ANALYSIS AND DESIGN OF SCALABLE SOFTWARE AS A SERVICE ARCHITECTURES

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Onur Özcan
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SOFTWARE AS A SERVICE ARCHITECTURES
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We certify that we have read this thesis and that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

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ABSTRACT

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January, 2015

Different from traditional enterprise applications that rely on the infrastructure and services provided and controlled within an enterprise, cloud computing is based on services that are hosted on providers over the Internet. Hereby, services are fully managed by the provider, whereas consumers can acquire the required amount of services on demand, use applications without installation and access their personal files through any computer with internet access. Recently, a growing interest in cloud computing can be observed thanks to the significant developments in virtualization and distributed computing, as well as improved access to high-speed Internet and the need for economical optimization of resources.

An important category of cloud computing is the software as a service domain in which software applications are provided over the cloud. In general when describing SaaS, no specific application architecture is prescribed but rather the general components and structure is defined. Based on the provided reference SaaS architecture different application SaaS architectures can be derived each of which will typically perform differently with respect to different quality factors. An important quality factor in designing SaaS architectures is scalability. Scalability is the ability of a system to handle a growing amount of work in a capable manner or its ability to be enlarged to accommodate that growth. In this thesis we provide a systematic modeling and design approach for designing scalable SaaS architectures.

To identify the aspects that impact the scalability of SaaS based systems we have conducted a systematic literature review in which we have identified and analyzed the relevant primary studies that discuss scalability of SaaS systems. Our study has yielded the aspects that need to be considered when designing scalable systems. Our research has continued in two subsequent directions. Firstly, we have defined a UML profile for supporting the modeling of scalable SaaS architectures. The profile has been defined in accordance with the existing practices on defining and documenting profiles. Secondly, we provide the so-called architecture design perspective for designing scalable SaaS systems. Architectural Perspectives are a collection of activities, tactics and guidelines to modify a set of existing views, to document and analyze quality properties. Architectural perspectives as such are basically guidelines that work on multiple views together. So far architecture perspectives have been defined for several quality factors such as for performance, reuse and security. However, an architecture perspective dedicated for designing scalable SaaS systems has not been defined explicitly. The architecture perspective that we have defined considers the scalability aspects derived from the systematic literature review as well as the architectural design tactics that represent important proved design rules and practices. Further, the architecture perspective adopts the UML profile for scalability that we have defined. The scalability perspective is illustrated for the design of a SaaS architecture for a real industrial case study.

Keywords: Cloud Computing, Software as a Service, SaaS, Scalability, Software as a Service Architectures, Systematic Literature Review, Architectural Perspective, Architecture design, UML Profiling.

ÖZET

ÖLÇEKLENEBİLİR HİZMET OLARAK SUNULAN YAZILIM MİMARİLERİNİN ANALİZ VE TASARIMI

Onur Özcan
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Tez Danışmanı: Yrd. Doç. Dr. Bedir Tekinerdoğan
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İşletme içinde sağlanan ve kontrol edilen altyapı ve hizmetlere dayanan geleneksel kurumsal uygulamalardan farklı olarak, bulut bilişim sağlayıcıları Internet üzerinden barındırılan hizmetleri temel alır. Bu vesileyle, hizmetler tamamen sağlayıcı tarafından yönetilirken, tüketiciler ise gerekli miktardaki hizmetleri talebi üzerine elde edebilir, yükleme olmadan uygulamaları kullanabilir ve internet erişimi olan herhangi bir bilgisayar üzerinden kişisel dosyalarına erişebilir. Son zamanlarda hem sanallaştırma ve dağıtılmış bilgi işlemdeki önemli gelişmeler, hem de yüksek hızlı İnternete gelişmiş erişim sağlanması ve kaynakların ekonomik olarak en uygun şekle sokma ihtiyacı sayesinde bulut bilişim üzerinde artan bir ilgi gözlenebilmektedir.

Yazılım uygulamalarının bulut üzerinden sağlandığı hizmet olarak sunulan yazılım alanı bulut bilişimin önemli bir kategorisidir. Hizmet olarak sunulan yazılımı anlatırken genellikle, belirli bir uygulama mimarisi belirtilmez, ancak bunun yerine genel bileşenler ve yapı tanımlanır. Sağlanan referans hizmet olarak sunulan yazılım mimarisine dayanarak farklı hizmet olarak sunulan yazılım mimarileri elde edilebilir. Bu mimarilerin her biri genel anlamda farklı kalite faktörlerini uygulayacaktır. Ölçülebilirlik, hizmet olarak sunulan yazılım mimarileri tasarımı konusunda önemli bir kalite faktörüdür. Ölçülebilirlik, sistemin artan iş yükü miktarıyla yetenekli bir şekilde başa çıkabilme veya bu artışa uyum sağlayabilmek için genişleyebilmesidir. Bu tezde ölçeklenebilir hizmet olarak sunulan yazılım mimarilerinin tasarımı için sistematik modelleme ve bir tasarım yaklaşımı sunuyoruz.

Hizmet olarak sunulan yazılım tabanlı sistemlerin ölçülebilirliğini etkileyen yönleri tespit etmek için ilgili birincil çalışmaları tespit ettiğimiz ve incelediğimiz sistematik bir kaynak taraması yaptık. Çalışmamız ölçeklenebilir sistemlerin tasarımında dikkate alınması gereken yönleri açığa vurmuştur. Araştırmamız, sonraki iki yönde devam etti. İlk olarak, ölçeklenebilir hizmet olarak sunulan yazılım mimarilerinin modellemesini desteklemek için bir UML profili tanımladık. Bu profil, profiller tanımlayan ve belgeleyen mevcut uygulamalara uygun olarak tanımlanmıştır. İkinci olarak, ölçeklenebilir hizmet olarak sunulan yazılım sistemlerini tasarlamak için mimari perspektifi sunduk. Mimari perspektifler, varolan bir dizi görünümleri değiştirmek, kalite özelliklerini belgelemek ve analiz etmek için kullanılan faaliyetler koleksiyonundan, taktiklerden ve talimatlardan oluşmaktadır. Mimari perspektifler temelde birden çok görünüm üzerinde birlikte çalışan talimatlardır. Şimdiye kadar mimari perspektifler performans, yeniden kullanım ve güvenlik gibi çeşitli kalite faktörleri için belirlenmiştir. Ancak, ölçeklenebilir hizmet olarak sunulan yazılım sistemlerini tasarlamaya özel bir mimari perspektif açıkça tanımlanmış değildir. Bizim tanımladığımız mimari perspektif, hem sistematik kaynak taramasından elde edilen ölçeklenebilirlik yönlerini hem de önemli olduğu kanıtlanmış tasarım kurallarını ve uygulamalarını temsil eden mimari tasarım taktiklerini göz önünde bulundurur. Ayrıca, mimari perspektif ölçeklenebilirlik için bizim tanımladığımız UML profili benimser. Ölçeklenebilir perspektif, gerçek bir endüstriyel vaka çalışmasının hizmet olarak sunulan yazılım mimari tasarımı üzerinde gösterilmiştir.

Anahtar sözcükler: Bulut Bilişim, Hizmet Olarak Sunulan Yazılım, Hizmet Olarak Sunulan Yazılım Mimarileri, Sistematik Kaynak Taraması, Mimari Perspektifi, Mimari Tasarımı, UML Profili.

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Chapter 1

Introduction

1.1. Background

1.1.1. Cloud Computing

The need for economical optimization of resources leads to various improvements in the information technology. We have improved access to high-speed Internet. Besides, we have realized significant developments in virtualization and distributed computing. As a result, cloud computing has emerged, it has received significant interest, and use of it has increased in recent years. It is an important trend recently. It has not only changed today's computing resources, infrastructure, platform, and software services, but also alters the way of obtaining, managing, and delivering them for all participants, and also alters technology and solutions contributing to realize that. The definition of it is “a model for enabling convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction” [37]. In this definition, the most essential characteristics of cloud computing are identified as on-demand self-service, resource pooling, broad network access, measured service and rapid elasticity, respectively.

Cloud computing has a significant difference from traditional enterprise applications. Instead of accessing the infrastructure, platform, and software within the existing system, customers access them through cloud computing services providing them from a central unit. These services are hosted and fully managed by the providers. Consumers can buy the required amount of services on demand, they can access the services and their data through any device over the Internet, and they can use services without installation. Supplying resources as a service from a central unit allows more cost-effective, flexible, and efficient computing. It reduces hardware and software costs by leveraging cloud resources in a pay-as-you-go way using virtual resources.

Cloud computing includes several categories of service, such as software as a service (SaaS), platform as a service (PaaS), and infrastructure as a service (IaaS). All of these services are offered on-demand over the Internet in a pay-as-you-go model. Briefly, SaaS provides on-demand software applications, PaaS provides on-demand software development platforms, and IaaS provides on-demand computing infrastructures. Cloud taxonomy has other elements, such as cloud software, service as a service, and cloud client. Cloud software is unique purchased/packaged software used to build and run cloud services. Service as a service is horizontal service that is subscribed to and used as a component of SaaS, IaaS, or PaaS offerings, such as a billing service. Cloud client is client-centric services and run-time software for cloud execution.

1.1.2. Software as a Service

Software as a Service (SaaS) is a web-based software distribution model that delivers on-demand applications. It is the most mature the cloud service model, since it evolved from the application-service-provider (ASP) model of software hosting. The software is owned, hosted, and managed at a central site by the service provider. It is accessed remotely over the Internet by multiple tenants. It does not reside on client computers. Thus, users subscribe to the use of software rather than acquiring it. And they pay for on a subscription basis as opposed to purchasing it. Metric for subscription fee varies; it can be per month, per document, per employee, etc.

Among IT business models SaaS is the only model that is growing in a double-digit fashion, because it yields benefits for both service providers and end-users, such as reduced cost, faster-time-to-market, anywhere access, and enhanced scalability. From end-users perspective, instead of having to purchase hardware, software, and the licenses in order to execute a specific application, they are just subscribing to provider and using the application. So they have much lower and predictable costs. In addition, SaaS offers high level of agility; the duration between the time that an end-user identifies the need of having an application and the time it finds the provider and it can start using that application is generally very short. Another advantage is that an application become available at once and can be reachable by all end-users all over the world. On the other hand, being reachable increase the possibility for providers to reach the global market and have more potential to grow their customer base. Finally, SaaS ensures cost effective dynamic scalability. Executing processes that take a large amount of resources is possible with more powerful hardware. Realization of this by multiple end-users is hard in terms of cost and scalability. However, providers can increase number of resources and they can upgrade them only once or few times in a year more easily.

A SaaS application should have three key characteristics that are multi-tenancy, configurability, and scalability [8]. Multi-tenancy is a software architecture principle that offers a single instance of the software runs on a server to multiple tenants. A tenant is a customer and each tenant has multiple users. Every tenant experience application as if it were dedicated only to them. It allows computing resources to be shared among tenants. Besides, SaaS can be configurable by supporting customization. In other words, an end-user should have the ability to alter a set of configuration options that affect functionality, communication, or appearance of SaaS application. Each tenant may have its own settings for configuration options. Lastly, we will explain scalability in detail in next section.

1.1.3. Scalability

Increase in the usage of cloud services brings new issues, challenges, and needs in software analysis, design, development, testing, evaluation, and measurement due to the crucial qualities, such as scalability. Scalability is the ability of a system to handle a growing amount of task and to be adjustable to accommodate that growth [48]. Scalability can be measured in various dimensions such as load, geographic, functional, administrative, and generation scalability. Each dimension has the same abstract purpose of having ability of handling more and less tasks efficiently, yet these things depend on the dimension.

- Functional scalability describes whether a functionality of a distributed system can be easily expanded and contracted by adding or removing new functional modules [48]. We can say a system is functional scalable if software architecture of it can support addition and subtraction of functional modules easily.
- Load scalability describes whether hardware resources of a distributed system can be easily expanded and contracted by adding or removing resources in order to accommodate heavier or lighter loads [48]. We can say a system is load scalable if it can cope with heavier data loads and also can maintain its operation with fewer resources when it has lighter loads. Functional scalability eases achieving load scalability.
- Geographic scalability describes whether area of a distributed system can be easily expanded and contracted by distributing into wider area or assembling in a local area [48]. We can say a system is geographic scalable if it can perform well even its service area is expanded and also can maintain its operation with fewer resources when it services in a limited area.
- Administrative scalability describes whether a distributed system can be easily shared and managed even when the number of users and tenants are increased or decreased [48]. We can say a system is administrative scalable if it can deal with high number of users and also can maintain its operation with fewer resources when it has less number of users.

- Generation scalability describes whether a distributed system can be easily scaled up and down by adding and removing new generations of components [48]. We can say a system is administrative scalable if it can support addition and subtraction of components easily.

Providing scalability for a system is a time course that involves analysis, design, and development phases [47]. Even execution of the system is included in this duration, as demands for a system grow, new scalability requirements are born and existing requirements need to be improved. Any fault in these phases may lead to loss of customer, money, labor, and time due to unsatisfying scalability. A software system that is not scalable for the recent demands will probably face with breakdown. If this breakdown occurs frequently or longtime, customers will give up using it and the company will lose money. In order to avoid this situation, the company will probably try to redesign software architecture of the system and will purchase new hardware, so this causes loss of time and labor.

Scalability has tight relation with other non-functional properties of a system, such as performance, availability, and reliability. Scalability is usually come up with performance; performance of a system has impact on scalability. However, scalability is more than performance, since it does not only cover the existing performance, but also answers what happens if the number of users becomes bigger than the specified number. Even though a system can run in the normal conditions now, when unprepared or unpredicted case for the system occurs, the system may crash, and cannot service to its users until it is fixed or until the case ends. Thus, availability and reliability is also affected by scalability.

Scalability was one of the underestimated non-functional requirements in the past. Several products were successful but not sustainable due to their limitations on the scale. However, a solid system needs to be able to handle also growing demands, for example number of user for load scalability, and to be able to arrange itself according to this grow. To be able to realize this quality architect of the system needs to produce a well-design.

1.2. Problem Statement

We have identified the following problems in scalability analysis and design of SaaS. Below we describe each problem separately.

- Lack of a guideline that briefly presents all aspects of a SaaS system that affects scalability and the most applied tactics to enable scaling easily.
- Lack of a formal approach for scalability analysis models.
- Lack of a guideline that explains the procedure of making a system scalable.

Lots of studies have discussed their experience on SaaS scalability. These studies have both common and distinct parts. A developer, who wants to scale its SaaS system, should be able to understand where the problem is and to find the correct solution alternatives easily and rapidly. In order to realize that there should be a guideline study that gathers the most covered aspects and tactics addressed by studies. These aspects and tactics should be explained briefly and clearly, and they should be understandable. However, in the existing studies aspects of SaaS have not been presented explicitly, they have usually focused on the tactics and mentioned aspects in descriptions of tactics. Also, analytics about how many times a tactic has been included in primary studies, and to which aspect it has been addressed most should be covered.

Most of large-scale systems suffer from scalability, and the reason of that is; these systems have not designed and implemented as a system that can handle larger scale of demands. How system scalability is required to be should be described before actually testing it in real life. Firstly, unambiguous, sufficient, detailed information about system scalability should be obtained. Secondly, the scalability requirements should be well understood. In order to achieve that, scalability models of the system should be provided. Scalability models enable us to see both run-time behavior and deployment of the system with scalability features. These models should be obvious, concrete, testable, and they should also be understandable by all of the stakeholders. Also, scalability modeling should be made in a formal and systematic manner. Finally, analysis of system scalability should be made in every phase of the system development. During this analysis scalability requirements should be validated and modifications should be made.

Scalability is usually taken into consideration as a performance concern. However, it should be studied in detail separately. We should be able to ensure that the architecture exhibits the desired scalability properties via using existing architectural views. Activities, tactics, and guidelines related to analysis and design of system scalability should be precise. The steps to follow to be able to assess scalability should be identified, so that the parts of the system that cannot scale can be eliminated early, before testing the system with the participation of stakeholders.

1.3. Approach

In order to provide a scalability guideline to address above problems, we have initially needed to fetch brief, beneficial, and related information from high number of primary studies. Instead of doing our domain research study in a careless way, we have decided to follow Kitchenham's guideline to perform systematic literature review. This approach has provided us regular progress in our research, and has enabled us to reach detailed and clear results. We have started with defining our research questions, whose purpose is to understand the aspects and tactics mentioned in the primary study. A search string to filter the related primary studies while doing search operation in the database has been constituted. We have assembled the primary studies that have been listed after executing our search string on each search database. Then, we have eliminated the false-positive ones by applying our exclusion criteria on studies. Finally, we have analyzed the remaining studies while thinking our research questions. We have acquired data from them to constitute list of aspects that affects SaaS scalability and list of tactics that can be applied to make a SaaS system scalable. Then, we have produced analytics on aspects and tactics described in studies.

In order to fulfill the issue in formal scalability modeling we have benefited from the framework for quality analysis model offered by OMG. We have followed their guideline format and have defined scalability domain and UML viewpoints. Firstly, we have examined the general resource model and performance analysis model, and then we have determined the elements that also take place in scalability analysis. Secondly, we have extended our analysis on scalability domain to define each unit involving in scalability. We have identified relations among all scalability domain elements. Also, we have defined UML equivalents of all domain elements which are stereotypes and association tags. Scalability models have been derived from the viewpoint models of the system. They have been constituted via placing defined stereotypes and association tags that include specific scalability features.

We have thought that a procedure that explains the steps of achieving system scalability can be achieved by defining a software architecture perspective. We have adopted Rozanski and Woods' architecture perspective catalogue. Defining a perspective includes identifying applicability, concerns, activities, and problems. Firstly, architecture viewpoints of the system should be evaluated whether they require any modifications to provide scalability, and whether these modifications are applicable. Concerns of scalability have been determined to be able to evaluate and measure the quality. Activities have been constituted from five steps, which are capturing scalability requirements, creating scalability models, analyzing scalability, assessing scalability, and reworking architecture. We have followed IEEE Software Engineering Book of Knowledge (SWEBOK) [26] to carry out capturing scalability requirements. In creating scalability models we have utilized from our UML profile for scalability. In analysis part we have included both architecture design and code levels. We have adopted SAAM for architecture design level analysis, and have benefited from some software testing types, such as performance, load, spike testing. Finally, we have presented common problems and pitfalls that are possible to occur during applying scalability perspective.

Finally, we have provided application of scalability perspective on our case study, Cloud Hotel Management System. We have presented architectural viewpoints of the system, have described scalability requirements, and have provided scalability analysis models.

1.4. Contribution

The contributions of this thesis can be defined as follows:

- *Systematic Literature Review (SLR) of SaaS Scalability*

Up to now no studies have performed systematic literature review on the studies related to SaaS scalability. Studies and resources on this topic are discrete, and needs to be reviewed and assembled. We have detected this need and have filled this gap. We have scanned all primary studies in search databases, have examined 99 of them residing in databases, and have selected 32 of them after applying our exclusion criteria. We have constituted a list of aspects that affects SaaS scalability and a list of tactics that can be applied to make a SaaS system scalable. We have provided a description for each of aspects and tactics. Moreover, we have provided analytics that involve the number of occurrence an aspect is contained or the number of occurrence a tactic is presented.

- *UML Profile for Scalability*

We have found out that scalability analysis modeling should have rules and standards, so that people can use scalability models in a unique and formal way to reveal problems before testing their systems. We have extended framework for quality analysis model offered by OMG and have defined UML Scalability Profile based on General Resource Model (GRM). Thus, we have provided a tool for scalability assessment for the stakeholders. In order to realize this profile we have defined scalability domain viewpoint to understand and to cover domain well, and we have also defined stereotypes and association tags, which describe domain concepts, are used in UML models.

- *Software Architecture Perspective for Scalability*

Scalability quality of the system is closely related to performance and has presented together in the existing studies. We have claimed that scalability should be separated and we have defined architectural perspective for scalability. We have extended Rozanski and Woods' architectural perspective catalog. We have identified concerns of scalability and we have defined the steps to apply the perspective. We have presented a study that will guide you to achieve your system scalability. We have also provided a chapter that explains application of the perspective for a case study.

1.5. Outline of the Thesis

This thesis is organized as follows: Chapter 2 provides background information for SaaS architecture and presents systematic literature review made on studies related to scalable architectures for SaaS. We present the results of our research and provide a list of aspects that affect scalability of SaaS and a list of tactics to achieve scalability of SaaS. Chapter 3 introduces UML profile for scalability that is based on general resource model. Firstly, background information about general resource and scalability analysis modeling is given. Then, domain viewpoint is defined using scalability concepts. Also, stereotypes and associated tags are defined while mapping domain viewpoint elements to UML equivalents. In Chapter 4, software architecture perspective for scalability is presented. Firstly, definitions and overview of the perspective is given. Then, parts, such as concerns, activities, and problems are examined in detail. Chapter 5 presents our case study, Cloud Hotel Management System, in order to show application of information given in previous chapters on a real system. Chapter 6 gives the related work. Finally, Chapter 7 presents the conclusions and discussions.

Chapter 2

Software as a Service Architecture for Scalability

2.1. Software as a Service Architecture

2.1.1. Reference Architecture

Reference software architecture represents the structures and respective elements, and relations provide templates for concrete architectures in a particular domain or in a family of software systems [9]. It utilizes reference model which is an abstract framework aiming to encourage clear communication includes a set of clearly defined terms and concepts linking together. It provides a template based on the generalization of a set of solutions. Each of reference architecture is formed for a particular domain. Reference architecture is beneficial for people and organizations that work in the same domain. Concrete architecture is formed on the basis of it. Reference architecture accelerates the design of concrete architecture and implementation by reusing an effective architecture. Concrete architecture uses business requirements, and system requirements are also included since they are used by reference architecture. Figure 1 shows the conceptual model that represents reference architecture and its factors.

