FAKULTÄT FÜR INFORMATIK

TECHNISCHE UNIVERSITÄT MÜNCHEN

Master's Thesis in Informatics

Designing a business platform using microservices.

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Designing a business platform using microservices.

Entwerfen einer Business-Plattform mit microservices.

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I confirm that this master's thesis in informatics is my own work and I have documented all sources and material used.

Munich, Rajendra Kharbuja

Acknowledgments

Abstract

Microservices architecture provides various advantages compared to monolith architecture and thus has gained a lot of attention. However, there are still many aspects of microservices architecture which are not clearly documented and communicated. This research attempts to provide a clear picture of various concepts of microservices architecture such as granularity, modeling process and then finally create a comprehensive guidelines for implementing microservices.
Various keywords from different definitions were taken and cateogorized into various conceptual areas. Theses concepts along with the keywords were researched throroughly to understand the concepts of microservices architecture. Additionally, the three important drivers: quality attributes, constraints and principles, are taken as the major focus for creating guidelines.
A lot of interesting findings were made. Although, the concept of microservices emphasize on small services, the notion of appropriate granularity is more important and depends upon four basic concepts which are : single responsibility, autonomy, infrastructure capability and business value. Additionally, the quality attributes such as coupling, cohesion etc should also be considered for identification of microservices. A list of basic metrices were created which can make it easy to qualify microservices.
In order to identify microservices, either domain driven design or use case refactoring can be used. Both these approach can be effective but the concept of bounded context in domain driven design identifies autonomous services with single responsibility. Apart from literature, thorough study of the architectural approach used in industry called SAP Hybris was done. A number of interviews conducted with their key personnels gave important insight into the process of modeling as well as operating microservices. Again, challenges for implementing microservices as well as the approach to tackle them were done based on the literature and interviews done at SAP Hybris.
Finally, all the findings were used to create a detail guidelines for implementing microservices. This is one of the major outcome of the research which dictates how to approach modeling microservices architecture as well as its operational complexities.

Contents

1 Introduction

Architecture is the set of principles assisting system or application design. [DMT09] It defines the process to decompose a system into modules, components and their interactions. [Bro15] In this chapter, two different approaches will be taken. Firstly, a conceptual understanding of monolithic architecture style will be presented, which will then be followed by its various advantages and disadvantages. Then, an overview of microservices architecture will be given. In Section 1.3, the motivation for the current research is explained which is then followed by list of various reseach questions 1.3 being focused. Finally, in Section 1.4 the approach which will be used to conduct the research is presented. The purpose of this chapter is to provide a basic background context for the following chapters.

1.1 Monolith Architecture Style

A Mononlith Architecture Style is the one in which an application is deployed as a single artifact. The architecture inside the application can be modular and clean. In order to clarify, the figure 1.1 shows architecture of an Online-Store application. The application has clear separation of components such as Catalog, Order and Service as well as respective models such as Product, Order etc. Despite of that, all the units of the application are deployed in tomcat as a single war file.[Ric14a][Ric14c]

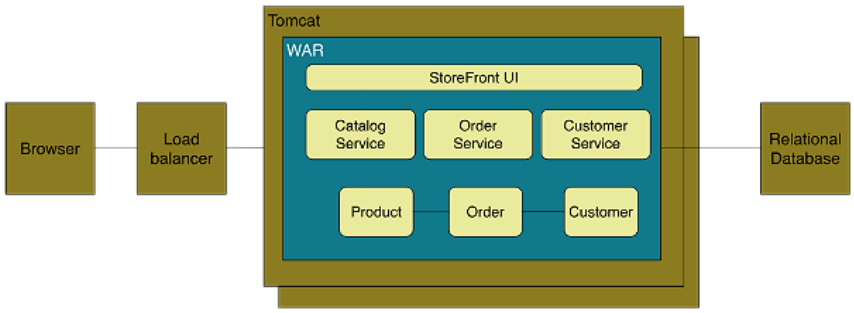


Figure 1.1: Monolith Example from [Ric14a]

1.1.1 Types of Monolith Architecture Style

According to [Ann14], a monolith can be of several types depending upon the viewpoint, as shown below:

1. Module Monolith: If all the code to realize an application share the same codebase and need to be compiled together to create a single artifact for the whole application then the architecture is Module Monolith Architecture. An example is show in figure 1.2. The application on the left has all the code in the same codebase in the form of packages and classes without clear definition of modules and get compiled to a single artifact. However, the application on the right is developed by a number of modular codebase, each has separate codebase and can be compiled to different artifact. The modules uses the produced artifacts which is different than the earlier case where the code referenced each other directly.

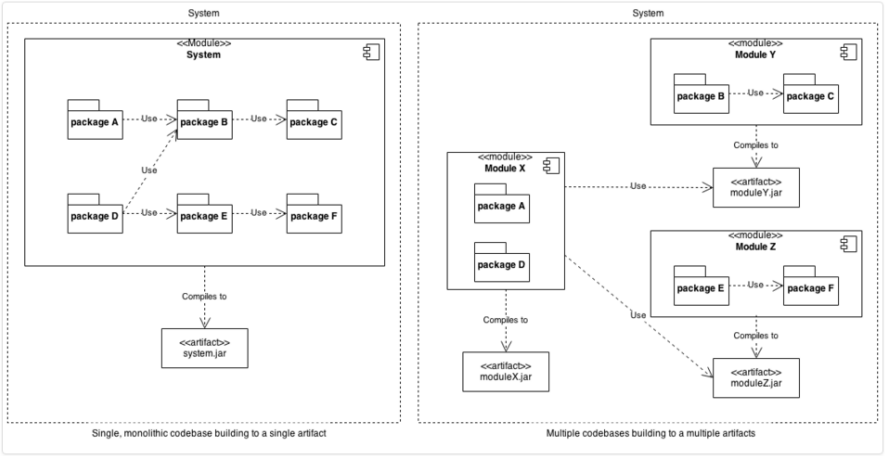


Figure 1.2: Module Monolith Example from [Ann14]

2. Allocation Monolith: An Allocation Monolith is created when all code is deployed to all the servers as a single version. This means that all the components running on the servers have the same versions at any time. The figure 1.3 gives an example of allocation monolith. The system on the left have same version of artifact for all the components on all the servers. It does not make any differenct whether or not the system has single codebase and artifact. However, the system on the right as shown in the figure is realized with multiple version of the artifacts in different servers at any time.

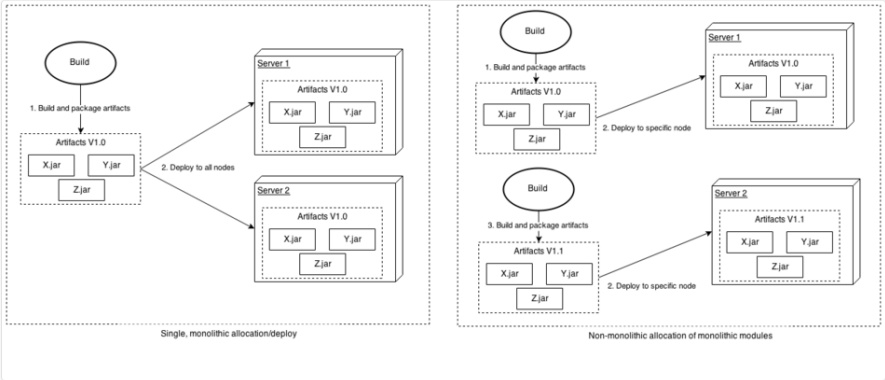


Figure 1.3: Allocation Monolith Example from [Ann14]

3. Runtime Monolith: In Runtime Monolith, the whole application is run under a single process. The left system in the figure 1.4 shows an example of runtime monolith where a single server process is responsible for whole application. Whereas the system on the left has allocated multiple server process to run distinct set of component artifacts of the application.

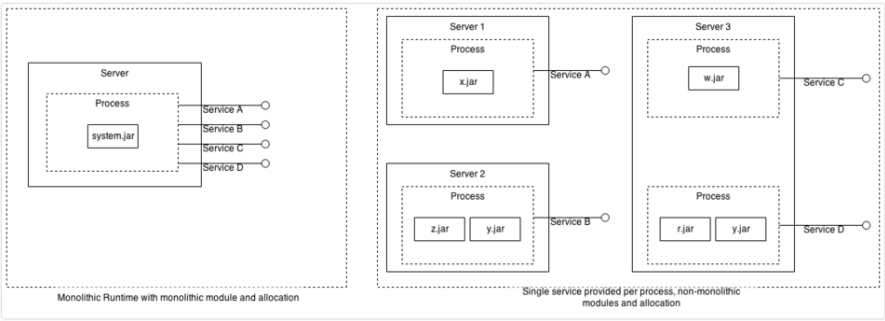


Figure 1.4: Runtime Monolith Example from [Ann14]

1.1.2 Advantages of Monolith Architecture Style

The Monolith architecture is appropriate for small application and has following benifits:[Ric14c][FL14][Gup15][Abr14]

- It is easy to develop a monolith application since various development tools including IDEs are created around the single application concept. Nevertheless,

it is also easy to test the application by creating appropriate environment on the developer's machine.

- The deployment can be simply achieved by moving the single artifact for the application to an appropriate directory in the server.
- The scaling can be clearly and easily done by replicating the application horizontally across multiple servers behind a load balancer as shown in figure 1.1
- The different teams are working on the same codebase so sharing the functionality can be easier.

1.1.3 Disadvantages of Monolith Architecture Style

As the requirement grows with time, alongside as application becomes huge and the size of team increases, the monolith architecture faces many problems. Most of the advantages of monolith architecture for small application will not be valid anymore. The challenges of monolith architecture for such agile and huge context are as given below:[NS14][New15][Abr14][Ric14a][Ric14c][Gup15]

- Limited Agility: As the whole application has single codebase, even changing a small feature to release it in production takes time. Firstly, the small change can also trigger changes to other dependent code because in huge monolith application it is very difficult to manage modularity especially when all the team members are working on the same codebase. Secondly, to deploy a small change in production, the whole application has to be deployed. Thus continuous delivery gets slower in case of monolith application. This will be more problematic when multiple changes have to be released on a daily basis. The slow pace and frequency of release will highly affect agility.

- Decrease in Productivity: It is difficult to understand the application especially for a new developer because of the size. Although it also depends upon the structure of the codebase, it will still be difficult to grasp the significance of the code when there is no hard modular boundary.Additionally, the developer can be intimidated due to need to see the whole application at once from outwards to inwards direction. Secondly, the development environment can be slow to load the whole application and at the same time the deployment will also be slow. So, in overal it will slow down the speed of understandability, execution and testing.

- Difficult Team Structure: The division of team as well as assigning tasks to the team can be tricky. Most common ways to partition teams in monolith are by technology and by geography. However, each one cannot be used in all the situations. In any case, the communication among the teams can be difficult and slow. Additionally, it is not easy to assign vertical ownership to a team from particular feature from development to relase. If something goes wrong in the deployment, there is always a confusion who should find the problem, either operations team or the last person to commit. The approprate team structure and ownership are very important for agility.

- Longterm Commitment to Technology stack: The technology to use is chosen before the development phase by analysing the requirements and the maturity of current technology at that time. All the teams in the architecture need to follow the same techonology stack. However, if the requirement changes then there can be situation when the features can be best soloved by different sets of technology. Additionally, not all the features in the application are same so cannot be treated accordingly in terms of technology as well. Nevertheless, the technology advances rapidly. So, the solution thought at the time of planning can be outdated and there can be a better solution available. In monolith application, it is very difficult to migrate to new technology stack and it can be rather painfull process.

- Limited Scalability: The scalability of monolith application can be done in either of two ways. The first way is to replicate the application along many servers and dividing the incoming request using a load balancer in front of the servers. Another approach is using the identical copies of the application in multiple servers as in previous case but partitioning the database access instead of user request. Both of these scaling approaches improves the capacity and availability of the application. However, the individual requirement regarding scaling for each component can be different but cannot be fulfilled with this approach. Also, the complexity of the monolith application remains the because we are replicating the whole application. Additionally, if there is a problem in a component the same problem can affect all the servers running the copies of the application and does not improve resilency.[Mac14][NS14]

1.2 Microservice Architecture Style

With monolith, it is easy to start development. But as the system gets bigger and complicated along time, it becomes very difficult to be agile and productive. The disadvantages listed in Section 1.1.3 outweighs its advantages as the system gets old. The various qualities such as scalability, agility need to be maintained for the whole lifetime of the application and it becomes complicated by the fact that the system needs to be updated side by side because the requirements keeps coming always. In order to tackle the disadvantages, microservices architecture style is followed.
Microservices architecture uses the approach of decomposing an application into various dimensions as proposed by scale-cube. The detailed process of scale-cube is discussed in section 1.2.1.

1.2.1 Decomposition of an Application

There are various ways to decompose an application. This section discuss two different ways of breaking down an application.

1.2.1.1 Scale Cube

The Section 1.1.3 specified various disadvantages related to monolith architecture style. The book [FA15] provides a way to solve most of the discussed problems such as agility, scalability, productivity etc. It provides three dimensions of scalability as shown in figure 1.5 which can be applied alone or simultaneously depending upon the situation and desired goals.

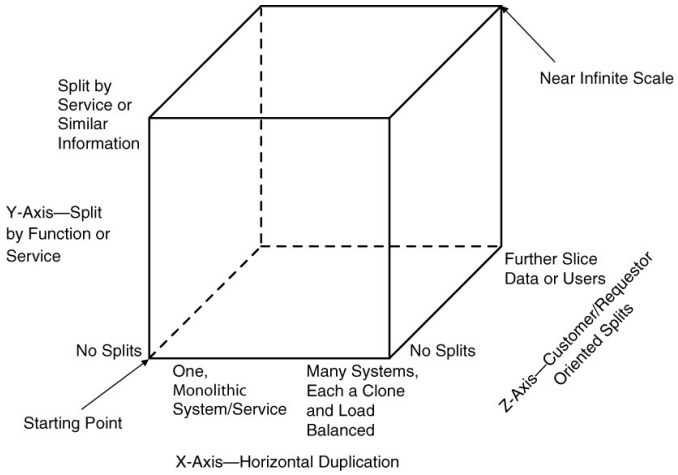


Figure 1.5: Scale Cube from [FA15]

The scaling along each dimensions are described below. [FA15][Mac14][Ric14a]

1. X-axis Scaling: It is done by cloning the application and data along multiple servers. A pool of requests are applied into a load balancer and the requests are deligated to any of the servers. Each of the server has the full capability of the application and full access to all the data required so in this respect it does not make any difference which server fulfills the request. Rather, it is about how many requests are fulfilled at any time. It is easy to scale along X-axis as the number of requests increases. The solution is as simple as to add additional clones. However, with this type of scaling, it is not scale with the increase in data. Moreover, it also does not scale when there are large variation in the frequency of any type of requests or there dominant requests types because all the requests are handled in an unbiased way and allocated to servers in the same way.

2. Z-axis Scaling: The scaling is done by spliting the request based on certain critera or information regarding the requestor or customer affected by the request. It is different than X-axis scaling in the way that the servers are responsible for different kinds of requests. Normally, the servers have same copy of the application but some can have additional functionalies depending upon the requests expected. The Z-axis scaling helps in fault isolation and transaction scalability. Using this scaling, certain group of customers can be given added functionality or a new functionality can be tested to a small group and thus minimizing the risk.

3. Y-axis Scaling: The scaling along this dimension means the spliting of the application responsibility. The separation can be done either by data, by the actions performed on the data or by combination of both. The respective ways can be referred to as resoure-oriented or service-oriented splits. While the x-axis or z-axis split were rather duplication of work along servers, the y-axis is more about specialization of work along servers. The major advantage of this scaling is that each request is scaled and handled differently according to its necessity. As the logic along with the data to be worked on are separated, developers can focus and work on small section at a time. This will increase productivity as well as agility. Additionally, a fault on a component is isolated and can be handled gracefully without affecting rest of the application. However, scaling along Y-axis can be costly compared to scaling along other dimensions.

1.2.1.2 Shared Libraries

Libraries is a standard way of sharing functionalities among various services and teams. The capability is provided by the feature of programming language. However there are various downsides to this approach. Firstly, it does not provide technology heterogeneity. Next, unless the library is dynamically linked, independent scaling, deployment and maintainance cannot be achieved. So, in other cases, any small change in the library leads the redeployment of whole system. Sharing code is a form of coupling which should be avoided.

Decomposing an application in terms of composition of individual features where each feature can be scaled and deployed independently, gives various advantages along agility, performance and team organization as well. Thus, microservices uses the decomposition technique given by scale cube. A detail advantages of microservices are discussed further in Section 6.1.

1.2.2 Definitions

There are several definitions given by several pioneers and early adapters of the style.

Definition 1: [Ric14b]

"It is the way to functionally decompose an application into a set of collaborating services, each with a set of narrow, related functions, developed and deployed independently, with its own database."

Definition 2: [Woo14]

"It is a style of software architecture that involves delivering systems as a set of very small, granular, independent collaborating services."

Definition 3: [Coc15]

"Microservice is a loosely coupled Service-Oriented Architecture with bounded contexts."

Definition 4: [FL14][RTS15]

"Microservices are Service-Oriented Architecture done right."

Definition 5: [FL14]

" Microservice architecture style is an approach to developing a single application as a suite of small services, each running in its own process and communicating with lightweight mechanisms, often an HTTP resource API. These services are built around business capabilities and independently deployable by fully automated deployment machinery. There is a bare minimum of centralized management of these services, which may be written in different programming languages and use different data storage technologies."
As other architectural styles, microservices presents its approach by increasing cohesion and decreasing coupling. Besides that, it breaks down system along business domains following single responsibility principle into granular and autonomous services running on separate processes. Additionally, the architecture focus on the collaboration of these services using light weight mechanisms.

1.3 Motivation

The various definitions presented in section highlights different key terms such as:

1. collaborating services
2. developed and deployed independently

3. build around business capabilities
4. small, granular services

These concepts are very important to be understood in order to approach microservices correctly and effectively. The first two terms relate to runtime operational qualities of microservices whereas the next two address modeling qualities. With that consideration, it indicates that the definitions given are complete which focus on both aspects of any software applications.
However, if attempt is made to have clear indepth understanding of each of the key terms then various questions can be raised without appropriate answers. The various questions (given in column 'Questions') related to modeling and operations (given in column 'Type') are listed in the Table 1.1.

#	Questions	Type
1	How small should be size of microservices?	Modeling
2	How does the collaboration among services happen?	Operation
3	How to deploy and maintain independently when there are dependencies among services?	Operation
4	How to map microservices from business capabilities?	Modeling
5	What are the challenges need to be tackled and how to?	Operation

Table 1.1: Various Questions related to Microservices

Without clear answer to these questions, it is difficult to say that the definitions presented in section are complete and enough to follow the microservices architecture. The process of creating microservices is not clearly documented. There is no enough research papers defining a thorough process of modeling and operating microservices. Additionally, a lot of industries such as amazon, netflix etc are following this architecture but it is not clear about the process they are using to define and implement microservices. The purpose of the research is to have a clear understanding about the process of designing microservices by focusing on following questions.

Research Questions

1. How are boundary and size of microservices defined?
2. How business capabilities are mapped to define microservices?
3. What are the best practices to tackle challenges introduced by microservices?
   a) How does the collaboration among services happen?

b) How to deploy and maintain independently when there are dependencies among services?

c) How to monitor microservices?

1.4 Research Approach

A research is an iterative procedure with a goal of collecting as many relevant documents as possible so that the research questions could be answered rationally. So, it becomes very important to follow a consistent research procedure. For the current research, the approach is chosen by refering to [np07]. It consists of two major phases.

1. Data Collection Phase
2. Data Synthesis Phase

The following sections explains each phase in detail.

1.4.1 Data Collection Phase

In this phase, papers related to the reseach questions are collected. The Figure 1.6 shows basic steps in this phase.

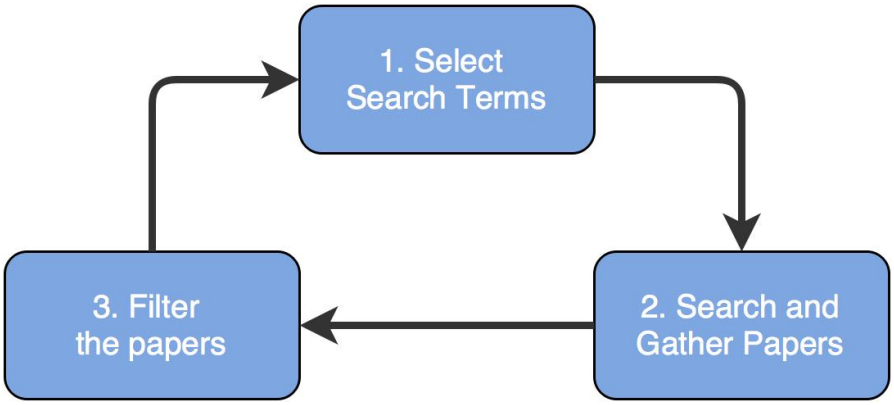


Figure 1.6: Data Collection Phase

1. **Select Search Terms**
   At first, various search terms which defines the research topics and questions well, are selected using following strategies.
   a) keywords from research questions and various definitions

b) synonyms of keywords

c) accepted and popular terms from academics and industries

d) references discovered from selected papers

A consise list of initial keywords which are selected from various definitions of microservices are given in Table 1.2.

2. **Search and Gather Papers**
The search terms selected in previous step are utilized to discover various papers. In order to achieve that, the search terms are used against various resources listed below.

   a) google scholar

   b) IEEExplore

   c) ACM Digital Library

   d) Researchgate

   e) Books

   f) Technical Articles

3. **Filter the Papers** Finally, the various papers collected from various resources are filtered first to check if the papers have profound and thorough base to back up their result. Using only authentic papers is important to provide rational base to current research. The various criteria used to filther the papers are listed below.

   a) Is the paper relevant to answer the research question?

   b) Does the paper have good base in terms of sources as well as provide references of the past studies?

   c) Are there any case studies or examples provided to verify the result of the reseach?

