description
1	Identification of Case Studies & SLAs	On this step we aim to identify examples where a Database transition is needed or recommended in order to satisfy a SLA. We will try to work on production-ready and open-source softwares. If the complexity of these projects is too large for our scope, we will design and develop our own scenarios.
2	Plan	After the scenarios have been identified, we will propose architectural changes that could satisfy the SLA. These changes will be proposed by literature reviews and survey of industry experts.
3	Do	On this step we implement the architecture proposed on the previous step.
4	Check	On the check step we will verify if the proposed architecture and implementation satisfies the SLAs identified on the first step.
5	Act	Tweaks can be needed on the proposed architecture and implementation if the SLA is still not satisfied by the changes made on the previous step. On the act phase we investigate what else can be done to satisfy the SLA and refine the process defined on step 2.
6	Final Results	On the final step we aim to publish the results of our work on relevant database-related conferences and workshops.

(c) Step 1.3 - Implementation of “runnable SLAs” : On this step we will implement executable versions of the SLA identified on the previous step. These “runnable SLAs” will be used to verify that a set of constraints is not being met by the current architecture.

(d) Step 1.4 - Execution reports: After an executable SLA has been identified and implemented, execution reports will be consolidated to prove that the constraints of the SLA are being broken by the current architecture of the scenario.

2. Phase 2 - Plan

(a) Step 2.1 - Literature Review for each scenario: We will evaluate and search for solutions on how each scenario can make use of a NoSQL Database to meet the desired SLA;

(b) Step 2.2 - Survey of industry experts: We will survey industry experts on how they would propose a NoSQL architecture to solve the problem described on

each scenario.

3. Phase 3 - Do

- (a) Step 3.1 - Planning of changes: We will gather the results from the previous phase and design the changes that will be performed on each scenario;
- (b) Step 3.2 - Implementation: We will implement the changes identified on the previous step.

4. Phase 4 - Check

- (a) Step 4.1 - New Execution Reports: The same SLAs identified on the first step will be run on the modified scenarios, and execution reports will be consolidated.
- (b) Step 4.2 - Comparison of Results: The reports extracted on steps 4.1 and 1.4 will be compared to check if the changes made on Phase 3 satisfied the proposed SLA.

5. Phase 5 - Act

- (a) Step 5.1 - Tweaks on the proposed architecture: If the SLA isn't being met yet, new changes might be needed, and on this step we join together the phases 2, 3 and 4 to iterate over the needed changes.

6. Phase 6 - Final Results

- (a) Step 6.1 - Publish the results: We will submit the results of this study to academical conferences to have feedback from the community.
- (b) Step 6.2 - Write the final results: All the documents produced by our study and a final dissertation will be sent to the Universidade Federal do Rio Grande do Norte (UFRN).

3.4 Schedule

A detailed view of the execution flow of our steps can be seen on Figure 11.

A	B	C	D	E	F	G	H	I	J
Phase	Step Description	25/07/2015	15/08/2015	5/9/2015	26/09/2015	17/10/2015	7/11/2015	28/11/2015	19/12/2015
Phase 1	Scenario identification / Implementation	x							
	Identification of broken SLAs		x						
	Implementation of "runnable SLAs"		x						
	Execution reports		x						
Phase 2	Literature Review for each scenario			x					
	Survey of industry experts			x					
	Planning of changes			x					
Phase 3	Implementation			x	x	x			
Phase 4	New Execution Reports					x			
	Comparison of Results					x			
Phase 5	Tweaks on the proposed architecture					x	x		
Phase 6	Publish the results						x	x	x
	Write the final results						x	x	x

Figura 11: Schedule.

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 we had 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-seouces 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 the following section is used on Scenarios 1, 2 and 3, detailed later on this chapter.

4.1 Building the Environment

To validate the guidelines presented on Chapter 3 we have modeled *the DB Schema core* of an application that gathers posts from social networks and presents them to users.