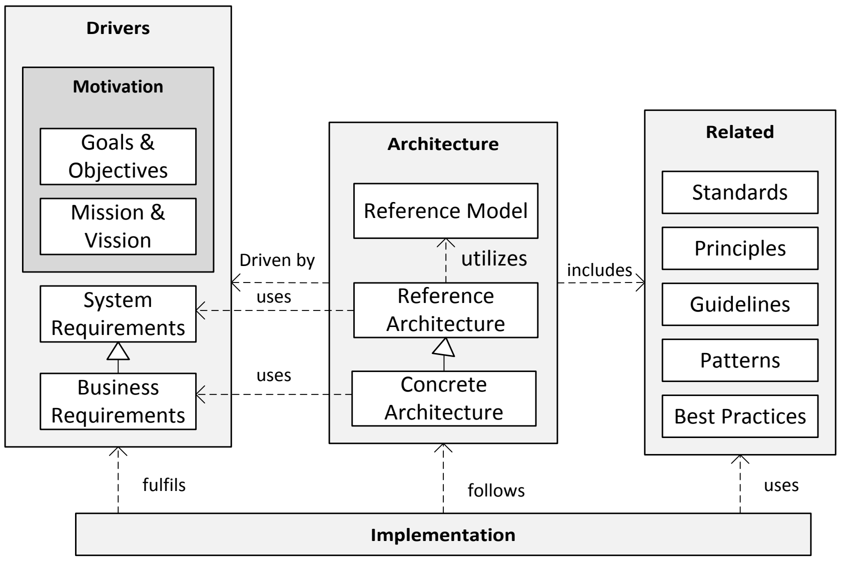


Figure 1: A conceptual model representing reference architecture and its factors

2.1.2. Reference Architecture for SaaS

Software provided by SaaS provider is rent and accessed through internet by multiple clients. Basic SaaS architectures are often variations of the classic three-tier web application hosting model that contains presentation, application, and data tiers. Traditional web application architecture is illustrated in Figure 3. Distribution tier has a load balancer and web servers that handle HTTP requests. Application tier has a load balancer and application servers that run business logic. Data tier consists of master, slave, and backup database servers. Thus, this architecture has already been designed to scale out by adding additional hosts at the persistence or application layers and has built-in performance, failover and availability features.

Increase in SaaS adoption as well as the new technology innovations has significantly evolved SaaS architecture. Now, SaaS applications may have different purpose and design priorities such as reliability, security, availability, performance, scalability, and cost. Design priorities of three-tier architecture are typically availability and cost, so it is not sufficient for all purposes. A study made by Tekinerdoğan and Öztürk [53] have examined various architectures and addressed reference architecture of SaaS. Many architecture structures harvest a set of patterns which have been in a number of successful implementations. They have worked on these architectures and have provided a reference architecture for SaaS, see Figure 2, after generalization and structure of them. SaaS has a multi-tier architecture which is composed of user tier on the client-side, and distribution, presentation, business service, application, data access, data storage, and supporting service tiers on the provider side.

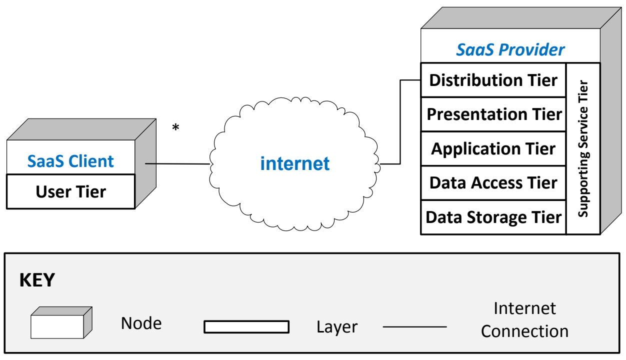


Figure 2: SaaS Reference Architecture

User tier consists of presentation functionality that is used by web browser and data integration functionality which is used by web services of the provider. Distribution tier contains load balancing and routing functionalities. Presentation tier is responsible from presenting the formatted data to the user and adapting user interactions. Application tier is formed by modules or services, such as identity management, application integration, and communication. Data access tier involves the functionality of accessing the data through caches or database through management system. Data storage tier has database servers. Supporting service tier plays as an assistant tier for all horizontal tiers. It provides functionalities such as monitoring, billing, additional security services, and fault management.

2.1.3. Reference Architecture for Scalable SaaS

A well designed SaaS application is generally distinguished by mainly three qualities, multi-tenant efficiency, configurability, and scalability. A multi-tenant architecture (MTA), in which all users and applications share a single, common infrastructure, and code base, that is centrally maintained. Configurability is the ability for each user to easily customize applications to fit their business processes without affecting the common infrastructure. To support scalability the application is installed on powerful or/and multiple machines. In order to distribute the system efficiently application should have a scalable architecture. Reference architecture for scalable SaaS is illustrated in Figure 4. Using scalable architectures in applications have various advantages, such as handling peak load behavior and addition of new features [1]. You can overcome problems that emerge during viral events. You can leverage the scalability the cloud affords to make the most productive use of development and testing time when introducing new features to an application. You can absorb sudden increases in processing time due to the addition of new features by scaling to accommodate the increased load they impart on the system until you can isolate and optimize the performance bottlenecks. It is not uncommon for new features to place unexpected loads on a system when they are introduced. Exhaustive testing of the performance characteristics of these new features before release may be possible, but this often comes with significant cost both in time to market as well as in infrastructure and manpower.

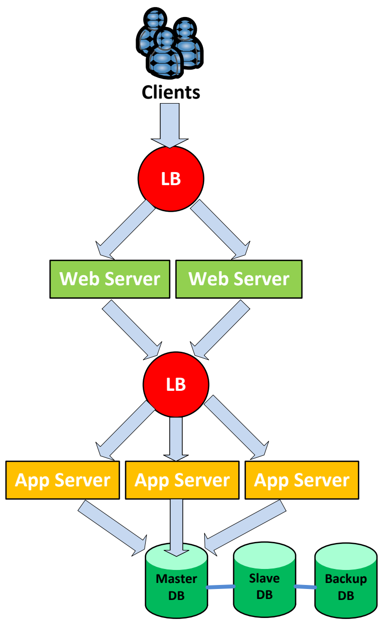


Figure 3: A traditional web application architecture

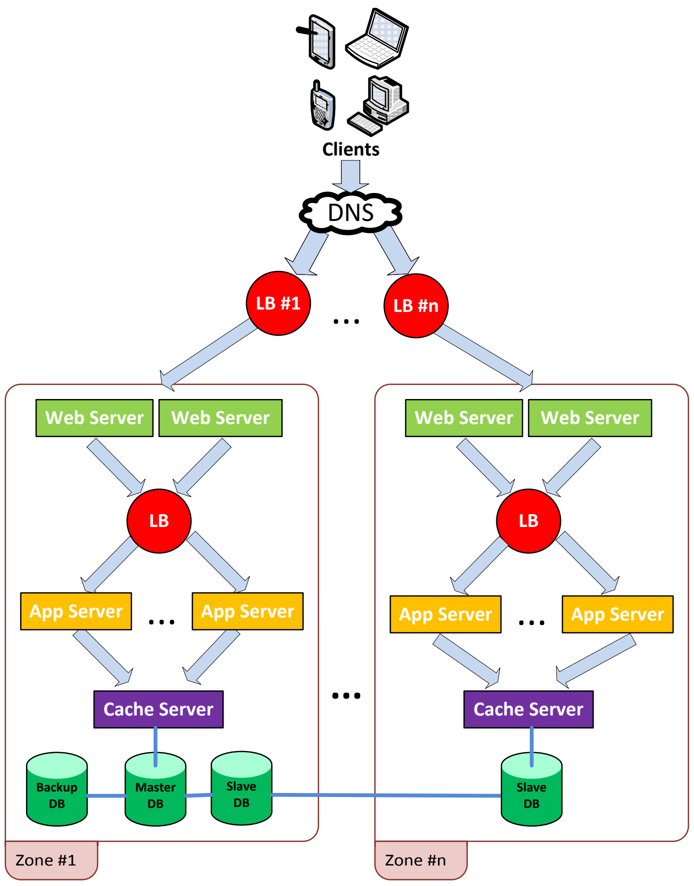


Figure 4: Reference Architecture for Scalable SaaS

2.2. Systematic Literature Review

We have aimed to analyze and have defined the key concerns related to SaaS and scalability. Our research method has adopted systematic literature review in which we have selected 32 primary studies. As a result of the data extraction and synthesis process of the systematic literature review we have provided a list that characterizes the various important concerns with respect to scalability and SaaS. The outcome of the paper can be useful for both practitioners and researchers to know the current scalability aspects and tactics.

After the observation that some aspects of the SaaS has impact on the scalability, and there are some techniques that can be applied to provide scalability of SaaS. To identify the aspects that have impact on scalability of SaaS and approaches to achieve scalability we have conducted a systematic literature review using the guidelines as described by Kitchenham [33]. In particular we have interested in the answers to the following research questions:

RQ1: What are the factors that affect scalability in SaaS?

RQ2: What are the current approaches for achieving scalability in SaaS?

Our search scope has included all the papers that were published in 2003 to 2014. We have searched for full papers in selected venues that publish high quality papers. We have used the following search databases: IEEE Xplore, ACM Digital Library, Wiley Inter Science Journal Finder, ScienceDirect, ISI Web of Knowledge, Springer, and other channels including Microsoft Academic Search and manual search channels. These venues are listed in Table 1. Our targeted search items are journal papers, conference papers, and workshop papers.

Table 1: Publication Sources Searched

Source	**Number of Included Studies After Applying Search Query**	**Number of Included Studies After Exclusion Criterion**
IEEE Xplore	33	17
ACM Digital Library	5	3
Wiley Interscience	3	0
Science Direct	1	0
ISI Web of Knowledge	16	2
Springer	25	4
Other Channels	16	6
Total	**99**	**32**

To search the selected databases we have used both manual and automatic search strategies. Automatic search has been realized through entering search strings on the search engines of the electronic data source. Manual search has been realized through manually browsing the conferences, journals or other important sources and checking the references of selected papers. The manual searches have appeared to be quite useful since we retrieved some good-quality articles that an automatic search could not reveal.
The adopted search string is as follows:

("Document Title": scalability OR "Document Title": scalable OR "Document Title": scaling)
AND
("Document Title": architecture OR "Document Title": software OR "Document Title": SaaS OR "Document Title": "Software as a Service")
AND
("Abstract": cloud OR "Abstract": SaaS OR "Abstract": "Software as a Service")

The result of the overall search process after applying the search queries and the manual search is shown in the second column of Table 1. As it can be seen from the table we could identify 99 papers at this stage of the search process. After the initial set of exclusion, we are unable to find any papers that discuss this issue.

In accordance with the SLR guidelines [33] we have further applied an exclusion criterion on the large number of papers in the first stage. The overall exclusion criteria that we have used are as follows:

- Abstract or title does not explicitly primarily discuss scalability
- Not a primary study
- The primary study does not consider SaaS architecture in particular
- Repeated in an already mined source
- Most of the content is repeated in a similar paper (Extended version is chosen over the shorter one)

The exclusion criteria have been checked by a manual analysis by both of the authors. According to the best of our knowledge, there has been no secondary study related to aspects and approaches for scalability of SaaS. After applying the exclusion criteria 32 papers of the 99 papers remained. For data extraction and synthesis process as required by the systematic review protocol we have thoroughly studied the primary studies in detail to answer our two defined research questions. The answers to the research questions have been described in the following paragraphs in which we have provided a short summary of each identified primary study with the basic conclusions.

2.3. Data Extraction

In order to extract data needed to answer research questions, we have read the full-texts of 32 selected primary studies. We have designed a data extraction form to collect all the information needed to address the review questions and the study quality criteria. The data extraction form has included standard information such as study ID, document title, year, authors, repository, and contribution type. In order to collect information directly related to answering research questions, we have added some fields such as targeted domain, motivation for study, main theme of study, aspects that affect scalability of SaaS, and approaches to achieve scalability of SaaS. We have kept a record of the extracted information in a spreadsheet to support the process of synthesizing the extracted data.

2.3.1. Aspects

An aspect is a particular part or feature of SaaS. Based on the primary studies we could identify the following key aspects that impact the scalability of SaaS; capacity, database access, network traffic, data management, disk architecture, data architecture, data model, workload, migration, fault-tolerance and recovery, software architecture, multi-tenancy, application complexity, and levels of scalability mechanisms.

2.3.1.1. Capacity

Capacity describes quantity and quality of hardware resources and specifications of the system software. The scalability of the system is in direct proportion with the capacity. Computing hardware resources, such as RAM, CPU, disk, memory, network bandwidth, the number of concurrent TCP connections the server can support, operating system, software resource allocation and utilization, define the capacity of the system. The scalability of the system is in direct proportion with the capacity [45]. As the power of resources increase or the number of the nodes increase the system can scale more. The need to host scalable systems leads to emergence of large-scale data centers comprising thousands to hundreds of thousands of compute nodes.

2.3.1.2. Database Access

The communication between components in business layer and database server is done via database access. The components obtain and save the required data through this connection, which makes data access the key aspect of scalability in the multi-tenant SaaS [58]. It will be the bottleneck of a SaaS system, if accessing a database is not efficient and is slow [23]. Database connection can be either direct or indirect. Direct access allows applications to perform necessary database operations directly, so scalability technique is done for the entire system. For instance, Database integrated SaaS, which is a SaaS system fully integrated with a database, has direct access, such as Salesforce.com [6]. On the other hand, in the indirect access to database there is a middle layer, APIs provided by database services, between business components and underlying database server. Indirect access allows the software and database to have its own scalability mechanism. For example, kernel-based SaaS, which is a SaaS system running on top of kernel that runs on top of databases. Any communication between software applications and databases occurs via the kernel, such as Corenttech.com [23].

2.3.1.3. Network Traffic

Another crucial issue in SaaS scalability is network traffic, which is the flow of data around a network. Data is encapsulated in network packets. Major concerns of network traffic that have impact on scalability include latency, packet size, packet count, and packet loss. Latency is a time interval between the stimulation and response. It is affected by both communication hardware specifications and distance between servers and clients. High distance leads to high latency. When latency in network traffic increases, response time of the system increases as well [24]. Packet loss occurs when one or more packets of data travelling across a network fail to reach their destination. It is typically caused by network congestion. It reduces the throughput of the system. Packet size and count is proportional to the workload created by users. As the number of users increases the latency and packet losses may increase. Thus, increase in these concerns causes a decrease in system performance and makes achieving scalability more difficult [46].

2.3.1.4. Data Management

Data is the mostly essential in cloud computing systems and it is the element that systems should handle heavier or lighter loads of data efficiently. In order to satisfy scalability data management should be carried out in a scalable manner. Data management comprises all the disciplines related to managing data as a valuable resource, such as development, execution of plans that control the data [38]. Data management has mainly two topics that affect scalability, disk architecture and data architecture.

2.3.1.4.1. Disk Architecture

Data storage is one of the central issues to achieve system scalability. Data is stored in disks, but storing data in scalable way is determined by disk architecture. Disk architecture is a distributed computing architecture. A distributed system is a software system in which components located on networked computers communicate and coordinate their actions by passing messages. Two most common cloud database architectures are shared disk and shared nothing. Shared disk architecture (SD) is a distributed computing architecture where all disks are accessible from all cluster nodes [2]. Since the persistent data is stored and shared in network attached storage (NAS), it is a candidate for single point of failure. However, it has some advantages that affect system scalability. It does not need migration. It is utilized for their ability to abstract replication, fault-tolerance, consistency, and independent scaling of the storage layer from the DBMS logic. On the other hand, in shared nothing architecture (SN) each node is independent, self-sufficient, and has sole access to distinct disks, generally locally attached storage, and there is no single point of contention across the system [60]. None of the nodes shares memory or disk storage. So if one of the instances is down, the requests of users will be forward to another node and the process is transparent to users. SN is popular for web development because of its scalability. A pure SN system can scale almost infinitely simply by adding nodes in the form of inexpensive computers, since there is no single bottleneck to slow the system down. A SN system typically partitions its data among many nodes on different databases assigning different computers to deal with different users or queries, or may require every node to maintain its own copy of the application's data, using some kind of coordination protocol. This is often referred to as database sharding. Both the load balance and the fault-tolerance requirements can be addressed. Also live migration requires that all database components are migrated between nodes, including physical storage files.

2.3.1.4.2. Data Architecture

In SaaS a single application instance of the software is shared among multiple independent users. A well-designed SaaS application is scalable, multi-tenant-efficient, and configurable. To satisfy these qualities it needs to have scalable and multi-tenant data architecture. Data architecture contains models, policies, rules or standards that specify data structure, determine which data is collected, and manage the way how it is stored, arranged, integrated, and put to use in systems. A component of data architecture, database, is an organized collection of data. Three data architecture models that implement and manage scalable multi-tenancy are separate databases, shared database-separate schemas, and shared database-shared schema [28]. Separate databases are stored on distributed shared-nothing environment [7].

A database should be scaled when it can no longer meet baseline performance metrics, as when too many users are trying to access the database concurrently or the size of the database is causing queries and updates to take too long to execute, or when operational maintenance tasks start to affect data availability. So providing scalable data model is crucial for all multi-tenant cloud computing systems and is a grand challenge for a decade.

Separate databases were the first general solution that is able to deal with large datasets stored on distributed shared-nothing environment [7]. Computing resources and application code are generally shared between all the tenants on a server, but each tenant has its own set of data that remains logically isolated from data that belongs to all other tenants. It is easy to customize the data model of the system for each tenant’s needs and to restore tenant’s data from backups in case of a failure. However, these systems have some disadvantages, they require higher hardware costs for maintaining equipment and backing up tenant data and they cannot scale beyond a few machines as the performance degrades dramatically due to synchronization overhead and partial failures. The second approach, shared databases-separate schemas, involves housing multiple tenants in the same database, with each tenant having its own set of tables that are grouped into a schema created specifically for the tenant. Like the isolated approach, the separate-schema approach is relatively easy to implement, and tenants can extend the data model as easily as with the separate-database approach. A third approach involves using the same database and the same set of tables to host multiple tenants' data.

2.3.1.4.3. Data Model

A data model organizes data elements and standardizes how the data elements relate to one another [20]. There are various data models used currently by software systems, such as relational, object, document, etc. The choice of data model has impact on the database scalability that directly affects system scalability. For instance, a SaaS system can scale from dozens to thousands or even more number of tenants that may have their particular needs. This case brings major challenges to databases. To achieve scalability a database should be able to handle the increase of both data and request accompanied with the growth of tenants. While providing this it should maintain meeting the particular needs of one tenant efficiently and safely without affecting the others.

In relational model all data is represented in terms of tuples grouped into relations. Relational database, whose data is organized using relational model, have some obstacles to be able to achieve scalability. Although relational databases scale well on a single server node, during the past decade there has been a growing concern that RDBMSs cannot easily scale-out from a few machines to hundreds or even thousands of machines and fails to provide adequate tools and guidance [2]. Thus, the need of scalability and multi-tenant support in SaaS makes traditional RDBMS unappealing and calls for a better data storage solution [20]. RDBMS represents the bottleneck of a SaaS system and introduces single point of failure, since it severely limits the scalability of SaaS.

In a key/value database, schemas and relationships between tables are not explicitly defined unlike a relational database, and therefore it is more flexible when scaling to larger number of server nodes. Modern scalable cloud storage systems, such as BigTable, Dynamo, and Cassandra has key-value data model.

2.3.1.5. Workload

Data, previously stored locally and only available to one single tenant, now require much larger storage and available to multi-tenants, since SaaS systems store bigger in both individual file size as well as total number of files and serves to multi-tenants. Thus, this change in data storage yields a challenge in workload and storage of systems, scalability problems. Workload influences many application characteristics such as software architecture and algorithm. Workload depends on the number of currently online access clients, the total load forms from every user’s network traffic and application service usage. There are three types of workload and require different scalability mechanisms [23], OLAP, OLTP, and mixed type. In OLAP type workload a high portion of the requests are reading data from the system. Read operations are usually with the purpose of querying historical data and analysing it [21]. In this case, the system should be able to scale in case of high volume of read operations. In OLTP write operations are dominant operations. Although many SaaS applications require rare updates, there are many cases for OLTP like Facebook and Salesforce. Users of both systems update their enterprise data, profiles, pictures or status frequently. In this case, the system should be able to distribute the write operations to avoid bottleneck at a single node. Finally, in mixed type the portion of read and write operations can be close and the architecture needs to be designed to ensure there is no bias towards either type of operations to be able to satisfy scalability requirements.

2.3.1.6. Migration

The process of transferring data between nodes is called migration. It is usually performed automated to facilitate people’s task. Data migration occurs for a variety of reasons including server or storage replacements or upgrades to get better performance. It can be done online or offline [23]. While the system is operational migrating data is defined as online migration and it is more problematic than offline migration that is done when the SaaS shuts down its services for maintenance. Data migration basically consists of two processes that are data extraction where data is read from old node and data loading where data is written to a new node. Data to be moved is critical in terms of amount and the location of data, since it influences the scalability of the system. To achieve scalability there are some strategies, such as minimizing amount of data to minimize the bandwidth demand, moving to the closest node to minimize latency delay [2].