1.4.2 Data Synthesis Phase

The next phase is to gather data from the selected papers to create meaningful output and provide direction to the research. The Figure 1.7 shows various steps within this phase.

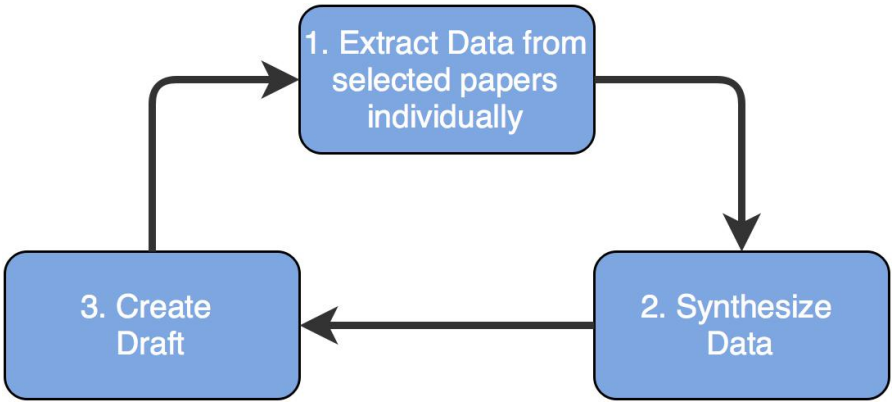


Figure 1.7: Data Synthesis Phase

1. **Extract Data from selected papers individually**
   Firstly, each papers are scanned and important data relevant to research are collected.

2. **Synthesize Data**
   The data collected from each paper are revised and compared for their similarities in concepts as well as differences in opinion. These individual contents from all papers are then synthesized.

3. **Create Draft**
   Finally, draft for the observations are created for future reference to be used later for creating final report.

1.5 Research Strategy

The Section 1.4 emphasize the importance of having consistent research procedure. Additionally, it is important to define a good strategy for achieving goals of the research. A good strategy is to narrow down the areas for conducting research. In this section, a list of areas will be identified.
The various definitions in Section 1.2.2 show that the authors have their own interpretation of microservices but at the same time agree upon some basic concepts regarding the architecture. However, each definition can be used to understand different aspect of the microservices. A distinct set of keywords can be identified which represents different aspects pointed by the authors and various concepts they agree. The Table 1.2 shows various keywords to focus. Additionally, there are other columns in the

table which represents various aspects of microservices architecture. These columns are checked or unchecked to represent the relevancy of each keyword.

#	keywords	size	Quality of good microservice	communication	process to model microservices
1	Collaborating Services			✓	
2	Communicating with lightweight mechanism like http			✓	
3	Loosely coupled, related functions		✓	✓	
4	Developed and deployed independently				✓
5	Own database		✓		✓
6	Different database technologies				✓
7	Service Oriented Architecture		✓		✓
8	Bounded Context	✓	✓		✓
9	Build around Business Capabilities	✓	✓		✓
10	Different Programming Languages				✓

Table 1.2: Keywords extracted from various definitions of Microservice

These keywords provide us some hint regarding various topics of discussion related to microservices, which are represented by columns. Finally, answering various questions around these keywords can be the **first approach** to understand the topics shown in columns such as size, quality of microservices etc.
The **next approach** to look around the architecture process is to understand various drivers. According to [Bro15], the important drivers which clarify the architecture are:

1. **Quality Attributes**
   The non-functional requirements have high impact on the resulting architecture. It is important to consider various quality attributes to define the process of architecture.

2. **Constraints**
   There are always limitations or disadvantages faced by any architecture however the better knowledge is useful in the process of explaining the architecture with satisfaction.

3. **Principles**
   The various principles provides a consistent approaches to tackle various limitations. They are the keys to define guidelines.

So, in order to define the process of modeling microservices, the key aspects related to **quality attributes**, **constraints** and **principles** will be studied thoroughly.

Considering both the Table 1.2 and List 1.5, the approach to be used to define the guidelines will be to first look deep into various quality attributes influencing microservices architecture. Then, the process of identifying or modeling individual microservices from problem domain will be defined. At first, the research is performed based on

various research papers. Then, the approach used by industry adopting microservices architecture will be studied in order to answer the research questions. The study will be performed on SAP Hybris. Finally, the various constraints or challenges which affects microservices will be identified. The results of previous research will be mapped into a form of various principles and these principles will ultimately provide sufficient ground to create guidelines for microservices architecture.

1.6 Problem Statement

Considering the case that the size of microservice is an important concept and is discussed a lot, but no concrete answer regarding this topic exists. Moreover, the idea of size has a lot of interpretations and no definite answer regarding how small a microservice should be. So, the first step should be to understand the concept of granularity in the context of microservices. Additionally, it would be great if some answers regarding the appropriate size of microservices could be given.

2 Granularity

In this chapter, a detailed concept regarding size of microservices will be discussed. A major focus would be to research various qualitative aspects of granularity of microservices. The Section 2.2 lists various principles which can guide to model correct size considering various important aspects. Later, in Section 2.3, various interpretations defining dimensions of microservices are presented. Finally, the secion provides a complete picture of various factors which determine granularity.

2.1 Introduction

The granularity of a service is often ambiguous and has different interpretation. In simple term, it refers to the size of the service. However, the size itself can be vague. It can neither be defined as a single quantitative value nor it can be defined in terms of single dependent criterion. It is difficult to define granularity in terms of number because the concepts defining granularity are vague and subjective in nature. If we choose an activity supported by the service to determine its granularity then we cannot have one fixed value instead a hierarchical list of answers; where an activity can either refer to a simple state change, any action performed by an actor or a complete business process. [Linnp], [Hae+np]
Although, the interest upon the granularity of a component or service for the business users only depends upon their business value, there is no doubt that the granularity affects the architecture of a system. The honest granularity of a service should reflect upon both business perspective and should also consider the impact upon the overall architecture.
If we consider other units of software application, we come from object oriented to component based and then to service oriented development. Such a transistion has been considered with the increase in size of the individual unit. The increase in size is contributed by the interpretation or the choice of the abstraction used. For example, in case of object oriented paradigm, the abstraction is chosen to represent close impression of real world objects, each unit representing fine grained abstraction with some attributes and functionalities.
Such abstraction is a good approach towards development simplicity and understanding, however it is not sufficient when high order business goals have to be implemented.

It indicates the necessity of coarser-grained units than units of object oriented paradigm. Moreover, component based development introduced the concept of business components which target the business problems and are coarser grained. The services provide access to application where each application is composed of various component services. [Linnp]

2.2 Basic Principles to Service Granularity

In addition to quantitative perspective on granularity, it can be helpful to approach the granularity qualitatively. The points below are some basic principls derived from various scientific and research papers, which attempt to define the qualitative properties of granularity. Hopefully, these principles will be helpful to come with the service of right granularity.

1. The correct granularity of a component or a service is dependent upon the time. The various supporting technologies that evolve during time can also be an important factor to define the level of vertical decomposition. For eg: with the improvement in virtualization, containerization as well as platform as a service technologies, it is fast and easy for deployment automation which supports multiple fine-grained services creation.[HS00]

2. A good candidate for a service should be independent upon the implementation but should depend upon the understandability of domain experts.

   [Hae+np; HS00]

3. A service should be an autonomous reusable component and should support various cohesion such as functional (group similar functions), temporal(change in the service should not affect other services), run-time(allocate similar runtime environment for similar jobs; eg. provide same address space for jobs of similar computing intensity) and actor (a component should provide service to similar users). [Hae+np], [HS00]

4. A service should not support huge number of operations. If it happens, it will affect high number of customers on any change and there will be no unified view on the functionality. Furthermore, if the interface of the service is small, it will be easy to maintain and understand.[Hae+np], [RS07]

5. A service should provide transaction integrity and compensation. The activities supported by a service should be within the scope of one transaction. Additionally, the compensation should be provided when the transaction fails. If each operation

provided by the service map to one transaction, then it will improve availability and fault-recovery. [Hae+np], [Foo05] [BKM07]

6. The notion of right granularity is more important than that of fine or coarse. It depends upon the usage condition and moreover is about balancing various qualities such as reusability, network usage, completeness of context etc. [Hae+np], [WV04]

7. The level of abstraction of the services should reflect the real world business activities. Doing so will help to map business requirements and technical capabilities. [RS07]

8. If there are ordering dependencies between the operations, it will be easy to implement and test if the dependent operations are all combined into a single service. [BKM07]

9. There can be two better approaches for breaking down an abstraction. One way is to separate redundant data or data with different semanting meaning. The other approach is to divide services with limited control and scope. For example: A Customer Enrollment service which deals with registration of new customers and assignment of unique customer ID can be divided into two independent fine-grained services: Customer Registration and ID Generation, each service will have limited scope and separate context of Customer.[RS07]

10. If there are functionalities provided by a service which are more likely to change than other functionalities. It is better to separate the functionality into a fine-grained service so that any further change on the functionality will affect only limited number of consumers. [BKM07]

2.3 Dimensions of Granularity

As already mentioned in Section 2.1, it is not easy to define granularity of a service quantitatively. However, it can be made easier to visualize granularity if we can project it along various dimensions, where each dimension is a qualifying attribute responsible for illustrating size of a service. Eventhough the dimensions discussed in this section will not give the precise quantity to identify granularity, it will definitely give the hint to locate the service in granularity space. It will be possible to compare the granularity of two distinct services. Moreover, it will be interesting and beneficial to know how these dimensions relate to each other to define the size.

2.3.1 Dimension by Interface

One way to define granularity is by the perception of the service interface as made by its consumer. The various properties of a service interface responsible to define its size are listed below.

1. Functionality: It qualifies the amount of functionality offered by the service. The functionality can be either default functionality, which means some basic group of logic or operation provided in every case. Or the functionality can be parameterized and depending upon some values, it can be optionally provided. Depending upon the functionality volume, the service can be either fine-grained or course-grained than other service. Considering functionality criterion, A service offering basic CRUD functionality is fine-grained than a service which is offers some accumulated data using orchestration. [Hae+np]

2. Data: It refers to the amount of data handled or exchanged by the service. The data granularity can be of two types. The first one is input data granularity, which is the amount of data consumed or needed by the service in order to accomplish its tasks. And the other one is ouput data granularity, which is the amount of data returned by the service to its consumer. Depending upon the size and quantity of business object/objects consumed or returned by the service interface, it can be coarse or fine grained. Additionally, if the business object consumed is composed of other objects rather than primitive types, then it is coarser-grained. For example: the endpoint "PUT customers/C1234" is coarse-grained than the endpoint "PUT customers/C1234/Addresses/default" because of the size of data object expected by the service interface. [Hae+np]

3. Business Value: According to [RKKnp], each service is associated with an intention or business goal and follows some strategy to achiee that goal. The extent or magnitude of the intention can be perceived as a metric to define granularity. A service can be either atomic or aggregate of other services which depends upon the level of composition directly influenced by the extent of target business goal. An atomic service will have lower granularity than an aggregate in terms of business value. For example, sellProduct is coase-grained than acceptPayment, which is again coarse-grained than validateAccountNumber. [Hae+np]

2.3.2 Dimension by Interface Realization

The Section 2.3.1 provides the aspect of granularity with respect to the perception of customer to interface. However, there can be different opinion regarding the same properties, when it is viewed regarding the imlementation. This section takes the same aspects of granularity and try to analyze them when the services are implemented.

1. Functionality: In Section 2.3.1, it was mentioned that an orchestration service has higher granularity than its constituent services with regard to default functionality. If the realization effort is focused, it may only include compositional and/or compensation logic because the individual tasks are acomplshed by the constituent service interfaces. Thus, in terms of the effort in realizing the service it is fine-grained than from the view point of interface by consumer. [Hae+np]

2. Data: In some cases, services may utilize standard message format. For example: financial services may use SWIFT for exchanging finanicial messages. These messages are extensible and are coarse grained in itself. However, all the data accepted by the service along with the message may not be required and used in order to fulfil the business goal of the service. In that sense, the service is coarse-grained from the viewpoint of consumer but is fine-grained in realization point of view. [Hae+np]

3. Business Value: It can make a huge impact when analyzing business value of service if the realization of the service is not considered well. For example: if we consider data management interface which supports storage, retrieval and transaction of data, it can be considered as fine-grained because it will not directly impact the business goals. However, since other services are very dependent in its performance, it becomes necessary to analyse the complexity associated with the implementation, reliablity and change the infrastructure if needed. These comes with additional costs, which should well be analyzed. From the realization point of view, the data service is coarse-grained than its view by consumer. [Hae+np]

Principle: A high Functionality granularity does not necessarily mean high business value granularity
It may seem to have direct proportional relationship between functionality and business value granularity. The business value of a service reflects business goals however the functionality refers to the amount of work done by the service. A service to show customer history can be considered to have high functionality

granularity because of the involved time period and database query. However, it is of very low business value to the enterprise. [Hae+np]

2.3.3 R^3 Dimension

Keen [Kee91] and later Weill and Broadbent [WB98] introduced a separate group of criteria to measure granularity of service. The granularity was evaluated in terms of two dimensions as shown in the Figure 2.1

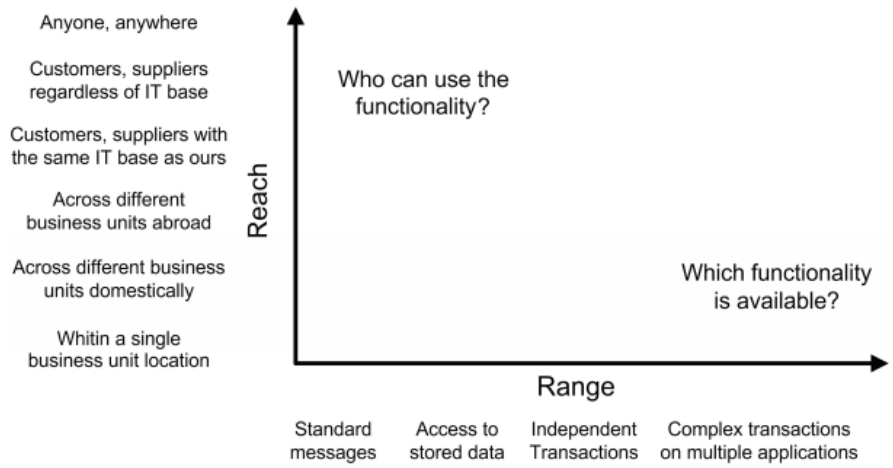


Figure 2.1: Reach and Range model from [Kee91; WB98]

Reach: It provides various levels to answer the question "Who can use the functionality? ". It provides the extent of consumers, who can access the functionality provide by the service. It can be a customer, the customers within an organization, supplier etc. as given by the Figure 2.1.
Range: It gives answer to "Which functionality is available? ". It shows the extent to which the information can be accessed from or shared with the service. The levels of information accessed are analyzed depending upon the kind of business activities accessible from the service. It can be a simple data access, a transaction, message transfer etc as shown in the Figure 2.1 The 'Range' measures the amount of data exchanged in terms of the levels of business activities important for the organization. One example for such levels of activities with varying level of 'Range' is shown in Figure 2.2.

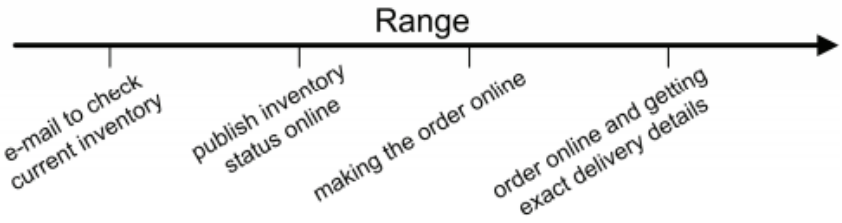


Figure 2.2: Example to show varying Range from [Kee91; WB98]

In the Figure 2.2, the level of granularity increases as the functionality moves from 'accessing e-mail message' to 'publishing status online' and then to 'creating order'. It is due to the change in the amount of data access involved in each kind of functionality. Thus, the 'Range' directly depends upon the range of data access.
As the service grows, alongside 'Reach' and 'Range' also peaks up, which means the extent of consumers as well as the kind of functionality increase. This will add complexity in the service. The solution proposed by [Coc01] is to divide the architecture into services. However, only 'Reach' and 'Range' will not be enough to define the service. It will be equally important to determine scope of the individual services. The functionality of the service then should be define in two distinct dimensions 'which kind of functionality' and 'how much functionality'. This leads to another dimension of service as described below. [Kee91; WB98; RS07]
Realm: It tries to create a boundary around the scope of the functionality provided by the service and thus clarifies the ambiguity created by 'Range'. If we take the same example as given by Figure **??**, the range alone defining the kind of functionaly such as creating online order does not explicitly clarifies about what kind of order is under consideration. The order can be customer order or sales order. The specification of 'Realm' defining what kind of order plays role here. So, we can have two different services each with same 'Reach' and 'Range' however different 'Realm' for customer order and Sales order. [Kee91; WB98; RS07]

The consideration of all aspects of a service including 'Reach', 'Range' and 'Realm' give us a model to define granularity of a service and is called R^3 model. The volume in the R^3 space for a service gives its granularity. A coarse-grained service has higher R^3 volume then fine-grained service. The Figure **??** and Figure 2.4 show such volume-granularity analogy given by R^3 model. [Kee91; WB98; RS07]

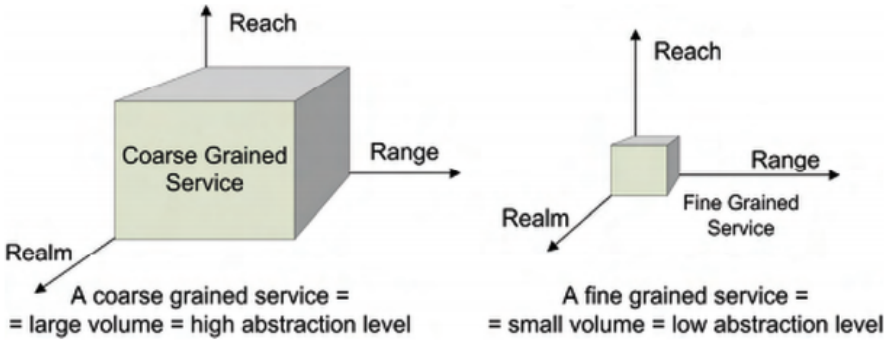


Figure 2.3: R^3 Volume-Granularity Analogy to show direct dependence of granularity and volume [RS07]

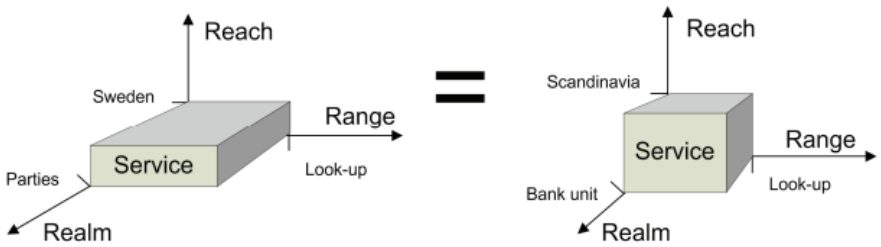


Figure 2.4: R^3 Volume-Granularity Analogy to show same granularity with different dimension along axes [RS07]

2.3.4 Retrospective

The Section 2.3.1 and Section 2.3.2 classified granularity of a service along three different directions: data, functionality and business value. Moreover, the interpretation from the viewpoint of interface by consumer and the viewpoint of producer for realization were also made. Again, the Section 2.3.3 divides the aspect of granularity along Reach, Range and Realm space, the granularity given by the volume in the R^3 space. Despite of good explanation regarding each aspect, the classification along data, functionality and business value do not provide discrete metrics to define granularity in terms of quantitatively. However, the given explanations and criteria are well rounded to compare two different services regarding granularity. These can be effectively used to classify if a service is fine-grained than other service. The R^3 model in Section 2.3.3

additionally provides various levels of granularity along each axis. This makes it easy to at least measure the granularity and provides flexibility to compare the granularity between various services.
A case study [RS07] using data, functionality and business criteria to evaluate the impact of granularity on the complexity in the architecture is held. The study was done at KBC Bank Insurance Group of central Europe. Along the study, the impact of each kind of granularity is verified. The important results fromt the study are listed below.

1. A coarse-grained service in terms of 'Input Data' provides better transactional support, little communication overhead and also helps in scalability. However, there is a chance of data getting out-of-date quickly.

2. A coarse-grained service in terms of 'Output Data' also provides good communication efficiency and supports reusability.

3. A fine-grained service along 'Default Functionality' has high reusability and stability but low reuse efficiency.

4. A coarse-grained service due to more optional functionalities has high reuse efficiency, high reusability and also high stability but the implementation or realization is complicated.

5. A coarse-grained service along 'Business Value' has high consumer satisfaction value and emphasize the architecturally crucial points fulfilling business goals.