Users might use this application to search for relevant topics across Social-Media posts, to classify the subjects of posts, and to build terms cloud and figure out what are the most relevant topics, for example.

From a user perspective, some features of this application are:

1. **Boolean search** - Search posts that mention a boolean query string. *i.e:* (*Brazil AND Neymar*) *OR* (*Orlando AND Kaka*)
2. **Classify posts (add tags)** - *N* tags (subjects) can be added to a single post.
3. **Archive post by query:** A user may archive all posts with a specific characteristic. *i.e:* it's possible to archive all posts from 01/01/2015 to 02/01/2015 that have the tag "Soccer Player"

Other features of the application are not listed to ease the understanding of the scenarios that are presented on the following sections.

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

On Figure 12 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.

On Figure 13 it is possible to verify 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.

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)

Figura 12: Posts table.

The Tags table is also denormalized, as *tag_user* and *tag_name* are entities that should 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)

Figura 13: Tags table.

Tags information is purposely redundant. This way, it is possible to retrieve the tags of a post from a **JOIN** query between the Tags and Post tables and by searching it within the *tags* column of the Posts table. This data-redundancy was planned to test which option has better performance on a production scenario.

4.2 Application SLA

According to the SLA monitoring-models defined by (RANA et al., 2008), we have defined that a suitable SLA for our application would be a *All-or-nothing*. This way, all the SLOs must be satisfied to guarantee that the SLA is still valid.

The SLOs defined on our SLA are:

1. *Search Operation Time*: All search operations must be executed in up to three seconds from the moment that the server receives the request to the moment it sends the response.
2. *Search by tags time*: Given an array of tags, the application should respond in up to 3 seconds all posts that match this tags array.
3. *Update-by-query operations time*: All update-by-query operations should last up to 3 minutes, even if the entire database is updated.

4.3 The application setup

To prepare our database to the scenarios that will be discussed on the following section, some tasks were necessary:

4.3.1 Server Setup

Setup servers to host the data: A cloud server was needed to host the database that is used on the application. 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

4.3.2 Software Setup

The machine hosted the following software configuration:

- 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

4.3.3 Data Setup

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.

A total number of 3332534 posts (3 milion posts) were captured and the Dump file with these posts is available on XXXXXXXXXXXX. TODO: Upload dump file somewhere.

4.4 Scenario 01

A possible claim from the application users' is that the Search Speed is slowing down as the number of posts grow in the database. In fact, intuition tells us that the search speed slows down as the number of posts in the database grows. With that, *intuitively* one can say that in some point the first SLO (*Search Operation Time*) will be broken.

To verify this scenario within our database, we have implemented a runnable SLA checker in Python programming language. The algorithm, shown on Figure 14 performs fulltext-search operations on our MySQL database and verifies if the SLA is broken in this scenario.

First, we define several query sizes, and for each query size we generate random strings. Then, a query with of the following style is performed on our MySQL Database:

“SELECT COUNT(*) FROM posts WHERE message like %myQueryString%”

For each query size, we repeat the operation with a distinct word for three times (NUMBER_OF_ATTEMPTS_FOR_EACH_QUERY_LENGTH = 3). On our experiments, we found out that there's no noticeable difference between querying random generated ascii-chars and words from the dictionary.

```

1  mysql_queries = []
2  for query_length in [50, 30, 20, 10, 5, 2]:
3      for attempt in range(NUMBER_OF_ATTEMPTS_FOR_EACH_QUERY_LENGTH):
4          query_string = get_random_string_with_size(query_length)
5          print "... "
6          mysql_queries.append((query_length, search_time_mysql(query_string)))
7
8  print "MySQL Queries: %s" % mysql_queries
9  print "MySQL SLA is broken? %s" % slaIsBroken(mysql_queries, MAX_SECONDS)

```

Figura 14: Runnable SLA v0.1 .