2.3.1.7. Fault-Tolerance and Recovery

Fault-tolerance determines the ability of a system to maintain its operation properly in the case of the failure of some of its components, such as processors or storage. The data in the failed components can be obtained and corrected via recovery process. The causes of failure may be physical or logical damage. The solution for fault-tolerance and recovery affects the system scalability [23], and if an appropriate solution is not chosen the system may suffer. The solution should include detection of the nodes failed. The system should scale down without a significant performance downgrade, when a node fails. And when the failed node comes back to the system, it should automatically scale up and recover to previous working status.

2.3.1.8. Software Architecture

Scalability of SaaS systems is not only determined by the available resources, but also by software architects' early design decisions. Software architecture is the set of structures needed to reason about the software system, and comprises the software elements, the relations between them, and the properties of both elements and relations [9]. Scalability is impacted by how the control and data flow of the application or service is designed and implemented [23]. If software system is not well-designed, it cannot satisfy scalability and it needs expensive re-implementations [47]. A well-designed software architecture that satisfies scalability depends on the features of the system. Since each system has different features there is no one scalable software architecture design. For example, [23] classifies SaaS systems into four categories, such as Database integrated SaaS, Kernel-based SaaS, Service-oriented SaaS, and PaaS-based SaaS. All of them have different software architecture. We explain them in approaches section.

2.3.1.9. Multi-Tenancy

SaaS is characterized by its multi-tenancy architecture (MTA) that enables the sharing a single application instance of the software runs on a server among multiple independent users [34]. The term tenant refers to a group of users sharing the same view on an application. This view includes the data they access, the application configuration, the user management, particular functionalities, and related non-functional properties. MTA provides flexible customization to individual tenant. Each tenant runs the customized instance of SaaS that is designed to virtually partition its data and configuration while sharing the hardware, the operating system, the middleware and the application components [23]. However, the multi-tenancy architecture and customization requirements have brought up challenges in SaaS scalability. These challenges mainly comprise the high number of concurrent accesses from the users and handling large amount of tenants effectively in addition the amount of data for an application that rises rapidly.

2.3.1.10. Application Complexity

Another significant topic in SaaS that needs high levels of scalability is the way of processing large-scale data sets [23]. Storing and saving efficiently or blindly adding hardware resources may not necessarily yield the desired scalability in the system, since the data is obtained to process and to make operations on it and then save it. To be able to process effectively brings out the algorithms and makes the scalability of a system closely related to the underlying algorithm or computation. Algorithm of the implementation defines application complexity that specifies the difficulty level of an application. An application can be implemented with different ways using different algorithms. It affects time takes for realization of a task, so performance and scalability of a system is affected by it. So there occurs a need for designing algorithms and mechanisms that are inherently scalable. Algorithms that implement parallel approach offer greater portability, manageability and compatibility of applications and data and address the scalability issues.

2.3.1.11. Levels of Scalability Mechanisms

The architects can achieve the total scalability of the SaaS by taking on scalability of each tier of the SaaS having multi-layers separately [23]. Scaling a tier means applying a scalability technique to a tier. The techniques applied to a tier may be different for each single tier, because each tier has its own constraints and objectives. Furthermore, a tier of the architecture includes third-party business services, so the scalability of these services can be solved solely in its design.

Figure 5 shows the chart that indicates names of each aspect and their number of inclusion in primary studies.

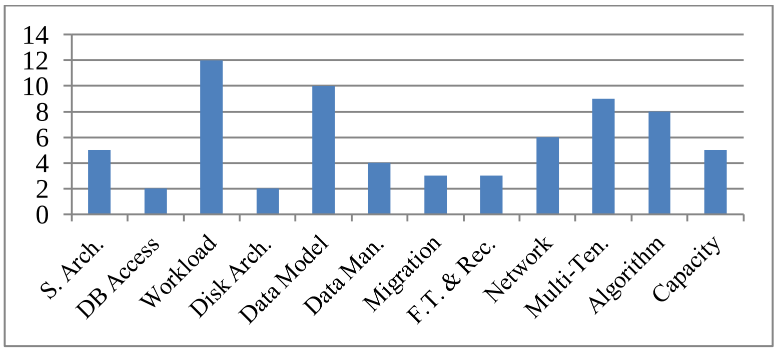


Figure 5: Chart that shows aspects and number of inclusion

2.3.2. Tactics

Architectural tactics are the approaches that should be applied to satisfy and improve scalability of the system. Based on the primary studies that we have found and examined during our systematic literature review study on the cloud-based software systems we could identify the following key architectural tactics; component-based architecture, service-oriented architecture, minimize the workload on the server, scale-up, scale-out, database partitioning, key-value stores, dynamic provisioning, caching, replication, virtualization, load balancing, parallel processing, and distributing processing in time.

2.3.2.1. Component-based Architecture

To be able to satisfy scalability of SaaS, the software architecture should have been designed in a way that in any condition the SaaS can scale up and down. And to achieve that the software architecture should have divided into layers and layers should be composed of components. Components are self-contained pieces of software and they are generally considered to be larger units of composition than objects [29]. In well-designed scalable software, the components should be separated according to their functional domain, i.e. the separation of concerns design principle should be applied and these components should have high cohesion internally and low coupling to the outside. Also, they should have minimum dependency among themselves, i.e. they should be loosely coupled independent components. They should not interfere with each other and they can be developed in parallel, i.e. they are stateless. This approach ensures that when a component or a layer causes being a bottleneck in the scalability, the developer can easily intervene in that component or that layer to fix it using a scalability approach. It facilitates applying scale-out, load balancing, and replication [35].

2.3.2.2. Service-oriented Architecture

Service-oriented architecture (SOA) is a software architecture design pattern that is composed of services, pieces of software providing application functionality [30]. As we indicate in previous approach in order to provide excellent scalability of SaaS, each part of the application should be able to be independently scaled [57]. Thus, it is necessary to avoid coupling in the architecture so that a change in a part of the software system should not affect other parts [23]. SOA achieve this, since services are unassociated units of functionality that are self-contained. SOA also provides asynchrony meaning system can perform useful work while waiting for input and output to complete, and concurrency meaning tasks can be done in parallel taking advantages of the distributed nature of hardware and software.

2.3.2.3. Minimize the Workload on the Server

Most of the cloud-based SaaS applications have some similar operations, such as making a request, authorization of the requests, fetching data from the database, inserting or updating or deleting data, validation of data, and making some operations, calculations, merging, etc. on data. These operations are either done in the client or in the server. If all of these operations are done in the server, then server may become unresponsive, even unavailable. Scaling-up the server solves this problem just temporarily, since as the demands grow the server always needs to be scaled-up and it is costly. The correct way to handle this problem is to move the workload from the server to the clients as much as possible and minimize the workload on the server [23], [47].

2.3.2.4. Scale-up

To cope with dynamically increasing demands from multiple tenants, the first approach that comes to mind is scaling the system vertically (scaling-up). It means to add resources to a single node in a system, typically involving the addition of processors or memory to a single computer [48]. In order to be scalable, the more nodes are added to the system, the higher the achievable throughput should be. When adding new hardware to the platform, the total capacity of the entire environment increases, becoming more scalable for not just a single customer, but for the entire client base. Such vertical scaling of a system also enables to use virtualization approach more effectively, as it provides more resources for the operating system and application modules to share [2]. Also, in order to avoid service outages, a system needs to allocate computing resources for the application dynamically.

2.3.2.5. Scale-out

The other and a popular approach that includes hardware addition is scaling horizontally (scale-out). It means to add more nodes to a system, such as adding a new server to a distributed server cluster [48]. Vertical scalability is addressed by increasing the power of nodes whereas horizontal scalability uses more nodes for the same job. It provides a more cost effective and smooth scalability versus scale-up approach [22]. When more computing power is required, a multi-tenant architecture makes it easy to increase capacity. Since SaaS platform consists of many tenants and all tenants share the same application and data store, and tenants are usually distributed to servers.

2.3.2.6. Database Partitioning

In order to support scalability of SaaS and real-time high performance computing we apply divide-and-conquer principle to the software architecture. When this principle has applied to databases, it means tenant data are partitioned well in the back-end database so that processing and I/O can be done in parallel, and data can be repartitioned easily. Partitioning is the process of pruning subsets of the data from a database and moving the pruned data to other databases or other tables in the same database [8]. You can partition a database by relocating whole tables, or by splitting one or more tables up into smaller tables horizontally or vertically. Horizontal partitioning means that the database is divided into two or more smaller databases using the same schema and structure, but with fewer rows in each table. Two most widely used horizontal partitioning methods are application-based distribution keys in which choosing one or more attributes as a distribution key according to domain knowledge and tenant-used distribution keys where stores each tenant’s data in a single partition. Vertical partitioning means that one or more individual tables are divided into smaller tables with the same number of rows, but with each table containing a subset of the columns from the original. Partitioning is also an example of scale-out approach, since in order to improve the efficiency the number of databases or tables is increased [58].

In a multi-tenant SaaS data scaling approach for the data model aspect differs, since the approach you choose for your SaaS application's data architecture will affect the options available to you for scaling it to accommodate more tenants or heavier usage [8]. The scalability patterns address the different challenges posed by scaling shared databases and dedicated databases. For separate databases single tenant scale-out approach is applied. Shared database approaches are well-suited to the tenant-based horizontal partitioning pattern, because each hardware resource has its own set of data, so the managers can easily target individual tenant data and move it to another server.

Existing systems show that partitioning can effectively increase the scalability of database systems, by parallelizing I/O or by assigning each partition to separate workers in a cluster. Data partitioning is a proved technique that database systems provide to physically divide large logical data structures into smaller and easy manageable pieces (chunks) [54]. The data inside a database can be distributed across one or more partitions. Horizontal partitioning is writeable operation preferable, while column store and vertical partitioning is optimal for read operations. Also, a hybrid approach is used in SaaS that involves both read and write operations.

2.3.2.7. Key-value Stores

As we see in previous section most of the aspects of the SaaS are related to database, and this indicates us database comes out as being a bottleneck for the scalability. In a multi-tenant environment that has high number of requests, database must be able to execute large requests with low response times and also redistribute data and load on the new hardware. To be able to satisfy these requirements of the database and scale data layer successfully key-value stores are used [2]. Key-value stores (KVS) allow the application to store its data in a schema-less way. In KVS data is viewed as key-value pairs and atomic access is supported only at the granularity of single keys. Since the data could be stored in a data type of a programming language, there is no need for a fixed data model. In DBMS all data within a database is treated as a whole and it is the responsibility of the DBMS to guarantee the consistency of the entire data. In the context of key-value stores this relationship is completely severed into key-values where each entity is considered an independent unit of data or information and hence can be freely moved from one machine to the other. Also, single key atomic access semantics naturally allows efficient horizontal data partitioning. Moreover, the design of the key-value stores provides dynamic provisioning in the presence of load fluctuations easily. On the other hand, traditional DBMS are more appropriate for static provisioning. Due to the above desirable properties of key-value stores, they have almost limitless scalability. Key-value stores can be applied either from the beginning of the system setup or leveraging from it during using the conventional DBMS architecture.

2.3.2.8. Dynamic Provisioning

By adding new resources to system or partitioning data we just guarantee scalability of the system for a while. However, there is another challenge in SaaS; the system should provide scalability even sudden load fluctuations on an application or a service due to demand surges happens [2]. The basis of the mechanism that respond to sudden is dynamic provisioning which includes deploying and instantiating the server computing instances from a centralized administrative console. Briefly, this mechanism should make the system maintain and avoid any interruption. Dynamic provisioning mechanism uses scalability approaches dynamically, i.e. a system can be scaled-up dynamically by adding more nodes or can be scaled-down by removing nodes, and this is called as elasticity. With dynamic provisioning processing can be shifted to off-peak hours.

2.3.2.9. Caching

Caching is a common practice of storing data in a medium holding smaller amounts of data but which can deliver it faster than a secondary complete source when future requests are made [32]. The purpose of caching is to be able to serve data faster when dealing with thousands of requests per second. By serving data faster throughput of the system is increased, response time is decreased, and scalability can be satisfied. Almost every application can be configured to use caching either as a built in feature or third party library. Also, caching can be done in any tier, but generally the application tier caches database state for quick local access. The data to be cached is determined according to percentage and time of use of data. Data that has frequent use or recent use has the priority of caching. The probability of data being used increases when it just has been recently used, because it is the most likely data to be used in the near future. For read-intensive applications, caching approach can provide large performance gains, great scalability as application processing time and database access is reduced. On the other hand, write-intensive applications usually do not see as a great benefit, but solutions that include modifications to caching approach exist. For SaaS systems distributed caching, the extension of caching applied to multiple servers, is used. Distributed caching is scalable because of the architecture it employs [32]. It distributes its tasks across multiple servers. Since caching mechanism is much simpler than a DBMS, usage of distributed cache avoids the scalability problems that a database usually faces.

2.3.2.10. Replication

In a system in order to increase availability and performance, and also to be fault-tolerant the same data can be stored on multiple software or hardware components, this operation is called replication [23]. Replication is typically applied in databases. Since when running a high traffic site, one of the biggest bottlenecks becomes the database. In order to solve this problem and to achieve scalability of database, replication is applied as one of the most common techniques. In replication technique all or part of the data in a database is copied to another database, and then these replicas are kept synchronized with the original. This provides increasing the availability of the data, so that processes or threads that are waiting in the queue to be able to do some operation with data do not need to wait anymore. Since there are multiple copies of data, it can reach it from the next available one. However, the type of the operation is an issue that is needed to take care on. If the operation is writing, then to provide the consistency of data all of the copies need to be updated when one of them is changed. And this brings another workload to the database layer, so it may not be helpful for the scalability. Thus, replication of data is recommended for mostly read-type operations in terms of scalability perspective.

There is another type of replication in terms of the place the replication occurs, replicating application. Components in the application layer or the whole application layer can be stored on multiple server instances. Thus, workload on the application layer can be distributed to multiple machines and processed concurrently by each of the application instances, so a performance improvement can be satisfied and it can reply to more number of requests without performance degradation. Moreover, to support dynamically increasing demands from multi-tenants, the cloud service providers have to duplicate computing resources dynamically to cope with the fluctuation of requests from tenants. This is currently handled by virtualization and duplication at the application level in the existing cloud environment [55].

For instance, in horizontal scaling (scale-out) to distribute workload application instances are replicated onto multiple nodes, also data is replicated onto multiple database servers. The important point is careful data placement, since it minimizes the response times.

2.3.2.11. Virtualization

As we mentioned in scale-up approach increasing the number of resources in the system, also increases the performance of the system and lead to satisfy scalability. Resources can be provided to the system by not only plugging in the server machine. The resources of the system that is comprised of OS, memory, storage, network, etc. can be virtualized and creating a virtual of something is called virtualization. It allows the ability to run multiple systems on a single physical system or one operating system on multiple physical systems. To be able to dynamically respond to increasing demands of the multi-tenants virtualization is widely used in current cloud computing systems. Since virtualization needs to replicate the OS, middleware and application components for each customer, it is often insufficient to provide SaaS [49].

2.3.2.12. Load Balancing

With an increased number of end users, the performance of a SaaS degrades and it is necessary to distribute client requests to different servers in order to perform parallel processing and provide scalability. The process of distributing workloads across multiple computing resources is referred as load balancing. Its purpose is to optimize resource usage, maximize throughput, minimize response time, and avoid overload of any one of the resources. In most of the existing SaaS, client requests towards web servers are distributed using a front-end load balancer [60]. Load balancer that is either hardware or software distributes traffic over web servers. To do better load balancing among partitions of a database or application servers, an effective algorithm that can migrate, distribute and duplicate tenants among partitions through monitoring the load is highly desirable.

2.3.2.13. Parallel Processing

In multi-tenant environment the SaaS has high number of requests from users, and in order to respond to all of these requests in a very short time, an approach that improves SaaS scalability should be followed. A request is composed of many tasks, including computing operations, database access, etc. In order to be able to reduce execution time of tasks and to reduce the workload of each component, the tasks should be grouped and executed in a parallel and asynchronous manner [47]. MapReduce, a programming model for processing large data sets with a parallel algorithm on a cluster, is an example of this manner [54]. It is a good example of data-intensive computing, requiring task coordination, and is heavily linked to distributed storage. Many applications can be broken down into sequences of MapReduce jobs. A map task runs through each element of a list and produces a new list, and reduce applies a new function to a list, reducing it to a single final value or output.

2.3.2.14. Distributing Processing in Time

Software systems have wavy usage plots, since clients access the system randomly. However, for some periods there will be an excessive usage of the system. These periods can be hourly, daily, monthly, seasonally, etc. or randomly. The cause of these periods may be that being a specific time for the domain of that system. This excessive usage leads to peak load on the server and causes low response time and scalability problems. To overcome this problem the first thing to do is reducing the system load, and you may postpone some of the workload to other times in your processing cycle [47]. Some of the tasks on the server occur continually at all times of day or night, and some of them is not urgent, or not need to do real-time, so these tasks can be postponed to other times. Since the total workload will be reduced during the peak load times, you will achieve performance and scalability improvement. You can realize the tasks postponed during quieter times, and you can also utilize from your idle resources.

Figure 6 shows the chart that indicates names of each tactic and their number of inclusion in primary studies.

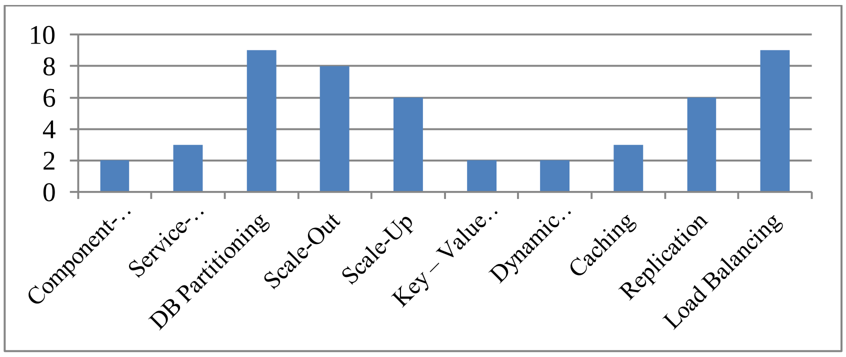


Figure 6: Chart that indicates tactics and their number of inclusion

Table 2 gives the relation between tactics and aspects of SaaS. It shows which aspects are affected when we apply a tactic.

Table 2: Tactics and Aspects of SaaS

Tactic	**Aspects**
Component-based Architecture	Software Architecture, Levels of Scalability Mechanisms, Database Access
Service-oriented Architecture	Software Architecture, Levels of Scalability Mechanisms, Database Access
Database Partitioning	Workload, Data Model, Data Management, Migration, Multi-Tenancy
Key – Value Stores	Workload, Data Model, Data Management, Migration
Load Balancing	Algorithm, Workload, Database Access, Disk Architecture, Network
Scale-Up	Workload, Capacity
Scale-Out	Workload, Capacity, Multi-Tenancy
Parallel Processing	Algorithm
Replication	Disk Architecture, Fault Tolerance & Recovery, Migration
Caching	Workload, Migration, Network
Virtualization	Multi-Tenancy, Capacity
Dynamic Provisioning	Workload, Network

Chapter 3

UML Profile for Scalability

3.1. UML Profile

UML model is used to represent viewpoints of software architecture that depicts both static and dynamic behaviors of the system [41]. Deployment viewpoint depicts static structure of the system, deployment of software on hardware resources. Activity and sequence models which are used to depict dynamic behavior, such as information flow. UML has been developed as an open extensible modeling language, and the intention and usage of its extension mechanisms has been described at an early stage. Two types of extensions are devised; lightweight extensions, based on stereotypes, tagged values, and constraints, and heavyweight extensions, based on direct modifications of the UML meta-model. In our study we take the first approach. A profile in UML for a software quality is a customized version, lightweight extension, of these UML models in order to present analysis of the quality. It contains stereotypes, tag definitions, and constraints, having quality information, applied to model elements. In theory a UML profile can be defined for any non-functional attribute of software and hardware systems in order to model quality of service with its distinctive properties. Creating UML profile consists of two parts; defining a domain model, which is a UML-independent description of the structural and behavioral patterns that characterize the considered domain, and mapping the concepts introduced in the domain model onto a UML viewpoint, which is a specification of how the domain elements are realized in UML. The resulting UML viewpoint is made of stereotypes, tags and constraints.

3.2. Modeling Scalability

Scalability modeling is the process of creating a model for a system that contains scalability specifications. In order to do scalability modeling sufficient information about system scalability should have been obtained. It describes how the scalability will be for a system without actually testing it in real life. It is created by software development engineers and system engineers, and it is used by all of the stakeholders. All of the large-scale systems need to determine, analyze, and create scalability models in the design phase and update them during system development iterations. Since these systems include a lot of detailed requirements, large numbers of stakeholders, multiple hardware platforms, distribution of components over several hardware platforms, high concurrency, and high complexity of interaction between components [47]. The purposes of scalability modeling include the following set:

- To make scalability requirements and estimations more understandable, visual, manageable, and easier for the stakeholders.
- To be able to see both run-time behavior and deployment of the system with scalability features.
- To provide a tool for scalability assessment for the stakeholders.
- To identify resources that cannot achieve scalability. These resources may have the following properties:
    - have high response time,
    - unable to support addition and removal of another resource or unable to upgrade them,
    - may face with heavier workload,
    - have complex, unambitious definition.