Similarly, a study was carried out in Handelsbanken in sweden, which has been working with Service-Oriented architecture. The purpose of the study was to analyze the impact of R^3 model on the architecture. It is observed that there are different categories of functionalities essential for an organization. Some functionality can have high Reach and Range with single functionality and other may have complex functionality with low Reach and Range. The categorization and realization of such functionalities should be accessed individually. It is not necessary to have same level of granularity across all services or there is no one right volume for all services. However, if there are many services with low volume, then we will need many services to accomplish a high level functionality. Additionally, it will increase interdependency among services and network complexity. Finally, the choice of granularity is completely dependent upon the IT-infrastructure of the company. The IT infrastructure decides which level of granularity it can support and how many of them. [RS07]

Principle: IT-infrastructure of an organization affects granularity.
The right value of granularity for an organization is highly influenced by its IT infrastructure. The organization should be capable of handling the complexities such as communication, runtime, infrastructure etc if they choose low granularity. [RS07]

Additionally, it is observed that a single service can be divided into number of granular services by dividing across either Reach, Range or Realm. The basic idea is to make the volume as low as possible as long as it can be supported by IT-infrastructure. Similarly, each dimension is not completely independent from other. For example: If the reach of a service has to be increased from domestic to global in an organization then the realm of the functionality has to be decreased in order to make the volume as low as possible, keep the development and runtime complexities in check. [RS07]

Principle: Keep the volume low if possible.
If supported by IT-infrastructure, it is recommended to keep the volume of service as low as possible, which can be achieved by managing the values of Reach, Range and Realm. It will help to decrease development and maintenance overload. [RS07]

2.4 Problem Statement

This chapter analysed various qualitative aspects related to granularity of microservices. The interesting thing to notice is various dimensions of size across data, functionality and business value. But it is also necessary to look into it in quantitative approach. Also, the various principles listed in Section 2.2 points to other qualities of microservices except granularity. The granularity is not only attribute which is important while modeling microservices but there are other quality attributes which affect granularity and influence on the quality of microservices. The next task will be to study various other quality attributes affecting microservices and derive their quantitative metrices.

3 Quality Attributes of Microservices

This chapter will attempt to find out various factors defining quality of microservices. Also, it will provide quantitative approach to evaluate the overal quality of microservice. At first, the Section 3.2 presents a list of quality attributes compiled from various research papers, which are considered important when defining quality of service. Next, in Section 3.3, various metrices to evaluate these attributes are given. Furthermore, in Section 3.4, a list of basic metrices being derived from complex metrices introduced in section are created. Again, the Section 3.5 lists various principles which shows impact of various attributes on the quality of microservices. Finally, based on the previous result on metrics and principles, relationship of granularity with other quality attributes is tabulated in Section 3.6.

3.1 Introduction

In addition to allign with the business requirements, an important goal of software engineering is to provide high quality. The quality assessment in the context of service oriented product becomes more crucial as the complexity of the system is getting higher by time. [ZL09; GL11; Nem+14] Quality models have been devised over time to evaluate quality of a software. A quality model is defined by quality attributes and quality metrics. Quality attributes are the expected properties of software artifacts defined by the chosen quality model. And, quality metrics give the techniques to measure the quality attributes. [Man+np] The software quality attributes can again be categorized into two types: internal and external attributes. [Man+np; BMB96] The internal quality attributes are the design time attributes which should be fulfilled during the design of the software. Some of the external quality attributes are loose coupling, cohesion, granularity, autonomy etc.[Ros+11; SSPnp; EM14] On the other hand, the external quality attributes are the traits of the software artifacts produced at the end of Software Development Life Cycle Some of them are reusability, maintainability etc. [EM14; Man+np; FL07; Feu13] For that reason, the external quality attributes can only be measure after the end of development. However, it has been evident that internal quality attributes have huge impact upon the value of external quality attributes and thus can be used to predict them. [HS90; Bri+np; AL03; Shi+08]The evaluation of both internal and external quality attributes are valuable in order to produce high quality

software.[Man+np; PRF07; Per+07]

3.2 Quality Attributes

As already mentioned in Section 3.1, the internal and external qualities determine the overall value of the service composed. There are different researches and studies which have been performed to find the features affecting the service qualities. Based on the published research papers, a comprehensive table 3.1 has been created. The table provides a minimum list of quality attributes which have been considerd in various research papers.

#	Attribute	[SSPnp]	[Xianp]	[AZR11]	[Shi+08]	[Ma+09]	[FL07]
1	Coupling	✓	✓	✓	✓	✓	✓
2	Cohesion	✓	X	✓	✓	✓	✓
3	Autonomy	✓	X	X	X	X	X
4	Granularity	✓	✓	✓	✓	✓	✓
5	Reusability	✓	X	X	✓	X	✓
6	Abstraction	✓	X	X	X	X	X
7	Complexity	X	X	X	✓	X	X

Table 3.1: Quality Attributes

The Table 3.1 gives a picture of the studies done so far around service quality attributes. It can be deduced that most of the papers focus on coupling and granularity of the service and only few of them focus on other attributes such as complexity and autonomy.

Coupling refers to the dependency and interaction among services. The interaction becomes inevitable when a service requires a functionality provided by another service in order to accomplish its own goals. Similarly, Cohesion of any system is the extent of appropriate arrangement of elements to perform the functionalities. It affects the degree of understandability and sensibility of its interface for its consumers. Whereas, the complexity attribute provides the way to evaluate the difficulty in understanding and reasoning the context of the service or component.[EM14]
The reusability attribute for a service measures the degree to which it can be used by multiple consumer services and can undergo multiple composition to accoplish various high order functionalities. [FL07]
Autonomy is a broad term which refers to the ability of a service for self-containment, self-controlling, self-governance. Autonomy defines the boundary and context of the service. [MLS07] Finally, granularity is described in Chapter 2 in detail. The basic

signifance of granularity is the diversity and size of the functionalities offered by the service. [EM14]

3.3 Quality Metrics

There have been many studies made to define metrics for quality components.A major portion of the research have been done for object oriented and component based development. These metrics are refined to be used in service oriented systems.[Xianp; SSPnp] Firslty, various papers related to quality metrics of service oriented systems are collected. The papers which conducted their findings or proposition based on quality amount of scientific studies and have produced convincing result are only selected. Additionally, the evaluation presented in the research papers were only done using the case studies of their own and not real life scenarios. Furthermore, they have used diversity of equations to define the quality metrics. On the basis of case studies made in the papers only, a fair comparision and choice of only one way to evaluate the quality metrics cannot be made. This is further added by the fact that the few papers cover most of the quality metrics, most of them focus on only few quality metrics such as coupling but not all of them focus on all the quality metrics. Nevertheless, they do not discuss about the relationship between all quality metrics. [EM14] This creates difficulty to map all the quality metrics into a common calculation family.
With such situation, this section will focus on facilitating the understanding of the metrics. Despite the case that there is no idea of threshold value of metrics discussed to define the optimal quality level, the discussed method can still be used to evaualte the quality along various metrics and compare the various design artifacts. This will definitely help to choose the optimum design based on the criteria. Also, there is complexity in understanding and confusion to follow a single proposed metrics procudure. But, the existing procedures can be broken down further to the simple understandable terms. By doing so, the basic terms which are the driving factors for the quality attributes and at the same time followed by most of the procedures as defined in the papers, can be identified.
The remaining part of this section will attempt to collaborate the metrics definitions proposed in various papers, analyze them to identify their conceptual base of measurement in simplest form.

3.3.1 Context and Notations

Before looking into the definitions of metrics, it will help understanding, to know related terms, assumptions and their respective notations.

- the business domain is realized with various processes defined as $P = \{p_1, p_2...p_s\}$
- a set of services realizing the application is defined as $S = \{s_1, s_2...s_s\}$; s_s is the total number of services in the application
- for any service $s \epsilon S$, the set of operations provided by s is given by $O(s) = \{o_1, o_2, ...o_o\}$ and $|O(s)|$ = O
- if an operation $o \epsilon O(s)$ has a set of input and output messages given by M(o). Then the set of messages of all operations of the service is given by $M(s) = \cup_{o \epsilon O(s)} M(o)$
- the consumers of the service $s \epsilon S$ is given by $S_{consumer}(s) = \{S_{c1}, S_2, ...Sn_c\}$; n_c gives the number of consumer services
- the producers for the service or the number of services to which the given service $s \epsilon S$ is dependent upon is given by $S_{producer}(s) = \{S_{c1}, S_2, ...Sn_p\}$; n_p gives the number of producer services

3.3.2 Coupling Metrics

[SSPnp] defines following metrics to determine coupling

$$SOCI(s) = number\_of\_operations\_invoked$$
$$= |\{o_i \epsilon s_i : \exists_{o \epsilon s} calls(o, o_i) \wedge s \neq s_i\}|$$

$$ISCI(s) = number\_of\_services\_invoked$$
$$= |\{s_i : \exists_{o \epsilon s}, \exists_{o_i \epsilon s_i} calls(o, o_i) \wedge s \neq s_i\}|$$

$$SMCI(s) = size\_of\_message\_required\_from\_other\_services$$
$$= | \cup M(o_i) : (o_i \epsilon s_i) \vee (\exists_{o \epsilon s}, \exists_{o_i \epsilon s_i} calls(o, o_i) \wedge s \neq s_i)|$$

where,

- SOCI is Service Operation Coupling Index
- ISCI is Inter Service Coupling Index
- SMCI is Service Message Coupling Index

- $call(o, o_i)$ represents the call made from service 'o' to service 'o_i'

[Xianp] defines

$$Coupling(S_i) = p \sum_{j=1}^{n_s} (-log(P_L(j)))$$

$$= \frac{1}{n} \sum_{j=1}^{n_s} (-log(P_L(j)))$$

where,

- n_s is the total number of services connected
- 'n' is the total number of services in the entire application
- $p = \frac{1}{n}$ gives the probability of a service participating in any connection

[Kaz+11] defines

$$Coupling = \frac{dependency\_on\_business\_entities\_of\_other\_services}{number\_of\_operations\_and\_dependencies}$$

$$= \frac{\sum_{i \epsilon D_s} \sum_{k \epsilon O(s)} CCO(i,k)}{|O(s)|.K}$$

where,

- $D_s = \{D_1, D_2, ...D_k\}$ is set of dependencies the service has on other services
- $K = |D_s|$
- CCO is Conceptual Coupling betweeen service operations and obtained from BE X EBP (CRUD) matrix table constructed with business entities and business operations, where BE is business entity and EBP any logical process defined in an operation.

[Shi+08] defines

$$coupling(s) = \frac{number\_of\_services\_connected}{number\_of\_services}$$

$$= \frac{n_c + n_p}{n_s}$$

where,

- n_c is number of consumer services
- n_p number of dependent services
- n_s total number of services

[AZR11] defines

$$coupling = \frac{number\_of\_invocation}{number\_of\_services}$$
$$= \frac{\sum_{i=1}^{|O(s)|}(S_{i,sync} + S_{i,async})}{|S|}$$

where,

- $S_{i,sync}$ is the synchronous invocation in the operation O_i
- $S_{i,async}$ is the asynchronous invocation in the operation O_i

The Table 3.2 shows simpler form of metrics proposed for coupling. Although, the table shows different way of evaluating coupling, they somehow agree to the basic metrics to calculate coupling. It can be deduced that the metrics to evaluate coupling uses basic metrics such as number of operations, number of provider services and number of messages.

3.3.3 Cohesion Metrics

[SSPnp] defines following metric for cohesion.

$$SFCI(s) = \frac{number\_of\_operations\_using\_same\_message}{number\_of\_operations}$$
$$= \frac{max(\mu(m))}{|O(s)|}$$

where,

- SFCI is Service Functional Cohesion Index

#	Papers	Metrics Definition
1	[SSPnp]	SOCI : number of operation of other services invoked by the given service ISCI : number of services invoked by a given service SMCI : total number of messages from information model required by the operations
2	[Xianp]	Coupling is evaluated as information entropy of a complex service component where entropy is calculated using various data such as total number of atomic components connected, total number of links to atomic components and total number of atomic components
3	[Kaz+11]	The coupling is measured by using the dependency of a service operations with operations of other services. Additionally, the dependency is considered to have different weight value for each kind of operation such as Create, Read, Update, Delete (CRUD) and based on the type of business entity involved. The weight is referred from the CRUD matrix constructed in the process.
4	[Shi+08]	given by the average number of directly connected services
5	[AZR11]	defines coupling as the average number of synchronous and asynchronous invocations in all the operations of the service

Table 3.2: Coupling Metrics

- the number of operations using a message 'm' is $\mu(m)$ such that $m \epsilon M(s)$ and $|O(s)| > 0$
  The service is considered highly cohesive if all the operations use one common message. This implies that a higly cohesive service operates on a small set of key business entities as guided by the messages and are relavant to the service and all the operations operate on the same set of key business entities. [SSPnp]

[Shi+08] defines

$$cohesion = \frac{n_s}{|M(s)|}$$

[PRF07] defines

$$SIDC = \frac{number\_of\_operations\_sharing\_same\_parameter}{total\_number\_of\_parameters\_in\_service}$$

$$= \frac{n_{op}}{n_{pt}}$$

$$SIUC = \frac{sum\_of\_number\_of\_operations\_used\_by\_each\_consumer}{product\_of\_total\_no\_of\_consumers\_and\_operations}$$

$$= \frac{n_{oc}}{n_c * |O(s)|}$$

$$SSUC = \frac{sum\_of\_number\_of\_sequentials\_operations\_accessed\_by\_each\_consumer}{product\_of\_total\_no\_of\_consumers\_and\_operations}$$

$$= \frac{n_{so}}{n_c * |O(s)|}$$

where,

- SIDC is Service Interface Data Cohesion
- SIUC is Service Interface Usage Cohesion
- SSUC is Service Sequential Usage Cohesion
- n_{op} is the number of operations in the service which share the same parameter types
- n_{pt} is the total number of distinct parameter types in the service
- n_{oc} is the total number of operations in the service used by consumers
- n_{so} is the total number of sequentially accessed operations by the clients of the service

[AZR11] defines

$$cohesion = \frac{max(\mu(OFG, ODG))}{|O(s)|}$$

where,

- OFG and ODG are Operation Gunctionality Granularity and Operation Data Granularity respectively as calculated in Section 3.3.4
- $\mu(OFG, ODG)$ gives the number of operations with specific value of OFG and ODG

#	Papers	Metrics Definition
1	[SSPnp]	defines SFCI which measures the fraction of operations using similar messages out of total number of operations in the service operations of the service
2	[PRF07]	SIDC : defines cohesiveness as the fraction of operations based on commonality of the messages they operate on SIUC : defines the degree of consumption pattern of the service operations which is based on the similarity of consumers of the operations SIUC : defines the cohesion based on the sequential consumption behavior of more than one operations of a service by other services
3	[Shi+08]	cohesion is given by the inverse of average number of consumed messages by a service
4	[AZR11]	cohesion is defined as the consensus among the operations of the service regarding the functionality and data granularity which represents the type of parameters and the operations importance as calculated in the Section 3.3.4

Table 3.3: Cohesion Metrics

The Table 3.3 gives simplified view for the cohesion metrics. The papers presented agree on some basic metrics such as similarity of the operation usage behavior, commanility in the messages consumed by operations and similarity in the size of operations.

3.3.4 Granularity Metrics

[SSPnp] defines

$$SCG = number\_of\_operations = |O(s)|$$
$$SDG = size\_of\_messages = |M(s)|$$

where,

- SCG is Service Capability Granularity
- SDG is Service Data Granularity

[Shi+08] defines

$$granularity = \frac{number\_of\_operations}{size\_of\_messages} = \frac{|O(s)|^2}{|M(s)|^2}$$

[AZR11] defines

$$ODG = fraction\_of\_total\_weight\_of\_input\_and\_output\_parameters$$
$$= \left(\frac{\sum_{i=1}^{n_i o} W_{pi}}{\sum_{i=1}^{n_i s} W_{pi}} + \frac{\sum_{j=1}^{n_j o} W_{pj}}{\sum_{j=1}^{n_j s} W_{pj}} \right)$$

$$OFG = complexity\_weightage\_of\_operation = \frac{W_i(o)}{\sum_{i=1}^{|O(S)|} W_i(o)}$$

$$granularity = sum\_of\_product\_of\_data\_and\_functionality\_granularity$$
$$= \sum_{i=1}^{|O(S)|} ODG(i) * OFG(i)$$

where,

- ODG is Operation Data Granularity
- OFG is Operation Functionality Granularity
- W_{pi} is the weight of input parameter
- W_{pj} is the weight of output parameter
- $n_i o$ is the number of input parameters in an operation
- $n_j o$ is the number of output parameters in an operation
- $n_i s$ is the total number of input parameters in the service
- $n_j s$ is the total number of output parameters in the service
- $W_i(o)$ is the weight of an operation of the service
- $|O(S)|$ is the number operations in the service

The Table 3.4 presents various view of granularity metrics based on different research papers. The Chapter 2 discuss in detail regarding the topic. Based on the Table 3.4, the granularity is evaluated using some basic metrics such as the number and type of the parameters, number of operations and number of messages consumed.

#	Papers	Metrics Definition
1	[SSPnp]	the service capability granularity is given by the number of operations in a service and the data granularity by the number of messages consumed by the operations of the service
2	[AZR11]	ODG : evaluated in terms of number of input and output parameters and their type such as simple, user-defined and complex OFG : defined as the level of logic provided by the operations of the services SOG : defined by the sum of product of data granularity and functionality granularity for all operations in the service
3	[Shi+08]	evaluated as the ratio of squared number of operations of the service to the squared number of messages consumed by the service

Table 3.4: Granularity Metrics

3.3.5 Complexity Metrics

[ZL09] defines

$$RIS = \frac{IS(s_i)}{|S|}$$

RCS

$$complexity = \frac{coupling\_of\_service}{number\_of\_services} = \frac{CS(s_i)}{|S|}$$

where,

- $CS(s_i)$ gives coupling value of a service
- |S| is the number of services to realize the application
- $IS(s_i)$ gives importance weight of a service in an application

The complexity is rather given by relative coupling than by coupling on its own. A low value of RCS indicates that the coupling is lower than the count of services where as RCS with value 1 indicates that the coupling is equal to the number of services. This

represents high amount of complexity.
Similarly, a high value of RIS indicates that a lot of services are dependent upon the service and the service of critical value for them. This increases complexity as any changes or problem in the service affects a large number of services to a high extent.
[AZR11] defines

$$Complexity(s) = \frac{Service\_Granularity}{number\_of\_services}$$
$$= \frac{\sum_{i=1}^{|O(s)|}(SG(i))^2}{|S|}$$

where,

- |S| is the number of services to realize the application
- SG(i) gives the granularity of ith service calculated as described in Section 3.3.4

#	Papers	Metrics Definition
1	[ZL09]	RCS : complexity given by the degree of coupling for a service and evaluated as the fraction of its coupling to the total number of services RIS : measured as the fraction of total dependency weight of consumers upon the service to the total number of services
2	[AZR11]	the complexity is calculated using the granunarity of service operations

Table 3.5: Complexity Metrics

The Table 3.5 provides the way to interprete complexity metrics. The complexity is highly dependent upong coupling and functionality granularity of the service.

3.3.6 Autonomy Metrics

[Ros+11] defines

$$Self - Containment(SLC) = sum\_of\_CRUD\_coefficients\_for\_each\_Business\_entity$$

$$= \frac{1}{h_2 - l_2 + 1} \sum_{i=l_2}^{h_2} \sum_{sr \epsilon SR} (BE_{i,sr} X V_{sr})$$

$$Dependency(DEP) = dependency\_of\_service\_on\_other\_service\_business\_entities$$

$$= \frac{\sum_{j=L1_i}^{h1_i} \sum_{k=1}^{BE} V_{sr_{jk}} - \sum_{j=L1_i}^{h1_i} \sum_{k=L2_i}^{j2_i} V_{sr_{jk}}}{nc}$$

$$\text{autonomy} = \begin{cases} SLC - DEP & \text{if SLC > DEP} \\ 0 & \text{otherwise} \end{cases}$$

where,

- nc is the number of relations with other services
- $BE_{i,sr} = 1$ if the service performs action sr on the ith BE and sr represents any CRUD operation and V_{sr} is the coefficient depending upon the type of action
- $V_{sr_{jk}}$ is the corresponding value of the action in jkth element of CRUD matrix, it gives the weight of corresponding business capability affecting a business entity
- $l1_i, h1_i, l2_i, h2_i$ are bounding indices in CRUD matrix of ith service

#	Papers	Metrics Definition
1	[Ros+11]	SLC : defined as the degree of control of a service upon its operations to act on its Business entities only DEP : given by the degree of coupling of the given service with other services autonomy is given by the difference of SLC and DEP if SLC > DEP else it is taken as 0

Table 3.6: Autonomy Metrics

The Table 3.6 shows a way to interprete autonomy. It is calculated by the difference SLC-DEP when SLC is greater than DEP. In other cases it is taken as zero. So, autonomy increases as the operations of the services have full control upon its business entities but decreases if the service is dependent upon other services.

3.3.7 Reusability Metrics

[SSPnp] defines

$$Reusability = number\_of\_existing\_consumers$$
$$= |S_{consumers}|$$

[Shi+08] defines

$$Reusability = \frac{Cohesion - granularity + Consumability - coupling}{2}$$

#	Papers	Metrics Definition
1	[SSPnp]	SRI defines reusability as the number of existing consumers of the service
2	[Shi+08]	evaluated from coupling, cohesion, granularity and consumability of a service where consumability is the chance of the service being discovered and depends upon the fraction of operations in the service

Table 3.7: Reusability Metrics

The table 3.7 shows the reusability metrics evaluation. Reusability depends upon coupling, cohesion and granularity. It decreases as coupling and granularity increases.

3.4 Basic Quality Metrics

The Section 3.3 presents various metrics to evaluate quality attributes based upon different papers. Additionally, the section analyzed the metrics and tried to derive them in simplest form possible. Eventually, the tables demonstrating the simplest definition of the metrics shows that the different quality attributes are measured on the basis of some basic metrics. Based on the Section 3.3 and based on the papers, this section will attempt to derive basic metrics. The Table 3.8 provides a list of basic metrices.