We have tested the scenario with [100, 1000, 10000, 100000, 1000000, 10000000, 20000000 and 300000] posts within our dataset. Execution reports shows us that, indeed, the first SLO is broken with a data-size of 1000000 (one million) posts.

Execution reports for each of these dataset values is available on Appendix B.

4.4.1 Guidelines

The **first step** of our guidelines states that to propose a database migration, it is necessary to identify that a requirement of the application is broken. In this case, the search speed requirement is broken).

The **second step** is to implement a runnable SLA that shows that the Service Level Objective is not being fulfilled. The runnable SLA that was explained shows that the Search Operation Time SLO is not being met.

Step number three is to show that the requirement (or SLO) is broken. Execution Report 01, available on Appendix A shows that Steps 1, 2 and 3 of our guidelines are done.

The fourth step of the guidelines is to propose modifications on the relational database.

TODO finish here. <http://blog.scoutapp.com/articles/2014/12/19/from-mysql-full-text-search-to-elasticsearch> reporta algumas opcoes para melhorar a performance de um full text search com MySQL.

Dentre as opcoes para melhorar o processo de search, ele aponta duas solucoes: (i) “To support full-text search, we needed to use the MySQL MyISAM storage engine. This has major downsides, the primary one being full table locks: when a table is updated, no other changes to that table can be performed.” A outra saida era (ii) “We ended up doing this. It was a fairly simple step and allowed us to switch to the InnoDB engine on the master, eliminating the table lock issues.

This bought us some time, but it wasn't a long-term solution: we basically were rolling our own search and this frequently involved complex queries that third-party search libraries could perform more efficiently. We ended up with massive queries composed of many JOINS plus AND/ORs - these aren't easy to maintain.

Besides query complexity, it's tough to beat the performance of a dedicated search solution. Our tables have considerable update activity, so this would result in sometimes-significant performance issues. ” Outros contra-pontos para implementar fulltext search em MySQL apontado por XXX, XXX and XXX sao X Y e Z. Falta terminar essa parte.

4.4.1.1 A new database

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

Elasticsearch (a.k.a. Elastic) was seemed to be a good alternative to the problem that we were facing with MySQL. Some discussion forums were consulted and comparisons and studies were considered on our research (STACKOVERFLOWELASTIC, 2015) (SOLRV-SELASTICSEARCH, 2015) (QUORAELASTIC, 2015). With that, **step number four** is done.

Step number five suggests that 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 post that we had on the posts table was transformed into a valid JSON document.

A new server with the same configuration of the one presented on the beginning of this chapter was provisioned and Elasticsearch[1.7.2] version was installed.

To dump the data from MySQL and import to Elasticsearch, a Python script was made (LEAL, 2015a). 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 situation, an open-source project that connects to MySQL via JDBC and imports data into Elasticsearch (JPRANTE, 2015) was used. With that, **the sixth step** is successfully executed.

A new runnable SLA was necessary to compare the execution time of the previous database architecture (MySQL) and the one that was proposed. We have joined both runnable SLAs into a single script, available on (LEAL, 2015b), **finishing the seventh step**.

It is possible to compare the Execution Report of both database architectures on Execution Report 02 (Appendix A).

With that, it is possible to show that the runnable SLA on the new architecture with all posts results in a significant performance improvement, proving that a database transition may be suitable to this scenario, **finishing Step 08**.

To proceed with a DB migration, Scenarios 02 and 03 must also be analyzed.

4.5 Scenario 02

Scenario 02 was searching for an unstructured document (a tag defined by a user, for example). Shows that even with joins is a costly operation and filling it in a text drives us to a Fulltext-search scenario.

TODO: everything

4.6 Scenario 03

Update by query scenario

Todo: everything

5 Conclusions

TODO: Fix References: <https://www.evernote.com/l/AD9tKczyJiBK9KJkJ-s1eNh-AxhMlqz3SXA>

TODO: Conclusions

The boundaries of this work could then be broadened to support the conception of a SLA-Guided process to support the migration/replacement of software components based on the cloud in future works.