Scalability models are derived from the viewpoint models of the system. To indicate scalability critical elements deployment viewpoint of the system should be used. Scalability requirements should be mapped to this view, and features of elements, such as process, network links, data storages, that need to be scalable, should display its scalability data. As an example for scalability data, we can say response time of functional elements and resources, the request latency between processes, duration of a database operation, the number of concurrent requests that each element can handle. Moreover, we can also present run-time behavior of the system by using sequence and activity diagrams. We can specify scalability requirements of functional modules and resources that are in action and communication with others.

To be able to create scalability models in a formal way, we define UML Scalability Profile based on General Resource Model (GRM). Figure 7 shows the conceptual model representing the relation between GRM and scalability model. In next sections, we firstly explain GRM, then UML Scalability Profile.

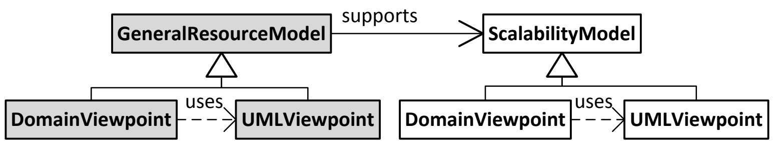


Figure 7: Conceptual model representing relation between General Resource Model and Scalability Model

3.2. General Resource Model (GRM)

As in other run-time qualities in scalability context resource has higher impact and importance than other aspects, since scalability is directly proportional to the capacity of hardware resources. So general resource model (GRM) is the thing we need while describing the scalability domain. GRM is a framework for modeling systems with the usage of quality of service (QoS) information [43]. QoS information represents, either directly or indirectly, the physical properties of the hardware and software environments of the application represented by the model. GRM has two viewpoints, domain and UML viewpoints. Domain viewpoint describes the common structural and behavioral concepts and patterns that characterize a system. UML viewpoint defines the realization way of the elements of domain model using UML. It consists of a set of UML extensions, such as stereotypes, constraints, tagged values, and is supplemented by specifications of the mappings of the domain concepts to those extensions. Figure 8 shows the conceptual model presenting the relation between domain and UML viewpoints. GRM provides mostly abstract concepts that are not applied directly to elements of a UML model. It provides a basis for UML profiles so that concrete extensions can be generated.

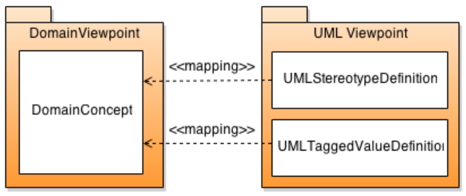


Figure 8: Conceptual model presenting the relation between domain and UML viewpoints

In domain viewpoint GRM describes the abstract analysis domain and its concepts. It has six packages that are core resource model, resource usage model, resource management, resource types, realization model, and causality model. Since we focus on and use the resource usage in scalability, now we give brief information about only resource usage model, given in Figure 9. The resource usage framework explains how a set of clients uses a set of resources and their services either statically or dynamically. In static usage the resource usage is described by static relationships between resources and it expresses how and when a resource is used. On the other hand, dynamic usage explains a resource usage scenario that contains order and time of the usage events.

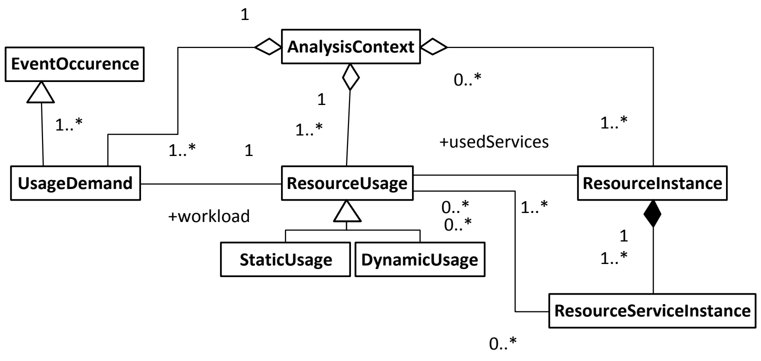


Figure 9: The Resource Usage Framework

3.3. Domain Viewpoint

In this section we describe how the scalability concepts can be represented in a domain model. Firstly, we discuss the mappings and relationships between concepts and model elements, and then present the scalability domain model.

3.3.1. Mapping Scalability Concepts into Domain Model

In previous chapters we have explained scalability concepts in detail and in section 2 we have explained resource usage framework that forms the basis of our domain model. In this section we provide the mapping of scalability concepts into domain model. Table 3 shows this mapping.

We can provide scalability of a system in load, functional, geographic, administrative, and generation dimensions. In the scalability context each dimension has one resource and a variable instance determined according to the dimension:

- Load scalability reveals data instance,
- functional scalability reveals functional module instance,
- geographic scalability reveals area instance,
- administrative scalability reveals user instance,
- and generation scalability reveals resource instance.

The preliminary and execution conditions we have **e**xplained in Chapter 2 is also covered and described in the domain model:

- Capacity is determined by all of the resources in the system context.
- Database access is done via communication resource. It is also affected by static usage models, such as disk architecture and software architecture.
- Network traffic is created by flow of data.
- Data management has three concepts:
    - Disk architecture is a static usage model for storage resources.
    - Data architecture contains static and dynamic usage models that manages how data is collected and how it is stored, arranged.
    - Data model organizes data elements that is stored and presents static usage of how the data elements relate to one another.
- Software architecture is represented by both static and dynamic usage models for application software components.
- Levels of scalability mechanisms show both static and dynamic application of scalability techniques on different tiers.

- Application complexity is related to the content of the functional module.
- Workload has user access, data storage access, and communication categories that are described by workload model element.
- Recovery contains three elements that have impact on scalability, flow of data that contributes to network traffic, workload that is produced because of it and functional module that is responsible to detect failures and recoveries.
- Migration contains both flow of data that occurs during transfer of data and workload that is formed during storage access and communication of nodes.

All of the ancillary tactics are met by ancillary tactic model element. Primary tactics, such as scale up and scale out, are met by primary tactics. Metrics are also mapped with metric model element.

Table 3: Mapping scalability concepts to scalability domain

Scalability Concept	**Domain Model Element**
Load Scalability	Data, Resource
Functional Scalability	Functional, Resource
Geographic Scalability	Area, Resource
Administrative Scalability	User, Resource
Generation Scalability	Resource
Capacity	Resource
Database Access	Communication Resource, Static Usage
Network Traffic	Flow of Data
Disk Architecture	Static Usage
Data Architecture	Storage of Data, Static Usage, Dynamic Usage
Data Model	Storage of Data, Static Usage
Workload	Workload
Software Architecture	Static Usage, Dynamic Usage
Levels of Scalability Mechanisms	Static Usage, Dynamic Usage
Application Complexity	Functional Module
Recovery	Flow of Data, Workload, Functional Module
Migration	Flow of Data, Workload
Ancillary Tactics {…}	Ancillary Tactic
Scale Up/Down	Primary Tactic
Scale Out	Primary Tactic
Metrics {…}	Metric

3.3.2. Scalability Domain and Its Concepts

The UML Profile describes a domain model. Figure 10 presents scalability analysis domain model which identifies the basic abstractions and relationships used in scalability analysis which is instance-based. The concepts in this model are fully consistent with the conceptual framework defined in the general resource model (GRM) [43]. Thus, in the scalability profile we can benefit from modeling styles and stereotypes provided for GRM. The relationship of the scalability modeling concepts to corresponding GRM concepts is depicted in the class diagram in Figure 11. We explain each concept that takes part in the scalability analysis model in depth below. Features and associations in each concept are described.

Scalability context explains a scalability case of a system and a system may have more than one scalability context. It is formed by four main elements which are *Instance*, *Instance Usage*, *Tactic*, and *Workload*. It may have multiple numbers of these elements. It describes the workloads that occur during usage of these instances and also describes tactics applied to these instances. It is described by presenting one or more instance usage models. And these usage models give QoS outputs, scalability metrics, such as response time, throughput, number of concurrent users, hardware resource specifications, etc. For instance, a scalability context may present peak load time for a SaaS application that describes the expected response time, throughput of the system, number of concurrent users, processor power, etc., during its operation.

Scalability context has relationship with other contexts, such as performance, predictability, reliability, and availability. Firstly, scalability is closely related to performance, since it is directly proportional to the performance of the system. Another context it is dependent on is predictability of the system's performance, since it must ensure that as the workload increases, it must satisfy scalability goals at the present time and in the future. Definition of *Predictability context* is that the degree to which a correct prediction of a system's state can be made either qualitatively or quantitatively [47]. Furthermore, scalability affects availability and reliability contexts. *Availability context* describes the capability of providing the intended service of a system fully or partly [47]. A system that has scalability problems cannot ensure its availability as well, since when the system has heavy workload it cannot response and it becomes unavailable. *Reliability context* explains the probability of failure or availability [47]. Reliability depends also scalability as availability, since a large-scale system needs to ensure its scalability before making it reliable.

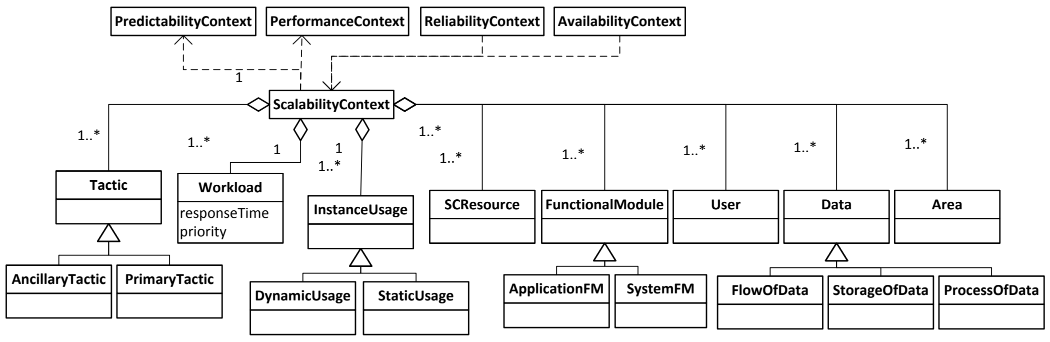


Figure 10: The scalability analysis domain model – Overview

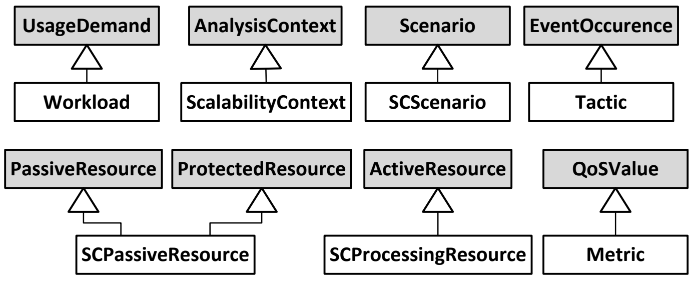


Figure 11: The relationship between the scalability concepts and GRM

Instance is a specific realization of any object in the scalability context. Scalability context has five main instances, which plays a key part in scalability, are resource, functional module, user, data, and area.

Resource is any physical or virtual component of limited availability within a computer management system. Its element name has "SC" prefix, since it is a concrete element of scalability context and it should not be confused with the abstract resource defined in GRM or a resource element of any other analysis domain. Resource has two categories, purpose kind and activeness kind. A resource can have only one value for each category. In terms of purpose resources include processor, storage, and communication. Processor represents either virtual or physical processing devices capable of storing and executing program code. Storage resources represent the device for storing data, such as disk, memory, etc. Communication resources provide communications, flow of data, between resources. A resource is used during the operation time of the system. Thus, according to usage activeness, it is either processing or passive resource. Passive resources can only respond to requests or stimulus, they cannot behave themselves. Processing resources can generate stimuli concurrently without being prompted by an explicit stimulus instance. You can see the scalability resource model in Figure 12.

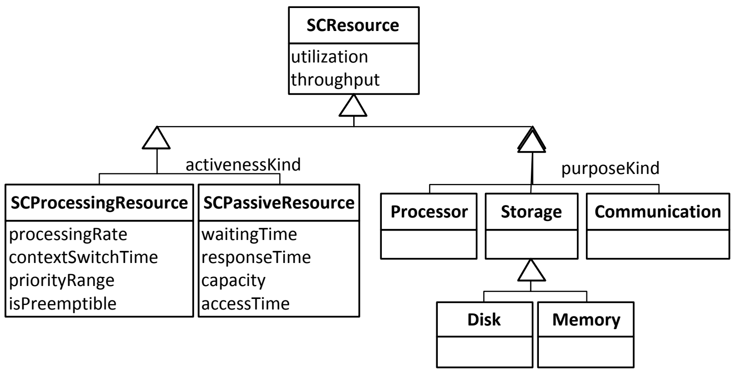


Figure 12: The scalability analysis domain model - Resource

Functional Module is any set of machine-readable instructions that directs a computer's processor to perform specific operations. It controls the resources and data flow of the system. It exists both at the client-side and server-side. It is divided into two, application and system functional module (FM). Application FM uses the computer system to perform special functions. System FM is designed to directly operate the computer hardware, to provide basic functionality needed by users and other software, and to provide a platform for running application software.

Data is a set of values of qualitative or quantitative variables. It is either the result of measurements or information given by the user. It is separated into three categories according to its place in the context that are flow of data, storage of data, and process of data. Flow of data, which flows through the system network, generates the network traffic. Storage of data resides in a storage resource. Process of data takes place in an operation and it is processed in one of the software component.

User is a person who interacts with a system through an interface to extract some functional benefit. It sends requests by using its own resources and the software the system provides. It can be either at the client-side or server-side.

Workload is the amount of work an instance has to do. It has two categories, occurrence kind and openness kind. In terms of occurrence kind the main concerns are *user access load, communication traffic load,* and *data storage access load*. *User access load* indicates the number of concurrent users who access the system, number of online users, in a given time unit. *Communication traffic load* indicates amount of incoming and outgoing communication messages and transactions in a given time unit. *Data storage access load* refers to the underlying system data store access load, such as the number of data store access, and data storage sizing. In terms of openness kind it is divided into two types being closed and open workloads [43]. *Closed workload* is a static workload in which the number of incoming requests and the number of active users is constant. An *open workload* is a dynamic workload in which number of incoming requests varies with respect to a given rate in some predetermined pattern. Figure 13 depicts the workload.

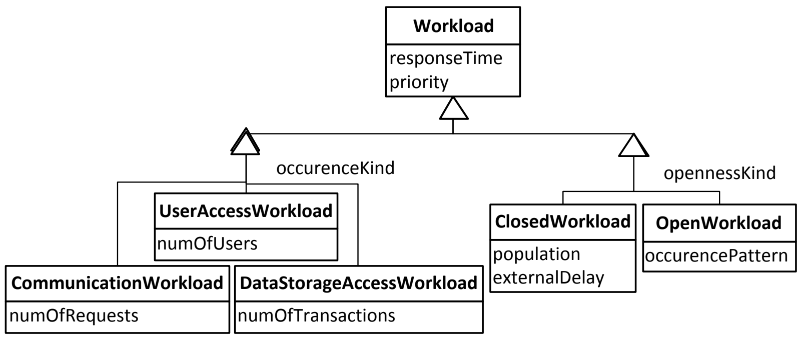


Figure 13: The scalability analysis domain model – Workload

Instance usage explains how a set of instances uses another set of instances and their services either statically or dynamically. In *static usage* the instance usage is described by static relationships between instances and it expresses how and when an instance is used. On the other hand, *dynamic usage* explains an instance usage whose details are determined by a scenario that contains order and time of the usage events. Dynamic usage domain model is presented in Figure 14. A scenario is an ordered series of *steps* called *action executions*. A *step* may be an elementary operation or a complex sub-scenario composed of many basic steps. It may include a scalability requirement or estimation like hardware resource specification, response times, or throughputs. Execution of scalability *scenario* produces workload on the system and also produces metrics as outputs, QoS values. *Metrics*, which are the result types of execution of a scenario, are monitored to be able to measure scalability of service, such as response time, throughput, requests per second, number of users, CPU usage, memory usage, network usage. These metrics can have four different types, such as a measured value, an estimated value, an assumed value, and a required value. A measured value is determined by monitoring the system while running. An estimated value is calculated by a tool. An assumed value is assigned by a human, determined according to its experience. A required value is specified in the system requirements. *Metrics* are included in the stereotype attributes. During the execution of a scenario we can see the change in values of these metrics, describing the scalability of the system.

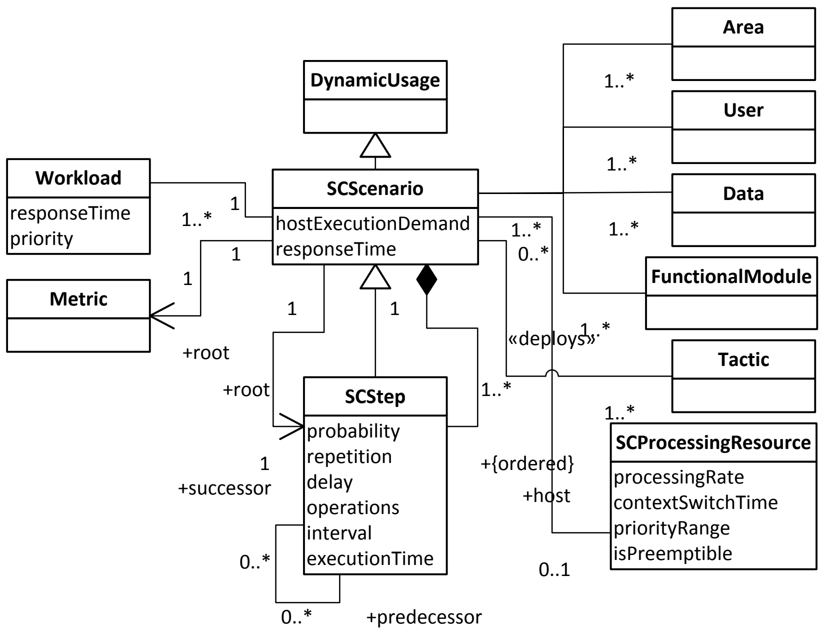


Figure 14: The scalability analysis domain model – Dynamic Usage

Tactic is the approach that should be applied to satisfy scalability of the system. It presents possible solutions in case of the system does not show its required quality properties the perspective addresses. Tactic is divided into two categories, ancillary and primary tactics. Table 4 shows the relation between tactics and instances. In the right column it has the instance names that the tactic in the left column can be applied to.

Table 4: Table that shows the instance that a tactic can be applied

Tactic	**Instance**
Scale-up/down	SCResource
Scale-out	SCResource
Load Balancing	SCResource, FunctionalModule
Parallel Processing	SCResource, FunctionalModule
Virtualization	SCResource
Dynamic Provisioning	SCResource
Multi-tiered Architecture	FunctionalModule
Component-based Architecture	FunctionalModule
Service-oriented Architecture	FunctionalModule
Caching	FunctionalModule, Data

Replication	FunctionalModule, Data
Database Partitioning	Data
Key-Value Stores	Data

3.4. UML Viewpoint

In this section we describe how the domain concepts can be represented in UML. First we discuss the mappings in general, and then introduce the actual UML extensions defined for this purpose.

3.4.1. Mapping Scalability Domain Concepts into UML Equivalents

Scalability domain concepts can be explained by only instance usage models. In static usage model we can specify scalability requirements and the estimations as well as the structure of the system instance, for example, functional, deployment models. In dynamic usage models we can show run-time attributes of a system. Scenarios facilitate our understanding about the scalability of the system. They are modeled using either collaboration or activity graphs. In both approaches Scenarios are represented by collections of graphical elements, so that it does not have any specific stereotype. Scalability attributes of a scenario can be described in the first step.

3.4.1.1. The Collaboration-Based Approach

Collaboration-based approach describes a scenario using UML sequence diagram. Table 5 shows the mapping scalability domain concepts into UML equivalents for collaborations and the stereotypes describing it.

Table 5: Mapping scalability domain concepts into UML equivalents in collaboration-based approach

Scalability Domain Concept	**UML – Collaboration**	**Stereotype**
Scalability Context	Collaboration	<<SCAcontext>>
Scenario	Set of Interactions	Not applicable

Step	Action Execution	<<SCAstep>>
Workload	Note, Message	<<SCAopenLoad>>, <<SCAclosedLoad>>, <<SCAuserAccesLoad>>, <<SCAcomTrafficLoad>>, <<SCAdbAccessLoad>>
Resource	Classifier, Instance	<<SCAhost>>, <<SCAresource>>, <<SCAstorage>>, <<SCAprocessor>>, <<SCAcommunication>>
Functional Module	Classifier, Instance	<<SCAfunctional>>
User	Classifier, Instance	<<SCAuser>>
Tactic	Message, Action Execution	<<SCAtactic>>

3.4.1.2. Activity-Based Approach

A scenario can also be modeled via an activity diagram.

Table 6 shows the mapping scalability domain concepts into UML equivalents for activity graphs and the stereotypes describing it.