#	Metrics	Coupling	Cohesion	Granularity	Complexity	Autonomy	Reusability
1	number of service operations invoked by the service	+			+	-	-
2	number of operation using similar messages		+				+
3	number of operation used by same consumer		+				+
4	number of operation using similar parameters		+				+
5	number of operation with similar scope or capability		+				+
6	scope of operation			+	+		-
7	number of operations			+	+		-
8	number of parameters in operation			+	+		-
9	type of parameters in operation			+	+		-
10	number and size of messages used by operations	+		+	+	-	-
11	type of messages used by operations		+				+
12	number of consumer services	+			+	-	+
13	number of producer services	+			+	-	-
14	type of operation and business entity invoked by the service	+			+	-	-
15	number of consumers accessing same operation		+				+
16	number of consumer with similar operation usage sequence		+				+
17	dependency degree or imporance of service operation to other service				+		
18	degree of control of operation to its business entities					+	

Table 3.8: Basic Quality Metrics

Moreover, the effect of the basic metrics upon various quality attributes are also evaluated and stated under each column such as 'coupling', 'cohesion' etc. Here, the meaning of the various symbols to demonstrate the affect are as given below:

- + the basic metric affect the quality attribute proportionlly
- - the basic metric inversely affect the quality attribute
- there is no evidence found regarding the relationship from the papers

3.5 Principles defined by Quality Attributes

The Section 3.1 has already mentioned that there are two distinct kind of quality attributes: external and internal. The external quality attributes cannot be evaluated during design however can be predicted using the internal quality attributes. This kind of relationship can be used to design service with good quality. Moreover, it is important to identify how each internal attributes affect the external attributes. The understanding of such relationship will be helpful to identify the combined effect of

the quality attributes and eventually to identify the service with the appropriate level of quality as per the requirement. The remaining part of the section lists relationship existing in various quality attributes as well as the desired value of the quality attributes.

1. When a service has large number of operations, it means it has large number of consumers. It will highly affect maintainability because a small change in the operations of the service will be propagated to large number of consumers. But again, if the service is too fine granular, there will be high network coupling. [FL07; Xianp][BKM07]

2. Low coupling improves understandability, reusability and scalability where as high coupling decreases maintainability. [Kaz+11][Erl05][Jos07]

3. A good strategy for grouping operations to realize a service is to combine the ones those are used together. This indicates that most of the operations are used by same client. It highly improves maintainability by limiting the number of affected consumer in the event of any change in the service. [Xianp]

4. A high cohesive quality attribute defines a good service. The service is easy to understand, test, change and is more stable. These properties highly support maintainability. enumerate[np01]

5. A service with operations those are cohesive and have low coupling which make the service reusable. [WYF03][FL07][Ma+09]

6. Services must be selected in a way so that they focus on a single business functionality. This highly follows the concept of low coupling. [PRF07][SSPnp]

7. Maintainability is divided into four distinct concepts: analyzability, changeability, stability and testability.[np01] A highly cohesive and low-coupled design should be easy to analyze and test. Moreover, such a system will be stable and easy to change.[PRF07]

8. The complexity of a service is determined by granularity. A coarse-grained service has higher complexity. However, as the size of the service decreases, the complexity of the over system governance also increases. [AZR11]

9. The complexity depends upon coupling. The complexity of a service is defined in terms of the number of dependencies of a service, number of operations as well as number and size of messages used by the service operations.[AZR11][SSPnp][Lee+01]

10. The selection of an appropriate service has to deal with multi-objective optimization problem. The quality attributes are not independent in all aspects. Depending upon goals of the architecture, tradeoffs have to be made for mutually exclusive attributes. For example, when choosing between coarse-grained and fine-grained service, various factors such as governance, high network roundtrip etc. also should be considered. [JSM08]

11. Business entity convergence of a service, which is the degree of control over specific business entities, is an important quality for the selection of service. For example: It is be better to create a single service to create and update an order. In that way change and control over the business entity is localized to a single service.[Ma+09]

12. Increasing the granularity decreases cohesion but also decreases the amount of message flow across the network. This is because, as the boundary of the service increases, more communication is handled within the service boundary. However, this can be true again only if highly related operations are merged to build the service. This suggests for the optimum granularity by handling cohesion and coupling in an appropriate level.[Ma+09][BKM07]

13. As the scope of the functionality provided by the service increases, the reusability decreases. [FL07]

14. If the service has high interface granularity, the operations operates on coarse-grained messages. This can affect the service performance. On the other hand, if the service has too fine-grained interface, then there will be a lot of messages required for the same task, which then can again affect the overall performance. [BKM07]

3.6 Relationship among Quality Attributes

In order to determine the appropriate level of quality for a service, it is also important to know the relationship between the quality attributes. This knowledge will helpfull to decide tradeoffs among them in the situation when it is not possible to achieve best of all. Based on the Section 3.2 and Section 3.5, the identified relationship among the quality attributes are shown in the Table 3.9.

Here, the meaning of the various symbols showing nature of relationship are as given below:

#	Quality Attributes	Coupling	Cohesion	Granularity
1	Coupling		-	+
2	Cohesion	-		
3	Granularity	+		
4	Complexity	+		+
5	Reusability	-	+	-
6	Autonomy	-		
7	Maintainability	-	+	-

Table 3.9: Relationship among quality attributes

- + the quality attribute on the column affects the quality attribute on the corresponding row positively
- - the quality attribute on the column affects the quality attribute on the corresponding row inversely
- there is no enough evidence found regarding the relationship from the papers or these are same attributes

Based on the Table 3.9, if granularit of a microservice increases then coupling of other microservices on this will also increase and again if coupling increases then autonomy of the microservice will decrease. Similarly, relationship among other quality attributes can also be derived using the table. The idea regarding impact of various quality attributes amongst each other can be helpful to make decision regarding trade offs.

3.7 Conclusion

There is no doubt that granularity is an important aspect of a microservice however there are other different factors which affect granularity as well as the overall quality of the service. Again, knowing the way to evaluate these qualities in terms of a quantitative figure can be helpful for easy decision regarding quality. However, most of the metrices are quite complex so the Section 3.4 compiled these complex mectrics in terms of simple metrices. The factors used to define these basic metrices are the kind which are accessible to normal developers. So, these basic metrices can be an efficient and easy way to determine quality of microservices.
Moreover, the external quality attributes such as reusability, scalability etc can be controlled by fixing internal quality attributes such as coupling, cohesion, autonomy etc. So, finding an easy way to evaluate and fix internal quality attributes will eventually

make it easier to achieve microservices with satisfactory value of external quality attributes.
Nevertheless, the quality attributes are not mutually exclusive but are dependent on each other. The Table 3.9 provides basic relationship among them. This kind of table can be helpful when needed to perform trade-offs among various attributes depending upon goals.

3.8 Problem Statement

Having collected important concepts regarding various quality attributes, which is one of the major drivers for defining architecture as mentioned in Section 1.4, the next important concept is to find the process of modeling microservices as stated in the Table 1.2. The quality attributes will be a major input for deciding the process of identifying microservices from a problem domain.

4 Modeling Microservices

In this chapter, various approaches to model microservices are identified from literature. Precisely, two distinct approaches are described in sections 4.2 and 4.3 respectively. For each process, a detailed set of steps are formulated. Finally, in order to make it useful, an example problem domain is taken, which is then broken down into microservices using each of these two distinct models.

4.1 Introduction

In the previous chapters, granularity and quality of a microservice was focussed. The qualitative as well as quantitative aspects of granularity were described. Additionally, various quality metrics were discussed to measure different quality attributes of a microservce. Moreover, a set of principle guidelines and basic metrics to qualify the microservices were also listed.
In addition to that, it is also equally important to agree on the process to identify the service candidates. In this chapter and following chapters, the ways to recognize microservices will be discussed. There are three basic approaches to identify service candidates: Top-down, bottom-up and meet-in-the-middle.
The top-down approach defines the process on the basis of the business model. At first, various models are designed to capture the overall system and architecture. Using the overall design, services are identified upfront in the analysis phase.
The next approach is bottom-up, which base its process on the existing architecture and existing application. The existing application is studied to identify the cohesion and consistency of the features provided by various components of the system. This information is used to aggregate the features and identify services in order to overcome the problems in the existing system.
Finally, the meet-in-the-middle approach is a hybrid approach of both top-down and bottom-up approaches. In this approach, the complete analysis of system as a whole is not performed upfront as the case of top-down approach. Where as, a set of priority areas are identified and used to analyse their business model resulting in a set of services. The services thus achieved are further analysed critically using bottom-up approach to identify problems. The problems are handled in next iterations where the same process as before is followed. The approach is continued for other areas of the

system in the order of their priority.[RS07][Ars04]
Considering the motive of the thesis, which is mainly concerned with green field development, top-down approaches will be taken into consideration. In this chapter, two different strategies discussed in literature which happen to be top-down approaches, will be explained in detail.

4.2 Modeling Using Usecases

A use case is an efficient as well as a fancy way of capturing requirements. Another technique of eliciting requirement is by features specification. However, the feature specification technique limits itself to answer only "what the system is intended to do". On the other hand, use case goes further and specifies "what the system does for any specific kind of user". In this way, it gives a way to specify and most importantly validate the expectation and concerns of stakeholders at the very early phase of software development. Undoubtedly for the same reason, it is not just a tool for requirement specification but an important software engineering technique which guides the software engineering cycle. Using use cases, the software can be developed to focus on the concerns that are valueable to the stakeholders and test accordingly.[NJ04]
It can be valueable to see the ways it has been defined.

Definition 1: [Jac87]

"A use case is a sequence of actions performed by the system to yield an observable result of value to a particular user."

Definition 2: [RJB99]

"A use case is a description of a set of sequences of actions, including variants, that a system performs that yield an observable result of value to an actor."

4.2.1 Use case Refactoring

According to [Jac87] it is not always intuitive to modularize use cases directly. As per the definitions provided in Section 4.2, a use case consists of a number of ordered functions together to accomplish a certain goal. [Jac87] defines these cohesive functionalites distributed across usecases as clusters. And the process of identifying the clusters scattered around the use cases is the process of identifying services. [NJ04] and

[Jac03] describes use case possibly consisting of various cross-cutting concerns. The papers use the term 'use case module' to define the cohesive set of tasks. The Figure 4.1 demonstrate the cross cutting functionalities needed by a use case in order to accomplish its goal. For example, the use case 'does A' has to perform separate functionalities on different domain entities X and Y. Similarly, the use case 'does B' needs to perform distinct functions on entities X, Y and Z.

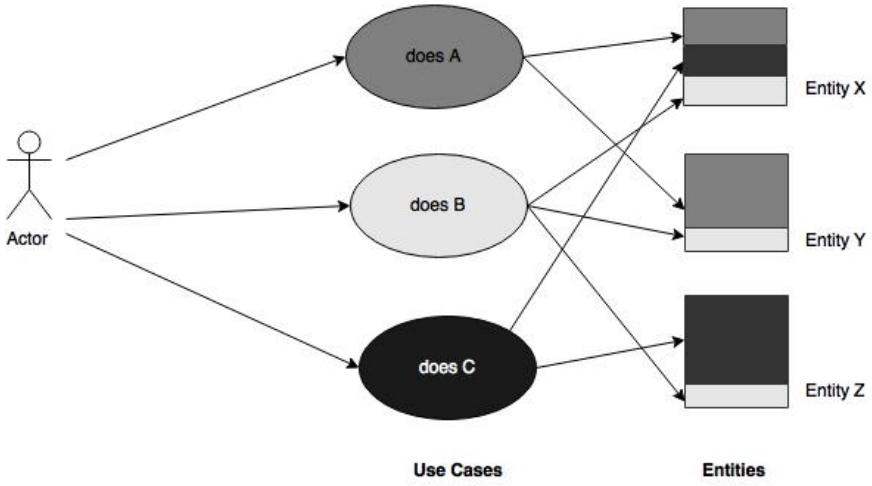


Figure 4.1: Use cases with cross-cutting concerns [NJ04]

This situation prompts for the analysis of the use cases for cross cutting tasks and refactoring them in order to map the cohesive functionalities and use cases. Refactoring helps to achieve the right level of abstraction and granularity by improving functionality cohesion as well as elimination of redundancy and finally promoting the reusablity. [DK07]
Furthermore, the refactoring is assisted by various relationships in use case model to represent dependencies between use cases, which are include, generalization and extend. [NJ04]

4.2.2 Process for Use Case Refactoring

In order to refactor the use cases and finally map use cases to the service, the papers [KY06], [YK06] and [DK07] provide a comprehensive method. It is a type of meet-in-the-middle approach where use case models are first created and then refactored to create new set of use cases to accomplish high cohesion in functionality and loose

coupling. This will ultimately create use cases supporting modularity and autonomy. [Far08] There are three distinct steps for service identification using service refactoring.

1. **TaskTree Generation**
   In this step, the initial use case model created during domain analysis is used to create task trees for each distinct use case. The task trees provide sequence of individual tasks required to accomplish in order to achieve the goal of the use case.

2. **Use Case Refactoring**
   In this step, the task tree generated in the previous step is analysed. As already mentioned in the Section 4.2.1, that the initial use case consists of various cross cutting functionalities which runs through large number of business entities. In order to minimize that, refactoring is performed. The detail rules are provided in Section 4.2.3.

3. **Service Identification**
   The use cases achieved after refactoring have correct level of abstractions and granularity representing cohesive business functionality. The unit use cases thus achieved appreciate reuse of common functionality. [DK07] Furthermore, the approach considers the concerns of stakeholders in terms of cohesive business functionalities to be represented by use cases.[Far08] Additionally, the process also clarifies the dependencies between various use cases. Thus, the final use cases obtained can be directly maped to individual services.

4.2.3 Rules for Use Case Refactoring

The context is first defined before distinct rules are presented.

Context 1

If U represents use case model of the application, t_i represents any task of U and T being the set of tasks of U. Then, $\forall t_i \in T$, t_i exists in the post-refactoring model U'. The refactoring of a use case model preserves the set of tasks.

Context 2

A refactoring rule R is defined as a 3-tuple (Parameters, Preconditions, Postconditions). Parameters are the entities involved in the refactoring, precondition defines the condition which must be satisfied by the usecase u in order for R to be applied in u. Postcondition defines the state of U after R is applied.
The various refactoring rules are as listed below.

4.2.3.1 Decomposition Refactoring

When the usecase is complex and composed of various functionally independent tasks, the tasks can be ejected out of the task tree of the usecase and represented as a new use case. The Table 4.1 shows the decomposition rule in detail.

Parameters	u: a use case to be decomposed t: represents task tree of u t': a subtask tree of t
Preconditions	t' is functionally independent of u
Postconditions	1. new use case u' containing task tree t' is generated 2. a dependency is created between u and u'

Table 4.1: Decomposition Rule

4.2.3.2 Equivalence Refactoring

If the two use cases share their tasks in the task tree, we can conclude that they are equivalent and redundant in the use case model. The Table 4.2 shows the rule for the refactoring.

Parameters	u_1 , u_2: two distinct use cases
Preconditions	the task trees of u_1 and u_2 have same behavior
Postconditions	1. u_2 is replaced by u_1 2. all the relationship of u_2 are fulfilled by u_1 3. u_2 has no relationship with any other use cases

Table 4.2: Equivalence Rule

4.2.3.3 Composition Refactoring

When there are two or more small-grained use cases such that they have related tasks, the use cases can be represented by a composite unit use case.

Parameters	u_1, u_2: the fine grained use cases t_1, t_2: the task trees of u_1 and u_2 respectively
Precondition	t_1 and t_2 are functionally related.
Postconditions	1. u_1 and u_2 are merged to a new unit use case u 2. u has new task tree given by $t_1 \cup t_2$ 3. the dependencies of u_1 and u_2 are handled by u 4. u_1 and u_2 are deleted along with their task trees t_1 and t_2

Table 4.3: Composition Rule

4.2.3.4 Generalization Refactoring

When multiple use cases share some volume of dependent set of tasks in their task trees, it can be implied that the common tasks set can be represented by a new use case. The Table 4.4 provides the specific of the rule.

Parameters	u_1 , u_2: two distinct use cases t_1 , t_2: task trees of u_1 and u_2 respectively
Precondition	t_1 and t_2 share a common set of task $t = \{x_1, x_2...x_n\}$
Postconditions	1. a new use case u is created using task tree $t = \{x_1, x_2...x_n\}$ 2. relationship between u with u_1 and between u with u_2 is created 3. the task tree $t = \{x_1, x_2...x_n\}$ is removed from task tree of both u_1 and u_2 4. the common relationship of both u_1 and u_2 are handled by u and removed from them

Table 4.4: Generalization Rule

4.2.3.5 Merge Refactoring

When a use case is just specific for another use case and the use case is only the consumer for it, the two use cases can be merged into one.

Parameters	u, u′: the use cases r defines the dependency of u with u′ t, t′: the task trees of u and u′ respectively
Precondition	there is no dependency of other usecases with u′ except u
Postconditions	1. u′ is merged to u 2. u has new task tree given by $t \cup t'$ 3. r is removed

Table 4.5: Merge Rule

4.2.3.6 Deletion Refactoring

When a use case is defined but no relationship can be agreed with other use cases or actors then it can be referred that the use case represent redundant set of tasks which has already been defined by other use cases.

Parameters	u: a distinct use case
Precondition	the use case u has no relationship with any other usecases and actors
Postconditions	the use case u is deleted

Table 4.6: Deletion Rule

4.2.4 Example Scenario

In this section, a case study will be taken as an example. The case study will be modeled using use case. Finally, the use case will be refactored using the rules given by **??**.

Case Study

The case study is about an international hotel named 'XYZ' which has branches in various locations. In each location, it offers rooms with varying facilities as well as prices. In order to make it easy for customers to find room irrespective of the location of customer, it is planning to offer an online room booking application. Using this application, any registered customer can search for a room according to his/her requirement in any location. When he/she is satisfied, can book the room online as well. The customer will be sent notification by email regarding booking. At present, the payment will be accepted in person, only after the customer gets into the respective branch. Finally, if the customer wants to cancel the room, he/she can do online anytime.

The customer will also be notified by e-mail to confirm the cancelation of booking. It is an initial case study so only priority cases and conditions are considered here.

The remaining part of this section presents the steps to indentify the services using use case refactoring following the process defined in Section 4.2.2 and rules presented in the Section 4.2.3

Step 1:

The initial analysis of the case study will produce use case model as given by figure 4.2.

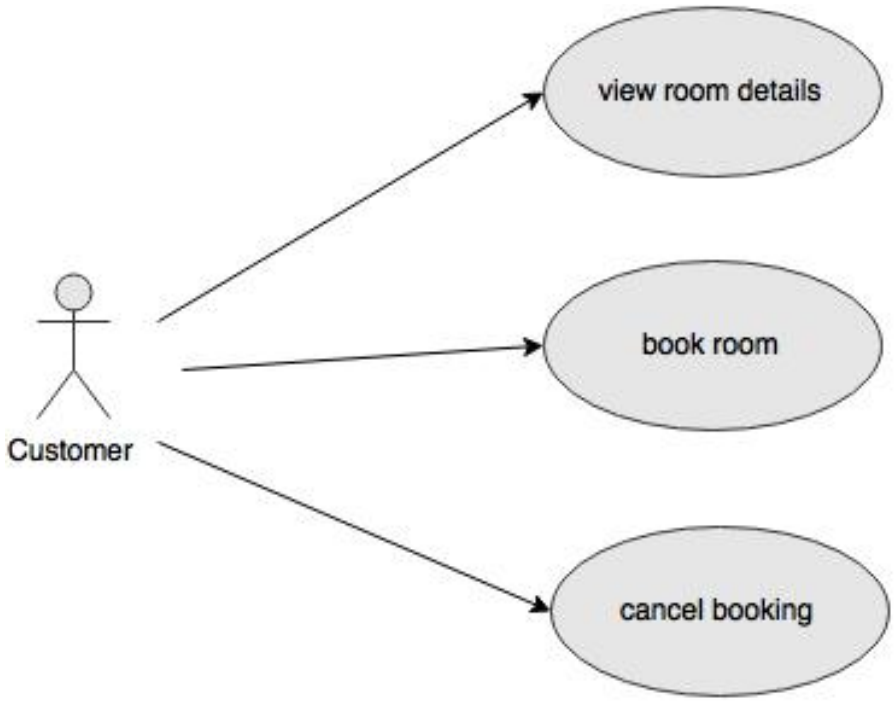


Figure 4.2: Initial Use Case Model for Online Room Booking Application

Step 2:

For each initial use case, task trees are generated which are needed to accomplish the desired functionality of respective use cases.

Use Case	Task Tree
book room	customer enters access credentials system validates the credentials customer enters location and time details for booking system fetch the details of empty rooms according to the data provided system displays the details in muliple pages customer choose the room and submits for booking system generates a booking number System updates the room system sends notification to the customer regarding booking
cancel booking	customer enters access credentials system validates the credentials customer enters the booking number system validates the booking number customer cancels the booking system updates the room system sends notification to the customer regarding cancelation
view room details	customer enters access credentials system validate the credentials customer enter location and time system fetch the details of empty rooms according to the data provided system display the details in multiple pages

Table 4.7: Task Trees for Initial Use Cases

Step 3:

The initial task trees created for each use case at Step 2 is analysed. There are quite a few set of tasks which are functionally independent of the use case goal and also few tasks which are common in more use use cases. The following Table 4.8 lists those tasks from the tasks trees 4.7 which are either functionally independent from their corresponding use cases or common in more use cases.