Referências

- 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>>.
- 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>>.
- CONNOLLY 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.tpc.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/>>.
- 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>>.
- 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.

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>>.

INSTACLUSTER. *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. *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. *Runnable SLA 01*. 2015. [Online; accessed 22-November-2015]. Disponível em: <https://github.com/fabiosl/ufrn-masters-research/blob/master/experiments/exp01_main.py>.

LEAL, F.; MUSICANTE, M. Todo: Update this reference - using sla to guide database transition to nosql on the cloud: a systematic mapping study. In: *AICCSA 2015*. ?: ?, 2015. (?), p. ? ISBN ? Disponível em: <?>.

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

PDFTOKENSMATCHER. 2015. <https://github.com/fabiosl/pdf-tokens-finder>. Accessed: 2015-05-01.

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, Winter1990QuinnWinterSloan 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.–.
- 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/1jhbncC>, v. 11, 2010. Disponível em: <<http://bit.ly/1jhbncC>>.
- 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/>>.
- 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>>.
- 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.; WOZNIK, 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.
- STURM, R.; MORRIS, W.; JANDER, M. {Foundations of Service Level Management}. Sams publishing, 2000.
- WIKIPEDIA. *John McCarthy (computer scientist)*. 2015. [Online; accessed 22-November-2015]. Disponível em: <[https://en.wikipedia.org/wiki/John_McCarthy_\(computer_scientist\)](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*, Citeseer, 2012. Disponível em: <"<http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.434.7867&rep=rep1&type=pdf#page>>

APÊNDICE A – Systematic Mapping

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

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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 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 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

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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

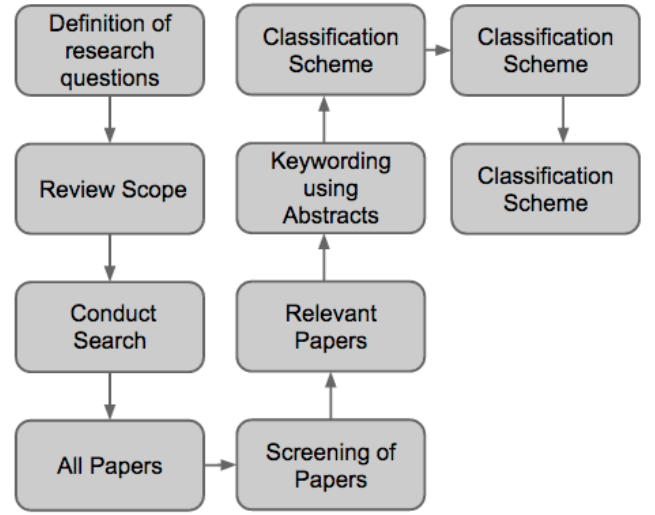


Fig. 1. Systematic Mapping Steps [3].

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 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 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

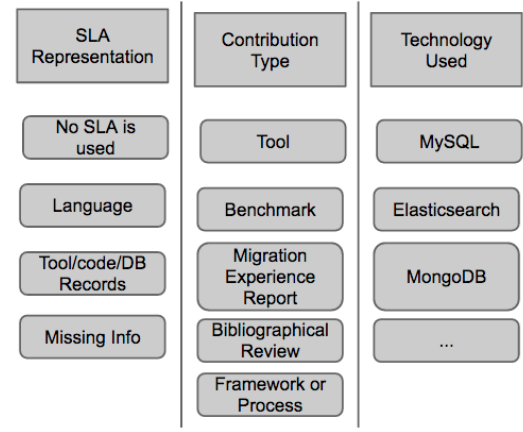


Fig. 2. Classification scheme for selected publications.

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 Scindirect 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 criteria¹.

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.