Table 6: Mapping scalability domain concepts into UML equivalents in activity-based approach

Scalability Domain Concept	**UML – Activity**	**Stereotype**
Scalability Context	Activity graph	<<SCAcontext>>
Scenario	Set of Activities and Transitions	Not applicable
Step	Activity	<<SCAstep>>
Workload	Note	<<SCAopenLoad>>, <<SCAclosedLoad>>, <<SCAuserAccesLoad>>, <<SCAcomTrafficLoad>>, <<SCAstorageAccessLoad>>
Resource	Swimlanes	<<SCAhost>>, <<SCAresource>>, <<SCAstorage>>, <<SCAprocessor>>, <<SCAcommunication>>
Functional Module	Swimlanes	<<SCAfunctional>>

User	Swimlanes	<<SCAuser>>
Tactic	Activity	<<SCAtactic>>

3.4.2. UML Extensions

In order to avoid naming conflicts with other profiles we add “SCA” prefix to all stereotypes.

3.4.2.1. Stereotypes and Associated Tags

In this section we explain how scalability domain concepts can be represented using UML.

<<SCAcontext>>

This stereotype models scalability analysis context. This context must have at least one instance usage that is either static or dynamic usage. If it has static usage, it must have at least one element stereotyped as a kind of instance. Or if it has dynamic usage which is formed by a scenario, it must have at least one element stereotyped as a kind of step. All of the instance usages must have at least a kind of workload stereotyped element.

Stereotype	Base Class
<<SCAcontext>>	Collaboration
	CollaborationInstanceSet
	ActivityGraph

<<SCAhost>>

This stereotype models a processing resource.

Stereotype	Base Class	Tags
<<SCAhost >>	Classifier	SCAutilization SCArate SCAthroughput
	Node	
	ClassifierRole	
	Instance	
	Partition	

Tag definitions:

Tag	Type	Multiplicity	Domain Attribute Name
SCAutilization	Real	[0..*]	Resource:: utilization
SCArate	Real	[0..1]	Resource::processingRate
SCAthroughput	Real	[0..1]	Resource:: throughput

<<SCAresource>>

This stereotype models a passive resource.

Stereotype	Base Class	Tags
<<SCAresource >>	Classifier Node ClassifierRole Instance Partition	SCAutilization SCAcapacity SCAaxTime SCArespTime SCAwaitTime SCAthroughput

Tag definitions:

Tag	Type	Multiplicity	Domain Attribute Name
SCAutilization	Real	[0..*]	Resource::utilization
SCAcapacity	Integer	[0..1]	PassiveResource::capacity
SCAaxTime	SCAscalaValue	[0..n]	PassiveResource::accessTime
SCArespTime	SCAscalaValue	[0..n]	PassiveResource::responseTime
SCAwaitTime	SCAscalaValue	[0..n]	PassiveResource::waitTime
SCAthroughput	Real	[0..1]	Resource::throughput

<<SCAopenLoad>>

This stereotype models an open workload.

Stereotype	Base Class	Tags
<<SCAopenLoad >>	Message Stimulus ActionState Action Operation Method Constraint	SCArespTime SCAoccurence

Tag definitions:

Tag	Type	Multiplicity	Domain Attribute Name
SCArespTime	SCAscalaValue	[0..*]	Workload::responseTime
SCAoccurence	RTarrivalPattern	[0..1]	OpenWorkload:: arrival

<<SCAclosedLoad>>

This stereotype models a closed workload.

Stereotype	Base Class	Tags
<<SCAclosedLoad>>	Message	SCArespTime SCApopulation SCAextDelay
	Stimulus	
	ActionState	
	Action	
	Operation	
	Method	
	Constraint	

Tag definitions:

Tag	Type	Multiplicity	Domain Attribute Name
SCArespTime	SCAscalaValue	[0..*]	Workload::responseTime
SCApopulation	Integer	[0..1]	ClosedWorkload::population
SCAextDelay	SCAscalaValue	[0..1]	ClosedWorkload::externalDelay

<<SCAuserAccessLoad>>

This stereotype models a user access workload.

Stereotype	Base Class	Tags
<<SCAuserAccessLoad>>	Message	SCAnumOfUsers
	Stimulus	
	ActionState	
	Action	
	Operation	
	Method	
	Constraint	

Tag definitions:

Tag	Type	Multiplicity	Domain Attribute Name
SCAnumOfUsers	Integer	[0..1]	UserAccessWorkload::numOfUsers

<<SCAcomTrafficLoad>>

This stereotype models a communication traffic workload.

Stereotype	Base Class	Tags
<<SCAcomTrafficLoad>>	Message	SCAcomDelay SCAnumOfRequests
	Stimulus	
	ActionState	

	Action	
	Operation	
	Method	
	Constraint	

Tag definitions:

Tag	**Type**	**Multiplicity**	**Domain Attribute Name**
SCAcomDelay	Integer	[0..1]	CommunicationTrafficWorkload::comDelay
SCAnumOfRequests	Integer	[0..1]	CommunicationTrafficWorkload::numOfRequests

<<SCAdbAccessLoad>>

This stereotype models a database access workload.

Stereotype	**Base Class**	**Tags**
<<SCAdbAccessLoad>>	Message	SCAconUsers SCAnumOfTransactions
	Stimulus	
	ActionState	
	Action	
	Operation	
	Method	
	Constraint	

Tag definitions:

Tag	**Type**	**Multiplicity**	**Domain Attribute Name**
SCAconUsers	Integer	[0..1]	StorageAccessWorkload::SCAconUsers
SCAnumOfTransactions	Integer	[0..1]	StorageAccessWorkload::numOfTransactions

<<SCAstep>>

This stereotype models a step in a scalability analysis scenario.

Stereotype	**Base Class**	**Tags**
<<SCAstep>>	Message	SCAdemand SCArespTime SCAprob SCArep SCAdelay SCAextOp SCAinterval
	Stimulus	
	ActionState	
	Action	
	ActionExecution	
	Transition	

Tag definitions:

Tag	Type	Multiplicity	Domain Attribute Name
SCAdemand	SCAscalaValue	[0..*]	Step::hostExecutionDemand
SCArespTime	SCAscalaValue	[0..*]	Step::responseTime
SCAprob	Real	[0..1]	Step::probability
SCArep	Integer	[0..1]	Step::repetition
SCAdelay	SCAscalaValue	[0..*]	Step::delay
SCAextOp	SCAextOpValue	[0..*]	Step::operations
SCAinterval	SCAscalaValue	[0..*]	Step::interval

<<SCAtactic>>

This stereotype models a tactic in a scalability analysis scenario.

Stereotype	Base Class	Tags
<<SCAtactic>>	Message	SCAtype
	Stimulus	
	ActionState	
	Action	
	ActionExecution	
	Activity	

Tag definitions:

Tag	Type	Multiplicity	Domain Attribute Name
SCAtype	String	[0..1]	Tactic::type

3.4.2.2. Tagged Value Types

The following types of tag value strings are defined for use with the stereotypes above. In representing the syntax of these types, we use the following standard BNF notational conventions:

- A string between double quotes (“) represents a literal.
- A token in angular brackets (<element>) is a non-terminal.
- A token enclosed in square brackets ([<element>]) implies an optional element of an expression.
- A token followed by an asterisk (<element>*) implies an open-ended number of repetitions of that element.

- A vertical bar indicates a choice of substitutions.

SCAscalaValue

These strings are used to specify a complex performance value. The value is an array in the following format:
"(" <source-modifier> "," <type-modifier> "," <time-value> ")".

Source modifier is a string that defines the source of the value meaning respectively: required, assumed, predicted, and measured:
<source-modifier>::= 'req' | 'assm' | 'pred' | 'msr'

Type modifier is a specification of the type of value meaning: average, variance, kth-moment (integer identifies value of k), percentile range (real identifies percentage value), probability distribution:
<type-modifier> ::= 'mean' | 'sigma' | 'kth-mom' , <Integer> | 'max' |'percentile,' <real> | 'dist'.

Time value is a time value described by the SCAtimeValue type.
{SCAduration = (1, 'sec')}

For example, the tagged value expression below represents a response time in a scenario step with a requirement 99% of requests are responded in 500 ms.
{SCArespTime = ('req', 'percentile', 99, 500, 'ms'))}

SCAextOpValue

This string is used to identify an external operation. It identifies either the number of repetitions of that operation that are performed or a scalability time value. The general format for this string is given as:
"(" <String> "," <integer> | <time-value> ")"

RTarrivalPattern

This string is used to specify concrete values of arrival patterns and the details are described in [42].

3.5. Difference of Scalability Profile

UML profile for scalability has new concepts which are not defined in any of profiles based on GRM. These differences from UML profiles for SPT [43] include tactic, functional module, data, user, area, workload types, and metric.

Scalability has five dimensions including load, functional, geographic, administrative, and generation scalability, so scalability context addresses these dimensions with concrete instances which are data, functional module, area, user, and resource. In load scalability load is represented by types of data element, flow of data, storage of data, and process of data. Architectural tactics are applied also on functional modules to provide any dimension of scalability. Area is used to represent the availability zones of the system. A geographically scalable system has many area elements. Administrative scalability concept has many user elements. Last, generation scalability uses resource elements.

Another difference from GRM exists in workload element of the scalability context. It has another kind property, occurrence kind. Types of occurrence are communication, user access, and data storage access workloads. Details are explained in section 3.3.2.

Steps of a performance scenario are executed on a host processing resource and performance of the resources staying on the host is measured. The performance measurements determine the features of the resources with respect to a given workload. On the other hand, executing a scalability scenario is more complex, since it is interested in the features of resources in a long duration. During this duration, features of workload and resource may change. Metrics are evaluated periodically in order to make a decision to provide scalability. A decision means applying a tactic. One or more tactics may be applied, and applying tactics affects some of the elements, such as functional module, data, in the context, you can see Table 4.

Chapter 4

Software Architecture Perspective for Scalability

4.1. Definitions

Rozanski and Woods give some crucial definitions about designing the architecture of a system [47]. They define a view as a representation of one or more structural aspects of an architecture that illustrates how the architecture addresses one or more concerns held by one or more of its stakeholders. Also, a viewpoint is defined as a collection of patterns, templates, and conventions for constructing one type of a view. They describe a number of perspectives and a guideline for defining new perspectives in their book. For each perspective in the catalog they present an outline that describes brief information about that perspective. The information contains the following properties:

- *Desired quality* gives the definition of the perspective
- The perspective's *applicability to views* examines the views that are impacted by the application of the perspective
- The most significant *concerns* the perspective takes care of
- An explanation of *activities for applying the perspective* to the architecture
- The *architectural tactics* present possible solutions in case of the architecture does not shows its required quality properties the perspective addresses
- Some *problems and pitfalls* to be aware of and risk-reduction techniques to prevent these possibly

- *Checklist* of things to consider when applying and reviewing the perspective to help ensure correctness, completeness, and accuracy

Furthermore, in the applicability to views section they examine six core viewpoints, functional, information, concurrency, development, deployment, and operational viewpoint.

- *Functional viewpoint* describes the system's functional elements, their responsibilities, interfaces, and primary interactions.
- *Information viewpoint* describes the way that the architecture stores, manipulates, manages, and distributes information.
- *Concurrency viewpoint* describes the concurrency structure of the system and maps functional elements to concurrency units to clearly identify the parts of the system that can execute concurrently.
- *Development viewpoint* describes the architecture that supports the software development process.
- *Deployment viewpoint* describes the environment into which the system will be deployed.
- *Operational viewpoint* describes how the system will be operated, administrated, and supported when it is running in its production environment.

4.2. Scalability Perspective

One of the perspectives in the Rozanski and Woods' perspective catalog [47] is performance and scalability. However, although performance and scalability is associated, scalability is not limited to only performance. Thus, we need to define a new perspective that is scalability alone. We present scalability perspective in Table 7 based on the guideline.

Table 7: Brief Description of Scalability Perspective

Desired Quality	The ability of a system to handle a growing amount of work and to be adjustable to accommodate that growth
Applicability	Any systems that have the possibility of increase in the amount of work; systems always require low response time; systems that needs additional resources in the future; systems with complex, unclear, or ambitious scalability requirements

Concerns	User access load, communication traffic load, data storage access load, transaction, response time, throughput, hardware resource requirements, cost, predictability, availability, and reliability
Activities	Capture the scalability requirements, create the scalability models, analyze the scalability models, assess against the requirements, and rework the architecture
Architectural Tactics	Multi-tiered Architecture, Component-based Architecture, Service-oriented Architecture, Database Partitioning, Scale-Out, Scale-Up, Key-Value Stores, Dynamic Provisioning, Caching, Replication, Virtualization, Load Balancing, Parallel Processing
Problems and Pitfalls	Inaccurate scalability goals, use of simple requirements for complex cases, unrealistic models, choice of inappropriate or redundant scalability approach, invalid environment, platform, and user behavior assumptions

4.3. Applicability to Views

Applying the scalability perspective impacts architectural views, defined by Rozanski and Woods [47], of the system, and Table 8 explains how it impacts them.

Table 8: Applicability of Scalability Perspective to Architectural Views

View	**Applicability**
Functional View	Applying this perspective leads to changes in some functional elements, such as adding new elements or splitting some elements into more, and to change some of the links between elements. Also it requires determining which elements need to be scalable. The models from this view can be used to create scalability models.
Information View	This view identifies shared resources, static data structure, dynamic information flow, information lifecycle, and transactional requirements. Some of the obstacles to scalability may be identified in this view. It gives information about which data can be cached or replicated, and also how the data can be partitioned. It may provide input to scalability models.
Concurrency View	Application of this perspective may change the concurrency design. It may divide the work on some functional elements or it may provide solutions for excessive contention on key resources. To meet requirements of the perspective will change the concurrency design. Elements in this view can also provide input to scalability models.
Development View	This view changes according to scalability approaches chosen. These approaches are done to avoid scalability problems, and indicate what actions to be done. There may be increase in the number of packages. Change in layers has low possibility, yet it may happen if the architectural pattern changes.
Deployment View	Scalability tactics that are chosen will affect this view and requires redefining types, specification, and quantity of hardware required, network requirements, third-party software requirements and physical constraints. Scalability models usually created by using this view.
Operational View	Applying this perspective makes performance monitoring more important, it also may cause to change the migration model.

4.4. Concerns

In last decades, most of the system needs to be capable to scale up or scale out. This need of scalability has some indicators that are used in the evaluation of system scalability. Meanwhile, since system scalability is dependent on the system performance, many published papers discussed these two issues together. However, scalability perspective has other concerns. The concerns of the scalability perspective describe what the main scalability measures are. The main concerns are user access load, communication traffic load, data storage access load, transactions, response time, throughput, hardware resource requirements, cost, peak load behavior, predictability, availability, and reliability [47], [24].

User Access Load: This indicates the number of concurrent users who access the system, number of online users, in a given time unit [24]. Concurrent connection determines the ability of connection to server from various locations at the same time. Each system has a limit of concurrent connections that specify the total number of device that can be connect to the server at the same time for a region. To address more users and to handle more workload in a time period, system should support concurrency as many as possible. User access load affects the communication traffic load of the servers and load on data storage access. The system should accommodate the growing user load in scalable systems.

Communication Traffic Load: It indicates amount of incoming and outgoing communication messages and transactions in a given time unit [24]. Request per second, hits per second, and transaction per second describes the communication traffic load on the servers.

Data Storage Access Load: It refers to the underlying system data store access load, such as the number of data store access, and data storage sizing [24].

Transactions: A transaction is a unit of work, typically encapsulating a number of operations, such as reading or writing an object, over a database. Every database transaction obeys the ACID rules. Transactions should be executed concurrently in a controlled manner to meet scalability requirements.

Response Time: Response time is the duration of a process between starting time, when a system takes an input, and the ending time, when the system finishes and reacts to the given input [47]. Response time is formed with service time and wait time. Service time varies as the workload changes, in other words it tends to increase as the workload increases. Wait time is the duration the request waits in a queue. It depends on the number of requests, service time of each request, and the scheduling algorithm of the system. For scalable systems there should be no high variations in the value of response time and always be available in its supported time period. Thus, varying workload should affect the response time as low as possible.

Throughput: Throughput is the amount of workload the system can handle in a unit time period [47]. In other words, as the system can finish a task more quickly, we can say the throughput becomes high. For scalable systems there should be no high variations in the value of throughput.

Hardware Resource Requirements: Hardware resource requirements have high impact on the scalability of the system, since how much workload the system can handle, how fast the system responds to requests, and how many devices connected it can support depends on the hardware resources of the system [47]. These requirements determine number, type, location of the resources, and the connection between them.

Cost: The deployment of the system takes important place in scalability of the system. However, when determining hardware resource requirements organizations should also think the cost of these resources. Generally, the more and better hardware resources bring higher throughput and better response times, yet higher costs. Since the important thing is to be able to satisfy the needs of stakeholders, they should try to get best configuration that can be afforded in low cost as possible as.

Predictability: Predictability is the degree to which a correct prediction of a system's state can be made either qualitatively or quantitatively [47]. Scalability focuses also predictability of the system's performance, since it must ensure that as the workload increases, it must satisfy scalability goals at the present time and in the future.

Availability: Availability is one of the several important non-functional requirements related to scalability. It is the capability of providing the intended service of the system fully or partly [47]. An available system should effectively handle failures and maintain its operation. A scalable system must be highly available during a certain period. However, increasing load of a system makes it difficult.

Reliability: Reliability is the probability of failure or availability [47]. It plays a key role in cost-effectiveness of a system. A scalable system is expected to be highly reliable. A potential overload of the system due to limited scalability harms reliability.

4.5. Activities for Applying Scalability Perspective

The activity diagram in Figure 15 displays the process for applying the scalability perspective. In this section, we describe the activities in this process.

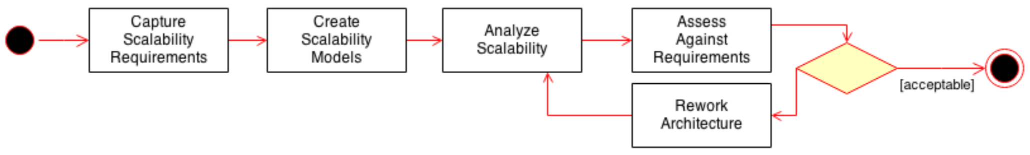

Capture Scalability Requirements
Create Scalability Models
Analyze Scalability
Assess Against Requirements
[acceptable]
Rework Architecture

Figure 15: Applying the Scalability Perspective

4.5.1. Capture Scalability Requirements

To be able meet the scalability goals of a system the only way is to specify each of them clearly and unambiguously. And they should be determined accurately at the earliest phase of the system development [16]. Defining them early provides you with a certain amount of flexibility in the future. The scalability of the system is also strongly dependent on the performance requirements, so performance requirements should be stated well before scalability requirements. It is a simple fact that if scalability is not a stated criterion of the system requirements, then the system designers will generally not consider scalability issues. While loose or incorrectly defined scalability specifications can lead to failures and dissatisfaction of users. Moreover, if they stated after the system is deployed, raising the level of the service to accommodate growth can be difficult and too costly. However, defining scalability requirements is usually difficult, since it involves quantitative goals and it is based on future needs. These goals and needs are determined according to certain amount of estimations, assumptions, and constraints. Another difficulty is that scalability requirements need more domain and deployment research, since each system has its own features decided according to stakeholders' needs. To be able to provide adequate inputs for architectural design and analysis, scalability requirements need to be specified accurately and precisely, and need to be testable. Moreover, as the amount of workload increases the scalability requirements should be re-examined and updated.

To be able to capture scalability requirements we follow existing requirements engineering techniques defined in the IEEE Software Engineering Book of Knowledge (SWEBOK) [26]. It defines four stages for requirements that are Elicitation, Analysis, Specification, and Validation. However, these techniques contribute little concrete support [16]. User stories and use-case-based approaches to requirements engineering overlook scalability concerns and other nonfunctional requirements altogether. In the papers [16], [17] authors present a systematic method for elaborating and analyzing scalability requirements and apply the rules of GORE (goal-oriented requirements engineering). To specify scalability requirements they follow the following steps:

i. Specifying Scaling Assumptions
ii. Specifying Scalability Goals
iii. Identifying Scalability Obstacles
iv. Assessing Scalability Obstacles
v. Resolving Scalability Obstacles

To reveal scalability goals the following must be clearly specified [47], [17]:

- Workload,
- Response Time,
- Throughput,
- And Hardware Resource Requirements.

Specify Workload Requirements: Description of workload goals should include user access load, communication traffic load, and data storage access load with the deployment information. When specifying workload, all relevant details should be covered. These details include number of users and what each of them is doing, and all of other operations such as management requests, backups, and error scenarios/handling. Once all loads have been considered, infrequent or inappropriate workloads can be eliminated. Furthermore, peak workload, a rare or unexpected increase in the workload, should be defined separately. Because it is an extreme scenario, the worst case of failure should be thought while defining it. Meanwhile, specifying the workload provides to detect and processing overload to ensure flood control mechanisms are in place to avoid the system crashing under intensive loads. Moreover, when defining workload requirements, researching past growth patterns of the system can help determine how demand on your system may grow. The expectation for the quantity of new users within the next few years, growth rate over the next few years in terms of data, users, and client applications should also be thought. If you already have a system that runs, then you should also specify whether there is an anticipated increase in entry volume and any new business processes are expected.