Tasks Type	Tasks
Independent Tasks	system validates the credentials system fetch the details of empty rooms according to the data provided system generates a booking number system validates the booking number system updates the room system sends notification to the customer
Common Tasks	system validates the credentials system fetch the details of empty rooms according to the data provided system updates the room system sends notification to the customer

Table 4.8: Common and Independent Tasks

Now, for independent tasks the docomposition rule given by 4.1 can be applied and for common tasks, the generalization rule given by 4.4 can be applied. The use cases obtained after applying these rules is shown by the figure 4.3

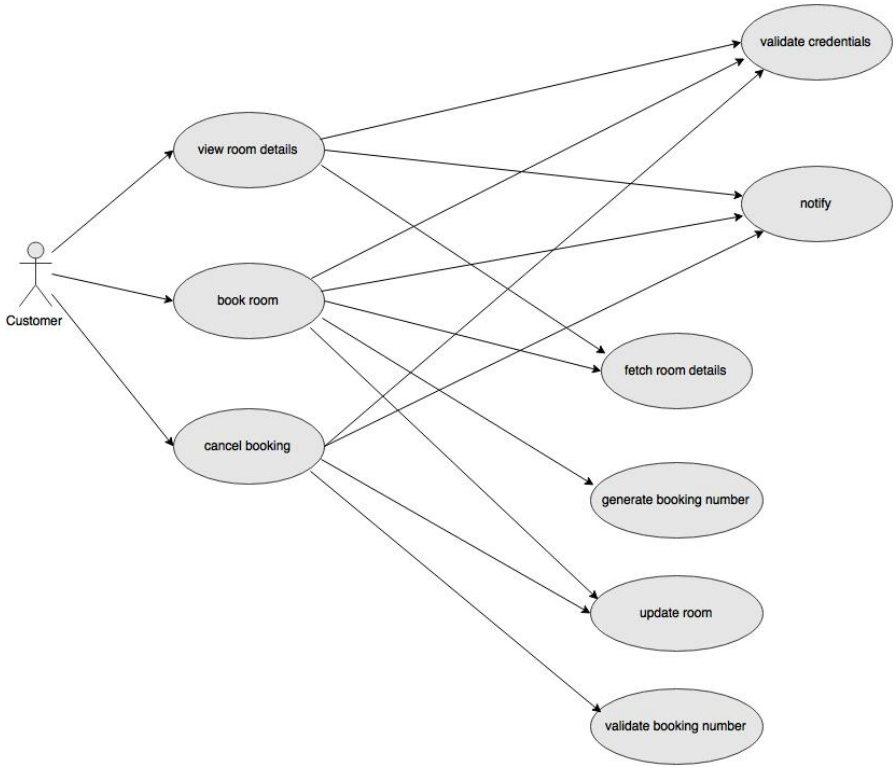


Figure 4.3: Use Case Model after applying Decomposition and Generalization rules

Step 4:

The use case model 4.3 obtained in Step 3 is analysed again for further refactoring. It can seen that the use cases 'fetch room details' and 'update room' are fine grained and related to same business model 'Room'. Similarly, the use cases 'generate booking number' and 'validate booking number' are related to business entity 'Booking Number'. The composition rule given by 4.3 can be applied to these use cases, which will then result in use case model given by figure 4.4

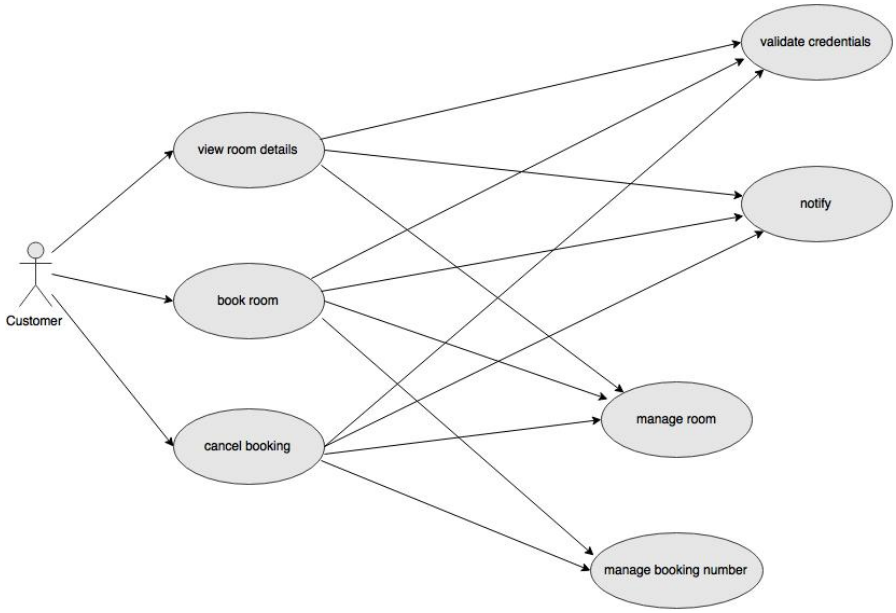


Figure 4.4: Use Case Model after applying Composition rule

Step 5:

Finally, the use case obtained in step 4 is used to identify the service candidates. The final use cases obtained in Step 4 have appropriate level of granularity and cohesive functionalities to be identified as individual services. Most importantly, the refactoring has now separated the cross cutting concerns in terms of various reusable fine grained use cases as shown by the figure. If we compare the the final use case model 4.5 with respect to Figure 4.1, then it can be implied that the functionalities operating on business entities as well as the business logic serving the candidate concerns are separated and represented by individual use cases. So, the each use case can be mapped to individual services. The services are as listed in the bottom of the Figure 4.5.

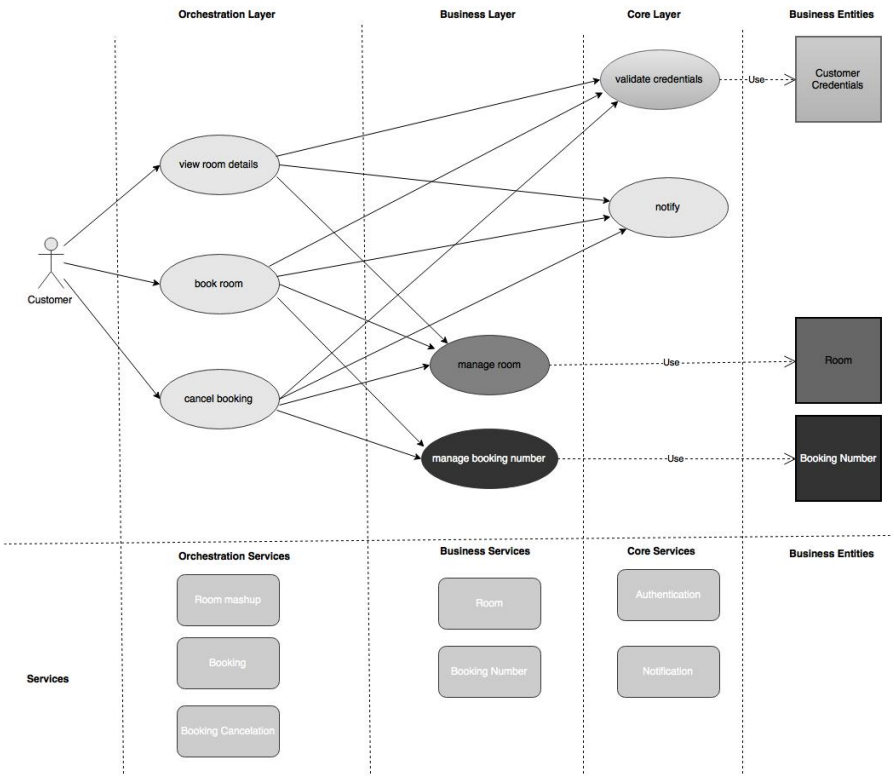


Figure 4.5: Use Case Model for identification of service candidates

Microservices Layers

The services or use cases obtained as shown in the Figure 4.5 from the refactoring process, creates various levels of abstractions. The levels of abstractions represents different level of functionality. The services at the bottom layer are core services which serve many higher level services. These services are not dependent on any other services. 'Notification' and 'Authentication' are core services obtained from refactoring. The layer above the core layer is business layer. The business service can either have entity services, which control some related business entities or can have task services which provides some specific business logic to higher level services. 'Room' and 'Booking Number' are the entity services obtained from refactoring. Finally, the top layer is mashup layer which contains high level business logic and collaborates with business services as well as core services. 'Room mashup' , 'Booking' and 'Booking Cancelation' are orchestration layer services obtained. The individual services as well as their respective layers are given in Figure 4.5. [Far08][Emi+np][Zim+05]

4.3 Modeling using Domain Driven Design

Understanding the problem space can be a very useful way to design software. The common way to understand the problem and communicate them is by using various design models. The design models are the abstraction as well as representation of the problem space. However, when the abstractions are created, there are chances that important concepts or data are ignored or misread. This will highly impact the quality of software produced. The software thus developed may not reflect the real world situation or problem entirely.
Domain Driven Design provides a way to represent the real world problem space so that all the important concepts and data from real world remains intact in the model. The domain model thus captured respects the differences as well as the agreement in the concepts across various parts of the problem space. Moreover, it also provides a way to divide the problem space into manageable independent partitions and makes it easy for developers as well as stakeholders to focus on the area of concern as well as be more agile. Finally, the domain models act as the understandable and common view of the business for both domain experts as well as the developers. This will make sure that the software developed using domain driven design will comply with business need.[Eva03][Ver13]

4.3.1 Process to Domain Driven Design

There are three basic parts to implement domain driven design:

1. Ubiquitous Language
2. Strategical Design
3. Tactical Design

As the focus is to describe the process of identifying microservice candidates, only the first two parts are relevant and will be focused in the later part of this chapter.

4.3.1.1 Ubiquitous Language

Ubiquitous Language is a common language agreed among domain experts and developers in a team. It is important to have a common understanding about the concepts of a business which is being developed and ubiquitous language is the way to assure that. Domain Experts understand the domain in terms of their own jargon and concept. It is difficult for a developer to understand them. Usually, developers translates

those jargons into the terms they understand easily during desing and implementation. However along the way of translation, major domain concepts can get lost and the immediate value of the resulting solution might decrease tremendously. In order to prevent creation of such low valued solution, there should be a meet-in-the-middle approach to define common vocabularies and concepts understood by all domain experts as well as the developers. These common vocabularies and concepts make the core of the ubiquitous language.[Eva03][Ver13]
Along with the common vocabulary and concepts, domain models provide backbone to create ubiquitous language. The models represents not only artifacts but also functionalities, rules and strategies. It is a way to express the common understanding in a visual form providing an easy tool to comprehend.[Eva03][Fow06b] According to [Fow03], domain model should not be confused with data model which represents the business in datacentric view but rather each domain object should contain data as well as logic closely related to the data contained. Domain models are conceptual models rather than software artifacts but can be effectively visualized using UML.[SR01]

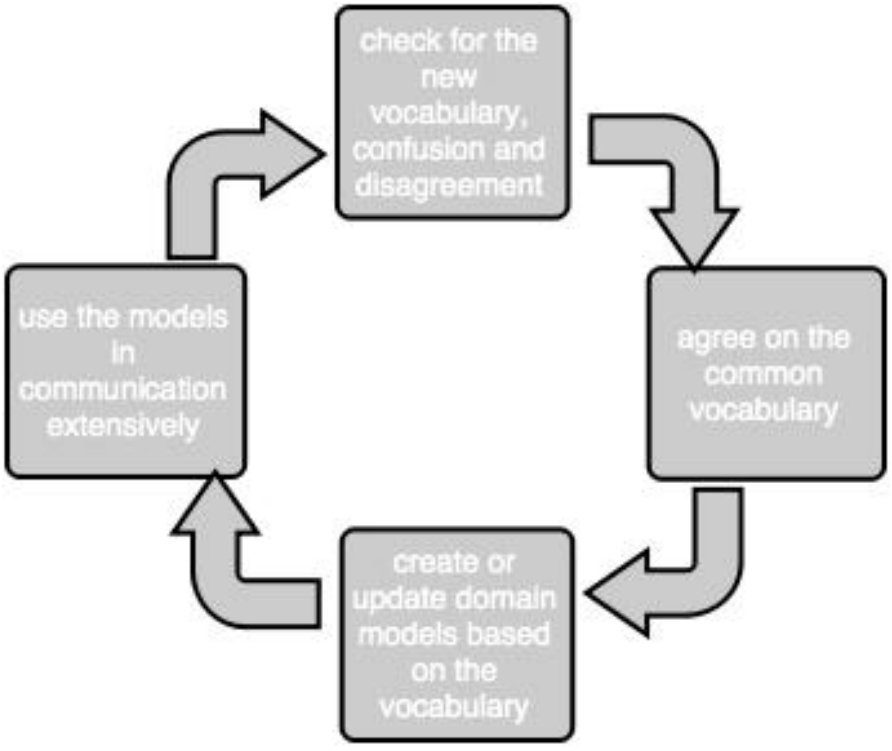


Figure 4.6: Process to define Ubiquitous Language [Eva03]

The Figure 4.6 visualizes the process of discovering the ubiquitous language in any domain. It is not a discretely timed phenomenon but a continous procedure with various phases occuring in a cycle throughout the development.
On arrival of any new term, concept or any confusion, the contextual meaning of those terms are made clear before adding to the domain vocabulary. Next, the vocabularies and concepts are used to create various domain models following UML. The domain models and various vocabularies for the common laguage among domain experts and developers within the team. It is very important to use only domain vocabularies for communication and understanding which will not only help to reflect the hidden domain concepts in the implementation but also create opportunities to create new vocabularies or refine existing ones in the event of confusion and disagreement.[Eva03]
Thus, the common vocabulary and domain models form the core of the ubiquitous language and the only way of coming up with the better one is by applying it in communication extensively. Ubiquitous language is not just a collection or documentation of terms but is the approach of communication within a domain.

4.3.1.2 Strategical Design

When applying model-driven approach to an entire enterprise, the domain models get too large and complicated. It becomes difficult to analyse and understand all at once. Furthermore, it gets worse as the system gets bigger. The strategical design provides a way to divide the entire domain models into small,manageable and interoperable parts which can work together with low dependency in order to reflect the functionalities of the entire domain. The goal is to divide the system into modular parts which can be easily integrated. Additionally, the all-cohesive unified domain models of the entire enterprise cannot reflect differences in contextual vocabularies and concepts.[Fow14a][Eva03][Ver13]
The strategical design specifies two major steps which are crucial in identifying microservices.

Step 1: Divide problem domain into subdomains

The domain represents the problem being solved by the software. The domain can be divided into various sub-domains based on the organizational structure of the enterprise, each sub-domain responsible for certain area of the problem. The [Eng+np] provides a comprehensive set of steps to identify sub-domains.

1. **Identify core business functionalities and map them into domain:**
   A core business functionality represents the direct business capability which holds high importance and should be provided by the enterprise in order for it to succeed. For example, for any general e-commerce enterprise, the core focus will on the high amount orders being received from the customers and maintain the inventory to fulfil the orders. So, for those kind of e-commerce enterprises, 'Order Management' and 'Inventory Management' will be the some of the core domains.

2. **Identify generic and supporting subdomains:**
   The business capabilities which are viable for the success of business but not represent the specialization of the enterprise falls into supporting subdomains. The supporting subdomain does not require the enterprise to excel in these areas. Additionally, if the functionalities are not specific to the business but in a way support the business functionalities, then these are covered by generic subdomains. For example: for an e-commerce enterprise, 'Payment Management' can be a supporting subdomain whereas 'Reporting' and 'Authentication' can be generic subdomains.[Ver13]

3. **Divide existing subdomains having multiple independent strategies:**
   The subdomains found from earlier steps are analyzed to check if there are mutually independent strategies to handle the same functionality. The subdomain can then be further divided into multiple subdomains along the dimension of strategies. For example: the 'Payment Managment' subdomain discovered in earlier step can have different way of handling online payment depending upon the provider such as bank or paypal etc. In that case 'Payment Management' can be further divided into 'Bank Payment Management' and 'Paypal Payment Management'.

Step 2: Indentify bounded contexts

As stated earlier of this section, the attempt to use a single set of domain models for the entire enterprise adds complexity for understanding and analysis. There is another important reason supporting the issue which is called unification of the domain models. Unification represents internal consistency of the terms and concepts described by the domain models. It is not always possible to have consistent meaning of terms without any contradictory rules throughout the enterprise. The identification of the logically consistent and inconsistent domain model creates a boundary around domain model.

This boundary will bind all the terms which share consistent logic from those which are different from them so that there is clear understanding of the concept inside the boundary without any confusion. The shared context inside the boundary is defined as the bounded context.
Definition 1:
" A Bounded Context delimits the applicability of a particular model so that team members hava a clear and shared understanding of what has to be consistent and how it relates to other contexts. A bounded context has specific functionality and explicitly defines boundary around team organization, code bases and database schemas."[Eva03]
Definition 2:
" A Bounded Context is an explicit boundary within which a domain model exists. Inside the boundary all terms and phrases of the Ubiquitous Language have specific meaning, and the model reflects the Language with exactness." [Ver13]
Definition 3: " A Bounded Context is a specific responsibility enforced by explicit boundaries." [Mik12]
Thus, the idea of bounded context provide the applicability of the ubiquitous language inside its boundary performing a specific responsibility. Outside the bounded contexts, teams have different ubiquitous language with different terms, concepts, meanings and functionalities. Apart from identifying independent and specific responsibilities inside a subdomain in order to identify bounded contexts, there are some general rules which can be considered as well.

1. **Assign individual bounded context to the subdomains identified in Step 1**
   Each subdomains have distinct functionalities and complete set of independent domain models to accomplish the functionalities. Thus, one to one mapping of subdomain and bounded context is possible ideally whereas in real cases, it may not be always possible which can be tackled using the rules discussed in further steps. For example: Order Management and Inventory Management can be two distinct bounded context each with own consistent ubiquitous language. [Fow14a][Gor13]

2. **Identify polysemes**
   Polysemes are the terms which have different meaning in separate contexts. If the example of the generic subdomain 'Authentication' is taken. It can have an model 'Account' however the same model can refer to multiple concept such as social account identified by e-mail or registered account identified by unique username. The handling of these two separate concepts is also different which clearly suggests two separate context for each within 'Authentication' subdomain. Additionally, there can be polysemes in two separate domains as well. For ex-

ample: there is also 'Account' model to identify bank account in the subdomain 'Bank Payment Management'. The identification of polysemes is vital to create clear boundary around which the concept and handling of such polysemes are consistent. [Fow14a]

3. **Identify independent generic functionality supporting the subdomain**
   There can be a necessity of independent technical functionality required to accomplish the business functionality of the subdomain only. Since it is only required by the particular subdomain, the functionality cannot be nominated as a generic subdomain. In such a case, the independent technical functionality can be realized as a separate bounded context. For example, in the subdomain 'Inventory Management', the functionality of full-text search can be assigned a separate bounded context as it is independent.[Gor13]

4.3.2 Microservices and Bounded Context

Analyzing various definitions of microservices provided in Section 1.2, a list of important features with respect to specific category such as granularity or quality was compiled in the table 1.2. In addition to the definitions of bounded context provided in Section 4.3.1.2, the following definition of Domain Driven Design can be helpful to find analogy between a microservice and a bounded context.

Definition: Domain Driven Design

"Domain Driven Design is about explaining what your company does in isolated parts, in performing these specific parts and you can have a dedicated team to do this stuff, and you can have different tools for different teams." [Rig15]

Using Table 1.2 and concepts extracted from various definitions of bounded context as well as Domain Driven Design provided, the Table 4.9 is generated.

The Table 4.9 lists various features expected by a microservices. Again, it shows that the tabulated features are fulfilled by a bounded context. It can be implied that a microservice is conceptually analogous to a bounded context. The Section 4.3.1 provided the detailed process to discover bounded contexts within a large domain, which ultimately also provides guidelines to determine microservices using domain driven design principles.
Furthermore, there can be found enough evidence regarding the analogy as well as

#	Expected features of a microservice	Fulfilled by Bounded Context
1	Loosely coupled, related functions	✓
2	Developed and deployed independently	✓
3	Own database	✓
4	Different database technologies	✓
5	Build around Business Capabilities	✓
6	Different Programming Languages	✓

Table 4.9: Analogy of Microservice and Bounded Context

practical implementation of the concept. The table lists various articles which agree on the analogy and in most cases, have utilized the concepts to create microservices in real world.

#	Articles	Agreement on the Concept	Utilized Bounded Context to create Microservices
1	[Mau15]	✓	✓
2	[Hug14]	✓	
3	[FL14]	✓	
4	[Sok15]	✓	
5	[Day+15]	✓	✓
6	[Rig15]	✓	
7	[Bea15]	✓	✓
8	[KJP15]	✓	✓
9	[Vie+15]	✓	✓
10	[BHJ15]	✓	✓

Table 4.10: Application of Bounded Context to create Microservices

4.3.3 Example Scenario

In this section, a case study will be discussed. The case study will be used to design the system using microservices architecture following the domain driven design given supported by the Section 4.3.1.

Case Study

The case study is for the same hotel introduced in the Section 4.2.4. The hotel 'XYZ' is thinking of upgrading its current system and adding new business usecases in order

to tune its competitive edge in the market.
Previously, the hotel only supported booking of the rooms, payment by cash, cancelation of booking and finally viewing of the room details.
The hotel has planned to provide various package offerings to the either general customers or specific group of customers satisfying certain profile. Firstly, a hotel staff creates a package with name, description, valid time period, applicable type of room and location and discount associated with the package. Furthermore, the package will also contain certain constraints such as maximum number of offerings and maximum number of offerings per customer. The offering is represented by coupon and has unique identity. Once a package is created, the package has to be activated either by the hotel staff or by the activation time trigger. Only, the activated packages are visible to the customers. The customers can apply for the active packages. The customer profile is validated against the expected profile for the package and then a new coupon is sent to the customer.
The room booking workflow has no changes from the old system where a customer can view list of rooms with various information and send room booking request to the system. The system will then send confirmation with unique booking code to the customer.
Finally, the payment can be done by debit card or by paypal. During the payment, the customer can specify a valid coupon. The payment system will then redeem the coupon so that the respective discount represented by the coupon is deducted from the overal price.
Additionally, a detailed report is planned to be made available for customers showing various transactions with the hotel for the room bookings along with the information of the rooms till date. Similarly, hotel staff has various types of reports such as profit statement and room booking status.
The steps listed in 4.3.1 can be used to design the system defined by the Case Study 4.3.3. **Step 1:**
With reference to the steps shown by the Figure 4.6, the first step would be to find out new domain vocabularies, understand the meaning, agree on them and use them as the common vocabularies. The Table 4.11 lists some important domain terms taken from the case study 4.3.3 and clarifies the meaning for each. It is interesting to notice that the term 'Profile' has two different meaning depending upon the context of package and customer and it is a polyseme.