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

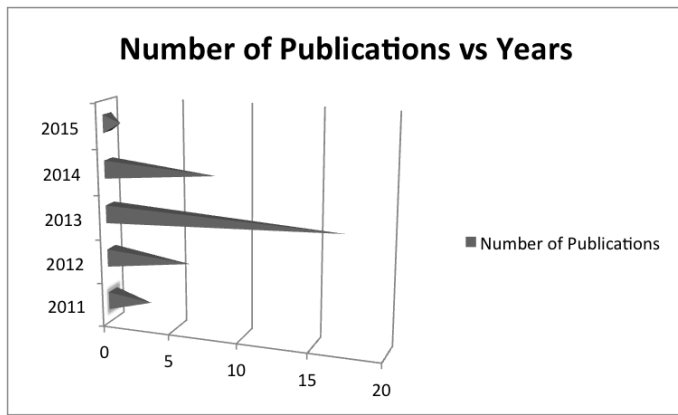


Fig. 3. Publications by year.

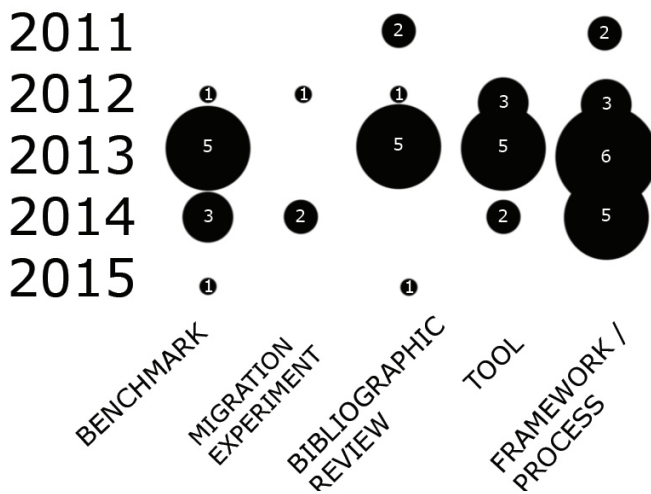


Fig. 4. Frequency - Publication type vs Years.

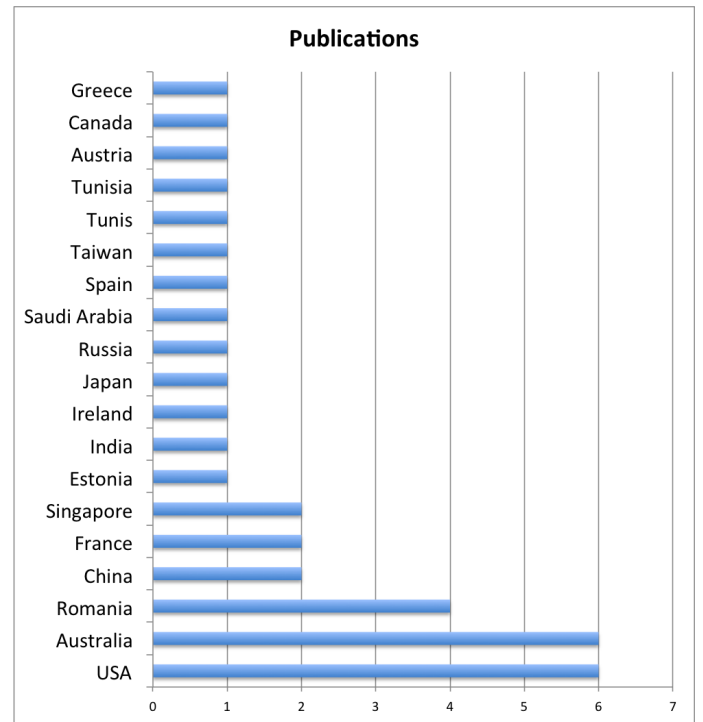


Fig. 5. Publications by country.