Specify Response Time Requirements: Response time goals should described with the information how much workload the system has, measurement location, and features of hardware resources during that time [47]. User access load, communication traffic load, data storage access load, and deployment features affect the response time. As these loads increase response time a user see increases as well. Also, the location of response time measurement is done should be specified. For instance, response time measurement that is done from a location being distant from the servers comes out higher than a location near data center because of network. Furthermore, features of hardware resources should be stated, since response time is directly proportional to the power of deployment. Response time is not only concern of scalability and performance perspectives, but also a concern of usability perspective. According to J. Nielsen's book [36][39] on usability response times must be less than 1 second for navigation to feel seamless and less than 10 seconds to prevent a user's attention from wandering. These time limits are caused by the human brain's structure and are thus firm and stable decade by decade. Finally, to be more accurate the acceptable error rate allowed during the measurement of the response times should be defined. Some systems may produce errors under high workloads and therefore the acceptable error rate need to be defined.

Specify Throughput Requirements: Scalability requirements should state how many requests or transactions of each kind processed and go through the system per unit time as throughput [45]. It should be determined for the steady cases when the number of incoming requests would be equal to the number of processed requests. Also, it should be determined for homogenous tasks when a system doing the same type of business operations for a given time. Its specification is more difficult for systems with complex workloads; the ratio of different types of requests can change with the time and season. Moreover, it should be defined for a specific time and workload, since it varies with time and workload. For instance, the throughput of a system during typical hour and during peak hour cannot be the same. Furthermore, the hardware configuration of the system should be specified while specifying it, since the hardware configuration is also affects it too.

Specify Hardware Resource Requirements: Features and quantities of CPU, memory, storage, I/O, network, etc. of the system should be specified [45]. We benefit from these requirements during capacity management, production monitoring, and resource utilization. The capability of these hardware resources and cost of them should be considered well before specifying. According to administrator's budget, a hardware plan can be made. For instance, they can purchase hardware at regular intervals to add to their existing deployment. If they have budget limitations, they can purchase servers that can be enhanced later by adding RAM or CPUs.

4.5.2. Create Scalability Model

A scalable system has a lot of detailed requirements as we examined in the previous section. Project includes large numbers of stakeholders, high complexity of interaction between components, multiple persistence mechanisms, multiple hardware platforms, distribution of components over several hardware platforms, and high concurrency [25]. Thus, dealing with such a complexity can be a challenge for every stakeholder. The scalability requirements should be used in an effective way to facilitate this problem and make it understandable and manageable. The solution is to create scalability models that provide a set of measures to make stakeholders assess the workload, concurrency by looking through useful estimates for capacity planning, and provides [47]. Scalability models are derived from the viewpoint models of the system. To indicate scalability critical elements deployment view of the system should be used. Scalability requirements should be mapped to this view, and features of elements, such as process, network links, data storages, that need to be scalable, should display its scalability data. As an example for scalability data we can say the processing time of functional elements, the request latency between processes, duration of a database operation, the number of concurrent requests that each element can handle.

4.5.3. Analyze Scalability

Scalability analysis is about determining the rate at which a system can perform its action when demands increase or decrease. As other quality requirements of software, scalability analysis can be carried out two different levels, either analysis at the architecture design level or analysis at the code level with respect to the defined requirements. In the first case, by using architecture design as an input we can measure the impact of predefined scenarios on it, so that we can detect conflicts in the requirements and incomplete design descriptions from a particular stakeholder's perspective [15]. This helps to predict the quality of the system before it is built, thereby reducing unnecessary maintenance costs. However, not all parameters/metrics can be evaluated at the architecture design level because of the run-time properties. These metrics need to be analyzed on a running code.

4.5.3.1. Analysis at Architecture Design Level

Software development consists of phases and initial output of this process is the architecture design. Architecture design has impact on the subsequent analysis, design, and implementation phases [52]. Architecture design should satisfy the software qualities determined by the various stakeholders. To be able to provide this the fundamental concerns for architecture design should be identified. To verify that right concerns have been identified usually architecture design are analyzed or a set of architecture analysis methods are adopted. According to The Software Architecture Review and Assessment (SARA) report [40] the architecture evaluation approaches are useful in making design decisions explicit and supporting the refactoring of the architecture to enhance its quality.

We can apply one or set of the architecture analysis approaches that have been proposed so far, such as the scenario-based architecture analysis method (SAAM), the architecture trade-off analysis method (ATAM), scenario-based architecture reengineering (SBAR), architecture level prediction of software maintenance (ALPSM), and a software architecture evaluation model (SAEM). A comprehensive overview of these architecture analysis methods is given in [15].

SAAM can be considered as a mature method which has been validated in various cases studies, such as [15], [52], among the architecture analysis methods. SAAM aims to verify basic architectural assumptions and principles against the requirements and use case scenarios which describe the desired properties of a software system [31]. Thus, SAAM evaluates the architecture for the given system requirements and architectural description. Also, it analyzes for the risks by running the scenarios on the architecture.

SAAM uses scenarios. A scenario is a brief description of some anticipated or desired use of the system [15]. It has two types, direct and indirect scenarios. Direct scenarios can be directly supported by the architecture. On the other hand, indirect scenarios require changes in the architecture design and this redesign needs to be done in order to make them direct scenarios.

4.5.3.2. Analysis at Code Level

The last step of the software development process or phase is about analyzing the software at code-level. Code analyzing reveals mistakes and potential risks in the software. Scalability analysis at code level analyzes the behavior of the system at various load levels, identifies scalability problems and the bottlenecks of the system. It enables us to verify and validate the quantitative scalability goals and provides us to examine and to make strong estimations for scalability concerns, such as response time, throughput, user access load, communication traffic load, data storage access load. We can also determine availability and reliability concerns of the software. It measures sufficiency of the underlying hardware components, so that we can take precautions by making modifications on deployment before releasing the software system. For analyzing the code in scalability perspective we can apply one or more of testing methods that involve performance testing, load testing, endurance testing, stress testing, spike testing, and scalability testing [36], [51].

- Performance testing: Performance testing determines the speed and stability characteristics of the system under test. It is concerned with achieving response times, throughput, and resource-utilization levels that meet the performance objectives for the product.

- Load testing: The aim of load testing is to examine how the software system behaves when it is exposed to varying workload during its production operations and to validate the scalability concerns of the system.

- Endurance testing: This test is focused on examining the behavior of the system during a long period of time while it is subjected to moderate load and to validate the scalability concerns of the system.

- Stress testing: Stress testing is done by pushing the limits, putting into conditions that are not anticipated, such as high workload, server failure, limited memory, insufficient disk space, etc., to find the breaking points of the system, under what conditions it fails, how it fails, and what indicators can be monitored to warn of an impending failure, during its production operations and to validate the scalability concerns of the system.

- Spike Testing: Spike testing is used to examine the behavior of the system while it is subjected to repeatedly increasing workload during a short period of time and to observe how well an application responds to sudden increases in the workload that exceeds the anticipated limits.

- Scalability testing: Scalability testing is carried out to examine how an application scales to handle increased load (i.e. serve more users) with added resources. Scalability tests can be implemented by running one or more of the above types of performance test against setups with differing resources and comparing the results. If a significant increase in application performance and/or capacity is observed, as a result of adding to available resources, then the system is said to scale well.

4.5.4. Assess Against Requirements

Requirements are specified, but they are written on estimations mostly. There is a need to validate and to verify these requirements. This is done by two ways, either by conducting practical testing and then checking requirements against test results or comparing with independent sources. In scalability analysis phase we realize the first step of the requirement validation. In the second step, after analyzing the software system in terms of scalability perspective, we should compare the results of the analysis with the scalability requirements and determine the differences on these requirements if there exist any. If most of them match, then it means requirements are valid. If there are cases that don’t match, then modifications on requirements should be done to correct them. After all comparison and modifications are done, we should also review all of the scalability requirements and consider any potential scalability risks.

4.5.5. Rework Architecture

We have validated and verified scalability requirements and analysis results. Therefore, as a last step it’s time to update the architecture of the system according to latest version of scalability requirements. We should start with the functional and the deployment viewpoints, since they are usually the most affected ones, and then continue updating with the rest of the viewpoints. While reworking the architecture we can benefit from the architectural tactics described below. Finally, when we have the modified, improved architecture, we should also modify our scalability model and repeat the steps we have followed until we have a stable, with desired quality architecture and system.

4.6. Problems and Pitfalls

In this section, we provide the potential scalability problems and pitfalls as well as the risk-reduction techniques.

4.6.1. Incomplete Scalability Goals

Incomplete or unambiguous scalability goals lead to failures in system scalability [16], [17], and [47]. If system designers use indefinite scalability goals, they do not think possible scalability problems and do not take precautions for them.
Risk Reduction:

- While defining scalability requirements, make you sure that they are testable, measurable.
- Always validate and verify the scalability requirements by comparing with another reliable, independent source or by results of tests performed by you.

4.6.2. Unrealistic Models

Scalability models should cover all of the requirements as well as their details [44], [47]. A model is an abstraction of reality, so having a lack of feature in the model yields a system that may encounter a scalability problem in the future. Besides, scalability models should be realistic.
Risk Reduction:

- Always validate and verify the scalability requirements by comparing with another reliable, independent source or by results of tests performed by you.

4.6.3. Use of Simple Measures for Complex Cases

While determining scalability requirements, we make estimations to specify the values of loads, latencies, and hardware features [16], [17], and [47]. Making wrong estimations is very possible, since the systems are complex and scalability is affected from various variables, so thinking all of them together is very hard. Since realizing a system is a long process, firstly we make estimations even they are wrong. However, these values estimated should not be far from its value that it is required to satisfy scalability. We should make estimations as strong as possible. Also, scalability testing should be done in a way that every detail should be thought and specified. If the test does not cover the realistic runtime environment, then the values that we compare with our estimations will probably be wrong. As a result, oversimplifying scalability goals and testing leads to wrong realizations of the system.

Risk Reduction:

- Consistently validate and verify your scalability goals.
- Consistently compare your testing with independent sources.
- Consider the differences between the test environment and the real system runtime environment to notice critical conflicts.

4.6.4. Inappropriate Partitioning

Partitioning is required when one or more elements involved in nearly all of the transactions in the system, since it prevents them from being bottlenecks of the system that violate scalability feature [2], [47]. Separations of concerns, distributing the tasks, and concurrent execution usually provide more scalability. However, these separation and distribution, partitioning, should be done appropriately according to some logic. Otherwise, it would result in a system with more scalable problems.

Risk Reduction:

- Consistently watch for functional elements that have high coupling to most of the other elements and avoid them from being the bottleneck of the system.

4.6.5. Invalid Environment and Platform Assumptions

Scalability of the software system is highly dependent on its execution environments and platforms [45], [47]. Hardware and software the system is deployed on should be determined according to scalability goals desired. Also, scalability testing should be done at the environments that are used in realistic runtime environment. Wrong environment assumptions may occur when you overestimate or underestimate your scalability goals or estimate for an unknown, new technology. These invalid assumptions lead to scalability problems.

Risk Reduction:

- Always validate and verify the scalability requirements by comparing with another reliable, independent source or by results of tests performed by you.

4.6.6. Concurrency-Related Contention

Systems usually have concurrency, and processing occurs in separate threads [45], [47]. However, these threads may work on some shared resources which cause allocation problems. A shared resource can be used for only read purpose at the same time by different threads. If a write task requires for a shared resource, then that resource can only be used by just one thread. This allocation process may be the bottleneck of the system, since while a shared resource is allocated by one thread; other threads wait until that resource become free. This situation may cause serious performance and scalability problems.

Risk Reduction:

- Examine your functional, information, and concurrency views to identify the functional elements that must work concurrently and to identify shared resources.
- Work on your concurrency view to adjust allocation of shared resources and wait time of threads in a sensible manner.
- Also consider other ways that provide threads to access the shared resources, such as partitioning, replication, caching, etc.
- During software development test the concurrent behavior of critical elements as early as possible and be sure that they will not become bottlenecks.

4.6.7. Careless Allocation of Resources

Since we can obtain more computing power and more space via better hardware, we may be careless for allocation of resources. However, our unconsciousness, an excessive allocation and freeing of runtime resources, leads to performance and scalability problems [45], [47].

Risk Reduction:

- Do not allocate and deallocate large amounts of dynamic resource in critical path elements.
- Try to allocate resources in advance and at less critical times, such as startup or during quiet periods.
- Choose the one that requires less effort consumption, between reuse of the allocated resource or freeing and reallocating them.
- Understand the problem thoroughly and document guidelines and patterns.

4.6.8. Disregard for Network and In-Process Invocation Differences

Most of the systems are distributed and provide the distribution of the resources over different geographical locations [46], [47]. However, while choosing these locations, we need to be careful, since accessing a resource on the network introduces latency and higher response times.

Risk Reduction:

- Ensure that the geographical locations of the resources provide less latency and reflect their inter-element invocation costs in your scalability model.

4.6.9. Checklist

In this section, we provide checklists in Table 9 for requirements capture and architecture definition to consider when applying and reviewing the perspective to help make sure correctness, completeness, and accuracy. While deciding on the checklist items, we have benefit from various resources, such as [17], [23], [45], and [47]. The [CH1] - [CH8] presents the checklist for requirements and the [CH9] - [CH20] presents the checklist for architecture definition.

Table 9: Checklist Table

Item	**Explanation**
[CH1]	Have you identified scalability goals with stakeholders?
[CH2]	Have you identified the platform features of the system?
[CH3]	Are scalability goals driven by business needs?
[CH4]	Does cost of your hardware requirements conform to your project budget plan?
[CH5]	Have you considered goals for user access load, communication traffic load, data access load, response time, and throughput?
[CH6]	Have you assessed your scalability goals for reasonableness?
[CH7]	Have you appropriately set expectations among your stakeholders of what is feasible in your architecture?
[CH8]	Have you defined all scalability goals within the context of a particular load on the system?
[CH9]	Have you identified possible scalability obstacles in your architecture?
[CH10]	Have you done sufficient analysis and testing to figure out the scalability need of the system?
[CH11]	What are the expected and maximum workloads the system can process?
[CH12]	Do you define the way how to detect the time when to apply the scalability solution?
[CH13]	Do you know to which components you will apply a scalability tactic?
[CH14]	Do you know by which tactics your architecture can be scaled when needed?
[CH15]	Have assessed the impact of the scalability solution on functionality and performance? Is this impact acceptable?
[CH16]	Have you reviewed your architecture for possible scalability problems?
[CH17]	Have external experts reviewed your scalability design?
[CH18]	Have you verified and validated estimations you have made for scalability goals?
[CH19]	Have you updated your scalability requirements after you validated the scalability goals estimated?
[CH20]	Have you applied the results of the scalability perspective to all of the affected views?

Chapter 5

Case Study

5.1. Background

Scalability has always been one of the major requirements in designing SaaS applications to meet the both growing and fluctuating demands. Since these fluctuating demands may occur at varying frequencies, such as hourly, daily, weekly, if the SaaS is not well-designed then it may be unresponsive or inconsistent during a high load. It causes loss in the number of customers and loss of time and monetary for the designers. To be able to examine this issue we have followed scalability perspective guideline described in previous sections on a SaaS application. This part presents our case study, cloud optimized SaaS framework for enterprise applications using RDBMS.

Cloud Optimized SaaS framework [11] uses the tables and the relations in a given RDBMS and automatically produces client interfaces. These interfaces provide listing, editing, and reporting data for the cross-platform devices. Its production occurs with the usage of a code-base that resides on cloud servers. The aim of this framework is to develop enterprise applications rapidly and platform independent. It is used in ERP systems, hotel and property management systems. In our case study we examine Cloud Hotel Management System (CHMS) that uses the SaaS framework [10]. This management system manages and tracks all operations related with different hotel departments. Since most of the hotels serve during only summer season, three months, they can rent the hotel management software service for only summer season instead of buying and keeping it for nine months unnecessarily. As we described above, to meet growing and fluctuating user load, and to achieve a well-designed SaaS, the system must be scalable. Major requirements of the system are as follows.

Multiple guests connect to CHMS via a travel agency or a hotel or a hotel web site or online travel agencies simultaneously. Some guests try to book, some of them download their invoices, and others generate reports. Also, hotel manager see details about their customers and search for a particular customer. All of these transactions are done real-time synchronized. As a result, the system should always be responsive, available, consistent, and scalable. For instance, all of the stakeholders should see the same condition for the reservation status of a particular room at the same time. When multiple transactions done by multiple guests exist on the server, the system may become out of service or some guests may experience performance issues unless the system is scalable. Scalable CHMS provides the stakeholders to guarantee access the system always, without any performance degradation, and without any failures.

5.2. Views

This section explains the application of scalability perspective to the views for our case study, which allows us to ensure that the architecture is suitable in terms of scalability perspective. Table 10 lists a summary of the application of scalability perspective to the views for our case study.

Table 10: Scalability Perspective Application for the Case Study

View	**Applicability to the case study**
Functional	Sessionless authorization has been applied. Field validations have been moved from database layer to client business logic layer. Data to be displayed in web view has been cached on the client device.
Information	We could see that hotel, guest, and other information related with them may cause a scalability problem, since with multi-tenancy number of their records is high. Also, we could understand reservation data is sensitive in terms of consistency and availability, so that we have taken care of that during applying scalability tactics.
Concurrency	No change has been made.
Development	Layers have been reorganized. Database has been separated from the server layer and as a result, the system has client, application, and database layers.
Deployment	Application layer and database has been placed on the same Amazon EC2 server machine. Database has been moved to another EC2

	instance. Instead of using shared memory TCP/IP will be started to use to access database. Memory cache will be added in front of the database, the contents of the application will be reproduced, and a load balancer will be put in front of them.
Operational	Performance monitoring and management has been started and metrics related to concerns have been collected and tracked periodically. It has seen that auto scaling can be needed and can be applied in the future.

5.2.1. Functional Viewpoint

CHMS is web-based hotel management software that automates the major hotel operations. Major stakeholders of it are guests, hotel managers, travel agencies. The system consists of nine subsystems that are Reservation and Booking, Room, POS, Guest, Accounting, Agency, Channel, General, and Report Management. Reservation and Booking Management module keeps track of reservations and. Room Management module is responsible from the operations related to hotel rooms, such as room availability, room schema, room status, room wakening list, and other activities. POS Management module manages the product selling and delivery operations made by the guests that stays in a hotel or visits for a day. Guest Management module keeps track of the information about guests that stays in a hotel or visits for a day. Accounting Management module manages all of the accounting operations that are done in a hotel. Agency Management module manages all the information about travel agencies and all of the sales information. Channel Management module keeps track of selling channels and administrators that a hotel is contracted out. General Management module is responsible from room settings, financial settings, etc. Finally, Report Management module manages generation of various types of reports.

Functional view of CHMS is shown in Figure 16. *Database* layer contains tables and stored procedures. SaaS framework automatically extracts the database schema and generates JavaScript business object model (JBOM) code files that indicate tables, relations, constraints, stored procedures in JavaScript Object Notation (JSON) format. They are used in client interface as *business logic*. Client interface includes HTML5 *UI components*, such as forms, views, grids, and reports that are displayed in web view. Client *communication manager* manages client requests and server responses.

In the application layer, four components, authorization, multi-tenant filtration, logging, and data transfer components exist. *Authorization component* is responsible from authorization of client requests, such as create, read, update, delete, and execute. We have chose session authorization, since it has less usage of computational power, reduces the response time of each request and makes both component and the system more scalable. We have explained the details in the section 5.4.3. As a future action when the scale-out is applied on application instances and a load balancer is added in front of them, the request can be spread to these instances, so more scalability can be achieved.

Multi-tenant filtration component process each query and eliminates the data that are not related to tenant of the requested client. *Data transfer* handles database operations that come from *authorization component*. *Logging component* keeps record of some events occurred in the application layer and saves these logs into *database*.

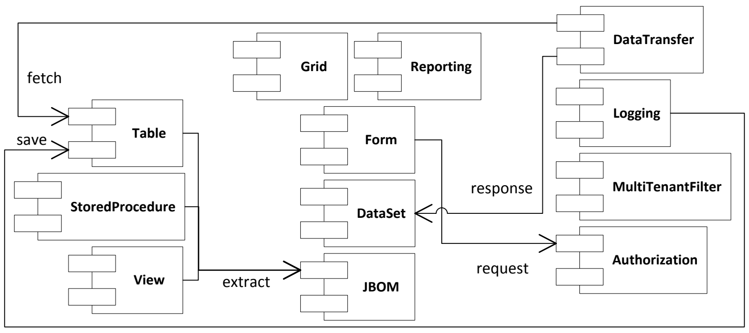


Figure 16: Functional View of CHMS

5.2.2. Information Viewpoint

With the help of information view we can see which data may cause a scalability problem, and also we can understand which data is sensitive in terms of consistency and availability so that we take care on during applying scalability tactics. For instance, in CHMS reservation information is significant, and it must be consistent and available during execution. Depending on the room availability and channel used the reservation can be waited, approved, checked-in, and finally checked-out. Also, number of hotels, guests, and the information related with them has large number of occurrence in requests, so scalability perspective should focus on them. All of the components that process the reservation information should be scalable too.

The system has different type of data transfers between clients and server. This data are auto-generated client code, client requests, server responses, and also data transfer between application unit and database. Initially, all of the tables and relations between them in the database are scanned and code is generated automatically by the SaaS framework accordingly. This generated code is sent to a client to be displayed in the interfaces. A request is sent to the server from a client. This request is either to send information to the server or to get information from the server. Another flow is logging of records that is; application unit saves some process results into database.