Domain Terms	Definition
Package	a discount offering to certain group of customers
Profile	the expected characteristics of customers to be elligible to apply a package
Discount	the reduction value offered in the total price for hotel service
Constraint	defines the limitation of creating coupons for any package
Coupon	represents the authorized assignment of a valid package to a valid customer, which can be used later
Customer Profile	the current characteristics of a customer
Room Booking	assignment of a room to a customer for certain period
Booking Code	a unique code representing the valid room booking
Redeem Coupon	request to use the coupon whereby the associated discount value is deducted from the total price
Price	the total amount for the hotel service

Table 4.11: Domain Keywords

Step 2:
Next, the subdomains are identified following the step 1 4.3.1.2 of strategical design. The core domains, supporting domains and generic domains are identified and listed in the table.

Core Domains	1 Package 2 Booking 3 Checkout
Supporting Domains	1 Payment 1.1 Paypal 1.2 CardPayment 2 User Management 2.1 Customer Management 2.2 Staff Management 3 Room
Generic Domains	1 Reporting 2 Authentication

Table 4.12: Subdomains

The supporting domain "User Management" has different stragegy for Customer and Staff so can be further divided into "Customer Management" and "Staff Management" subdomains. For the same reason, the "Payment" subdomain can also be further divided into "Paypal" and "CardPayment".

Step 3:
The next action is to identify bounded context following the process described in step 4.3.1.2. The process is implemented in each subdomains. In order to accomplish this, domain models can be constructed for each subdomain. Along the process, the various ambguities in the domain models and clear understanding of the concept of

the models can be clarified. This will highly help to achieve consistent ubiquitious language with the unification of domain models as well as shared vocabulary inside each subdomain. The boundary around the uniform and consistent domain represents the bounded contexts. Additionally, the rules given in the Section 4.3.1.2 can be applied when appropriate to identify bounded contexts. The following Section will provide the analysis of major subdomains to identify the bounded contexts within.

Customer Management

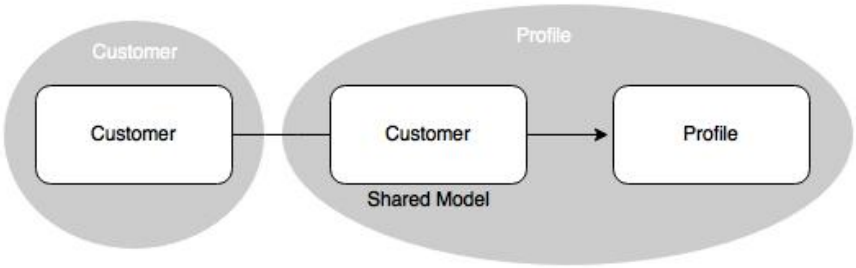


Figure 4.7: Domain Model for Customer Management

The management of customer includes two distinct broad task which are managing the customer itself and management of attributes of each customer which contribute to creating profile of customer at any point of time. Although, these two functionalities are related to customer, are actually loosely coupled and have different performance requirement. For eg: the change in the decision of adding attribute to a customer profile does not change the way customer is managed and also the rate at which customer profile is updated will definitely have high value than the rate customer is managed. Additionally, not all the attributes from customer is relevant to customer profile which makes 'Customer' a polyseme and a shared model between the two bounded contexts 'Customer' and 'Profile'.

Booking

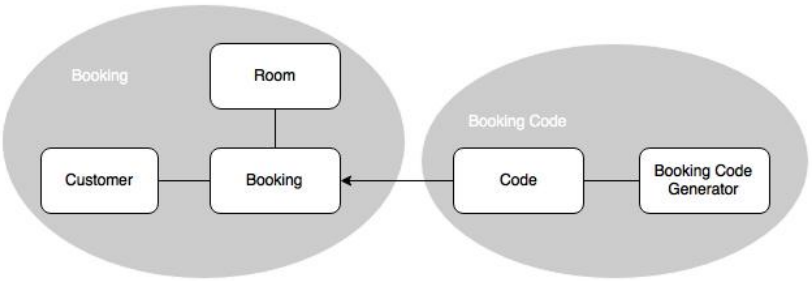


Figure 4.8: Domain Model for Booking

The Figure 4.8 shows the domain models of "Booking" subdomain. All the domain models and terms inside the subdomain are consistent and clear. However, the models 'Room', 'Customer', 'Booking' and 'Code' are closely related to booking functionality whereas the functionality of generating the booking code can be considered independent of booking. This gives two loosely coupled bounded contexts: "Booking" and "Booking Code". It is also interesting to notice that the models 'Customer' and 'Room' are polysemes with regard to other 'Customer' and 'Room' bounded contexts.

Checkout

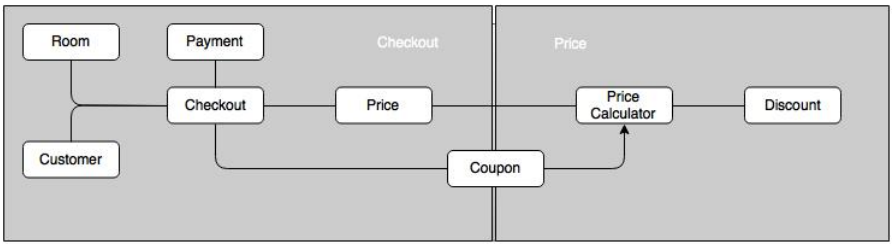


Figure 4.9: Domain Model for Checkout

The overall billing price calculation during checkout, which includes validation of coupon and redeem of the coupon onto the total price, is independent of the orchestration logic which occurs during checkout. The subdomain can be realized into two different bounded contexts 'Checkout' and 'Price'. Additionally, the domain models 'Customer, 'Discount', 'Room', 'coupon' and 'price' are polysemes for these bounded context with respect to other bounded contexts.

Package Management

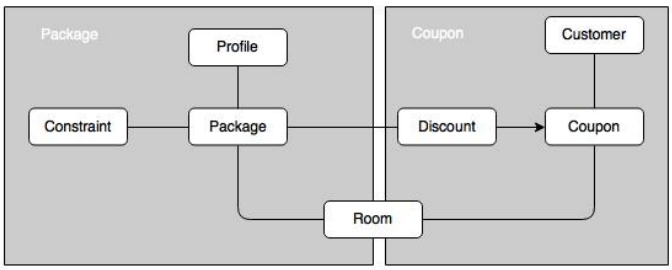


Figure 4.10: Domain Model for Package Management

The logic of package management can be considered independent of the way coupon is generated and validated. The packages are created by staff memeber whereas a coupon is created upon receiving a request from customer. Additionally, these are very specific and independent responsibilities, eligible of having own bounded contexts. The only data shared by the bounded contexts are about the information regarding eligible rooms and discount values. It should be made clear at this point that the 'Profile' domain model here is very different than 'Profile' domain model from 'Profile' boundend context of 'Customer Management' subdomain. In here, 'Profile' model defines the attributes of generic customer eligible for a specific package, however the 'Profile' domain model in 'Profile' bounded context provides the updated characteristics of any individual customer at the moment. Similarly, the models such as 'Customer' and 'Room' are polysemes.
The same process can be applied to identify bounded contexts for rest of the subdomains.

4.4 Conclusion

The use case refactoring process discussed in Section 4.2 highlights an important concept regarding usecases fulfilling multiple cross-cutting concerns and thus provides solutions by breaking down these concerns into individual usecase modules, each focused on cohesive tasks. This kind of decomposition truely relates to the characteristics of microservices. On the other hand, domain driven design technique presented in Section 4.3 provides a different approach of understanding the problem domain well using ubiquitous language, dividing the big problem domain into multiple manageable sub-domains and then finally using the concept of bounded context to determine individual microservices. The microservices thus obtained are autonomous and focus on single responsibility.
The usecase refactoring process utilizes usecases as its modeling tool, which is not only easy but the familiar tool to architects and developers. This makes usecase refactoring a faster approach to decompose a problem domain. Whereas, domain driven design has ubiquitous language and bounded context at its core. Both of these concepts are complex and new to most architects as well as developers. At the same time, understanding problem domain correctly at the first attempt is rare and it will take quite a few iterations to get the decomposition right. Thus, domain driven design is not the faster approach of modeling microservices.
Visualizing a problem domain in terms of diferent usecases seems like a natural way but dividing a big problem domain into smaller independent manageable sub-domains as stated by domain driven desing, can be a smart way to decompose. So, in case of big and complex problem domain, it can be very difficult to visualize in terms of large number of big usecase trees and task trees. This may lead to microservices without appropriate level of granularity and quality attributes.
A good thing about usecase refactoring is that it provides very easy way to break down usecase along various level of functionalites or abstraction. However, it undermines another crucial concept which is data ownership and data decompostion. An explicit assumption is made about an entity model being a single source of truth for whole domain, but it is rarely true. Using this approach will not necessarily produce autonomous services. However, the concept of ubiquitous lanugage and bounded context used by domain driven design, highly focus on different and unique local representation of same entity. This highly favors the autonomy of the resulting microservices. At the same time, the bounded context are responsible for small sets of cohesive functionality. This adheres to single responsibility principle. Thus, bounded context represents the appropriate size for a microservice.

4.5 Problem Statement

It is interesting to understand the various strategies defined in the literature to decompose a problem domain into microservices. The concept of microservices architecture is getting very popular recently among a lot of industries. So, the understanding of the process used in industries can also add bigger value to the thesis. For this reason, the next step is to study architecture at SAP Hybris as well as the process it followed for modeling microservices to build its commerce platform.

5 Architecture at SAP Hybris

In this chapter, a detail overview of the architecture at SAP Hybris will be studied. The Section 5.2 first clarifies the vision of YaaS. Then, the basic principles followed when modeling and developing microservices are listed in Section 5.3. In order to have a clear picture of the modeling and deployment process at SAP Hybris, Section 5.4 presents the detailed interview conducted with various key personnels. The modeling process deduces is further exmplained with an example in Section 5.6. Finally, the process of continuous deployment followed at hybris, which is considered as one of the major process when using microservices, is then discussed in Section 5.7.

5.1 Overview

SAP YaaS provides a variety of business services to support as well as enhance the products offered as SAP hybris front office such as hybris Commerce, hybris Marketing, hybris Billing etc. Using these offered services, developers can create their own business services focussed on their customer requirements.
The figure 5.1 provides the overview of YaaS. YaaS provides various business processes as a service (bPaaS) essential to develop applications and services thus filling up the gap between SaaS and HCP. For that purpose, it consumes the application services (aPaaS) provided by HCP.

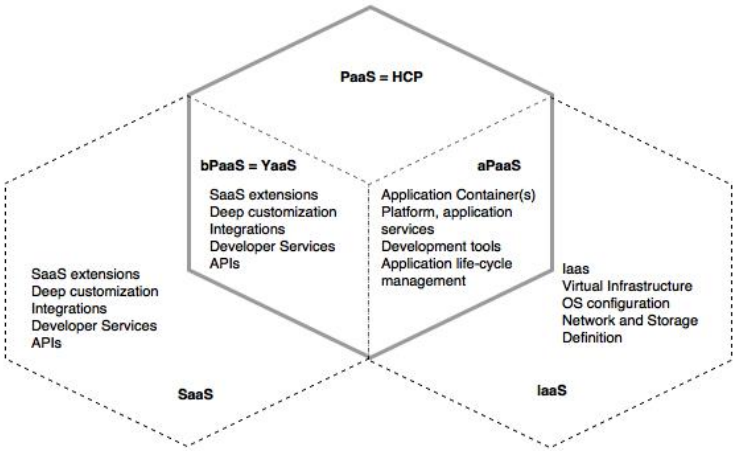


Figure 5.1: YaaS and HCP [Hir15]

5.2 Vision

The vision of YaaS can be clarified with the following statement.

> "A cloud platform that allows everyone to easily develop, extend and sell services and applications."
> [Stu15]

The vision can be broadly categorized into following objectives.

1. **Cloud First**
   The different parts of the application need to be scaled independently.
2. **Autonomy**
   The development teams should be able to develop their modules independent of other teams and able to freely choose the technology that fits the job.
3. **Retain Speed**
   The new features will be of value to customers if could be able to be released as fast as possible.

4. **Community**
   It should be possible for the components to be shared across internal and external developers.

The definition of microservices 1.2 as well as the characteristics of microservices [ref] signifies clearly that microservices architecture can be a good fit for YaaS architecture.

5.3 YaaS Architecture Principles

The Agile Manifesto [Bec+11] provides various principles to develop a software in a better way. It focus on fast response to the requirement changes with frequent continous delivery of software artifacts with close collaboration of customer and self-organizing teams.
The Reactive Manifesto [Bon+14] lists various qualities of a reactive system which includes responsiveness (acceptable consistent response time, quick detection and solution of problem), resilience (responsive during the event of failure) , elasticity (responsive during varying amount of workload) and asynchronous message passing. Loose coupling is highly focused.
Furthermore, the twelve factors from Heroku [Wig12] provides a methodology for minimizing time and cost to develop software applications as services. It emphasizes on scalability of applications, explicit declaration as well as isolation of dependencies among components, multiple continuous deployments from a single version controlled codebase with separate pipelines for build, release and run.
Finally, the microservices architecture provides techiques of developing an application as a collection of autonomous small sized services focused on single responsibility. [Section 1.2] It focus on independent deployment capability of individual microservices and suggest to use lightweight mechanisms such as http for communication among services. The architecture offers various advantages, few of them being individual independent scalability of each microservice, resilience achieved by isolating failure in a component and technology heterogeneity among various development teams.[New15]
Following the principles mentioned above, a list of principles are compiled to be used as guidelines for creating microservices. [Stu15] The list of principles are listed below.

The y-Factors

1. **Self-Sufficient Teams**
   The teams have independence and freedom for any decision related to the design

and development of their components. This freedom is balanced by the responsibility for the team to handle the complete lifecycle of their components including smooth running as well as performance in production and troubleshooting in case of any problems.

2. **Open Technology landscape**
   The team have freedom to choose any technology that they believe fits the requirement. They are completely responsible for the quality of their product. This gives teams, ownership as well as satisfaction for their products.

3. **Release early, release often**
   The agile manifesto and twelve factors from Heroku also focus on continuous delivery of product to the clients. This will decrease time of feedback and ultimately fast response to the feedback resulting in high customer satisfaction. The teams are responsible to create build and delivery pipeline for all available environments.

4. **Responsibility**
   The teams are the only responsible groups to work directly with the customers on behalf of their products. They need to work on the feedback provided by the customers. It will increase the quality of the products and relationship with customers. All the responsibilities including scaling, maintaining, supporting and improving products are handled by respective teams.

5. **APIs first**
   The API is a contract between service and consumers. The decision regarding design and development is very important as it can be one of the greatest assets if good or else can be a huge liability if done bad. [Blo16] The articles [Blo16] and [Bla08] list various characteristics of good API including simplicity, extensibility, maintainability, completeness, small and focussing on single functionality. Furthermore, a good approach to develop API is to first design iteratively before implementation in order to understand the requirement clearly. Another important aspect of a good API among many is complete and updated documentation.

6. **Predictable and easy-to-use UI**
   The user interfaces should be simple, consistent across the system and also consistent to various user friendly patterns.[Sol12] The articles [Mar13] and [Por16] specify additional principles to be considered when designing user interfaces. A few of them includes providing clarity with regard to purpose, smart organization and respecting the expectation as well as requirements of customers.

7. **Small and Simple Services** A service should be small and focused on cohesive functionalities. The concept closely relates to the single responsibility principle. [Mar16] A good approach is to explicitly create boundaries around business capabilities.[New15]

8. **Scalability of technology**
   The choice of technologies should be cloud friendly such that the products can scale cost-efficiently and without delay. It is influenced by the elasticity principle provided by the reactive manifesto.[Bon+14]

9. **Design for failure** The service should be responsive in the time of failure. It can be possible by containment and isolation of failure within each component. Similarly, the recovery should be handled gracefully without affecting the overal availability of the entire system. [Bon+14]

10. **Independent Services**
    The services should be autonomous. Each service should be able to be deployed independently. The services should be loosely coupled, they could be changed independently of eachother. The concept is highly enforced by exposing functionalities via APIs and using lightweight network calls as only way of communication among services. [New15]

11. **Understand Your System**
    It is crucial to have a good understanding of problem domain in order to create a good design. The concept of domain driven design strongly motivates this approach to indentify individual autonomous components, their boundaries and the communication patterns among them. [New15] Furthermore, it is also important to understand the expectations of consumers regarding performance and then to realize them accordingly. It is possible only by installing necessary operational capabilities such as continuous delivery, monitoring, scaling and resilience.

5.4 Modeling Microservices at Hybris

With the intension to anticipate the overall belief, culture and practice followed by hybris to develop YaaS, a number of interviews were conducted with a subset of key personnels who are directly involved in YaaS at different roles. The list of interviewees with their corresponsing roles is shown in the Table 5.1. In order to preserve anonymity, the real names are replaced with forged ones.

Names	Roles
John Doe	Product Manager
Ivan Horvat	Senior Developer
Jane Doe	Product Manager
Mario Rossi	Product Manager
Nanashi No Gombe	Product Manager
Hans Meier	Architect
Otto Normalverbraucher	Product Manager
Jan Kowalski	Senior Developer

Table 5.1: Interviewee List

5.4.1 Hypothesis

During the process of solving the concerned research questions, various topics of high value have been discovered. The topics are:

1. Granularity
2. Quality Attributes
3. Process to design microservices

Similarly, based on research findings, a list of hypothesis has been made with respect to each topic.

Hypothesis 1:

The correct size of microservices is determined by:

1. **Single Responsibility Principle**
2. **Autonomy, and**
3. **Infrastructure Capability**

According S.Newman, a good microservices should be small and focus on accomplishing one thing well. Additionally, it could be independently deployed and updated. This strongly suggests the requirement of SRP and autonomy respectively. [New15] Futhermore, M. Stine also agree that the size of a microservices should be determined

by single responsibility principle. [Sti14] Also, the principle mentioned in 2.3.4 indicate that the advancement in the current technology and culture of the organization also defines size of microservices. [RS07]

Hypothesis 2:

Domain driven design is the optimum approach to design microservices.

The concept of domain driven design to design microservices is promoted by S. Newman and M. Fowler. [New15] [FL14] Similary, there can be found evendence of domain driven design being used in various projects to design microservices. The list of projects is shown in the Table 4.10.

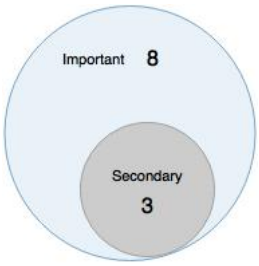
5.4.2 Interview Compilation

For each topic listed above in Section 5.4.1, a list of questionaires is prepared. The questions were then asked to the interviewees. In the remaining part of this section, an attempt is made to compile the response from the interviews on the questionaires for each topic.

1. Granularity

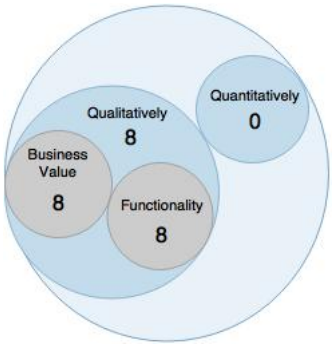
Question 1.1

"Do you consider the size of microservices when desigining microservice architecture?"



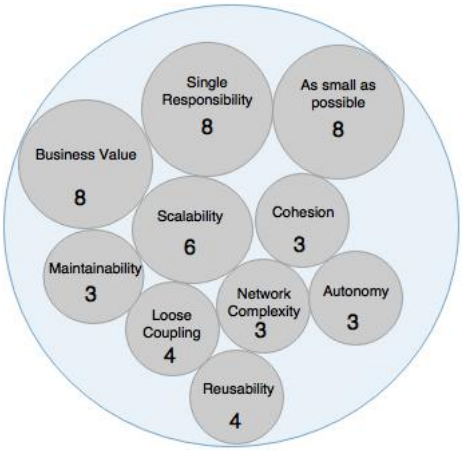
Question 1.2

"How do you measure size of a microservice?"



Question 1.3

"What kind of size do you try to achieve for a microservice?"



Question 1.4

"Suppose that you do not have the agile culture like continuous integration and delivery automation and also cloud infrastructure. How will it affect your decision regarding microservices and their size?"

Response 1.4	John	Ivan	Jane	Mario	Nanashi	Hans	Otto	Jan	**Score**
No microservices at all, start with Monolith, extract one microservice at a time as automation matures	1	1	0	1	1	1	1	1	**7**
Start with bigger sized microservices with high business value, low coupling and single Responsibility	0	0	1	0	1	0	1	0	**3**

Question 1.5

"Are you facing any complexities because of microservices architecture and the size you have chosen?"

Response 1.5	John	Ivan	Jane	Mario	Nanashi	Hans	Otto	Jan	**Score**
communication overhead in network	0	1	0	0	0	0	1	0	**2**
complexity in failure handling	0	1	0	0	0	0	0	0	**1**
Monitoring is difficult	0	1	0	0	0	0	1	0	**1**
Operational support is costly	0	1	1	0	0	0	0	0	**2**
difficult to trace a request	0	1	1	0	0	0	0	0	**2**
updates can be difficult due to dependencies among microservices	0	0	1	0	0	0	0	0	**1**

2. Quality Attributes

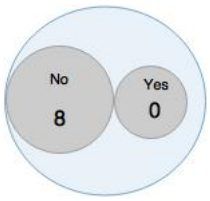
Question 2.1

"Do you consider any quality attributes when selecting microservices?"