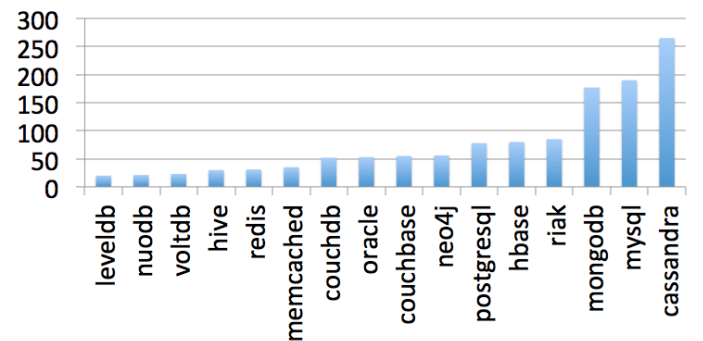


Fig. 6. Most-cited database technologies.

- **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].

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].

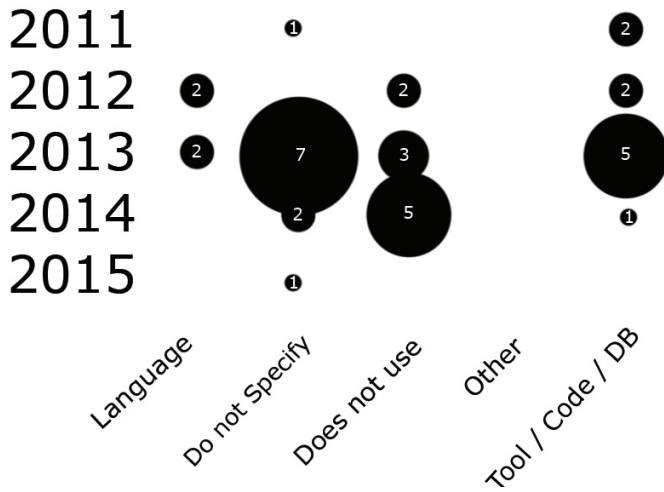


Fig. 7. SLAs representation.

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. CONNOLLY, 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/1N3DboEqthdKG3VDMKlqyJfHdC3pxrN1XtXtNoNrX8>, 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. Crciu, "Portable cloud applications from 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. Giannakis, 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. Jgadhish, 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 dbms,” 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 rdbs 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.

APÊNDICE A – Execution Reports

Execution Report 01

Running with Dataset Size: 100

...

MySQL Queries: [(50, 0.1901998519897461), (50, 0.1845710277557373), (50, 0.18726801872253418), (30, 0.18717598915100098), (30, 0.1875), (30, 0.18777203559875488), (20, 0.18753886222839355), (20, 0.18907999992370605), (20, 0.18427801132202148), (10, 0.1874251365661621), (10, 0.18940091133117676), (10, 0.18792486190795898), (5, 0.18765616416931152), (5, 0.1839289665222168), (5, 0.18367600440979004), (2, 0.1840989589691162), (2, 0.18876910209655762), (2, 0.18515491485595703)]

MySQL SLA is broken? False

#####

Running with Dataset Size: 1000

...

MySQL Queries: [(50, 0.20785880088806152), (50, 0.1742258071899414), (50, 0.17499303817749023), (30, 0.1735529899597168), (30, 0.1874690055847168), (30, 0.17806601524353027), (20, 0.17487502098083496), (20, 0.1774768829345703), (20, 0.17374396324157715), (10, 0.1745619773864746), (10, 0.17732787132263184), (10, 0.17468595504760742), (5, 0.17685604095458984), (5, 0.17804884910583496), (5, 0.1777651309967041), (2, 0.17557621002197266), (2, 0.17390799522399902), (2, 0.17412090301513672)]

MySQL SLA is broken? False

#####

Running with Dataset Size: 10000

MySQL Queries: [(50, 0.2052299976348877), (50, 0.19243288040161133), (50, 0.19191193580627441), (30, 0.19255805015563965), (30, 0.1887669563293457), (30, 0.19298601150512695), (20, 0.1880810260772705), (20, 0.19396185874938965), (20, 0.19248104095458984), (10, 0.18845915794372559), (10, 0.19563794136047363), (10, 0.19304609298706055), (5, 0.18861603736877441), (5, 0.1923990249633789), (5, 0.18983006477355957), (2, 0.1927800178527832), (2, 0.18825697898864746), (2, 0.18577885627746582)]

MySQL SLA is broken? False

#####

Running with Dataset Size: 100000

...