5.2.3. Concurrency Viewpoint

Application layer of CHMS has dependency on .NET 3.5, Windows Server 2012 r2, and IIS 7 and it uses default values of their configurations. Thus, they handle the web requests concurrently, and they open thread per request, and limit of concurrent requests are dependent on them. According to official Windows Server site [27] default value of maximum number of concurrent ASP requests that are allowed into the request queue is 3000 and default value of the maximum number of worker threads per processor that ASP can create is 25. Besides, in database layer MS SQL Server 2000 queues related queries for consistency of information. As a result, they continue to use the same environment and same configurations, and also no change in concurrency design of the application is made after applying scalability perspective.

5.2.4. Development Viewpoint

CHMS has two separate development views for client-side and server-side. Figure 17 represents the development view of both server-side and client-side of CHMS. For server-side it has four layers, domain, utility, platform and data layers. Domain layer consists of nine modules related to management of subsystems, such as Reservation and Booking, Room, POS, Guest, Accounting, Agency, Channel, General, and Report Management. Utility layer includes logging library, authorization controls, multi-tenant filtration, security controls, database access, and message handling library. Platform layer involves .NET 3.5 libraries. Data layer has tables and stored procedures stored in MSSQL2000 RDBMS.

On the client-side, the system has three-layered architecture that has presentation, business, and data access layers. Presentation layer contains HTML forms, views, grids, graphics, and reports. Business layer contains JavaScript files. Data access layer has datasets that are taken from database and cached in the client device.

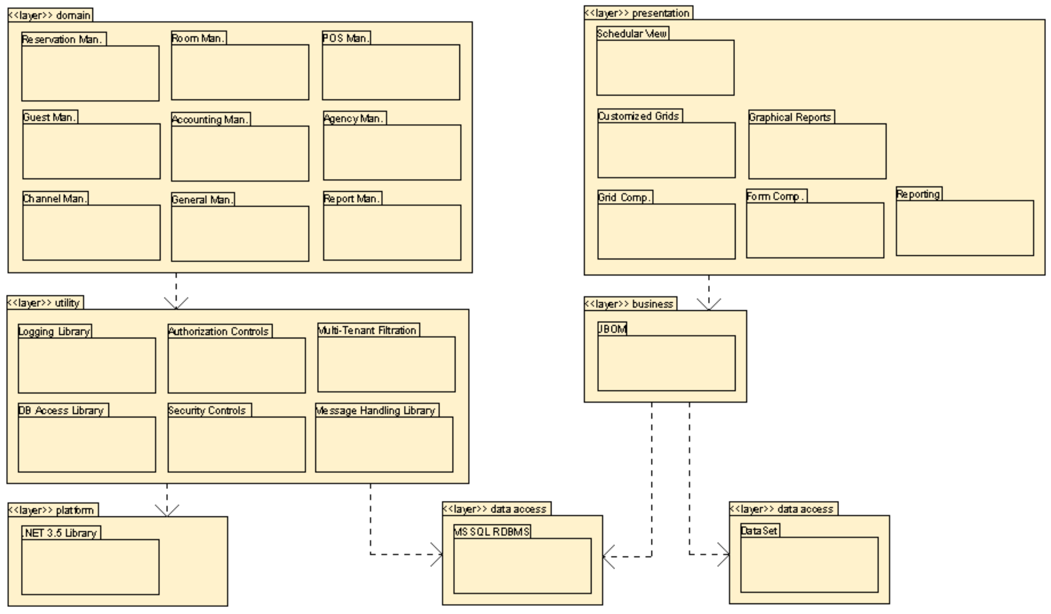


Figure 17: Development View of CHMS

As seen in left side of Figure 18, client layer makes requests to application layer, and application layer processes these requests, fetches data from database layer, and replies with the result data to client layer.

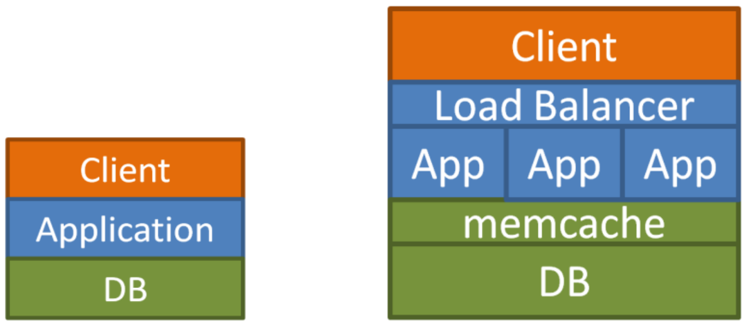


Figure 18: Development Views of CHMS after application of Scalability Perspective. Left one is the current one and the right one will be the final version.

Finally, as the demands and sources grow the system is planned to have the development view shown in right side of Figure 18. There will be no major changes in the contents of the layers instead there will be some additions to current layers. Memory cache will be added in front of the database, the contents of the application will be reproduced and a load balancer will be put in front of them.

5.2.5. Deployment Viewpoint

CHMS has client-server architecture like most of the cloud-based SaaS applications. In this pattern clients request functional operation to the server. Clients can access to the system from any device that has any environment (hardware, OS, etc.) specification. On the other hand, the server consists of the application and database layers. Instead of buying and maintaining hardware and software environments for the server, CHMS administrators decided to use Amazon’s EC2 machine. It allows them to launch server instance with the platform features that they can select among set of platform packages, to access the instance via web service interfaces, and to pay only for the resources they consume. Also, EC2 provides auto-scaling, elastic load balancing, monitoring whose details are explained in the architectural tactics section. They assess the requirements of the system, they think it is appropriate to select Amazon EC2 compute optimized c3.xlarge instance, hosted in Ireland as the server of CHMS [18]. It has 4 vCPUs 2.8 GHz High Frequency Intel Xeon E5-2680 v2 (Ivy Bridge) physical processors, 7.5 GiB memory, 2 40 GB SSD storage, and enhanced networking. Enhanced networking enables them to get significantly higher packet per second (PPS) performance and lower latencies. Moreover, since most of the CHMS customers are in Europe region, they select the nearest location, Ireland, among Amazon's hosting locations for the server instance. Choosing the nearest location decreases latencies in the network that has an impact on the scalability too. Furthermore, the OS is Windows Server 2012 r2, and it has MSSQL2000 DBMS. The server has IIS 7 and .NET 3.5 software dependencies.

Figure 19 shows the deployment diagram of current CHMS. The diagram can be used to identify scalability modules. SCL stereotype is used to tag scalability modules. Amazon EC2 server and business logic in the client device consists of application of scalability tactics which are described in tactics section. Scalability plan of this framework includes maintaining the system scalability for one server machine and multi-client environment in the first place.

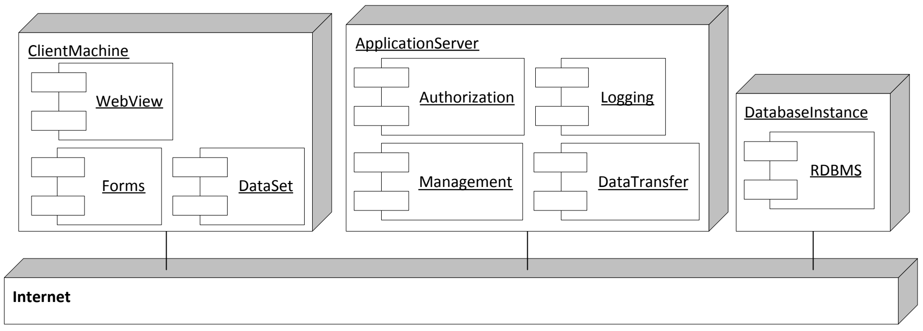


Figure 19: The deployment structure of CHMS

The one server contains both database and application components. Database contains multi-tenant data, a lot of information related to a large number of hotels, and millions of users that is registered to system. Also it contains not only data of hotel domain, but also data of other domains like property, hospital, etc. Such a large number of entries and such a large number of clients connected to database periodically cause a lot of requests and an overload on the server. To solve that scalability problem they will need to separate the RDBMS from the one server, and have execution of application and database on separate server machines. Also, when application layer and database are on the same machine, application layer accesses to database through shared memory, since it provides performance optimization. However, when they separate them, using TCP/IP protocol is preferred. Moreover, as the number of clients increase and demands grow they will start to scale-out, increase the number of application server machines, add load balancer in front of application servers, add memory cache in front of database server, etc. And possible outcome of application of these tactics will lead to a deployment diagram as you see in right side of the Figure 18.

5.2.6. Operational Viewpoint

As we describe in concerns section, response time, throughput, user access load, communication traffic load, data access load, usage and sufficiency of hardware resources are crucial for scalability perspective. To be able to collect information about these concerns and to be able to detect the scalability problems and to improve the system there is a need to periodic monitoring during the system is running in its production environment. Since server of CHMS run on the Amazon EC2 machine, they benefit from CloudWatch to monitor this machine. They collect and track throughput, processing time, disk usage, and data transfer metrics, such as number of the requests, latency. They also benefit from MS SQL Server 2000 counters to assess the volume of workload on database, time taken for application’s transactions to complete, IIS counters to assess the number of web requests being serviced and how long it is taking to service them, and Windows Server 2012 counters to assess the amount of workload that the application is performing and how long it is taking to perform the operations. Moreover, by logging component important events and statuses of important components are written into database. Furthermore, they can also set alarms to be able to be notified for peak load times. Also, they can use auto scaling feature of the service to dynamically add or remove EC2 instances by setting an alarm threshold.

Information stored in database is significant part of the system, and to satisfy consistency, reliability, and availability of the system a protection of information is a must. Therefore, information in the database should be backed up periodically. In CHMS two database backups occur per day. If any failure happens in the database, to rescue information as much as possible they can restore the last saved information from the backups. This is why two backup operations occur in a day.

Another important aspect of operational view is maintenance of the system and user training. User and developer guidelines and APIs are prepared during the project.

5.3. Applying Scalability Perspective

5.3.1. Scalability Requirements

Scalability requirements of CHMS include limits of user access load, communication traffic load, data access load, response time, throughput, and also they specify hardware resource requirements. Initial performance and scalability system requirements that are determined with customers are extended. Requirements include mostly quantitative descriptions so that they can be tested and be verified. These requirements are as follows.

- System shall be responsive, available, reliable, and consistent all the time.
- 95% of all visible pages for customers shall respond in 8 seconds or less, including infrastructure, excluding back-ends.
- The load time for user interface screens shall take no longer than two seconds.
- The log in information shall be verified within five seconds.
- System shall response to queries within five seconds.
- 50 records of any table shall be downloaded at most 1 second. (Max:50kb)
- System shall be able to deal with 100 users at the same time.
- System shall ensure that performance shall not fall below while supporting 3000 users.
- System shall be fast enough to support a 1000-transaction-per-day-workload.

- Under a load of 360 update transactions per minute, 95% of transactions shall return control to the user within 5 seconds of pressing the submit button.
- Under a load of 360 update transactions per minute, 90% of service requests should return a reply to the calling program within the following times:
  - Open account: 30 seconds
  - Update account details: 10 seconds
  - Retrieve account status: 5 seconds
  - Search operation: 5 seconds
  - List operation: 12 seconds
  - Filter and sort operations: 7 seconds
  - Display graphs, tables, calendars operation: 10 seconds
  - Save forms and reports operation: 6 seconds
- The DBMS shall support up to 100 concurrent users performing reservation transactions.
- Database of the system shall handle at least a 200 of users at any periods.
- Server machine shall have a powerful CPU and high speed internet access so that it can handle multiple users at the same time.
- Server machine shall have higher storage space so that it can have more user and bigger workspace per user so higher the storage, better the performance.
- Client-side web application shall be developed as a lightweight web app so that it can work on almost any platform even with slower internet connections.
- System shall handle 2 database backup operations without any performance degradation per day.

5.3.2. Modeling Guidelines and Examples

In this section we provide application of UML Scalability Profile on Cloud Hotel Management System (CHMS) that we present in our case study. The deployment of the logical elements across the engineering environment is shown in Figure 19.

Scenario: Scenario is composed of two parts, low-level and high-level scenarios.

Low-level Scenario: The user (us) requests business objects, table, view and stored-procedure schemes, from the SaaS framework. JBOM files are generated from RDBMS instance and extracted in the client machine. Client Application (ca) of CHMS is setup and ready to use. User requests one of web pages that have a list of records through the Web View (wv) that displays the web page. Then, user makes an update request and that request comes to program manager (pm) in the application instance. It, firstly, waits the result of authorization, the authorization component (ac) checks the credentials, session information by retrieving id and password from database (db) and comparing them with the data come. Any result of authorization is sent to logging component (lg). Logging component inserts the log record into database (db). At the same time, if the credentials are valid, program manager (pm) starts the processing operation. The result of the operation is sent through data transfer (dt) component to the client machine and the Web View (wv) displays the result data. The activity diagram in Figure 20 depicts this scenario.

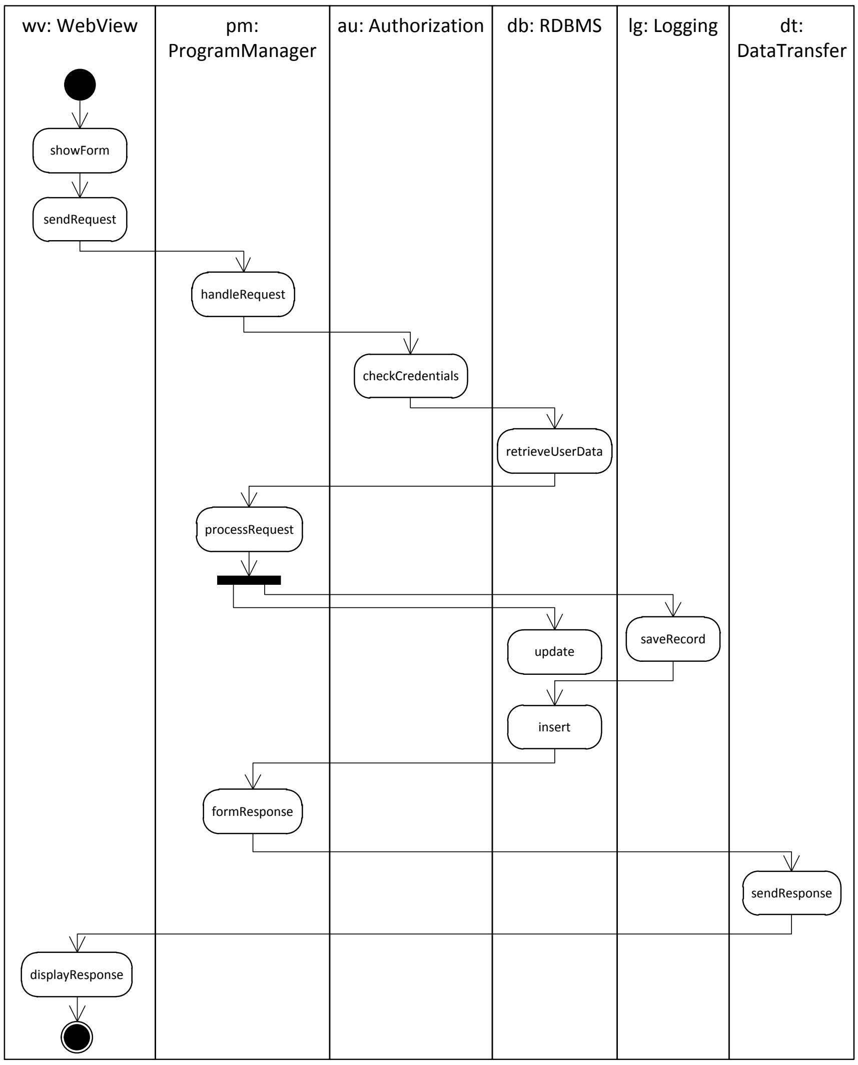


Figure 20: User request low-level scenario – activity diagram representation

High-Level Scenario: In high-level scenario there are a lot of users (us) that access to the CHMS from their client applications. All of the requests that are formed by these users are goes through communication links (cm) and reaches to the CHMS application server (as). Application servers make necessary operations that require also making database operations in the database instance (db). The low-level scenario explains the details of these requests and operations during the usage of one user. It can be thought as a sub-scenario that is occurred many times in this scenario. After the first iteration is realized, the number of users increases and the second iteration occurs. And to address demands of many users, the system is scaled vertically. Finally, the third iteration occurs. This scenario is represented by the sequence diagram in Figure 21.

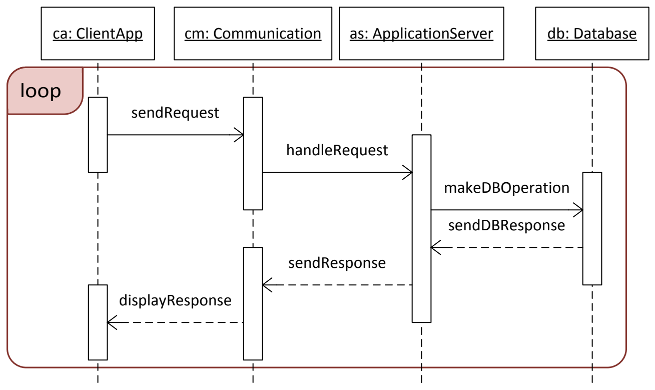


Figure 21: User requests high-level scenario – sequence diagram representation

Scalability Requirements

To analyze scalability, we need quantitative information on the execution of the components. We have the following values labeled as to whether they are measured values, estimates, or assumptions:

- (estimate) System shall ensure that performance shall not fall below while supporting 3000 users.
- (estimate) application instance processing duration: mean: 250 ms
- (estimate) database instance processing duration: mean: 150 ms
- (estimate) The DBMS support for concurrent users performing some transactions: 100
- (measured) Download duration per record of any table: 12 ms
- (assumed) network delay distribution: exponential with mean: 2 ms

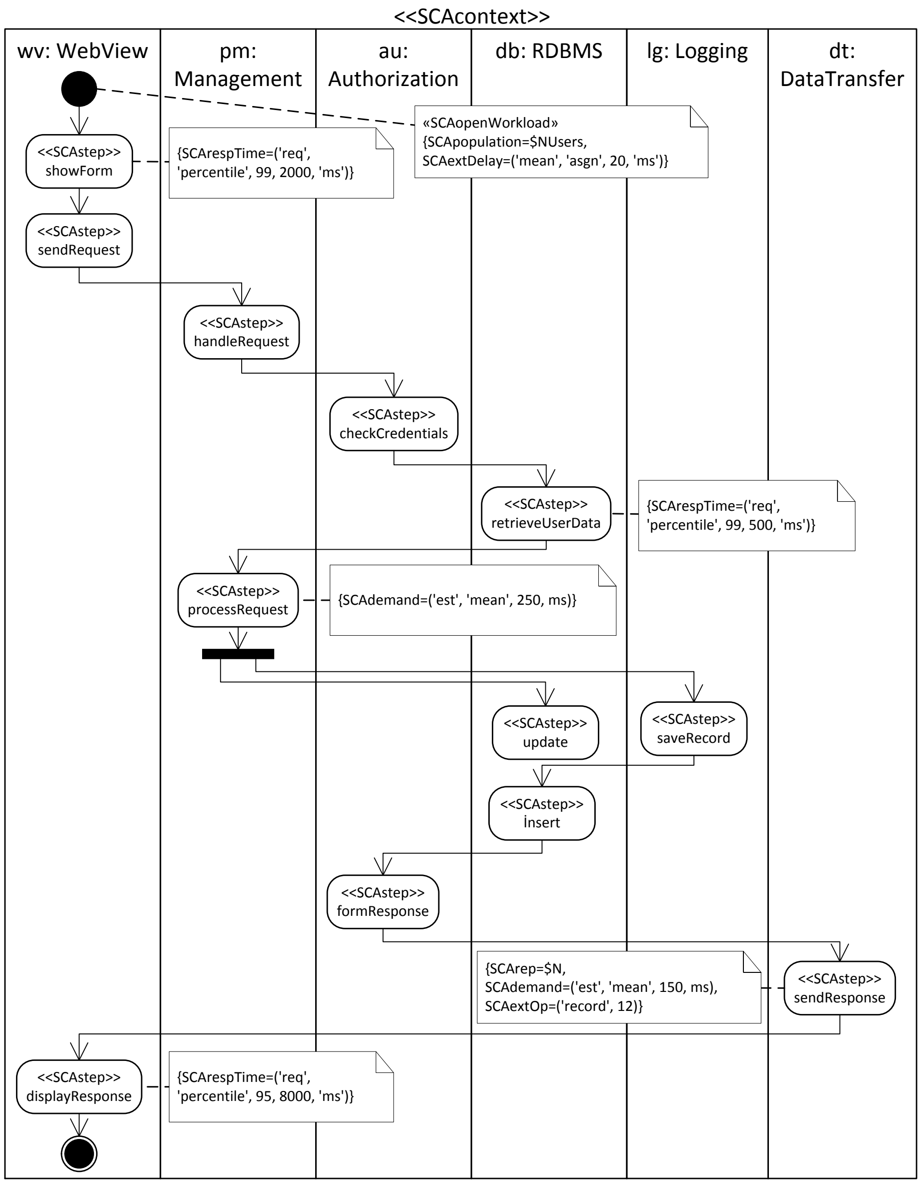
Additional parameters that are needed to complete an evaluation include the requirements, and a description of the workload intensity. Here, we will use the following additional parameters:

- initially the number of users active in the system: $NUsers, a variable
- external delay: each user has an average delay between ending one session and beginning another of 20 minutes
- records in a table: $N, a variable
- (requirement) Response time for any web page: 95% value < 8000 ms
- (requirement) Loading time for any web page: 99% value < 2000 ms

- (requirement) Verification duration of credentials in authorization component: 99% value < 5000 ms

The Annotated UML Model

The UML diagrams of CHMS can be annotated with scalability requirements defined. For example, events and actions of the low-level scenario in activity diagram shown above are associated with the scalability attributes and the resulting model is shown in Figure 22. It shows possible response times for critical operations.