Response 2.1	John	Ivan	Jane	Mario	Nanashi	Hans	Otto	Jan	**Score**
Loose Coupling	1	1	1	1	1	1	1	1	**8**
Cohesion	1	1	1	1	1	1	0	1	**7**
Autonomy	1	1	0	0	0	1	1	0	**4**
Scalability	1	0	0	1	1	0	1	1	**5**
Complexity	1	0	0	0	1	0	1	0	**3**
Reusability	0	1	0	0	0	0	1	0	**2**

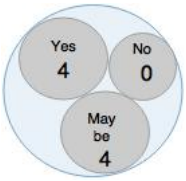
Question 2.2

"Do you consider any metrics for evaluating the quality attributes?"



Question 2.3

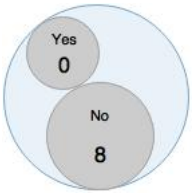
"Do you think the table of basic metrics can be helpful?"



3. Process to design microservices

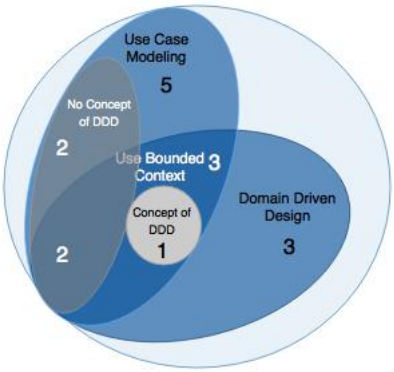
Question 3.1

"Do you follow specific set of consistent procedures across the teams to discover microservices?"



Question 3.2

"Can you define the process you follow to come up with microservices?"



5.4.3 Interview Reflection on Hypothesis

The data gathered from the interviews which are compiled in the Section 5.4.2 can be a good source to analyse the hypothesis listed on the Section 5.4.1.

Hypothesis 1

The correct size of microservices is determined by:

1. **Single Responsibility Principle**

2. **Autonomy, and**

3. **Infrastructure Capability**

The response from Question 5.4.2 has helped to point out some important constraints which play significant role in industry while choosing appropriate size of microservice. It is also interesting to notice how the terms in answer closely relate to the Hypothesis 5.4.1. The figure attempts to clarify the relationship among the terms with the hypothesis.

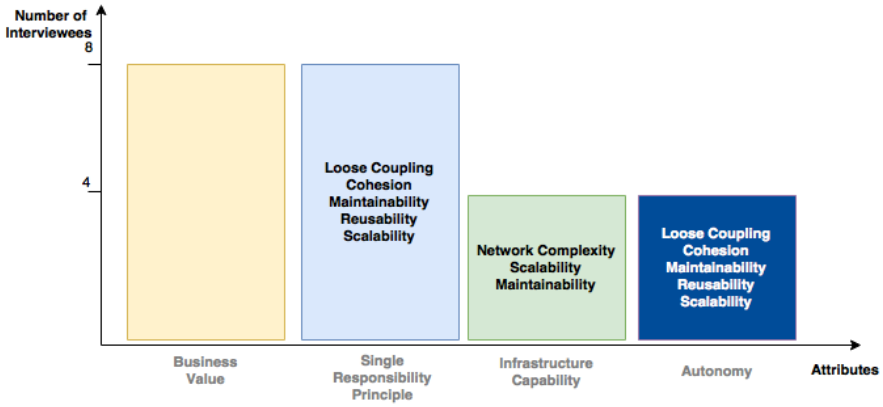


Figure 5.2: Attributes grouping from interview response

The interview unfolded various quality attributes which determine the correct size of a microservice. Moreover, these quality attributes can be classified into three major groups which are:

1. Single Responsibility Principle
2. Automony
3. Infrastructure Capability

Additionally, the response from the question 5.4.2 highly suggest the significance of availability of proper infrastructure to decide about size of microservices and the microservices architecture. This highly moves in the direction to support the hypothesis. Finally, there appears one additional constraint to affect the size of microservices, not covered by hypothesis but mentioned by all interviewees, which is the business value

provided by the microservices.

Hypothesis 2

Domain driven design is the optimum approach to design microservices.
From the response to Question 5.4.2, it can be implied that the organization has no consistent set of specific guidelines which are agreed and pratised across all teams. However, the various reactions to the Question 5.4.2 appear to fall with two class of process. The response from 5.4.2 is repeated here again for convenience 5.3.

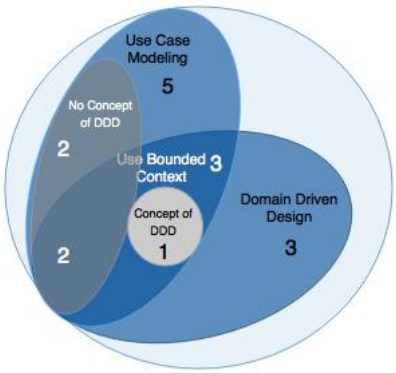


Figure 5.3: Process variations to design microservices

There is one group of reactions which follow a process to functionally divide a usecase into small functions based upon various factors such as single responsiblity and the requirements of performance. This strongly resemble to the usecase modeling technique as described in the Chapter **??**.
Moreover, within the same group, a partition are also using the concept of bounded context to ensure autonomy, which also suggests towards the direction of domain driven design as mentioned in the Chapter **??**. It is interesting to find out that some of the teams are using the concept of bounded context implicitly even without its knowledge. The rest of the teams who were not using bounded context, have no idea about the concept. It may be assumed that they will have different view once they get familiar with the concept.

Finally, the rest of the interviewees agree on domain driven design to be the process to design microservices. So, the response is of mixed nature, both usecase modeling and domain driven design are used in desigining microservices. However, it should also be stated that domain driven design are used on its own or along with usecase modeling to design autonomous microservices.

5.5 Derivation of Modeling Approach at Hybris by interview compilation

The response from the interviews as compiled in Section 5.4.2 is analyzed for each topic listed in 5.4.1 separately.

Granularity

Granularity of a microservice is considered as an important aspect when designing microservices architecture. The first impression in major cases is to make the size of microservice as small as possible however there are also various attributes and concepts which affects the decision regarding the size of microservices. The major aspects are single responsibility principle, autonomy and infrastructure capability.
The single responsibility gives impression to assume the size of a microservice as small as possible so that the service has minimum cohesive functionality and less number of consumers affected. Whereas, in order to make the microservice autonomous, the service should have full control over its resources and less dependencies upon other services for accomplishing its core logic. This suggests that the size of the service should be big enough to cover the transactional boundary upon its core logic and have full control on its business resources.
Moreover, the small the size of the service is, the number of required microservices increases to accomplish the functionalities of the application. This increases network complexity. Additionally, the logical complexity as well as maintainability will increase. Undoubtedly, the independent scalability of individual service will also increase. However, this increases the operational complexity for maintaining and deploying the microservices, due to the number of services and number of environment to be maintained for each services.
As shown in 5.2, various factors affect the size of microservices. The research findings as well as interview response leads to the idea that the question regarding "size" of a microservices has no straight answer. The answer itself is a multiple objective optimization problem whose answer depend upon the level of abstraction of the problem domain achieved, self-governance requirement, self-containment requirement and the

honest capability of the organization to handle the operational complexity.
Finally, there is an additional deciding factor called "Business Value". The chosen size of the microservice should give business and competitive advantage to the organization and closely lean towards the organizational goals. A decision for a group of cohesive functionalities to be assigned as a single microservice means that a dedicated resources in terms of development, scaling, maintainance, deployment and cloud resources have to be assigned. A rational decision would be to relate the expected business value of the microservice against the expected cost value required by it.

Quality Attributes

The teams do not follow any quantitative metrics for measuring various quality attributes. However, they agree on a common list of quality attributes to be considered as shown in the Table **??**. According to the reactions from interviews, the basic metrics to evaluate the quality attributes visualized in the Table 3.8 can be helpful to approach the design of microservices architecture in an efficient way.

Process to design microservices

There is no single consistent process followed across all the teams. Each team has its own steps to come up with microservices. However, the steps and decision are highly influenced by a set of YaaS standard principles 5.3. The reactions from the interviewees are already visualized in 5.3.
The process followed by a portion of teams closely relate to usecase modeling approach, where a usecase is divided into several smaller abstractions guided by cohesion, reusability and single responsibility principle. Within this group, a major number of teams also use the concept of bounded concept in order to realize autonomous boundary around the service. Finally, the remaining portion of the teams closely follow domain driven design, where a problem domain is divided into sub-domains and in each sub-domain, various bounded contexts are discovered, which is then mapped into microservices.
The domain driven design can be considerd as the most suitable approach to design microservices. Following this approach, not only the problem domain is functionally divided into cohesive group of functionalities but also leads to a natural boundary around the cohesive functionalities with respect the real world, where concept as well as differences are well understood and the ownership of business resources and core logic are well preserved.

5.6 Case Study

YaaS provides a cloud platform where customers can buy and sell applications and services related to commerce domain. In order to accomplish this, YaaS offers various basic business and core functionalities as microservices. The customers can either use or extend these services to create new services and applications focusing on their individual requirements and goals.
The following part of this section discuss the steps used to identify microservices under commerce domain in YaaS.
Step 1:
The problem domain is studied thoroughly to identify core domains, supporting domains and generic domains.

#	Sub-domain	Type	Description
1	Checkout	Core	handles overall process from cart creation to selling of cart items.
2	Product	Supporting	deals with product inventory
3	Customer	Supporting	deals with customer inventory
4	Coupon	Supporting	deals with coupon management
5	Order	Supporting	handles orders management
6	Site	Supporting	handles site configuration
7	Tax	Supporting	handles tax configuration and tax calculation
8	Payment	Supporting	handles payment for orders
9	Email	Generic	provides REST api for sending emails
10	Pubsub	Generic	provides asynchronous event based notification service
11	Account	Generic	handles users and roles management
12	OAuth2	Generic	provides authentication for clients to access resource of resource-owner
13	Schema	Generic	storing schema of documents
14	Document	Generic	provides storage apis for storing and accessing documents

Table 5.2: Sub-domains in YaaS

Step 2:
The major functionality of the commerce platform is to sell products, which makes 'Checkout' the core sub-domain. The sub-domain is responsible for a bunch of independent functionalities. The individual independent functionalities can be rightfully represented by respective bounded contexts. The bounded contexts are realized using microservices. The other major reason for them to be made microservices, in addition to single independent responsibility, is different scalability requirements for each functionality.

#	Bounded Context	Description
1	Checkout	handles the orchestration logic for checkout
2	Cart	handles cart inventory
3	Cart Calculation	calculates net value of cart considering various constraints such as tax, discount etc.

Table 5.3: Bounded Contexts in Checkout

Step 3:
The supporting sub-domain Product deals with various functionalities related to "Product".

#	Bounded Context	Description
1	Category	manage category of products
2	Product	manage product inventory
3	Price	manage price for products

Table 5.4: Functional Bounded Contexts in Product

The bounded contexts listed in Table 5.4 are based upon the independent responsibility and different performance requirement. Additionally, each functionality deals with business entity "Product". However, the conceptual meaning and scope of "Product" is different in each bounded context. "Product" is a polyseme.
Again, there are two more functionalities identified. The first one is a technical functionality to provide indexing of products so that searching of products can be can be efficient. The functionality is generic, technical and independent. It has a different bounded context and can be realized using different microservice. Furthermore, there is a requirement of mashing up information from product, price and category in order to limit the network data from client to each individual service and improve performance. This is realized using a separate mashup service. Also, these functionalities have different performance requirement.

#	Bounded Context	Description
1	Algolia Search	product indexing to improve search performance
2	Product Detail	provide mashup of product, price and category

Table 5.5: Supporting and Generic Bounded Contexts in Product

It is important to notice that the decision to realize the functionalities as microservices considered various technical aspects as performance, autonomy etc and also business value. The individual microservices such as Product, Category, Checkout have high

business value to YaaS because they are good candidate services required by their partners and customers.
The various microservices for the sub-domains checkout and product,identified following the steps listed above, forms layers of services based on their level of abstraction and reusability. The layers are shown in Figure 5.4. The core services are technical generic services used by business services and form the bottom layer. On the top of that are the domain specific business services focused on domain specific business capability. The individual business functionalites provided by business services are then used by Mashup layer to create high level services by orchestrating them.

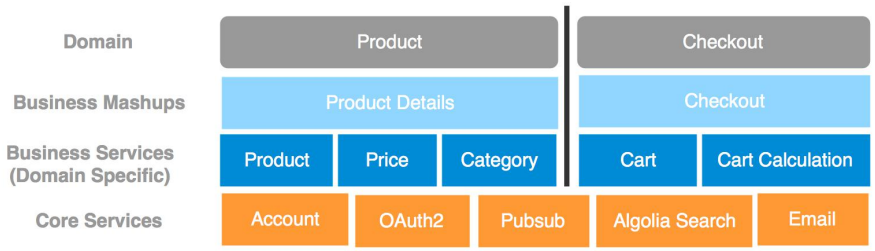


Figure 5.4: Microservices Layers

Step 4:
The same process from steps 1-3 are applied to remaining sub-domains listed in Table 5.2. The Table 5.6 shows a list of services discovered in each sub-domains within commerce domain. For example, 'Tax' and 'Tax Avalara' are microservices under 'Tax' sub-domain. Similarly, 'Order' and 'Order Details' are microservices related to 'Order' subdomain.

Sub-domain	Microservice	Description
Checkout	checkout cart Cart Calculation	handles the orchestration logic for checkout handles cart inventory calculates net value of cart considering various constraints such as tax, discount etc.
Product	Product Product Details Category Price	manages product inventory provides mashup of product, price and category manages category of products manage price for products
Order	Order Order Details	handles order management provide mashup of orders and products
Site	Site Shipping	handles site configuration handles shipping configuration for site
Tax	Tax Tax Avalara	handles tax configuration handles tax calculation using Avalara
Customer	Customer	deals with customer inventory
Coupon	Coupon	deals with coupon management
Payment	Payment Stripe	handles payment for oders using Stripe

Table 5.6: Services in YaaS Commerce domain

Including all the microservices in core, supporting and generic sub-domains considering only commerce domain, the resulting architecture is as shown in Figure 5.5. At the bottom are various generic microservices such as Pubsub, Document etc. They are utilized by various business services such as Customer, Coupon etc. On the top are various mashup services such as Checkout, Order-Details and they utilize various business services and core services underneath.

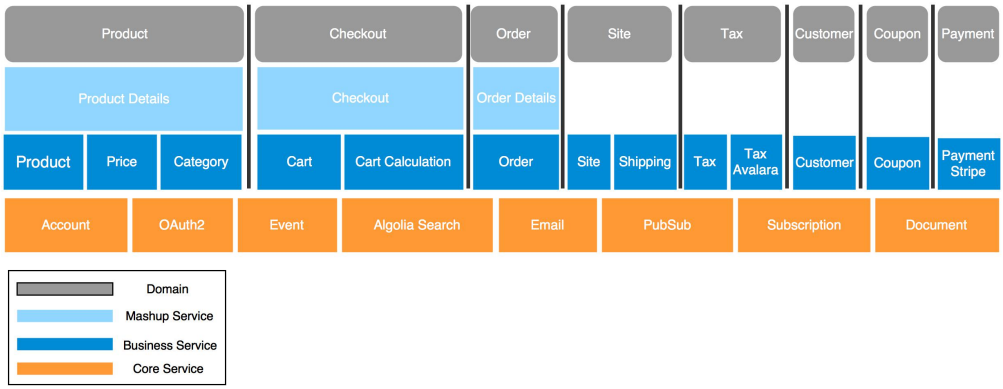


Figure 5.5: Microservices Layers For Commerce Domain

5.7 Deployment Workflow

Another major aspect apart from modeling microservices is continuous deployment. One of the major goals of implementing microservices architecture is agility. And agility can only be maintained when any small change in each microservice can be deployed into production smoothly without affecting other microservices.

5.7.1 SourceCode Management

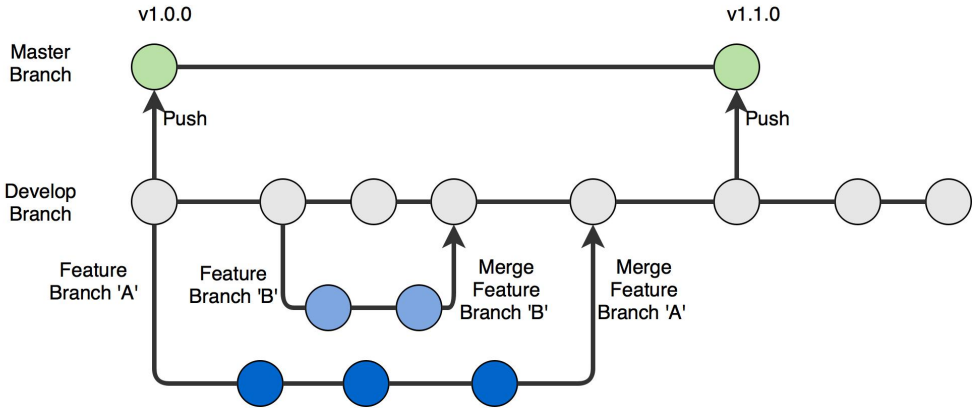


Figure 5.6: Sourcecode Management at Hybris

The sourcecode files for each microservices are maintained in BitBucket version control. The files are managed using Git. In order to support continuous deployment and efficient collaboration among various developers working in the same microservice, various branches are maintained within each repository. The major branch is called "Master" branch, which is used only for continuous deployment of production code. Another branch is "Develop" branch and is used by developers to add changes continuously. It is used to create development version of service and undergoes various level of tests. When sufficient features are ready and verified in "Develop" branch, they are merged into "Master" branch and realeased from "Master" branch. In this way, "Master" branch has always unbroken sourcecode.
For adding any major changes or features in microservices, a new "Feature" branch is created from "Develop" branch and undergoes various levels of testing before it is merged with develop branch. In this way, development and verification of any change can happen independently.

5.7.2 Continuous Deployment

In Section 5.7.1, the concept of maintaining feature branches were discussed. In this section, the process of deploying the changes of feature branch to production will be presented.
The Figure 5.7 shows the complete deployment flow for a microservice. Firstly, a developer "A" pushes his/her local changes to the remote "Feature" branch at BitBucket. The changes triggers Teamcity "Build" phase where the changes are first compiled and then a series of unit tests are run against the newly built application which is again followed by a series of integration tests.
If the tests are successful, the developer will create a pull request in BitBucket, reprensenting a request to merge his/her changes to "Develop" branch. Developer "B" from the same team will then review his/her changes and provides comments on BitBucket interface. After the changes are made and developer "B" is satisfied, he/she approves the pull request.
Then, the developer "A" or "B" will merge the feature branch into develop branch. This will again trigger "Build" phase in Teamcity. Again, the develop branch is compiled, followed by unit tests and integration tests. If the tests are successful, then it will trigger "Deployment" phase, code is deployed to "Stage" environment and a group of smoke tests are run to verify the deployment. Now, project owner or quality assurance team can access the service and perform user acceptance tests. If there is any feedback or changes to be made, it will follow the same process from the beginning.
Now, when there are sufficient features and it is time for release, the "Develop" branch is merged to "Master" branch. The merge will again trigger "Build" phase in Teamcity. After successful tests, the "Master" branch is first deployed into "Stage" environment, where a series of smoke tests runs. After the deployment is successful without any error, the "Master" branch is deployed into "Production" environment, where again various smoke tests are run to re-assure the deployment.

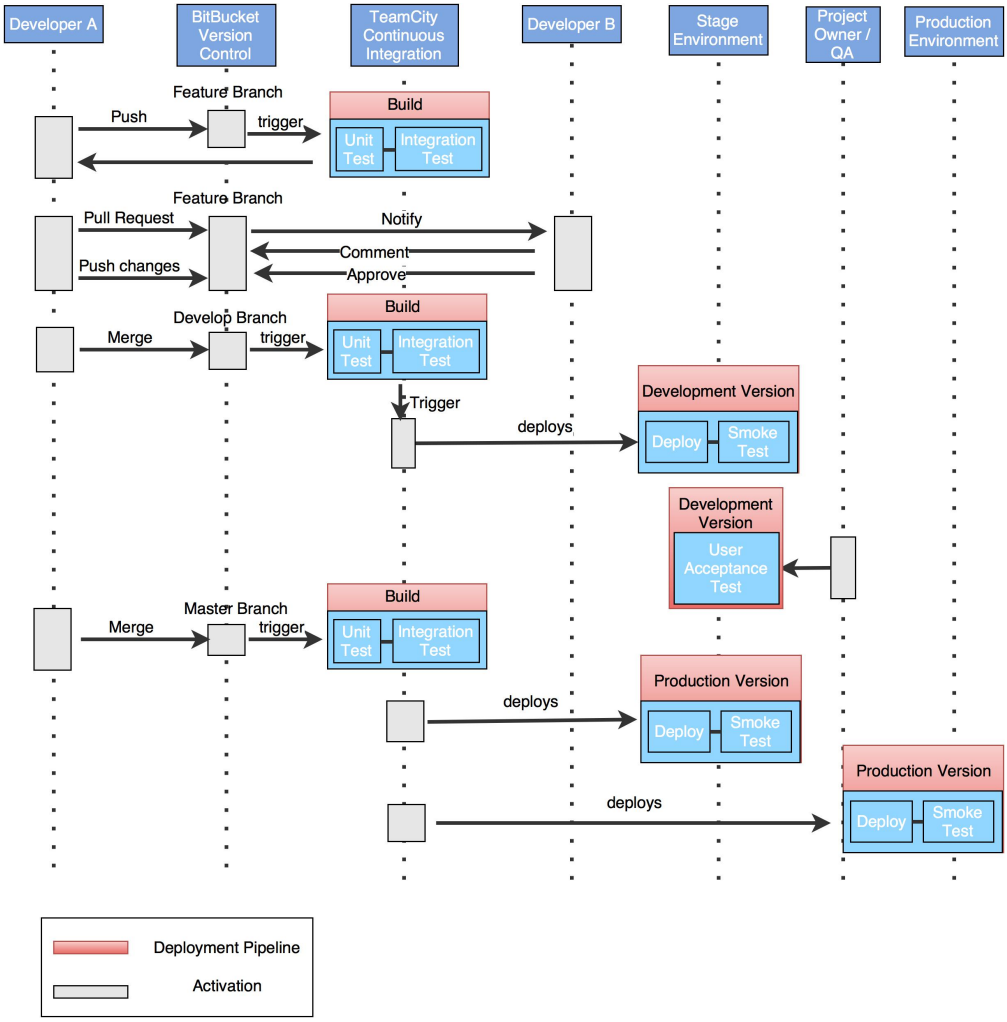


Figure 5.7: Continuous Deployment at Hybris

The deployment is done using cloud foundry which consists of AWS cloud underneath. The Figure 5.5 uncovers only microservices at the backend related to commerce domain. The complete architecture covering other domains such as Marketing etc and all layers including User- Interface, is shown by Figure 5.8. Apart from Commerce domain, there are various other domains such as Marketing, Sales etc. On each domain, same process as explained in 5.6 is followed to identify various microservices. For example, in 'Marketing' domain, there are microservices such as 'Loyalty', Loyalty Mashup' services.