MySQL Queries: [(50, 0.5140020847320557), (50, 0.30184102058410645), (50, 0.3160550594329834), (30, 0.30850696563720703), (30, 0.3058919906616211), (30, 0.31014108657836914), (20, 0.33054089546203613), (20, 0.34288787841796875), (20, 0.3059229850769043), (10, 0.30807995796203613), (10, 0.33196115493774414), (10, 0.30630993843078613), (5, 0.30664610862731934), (5, 0.30666184425354004), (5, 0.3065659999847412), (2, 0.30725812911987305), (2, 0.3074190616607666), (2, 0.33382105827331543)]

MySQL SLA is broken? False

#####

Running with Dataset Size: 1000000

...

MySQL Queries: [(50, 2.9074718952178955), (50, 3.169628143310547), (50, 3.068336009979248), (30, 2.946420907974243), (30, 2.983638048171997), (30, 3.0676960945129395), (20, 3.0680489540100098), (20, 3.0676097869873047), (20, 3.272584915161133), (10, 3.0661330223083496), (10, 2.9682278633117676), (10, 3.0668060779571533), (5, 3.0365960597991943), (5, 3.0023999214172363), (5, 3.267791986465454), (2, 2.9456560611724854), (2, 2.9858040809631348), (2, 3.067668914794922)]

MySQL SLA is broken? True

#####

Running with Dataset Size: 2000000

...

MySQL Queries: [(50, 5.984281063079834), (50, 5.900359869003296), (50, 5.8593878746032715), (30, 5.726871013641357), (30, 6.033170938491821), (30, 5.932153940200806), (20, 5.8248679637908936), (20, 5.867033004760742), (20, 6.104353904724121), (10, 6.338104963302612), (10, 6.007672071456909), (10, 5.742549896240234), (5, 5.86237096786499), (5, 5.806718111038208), (5, 6.033854007720947), (2, 6.1649181842803955), (2, 6.007449150085449), (2, 5.827448844909668)]

MySQL SLA is broken? True

#####

Running with Dataset Size: 3000000

...

MySQL Queries: [(50, 12.227512836456299), (50, 8.691967964172363), (50, 9.1024010181427), (30, 8.589695930480957), (30, 8.678112030029297), (30, 8.629335165023804), (20, 8.566416025161743), (20, 8.55915904045105), (20, 8.624006986618042), (10, 8.615052938461304), (10, 9.280121088027954), (10, 8.590642213821411), (5, 8.700731992721558), (5, 8.774307012557983), (5, 8.706260919570923), (2, 8.449976921081543), (2, 8.513587951660156), (2, 8.501986026763916)]

MySQL SLA is broken? True

Execution Report 02

Elastic Queries: [(50, 0.37639307975769043), (50, 0.34427809715270996), (50, 0.3618030548095703), (30, 0.35060906410217285), (30, 0.3810849189758301), (30, 0.35098695755004883), (20, 0.35475611686706543), (20, 0.36417102813720703), (20, 0.37682604789733887), (10, 0.3461129665374756), (10, 0.36162900924682617), (10, 0.3642888069152832), (5, 0.3701000213623047), (5, 0.3491690158843994), (5, 0.36877894401550293), (2, 0.3788158893585205), (2, 0.38399386405944824), (2, 0.3639249801635742)]

Elastic SLA is broken? False