<<SCAcontext>>
wv: WebView
pm: Management
au: Authorization
db: RDBMS
lg: Logging
dt: DataTransfer
«SCAopenWorkload» {SCApopulation=$NUsers, SCAextDelay=('mean', 'asgn', 20, 'ms')}
<<SCAstep>> showForm
{SCArespTime=('req', 'percentile', 99, 2000, 'ms')}
<<SCAstep>> sendRequest
<<SCAstep>> handleRequest
<<SCAstep>> checkCredentials
<<SCAstep>> retrieveUserData
{SCArespTime=('req', 'percentile', 99, 500, 'ms')}
<<SCAstep>> processRequest
{SCAdemand=('est', 'mean', 250, ms)}
<<SCAstep>> update
<<SCAstep>> saveRecord
<<SCAstep>> İnsert
<<SCAstep>> formResponse
{SCArep=$N, SCAdemand=('est', 'mean', 150, ms), SCAextOp=('record', 12)}
<<SCAstep>> sendResponse
<<SCAstep>> displayResponse
{SCArespTime=('req', 'percentile', 95, 8000, 'ms')}

Figure 22: User request low-level scenario – activity diagram representation with scalability annotations

Also, events and actions of the high-level scenario in sequence diagram shown above are associated with the scalability attributes, see Figure 23. It shows the impact of increase on number of users and the scale-up tactic. The impacts can be recognized by comparing the user access loads and the scalability metrics of the server resource. The values are assumed, so they may not be the same in the real scenario.

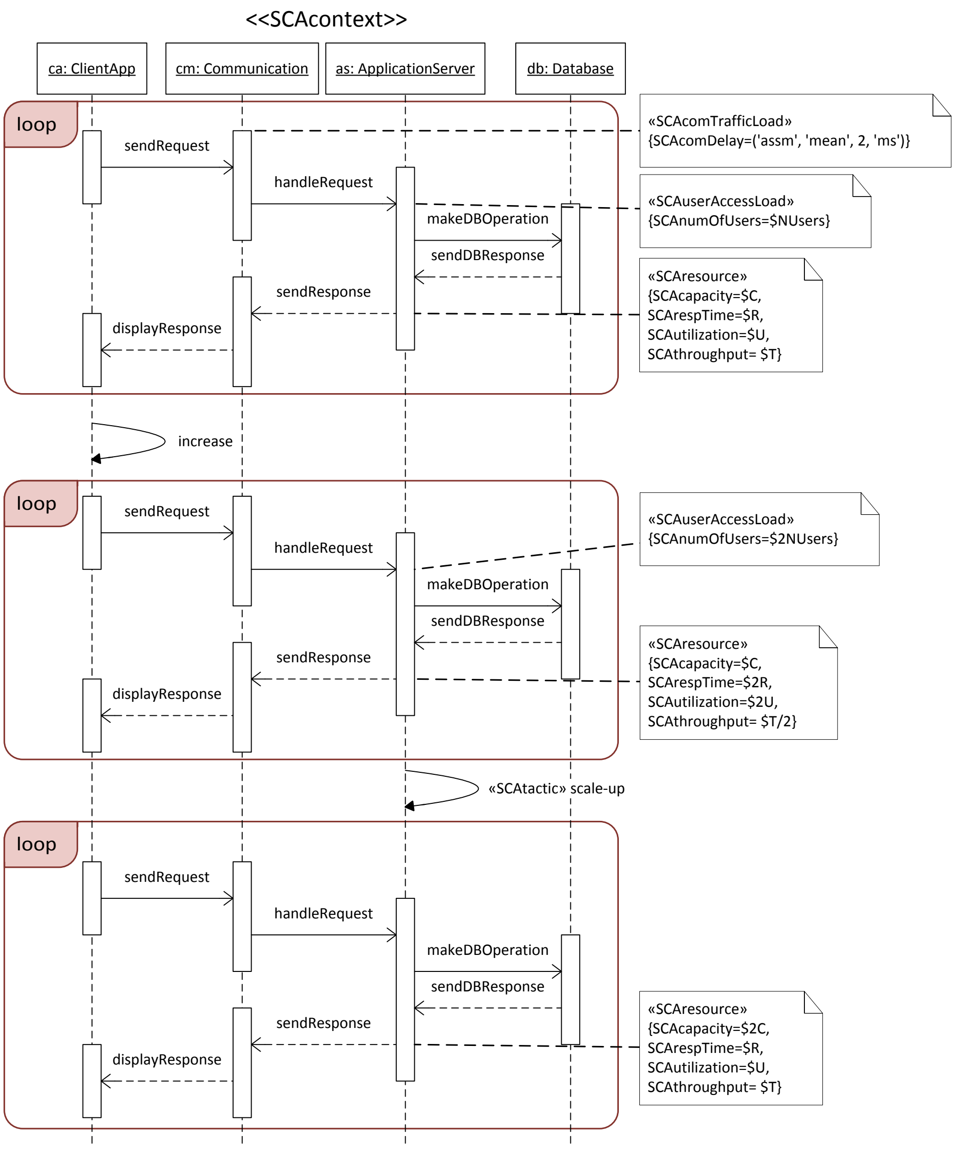
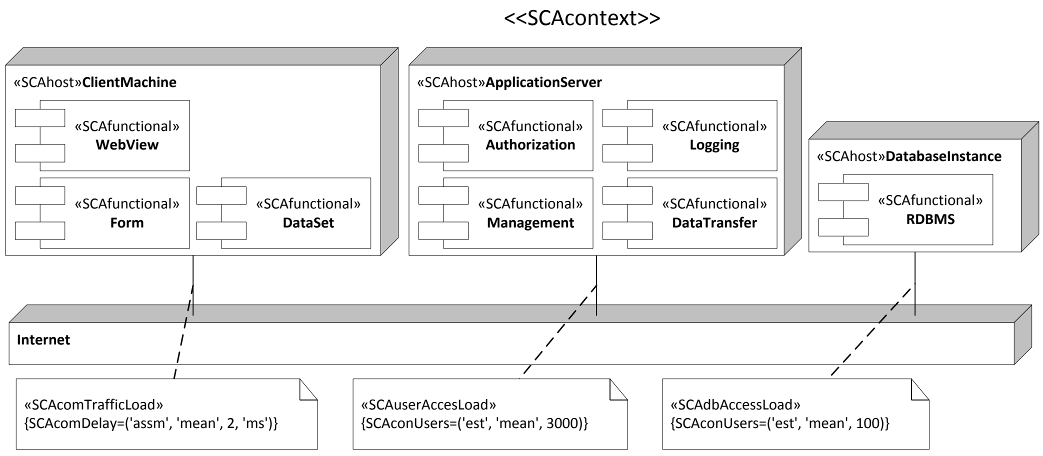


Figure 23: User request high-level scenario – sequence diagram representation with scalability annotations

Finally, we also present the annotated deployment diagram in Figure 24. We have annotations for the communication traffic, user access, and database access loads.



<<SCAcontext>>
«SCAhost»ClientMachine
«SCAfunctional» WebView
«SCAfunctional» Form
«SCAfunctional» DataSet
«SCAhost»ApplicationServer
«SCAfunctional» Authorization
«SCAfunctional» Logging
«SCAfunctional» Management
«SCAfunctional» DataTransfer
«SCAhost»DatabaseInstance
«SCAfunctional» RDBMS
Internet
«SCAcomTrafficLoad» {SCAcomDelay=('assm', 'mean', 2, 'ms')}
«SCAuserAccesLoad» {SCAconUsers=('est', 'mean', 3000)}
«SCAdbAccessLoad» {SCAconUsers=('est', 'mean', 100)}

Figure 24: Annotated deployment model for CHMS

5.4. Architectural Tactics

This section describes the scalability tactics that we have applied. As the demands and sources grow application, some possible scalability tactics that we will apply respectively are also listed below. The summary of all of the tactics are shown in Table 10. It shows which components are affected and in which aspects the tactic is applied.

5.4.1. Component-based Architecture

As you can see from the development view of CHMS, the system is divided into layers, client, application, and database. All of the functional elements of the system are placed in one of these layers, you can see functional view. Also, they are grouped into modules according to their functional domain to achieve high cohesion internally and low coupling to the outside. They have minimum dependency among themselves and do not interfere with each other. This condition facilitates finding the scalability obstacle and also applying the other scalability tactics, such as scale-out, load balancing, and replication.

5.4.2. Service-oriented Architecture

Built-in server components of the SaaS framework, such as authorization, multi-tenant filtration, logging, data transfer, have service behavior and totally they have provided service-oriented architecture. This provides scaling each part of the application independently. With the application of this pattern asynchrony is also satisfied, different components of the system can run parallel for concurrent requests and perform useful work while waiting for input and output to complete.

5.4.3. Minimize the Workload on the Server

CHMS have reduced the workload of the server, in other words it has moved and distributed some of the operations to clients and it has benefited from the computational power and memory of clients. Firstly, it has made use of cache part or all of the data used in a client. After the first fetch of data, it has been placed on the memory of client. This has provided making most of the operations like reading, validating, searching, and sorting, on the client-side rapidly without server connection. Thus, caching has reduced the number and the size of requests going to the server.

The requests have covered only the atomic create-read-update-delete-execute (CRUDE) operations that are computed at database. However, holding data has not been merely adequate. We have needed to move also the business logic, which processes this information for specific purposes, from server to client layer. For instance, field validations provide conformity of data to rules, such as minimum and maximum value or length, while doing operations with data. Before an operation the system should check whether data is valid or not. When data is not correct according to validation rules, the system should give an error as an output and should not continue the operation. Thus, when we have implemented this operation in client layer, we have made the system more responsive and scalable by reducing the network traffic and computational operations. Because we have moved a thing that consumes processing cycle of the whole application to a place that only one user is affected. Even if these operations must be done at the application layer, there exists a performance gain, since some of the checks are eliminated in first check in the client-side.

Difference between authorization mechanisms has also some effects on scalability. There are two ways of authorization, with session or sessionless. With session authorization client indicates its credentials only in its first request to the server. In its next requests it indicates its unique session key that is given by the server if its credentials are correct. Since requests have the session key, authorization component does not consume computational power for the validation of credentials On the other hand, in sessionless authorization client should indicate its credentials in every request to the server. For each request authorization component validates credentials of the incoming request. In the case of millions of requests this makes usage of a lot of computational power. As a result, since session authorization has less usage of computational power, it reduces the response time of each request and makes both component and the system more scalable.

5.4.4. Scale-up

Current hardware and software environment has been explained in the deployment view section. These features have been determined by thinking possible increase in demands. Therefore, up to now there has been no need to scale-up the system. But when a scalability problem, high response time, low throughput occurs the system can be scaled vertically by adding more and better hardware resources immediately. This can be done easily by editing the configuration of EC2. Also, EC2 provides auto-scaling that allows us to automatically scale EC2 capacity up or down according to conditions they define [18]. In other words, during peak loads they can increase the number resources to maintain performance, and decrease during low usage periods to minimize costs.

5.4.5. Scale-out

With the advantage of current multi-tenant architecture of CHMS they can easily scale the system horizontally. They can have more than one application and database nodes and tenants can be distributed to these nodes. Currently, scale-out has not been applied, yet in the future it is planned to be done. Firstly, database will be moved to another EC2 machine. Since multi-domain multi-tenant system brings high load on the server, a need to reduce the load on the server and to make it more responsive is obvious. Then, as the number of clients, their data, and their demands increase another horizontal scaling need will emerge. At this point, they will add more nodes in the application layer and requests will be processed in more than one application node. By the way, they can benefit from the auto-scaling feature of EC2 to realize this via web service. Thus, response time and throughput is stabilized on the same value ranges.

5.4.6. Caching

As we mention in the section 5.4.3 CHMS has applied caching in the client side to reduce communication traffic load, data access load, and usage of computational power of the server. Client does not request data from application layer any more after it has been requested initially. Also, since data can be fetched from memory rapidly, all of the information, such as customers, bookings, and invoices, that is displayed in guest or administrator interface is be searched and sorted quickly.

Another caching can be applied in database layer by adding a memory cache in front of database. By doing this they can optimize the repeated queries and reduce data access load.

5.4.7. Replication

As the number of requests increase, CHMS application layer cannot response all of these requests as fast as before. CHMS needs to catch the increase in the number of requests increase, so the response time should be lower and throughput should be higher than before. To realize this, replication, one of the scalability tactics, can be applied. There are two types of replication in terms of the place the replication occurs, replicating application or data. Firstly, components in the application layer or the whole application layer can be stored on multiple server instances. For instance, authorization component can work on multiple machines that reside in geographically different places. And each of them can hold session keys of clients who connect to the system from that region. Thus, workload of authorization on the application layer can be distributed to multiple machines, so a performance improvement can be satisfied. Or another example, during scale-out application layer as a whole can be placed in different instances. Thus, the total workload on the server can be distributed and processed concurrently by each of the application instances. Therefore, the system achieves a performance gain and can reply to more number of requests without performance degradation.

The second type of replication is multiplying the part or all of the data and storing them in multiple locations. The details have been explained in section 2.3.2.10. Database of CHMS has both shared data and tenant specific data. Shared data, such as countries, languages, currencies, is common data that contain any specific information to any of the tenants and can be usable by every tenant. It is usually used for read purposes. Thus, shared data should be replicated on another database instance. Tenant data has high usage ratio, since most of the requests coming to database includes it. Since it is used in write operations, it is not preferred to be replicated.

Moreover, SaaS framework provides the clients of CHMS to load the application code and parameters from the replicated file servers. Thus, the contention because of the JBOM files of each client is reduced.

5.4.8. Load Balancing

To reduce response time and waiting time of tasks they can use load balancing in CHMS. It can be done in the client layer, front-end load balancing, or in application layer, back-end load balancing. For front-end load balancer, a client decides a node to connect among available server nodes. This node can be selected randomly or via an algorithm. Another application of load balancing occurs in the application layer. When the application layer is horizontally scaled, number of application instances is increased and a need of distributing incoming requests to these instances emerges. In CHMS they can use Elastic Load Balancing service and automatically distribute incoming requests to multiple application EC2 instances in the application layer [19].

Chapter 6

Related Work

Scalability concern has been addressed by distributed systems and web-based systems for ten years. With vastly usage and proliferation of cloud computing, scalability has become a crucial quality concern for all of the large-scale systems. It has been addressed as a quality concern and as a problem of not meeting growing demands in studies of industrial cases. In these studies developers have shared their scalability problem and solution. Software architecture design books and guidelines have mentioned scalability concern in non-functional requirements and with performance criteria. Besides, some of the architectural patterns touch on the scalability of the software. However, there has been no study that addresses the scalability perspective as a standalone architectural perspective guideline that describes its concerns, activities, tactics, aspects, and problems. Rozanski and Woods [47] have discussed on the architectural perspectives and they have treated scalability perspective as a sub-concern of the performance perspective. They have aimed to avoid unexpected, complex, and expensive problems late in the system lifecycle. Also, there have been some papers and guidelines on scalability. For example, in [24] SaaS performance and scalability have been evaluated and analyzed with proposed graphical models and metrics, but they have not focused on scalability at the architectural level. In [23] the authors have discussed factors that have impact on SaaS scalability and some tactics to improve SaaS scalability, yet they have addressed subset of the factors and tactics. Some of the papers have described application of one scalability tactic or pattern. In [29] they have applied component-based scalability, in [60] they have worked on scalable SaaS database design.

OMG has proposed various UML profiles, such as profile for schedulability, performance and time (SPT) [43] and profile for modeling Quality of Service and Fault Tolerance (QoS & FT) [42]. SPT profile has enabled the construction of models that can be used for making quantitative predictions regarding these characteristics [42]. Performance profile has extended the UML meta-model with stereotypes, tagged values and constraints, which make it possible to attach performance annotations, such as resource demands and visit ratios, to a UML model. It has provided facilities for capturing performance requirements within the design context, associating performance-related QoS characteristics with selected elements of the UML model, specifying execution parameters which can be used by modeling tools to compute predicted performance characteristics, and presenting performance results computed by modeling tools or found by measurement. Firstly, it has described a domain model which identifies basic abstractions used in performance analysis. Then, it has mapped the classes from domain model to a stereotype that can be applied to a number of UML model elements, and each class attribute to a tagged value. Finally, it has provided activity or sequence diagrams with performance annotations that illustrate a scenario. Scenarios define response paths through the system, and can have QoS requirements such as response times or throughputs. QoS deals with the set of non-functional aspects of a system that determines the satisfaction level of its users, and it may be therefore intended as a multi-attribute resulting from the combination of basic non-functional attributes such as performance and usability [42]. Fault Tolerance is a very strictly related attribute that assesses the capability of a system to deliver continuous and failure-free service.

UML performance profile has been used by lots of existing studies. Petriu and Shen [44] have defined a model transformation method and they have used UML performance profile as an input to this method. Their method is based on graph-grammar and transforms automatically a UML model annotated with performance information into a Layered Queuing Network (LQN) performance model. Their reason of choosing UML performance profile is that it is easy to understand and it provides enough annotations for generating LQN models. They have also applied their method on their case study and have provided a deployment and an activity diagrams with performance annotations. Bennett and Field [5] have assessed the effectiveness of their performance engineering methodology using UML SPT profile with a case study, a mobile telecommunications billing system. They have reached that their methodology is effective at detecting, quantifying, and locating performance bottlenecks. Their methodology includes system scenarios and covers the early phases of development process. In order to assess their methodology, they have translated scenarios of their case study illustrated with using SPT profile into the stochastic process algebra FSP and have analyzed them using existing tools.

Another quality domain, reliability, has been addressed by various authors. Reliability is a measure of the continuous delivery of correct service. Zarras and Issarny [59] have proposed a UML profile for modeling and assessing software reliability. They have identified the main concepts of the reliability domain and have provided domain viewpoint. They have also presented a tool using their profile definition. Cortellessa and Pompei [13] have presented an UML extension to be able to model reliability of component-based systems. Their extensions have built on concepts introduced in SPT profile [42] and have contributed to QoS & FT profile [42]. They have defined domain model, stereotypes, tags, and constraints that are related to reliability of component-based systems. Their model has described the failure rates of components and combines them to obtain a reliability factor for the whole system. As an example they have included UML models with reliability annotations for an elevator control system.

Chapter 7

Conclusion

The need for economical optimization of resources has leaded to emergence of cloud computing. Software as a Service (SaaS), the most mature the cloud service model, addresses the software demands of users. In this model providers own, host, and manage software at a central site. They offer the same instance of an application to multiple customers, typically in a single-instance multi-tenant architecture model. On the other hand, users simply access it remotely over the Internet instead of installing and maintaining software, and managing hardware. Recently, SaaS is intended to be used by thousands of people simultaneously and this increase in SaaS adoption makes scalability as one of key characteristics of SaaS. Scalability is defined as the ability of a system to either handle a growing amount of work in a capable manner, or to be enlarged to accommodate that growth [48]. It brings significant challenges for providers in designing and maintaining SaaS. In order to fulfill this quality, understanding the scalability features of the system and being aware of existing scalability patterns are crucial. In this thesis, we have contributed systematic literature review of SaaS scalability, UML profile for scalability, and software architecture perspective for scalability.

We have conducted a domain analysis study on scalability of SaaS applications. In this study, we have aimed to provide a guide for new SaaS applications and to existing SaaS applications to be able to achieve scalability easily by showing the most common aspects affecting scalability of SaaS and tactics being applied to make a SaaS scalable determined so far. During this research we have followed the steps of Kitchenham’s systematic literature review methodology [33]. We have analyzed the primary studies we have found in search databases, we have filtered some of them according to our exclusion criteria, and finally have extracted the data needed and have provided the list of aspects and tactics.

Also, we have proposed UML profile for scalability, which has not been proposed by any study before. OMG has provided a study on UML profiling, but it has addressed to only three qualities that are schedulability, performance, and time [43]. Scalability profile is based on the general resource modeling. It enhances the comprehension of scalability requirements and estimations. It describes how the scalability will be for a system without actually testing it in real life.

Furthermore, Rozanski and Woods [47] have presented a perspective catalog that consists of perspectives for most common quality concepts, such as performance, availability, security, etc. These perspectives consist of patterns for each viewpoint to be able to achieve the quality in the architecture. Scalability has been addressed as a concern of the performance quality, but scalability is a separate quality that has a relation with performance. Therefore, we have provided a perspective for scalability, so that it supports the design and analysis of scalable SaaS architectures. It includes a collection of activities and guidelines that require consideration across a number of the architectural views. It can assist software architects in designing, analyzing, and communicating the decisions regarding scalability. We have illustrated the scalability perspective for a real industrial case study.

During this study we have identified some possible future works. SLR on search databases can be expanded to extend list of aspects and list of tactics. Also, a scalability model can be defined and can be offered to OMG to make it formal. If it is achieved, transformation between UML profile for scalability and scalability model can be also provided. A new tool, that allows designing UML diagrams with scalability annotations and automatically generates a scalability model, may be introduced. DSL for scalability can be proposed. It can use the stereotypes, tags, and constraints we have provided in UML profile. A tool that takes system requirements and architect preferences as inputs to produce scalable architecture can be implemented.

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Publications Related to This Thesis

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