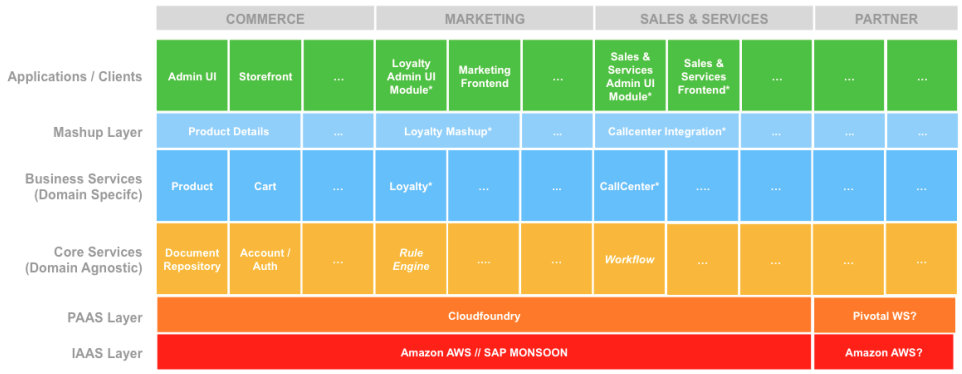


Figure 5.8: Hybris Architecture

5.8 Problem Statement

In this chapter, the modeling approach used in SAP Hybris was discussed. Again, the continuous deployment process for each microservice was presented. This will add value to the findings made regarding modeling process from literature. Now, as stated in Section 1.4, the constraints or challenges are driving points for defining guidelines. So, the next step is to rearch about various challenges when incorporating microservices along with the techniques to tackle them. While looking into that, it would also be interesting to find out how these challenges are being handled at SAP Hybris.

6 Challanges of Microservices Architecture

This chapter focus on various challenges faced while implementing microservices. In Section 6.1, various advantages of microservices along with its challenges are listed. Then each challenge is broken down along several sub-challenges and discussed further after Section 6.2. For each challenges, various techniques which can be used in order to handled them are also presented. Again, in order to provide benefit from industry experience, the techniques used by SAP Hybris are also presented.

6.1 Introduction

The Section 1.1.3 lists some drawbacks of monolithic architecture and these have become the motivation for adopting microservices architecture. Microservices offer opportunities in various aspects however it can also be tricky to utilize them properly. It does come with few challanges. The response from Interview Question 5.4.2 also highlights some prominent challanges. In this chapter, the challanges of microservices alongside its advantages will be discussed. [Fow15]

Advantages

Strong Modular Boundaries
It is not totally true that monolith have weaker modular structure than microservices but it is also not false to say that as the system gets bigger, it is very easy for monolith to turn in to a big ball of mud. However, it is very difficult to do the same with microservices. Each microservice is a cohesive unit with full control upon its business entities. The only way to access its data is through its API.

Challanges

Distributed System Complexity
The infrastructure of microservices is distributed, which brings many complications alongside, as listed by 8 fallacies.[Fac14] The calls are remote which are imminent to accomplish business goals. The remote calls are slower than local and affect performance in a great deal. Additionally, network is not reliable which makes it challanging to accept and handle the failures.

Independent Deployment
Due the nature of microservices being autonomous components, each microservice can be deployed independently. Deployment of microservices is thus easy compared to monolith application where a small change needs the whole system to be deployed.[New15]

Integration
It is challanging to prevent breaking other microservices when deploying a service. Similarly, as each microservice has its own data, the collaboration among microservices and sharing of data can be complex.

Agile
Each microservice is focused to single responsibility, changes are easy to implement. At the same time, as the microservices are autonomous, they can be deployed independently, making the release cycle time short.

Operational Complexity
As the number of microservices increases, it becomes difficult to deploy in an acceptable speed and becomes more complicated as the frequency of changes increase. Similary, as the granularity of microservices decreases, the number of microservices increases which shifts the complexity towards the interconnections. Ultimately, it becomes complex to monitor and debug microservices.

In the following sections of this chapter, various ways to tackle the challenges mentioned in 6.1 are discussed in detail.

6.2 Group: Integration

The collaboration among various microservices whilst maintaining deployment autonomy is challenging. In this section, various challanges associated with integration and their potential remedies are discussed.

6.2.1 Challenge: Sharing Data

An easiest way to collaborate, is to allow services to access and update a common data source. However, using this kind of integration creates various problems.[New15]

1. The shared database acts as a point of coupling among the collaborating microservices. If a microservice make any changes to its data schema, there is high probability that other services need to be changed as well. Loose Coupling is compromised.

2. The business logic related to the shared data may be spread across multiple services. Changing the business logic is difficult. Cohesion is compromised.

3. Multiple services are tied to a single database technology. Migrating to a different technology at any point is hard.

Alternatives
There are three distinct alternatives.[Ric15b]

1. **private tables per service** - multiple services share same database underneath but each service owns a set of tables.

2. **schema per service** - multiple services share same database however each service owns its own database schema.

3. **database server per service** - each service has a dedicated database server underneath.

Techniques

The logical separation of data among services increases autonomy but also make it difficult to access and create consistent view of data. However these can be compensated using following approaches.[Ric16] [Ric15b]

1. The implementation of business transaction which spans multiple services is difficult and not recommended because of Theorem 11.1. The solution is to apply eventual consistency 11.2 focussing more on availability.

2. The implementation of queries to join data from multiple databases can be complicated. There are two alternatives to achieve this.
   a) A separate mashup service can be used to handle the logic to join data from multiple services by accessing respective APIs.
   b) CQRS pattern 11.3 can be used by maintaining separate views as well as logic for updating and querying data.

3. The need for sharing data among various autonomous services cannot be avoided completely. It can be achieved by one of the following approaches.
   a) The data can be directly accessed by using the resource owner's API.
   b) The required data can be duplicated into another service and made consistent with the owner's data using event driven approach.

SAP Hybris uses the technique of maintaining private schema per microservice as listed in the Section 6.2.1 in order to share data. For this purpose, there is a generic microservice called "Document" which handles the task of managing data for all microservices per each tenant and application.

6.2.2 Challenge: Inter-Service Communication

As much as it is correct to say that a microservice is an autonomous component, for the same reason it is also reasonable to accecpt the necessity of interaction among microservices. The various possible interactions among microservices is shown in Figure 6.1.[Ric15a]

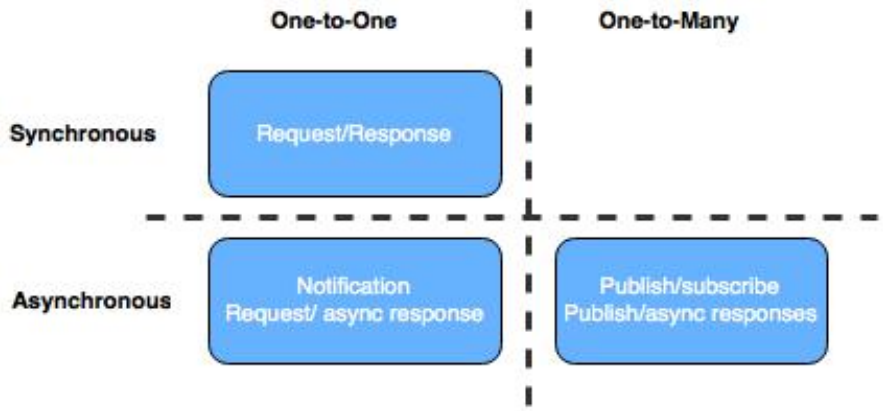


Figure 6.1: Inteaction Styles among microservices [[Ric15a]]

One to One interactions

1. **Request/Response**: It is synchronous interaction where client sends request and expects for response from server.
2. **Notification**: It is asynchronous one way interaction where cliend sends request but no reply is sent from server.
3. **Request/async Response**: It is asynchronous interaction where client requests server but does not block waiting for response. The server send response asynchronously.

One to Many interactions

1. **Publish/subscribe**: A service publishes notification which is consumed by other interested services.
2. **Publish/async responses**: A service publishes request which is consumed by interested services. The services then send asynchronous responses.

Techniques

6.2.2.1 Synchronous and Asynchronous

Each of the interactions listed in Section 6.2.2 has its own place in an application. An application can contained a mixture of these interactions. However, a clear idea about the requirement as well as drawbacks associated with the interaction is necessary.[New15][Ric14a][Mor15]

Synchronous Interaction

It is simple to understand to flow and natural easy way of implenting an interaction. However, as the interactions get higher, it increases the overal blocking period of client and thus increasing latency. The synchronous nature of interaction increases temporal coupling between services which demands both to be active at the same time. Since, the synchronous client needs to know the address and port of server to communicate, it also induces location coupling. With the cloud deployment and auto-scaling, this is not simple. Finally, to mitigate the location coupling, service discovery mechanishm is recommended to be used.

Asynchronous Interaction

The asynchronous interaction decouples services. It also improves latency as the client is not blocked waiting for the response. However, there is one additional component which is message broker to be managed. Additionally, the conceptual understanding of the flow is not natural, so it is not easy to reason about.

SAP Hybris uses both asynchronous as well as synchronous communication where appropriate. For, synchronous, it uses REST calls where as for asynchronous messaging it uses a genering service called "PubSub", which again uses Apache Kafka for managing publication and subscription of messages. An instance of the various communication is shown in the Example 6.2.2.2.

6.2.2.2 Example

The Figure 6.2 shows various interactions during creation of order. At first, the client, 'checkout service' in this case sends Restful Post order request to 'Order service'. Next, the 'order service' publishes 'Order Created' event and then sends response to the client. The 'OrderDetails service', which is subscribed to the event 'Order Created' reponds by first fetching necessary prodcut details from 'Product service' using Restful Get request. Finally, the 'OrderDetails service' sends request to 'Email service' for sending email to customer regarding order details but does not wait for response. The 'Email service' sends response to 'OrderDetails service' when email is sent successfully.

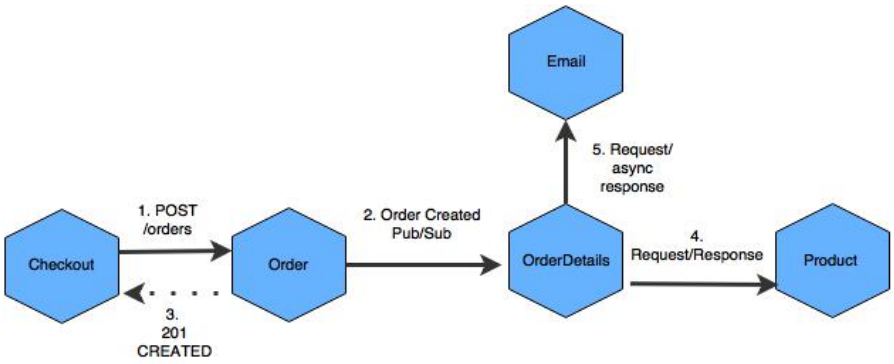


Figure 6.2: Interaction during Order creation

6.3 Group: Distributed System Complexity

6.3.1 Challenge: Breaking Change

Although microservices are autonomous components, they still need to communicate. Also, it is obvious that they undergo changes frequently. However, some changes can be backward incompatible and break their consumers. The breaking changes are inevitable but however the impact of the breaking changes can be somehow reduced by applying various techniques. [New15]

Techniques

1. Avoid as much as possible
   A good approach to reduce impact of incompatible changes to the consumers is

to defer it as long as it is possible. One way is by choosing the correct integration technology such that loose coupling is maintained. For example, using REST as an integration technology is better approach than using shared database because it encaptulates the underlying implementation and consumers are only tied to the interfaces.
Another approach is to apply TolerantReader pattern while accessing provider's API. [Fow11b] Consumer can get liberal while reading data from provider. Without blindly accepting everything from server, it can only filter the required data without carrying about the payload structure and order. So, if the reader is tolerant, the consumer service can still work if the provider adds new fields or change the structure of the response.

2. Catch breaking changes early
   It is also crucial to identify breaking change, if it happens, as soon as possible. It can be achieved by using consumer-driven contracts. Consumers will write the contract to define the expectations from the producer's API in the form of various integration tests. These integration tests can become a part of build process of the producer so the breaking change can be detected in the build process before the API is accessed by the real consumers.

3. Use Semantic Versioning
   Semantic Versioning is a way to identify the state of current artifact using compact information. It has the form MAJOR.MINOR.PATCH. MAJOR number is increased when backward incompatible changes are made. Similarly, MINOR number is increased when backward compatible functionalities are added. Finally, PATCH number represents that bug fixes are made which are backward compatible.
   With semantic versioning, the consumers can clearly know if the provider's current update will break their API or not. For example, if consumer is using 1.1.3 version of provider's API and the new updated version is 2.1.3, then the consumer should expect some breaking changes and react accordingly.

4. Coexist Different Endpoints
   Whenever a breaking change on a service is deployed, it should be carefully considered not to fail all the consumers immediately. One way is to support old version of end points as well as new ones. This will give some time for consumers to react on their side. Once all the consumers are upgraded to use new version of the provider, the old version end point can be removed. However, using this approach means that additional tests to verify both versions.

5. Coexist concurrent service versions

Another approach is to support both version of service at once. The requests from old consumers need to be routed to old versioned service and requests from new consumers to the new versioned service. It is mostly used when the cost of updated old consumer is high. However, this also means that two different versions have to be maintained and operated smoothly.

At SAP Hybris, breaking change is avoided as much as possible using REST and also Tolerant Reader pattern. When data is read from another microservice, the data is first handled by internal mapper library which maps the input data into the internal representation to be used by microservice. Also, for providing detailed information regarding state of current microservice version, semantic versioning is used. If there is breaking change in few endpoints, then multiple version of them is also maintained for short period of time give the consumer fair time to migrate. Similarly, if there are breaking changes in most of the endpoints then the entire microservice is maintained with different versions.

6.3.2 Challenge: Handling Failures

With a large number of microservices where communication is happening along not so reliable network, failures are inevitable. At the same time, it becomes challenging as well as highly necessary to handle the failures. Many strategies can be employed for the purpose. [New15][Ric15a][Nyg07]

Techniques

1. Timeouts
   A service can get blocked indefinitely waiting for response from provider. To prevent this, a threshold value can be set for waiting. However, care should be taken not to choose very low or high value for waiting.

2. Circuit Breaker
   If request to a service keep failing, there is less sense to keep sending request to the same server. It can be a better approach to track the request failures and stop sending further request to the service assuming that there is problem with the connection. By failing fast in such a way will not only save the waiting time for the client but also reduces unnecessary network load. Circuit Breaker pattern helps to accomplish the same. A circuit breaker has three states as shown in the

Figure 6.3. In normal cases when the connection to the provider is working fine, it is in 'closed' state and all the connections to the provider goes through it. Once the connection starts failing and meets the threshold (can be number of failures or frequency of failures), the circuit breaker switch to 'open' state. At this state, any more connections fail straight away. After certain time interval, the state changes to 'half open' to check the state of provider again. Any connection request at this point passes through. If the connection is succesful, the state switches back to 'closed' state, else to 'open' state.[Fow14b] [New15] [Nyg07]

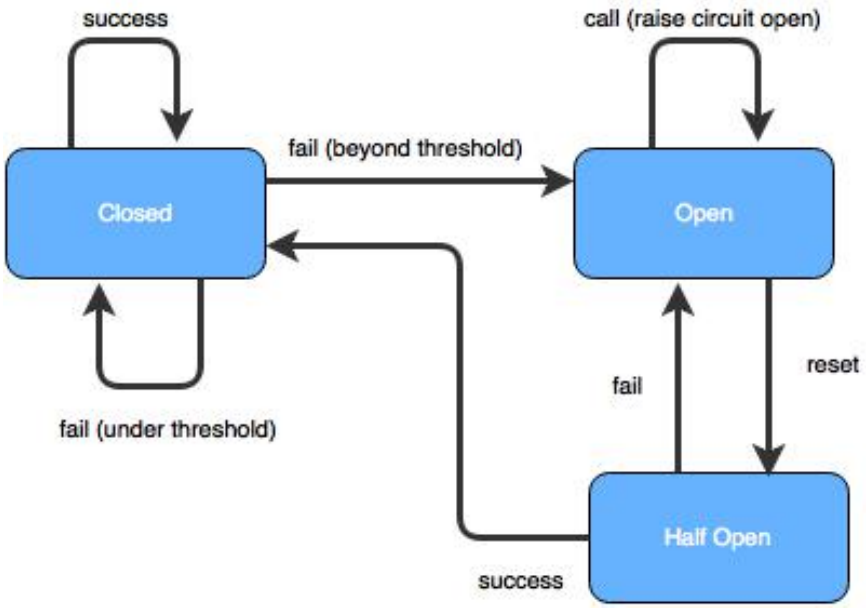


Figure 6.3: States of a circuit breaker [[Fow14b]]

3. Bulk Head
   Bulk Head is the approach of segregating various resources as per requirement and assigning them to respective purposes. Maintaining such threshold in available resources will save any resource from being constrained whenever there is problem in any section. One example of such bulkhead is the assignment of separate connection pool for each downstream resources. In this way, if problem in the request from one connection pool will not affect another connection pool. [New15] [Nyg07]

4. Provide fallbacks

Various fallback logic can be applied along with timeout or circuit breaker to provide alternative mechanism to respond. For example, cached data or default value can be returned.

At SAP Hybris, synchronous requests are attempted recursively for certain number of times, each attempt waits for the response only for certain fixed amount of time depending upon usecase. In order to save network resources and provide fault tolerance, circuit breaker pattern is used.

6.4 Group: Operational Complexity

6.4.1 Challenge: Monitoring

With monolithic deployment, monitoring can be achieved by sifting through few logs on the server and various server metrices. The complexity can get added to some extent if the application is scaled along multiple server, in which case, monitoring can be done by accumulating various server metrices and going through each log file on each host. The complexity goes to whole new level when monitoring microservice deployment because of large number of individual log files produced by microservices. As difficult it is to go through each log files, it is even more challenging to trace any request contextually along all the log files.

Techniques

There are various ways to work around these complexities. [New15] [Sim14]

1. Log Aggregation and Visualition
   A large number of logs in different locations can be intimidating. The tracing of logs can be easier if the logs could be aggregated in a centralized location and then visualized in a better way such as graphs. One of such variations can be achieved using ELK stack as shown in the Figure 6.4. [Ani14] [New15]

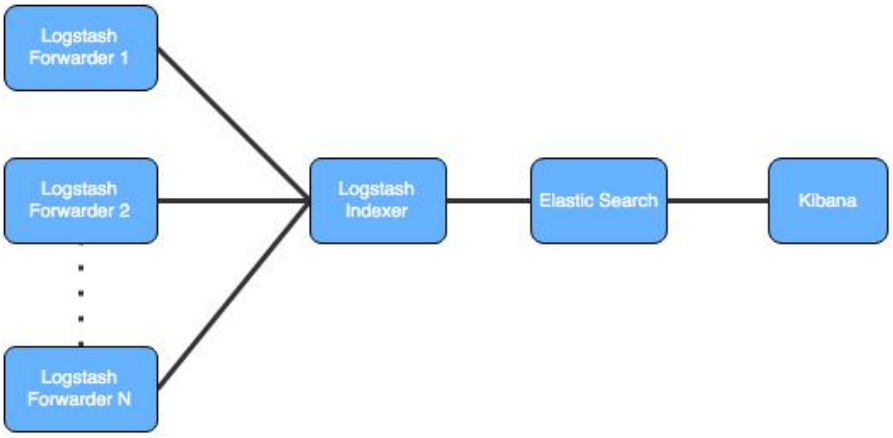


Figure 6.4: ELK stack

The ELK stack consists of following major components.

a) Logstash Forwarder
It is the component installed in each node which forwards the selected log files to the central Logstash server.

b) Logstash Indexer
It is the central logstash component which gathers all the log files and process them.

c) Elastic Search
The Logstash Indexer forwards the log data and stores into Elastic Search.

d) Kibana
It provides web interface to search and visualize the log data.
The stack makes it easy to trace log and visualize graphs along various metrices.

2. Synthetic Monitoring
Another aspect of monitoring which can be helpful, is to collect various health status such as availability, response time etc. There are many tools to make it easier. One such tool is 'uptime', which is a remote monitoring application and provides email notification as well as features such as webhook to notify a url using http POST.
Rather than waiting for something to get wrong, a selected sets of important business logic can be tested in regular interval. The result can be fed into notification subsystem, which will trigger notification to responsible parties. This

will ensure confidence that any problem will be detected as soon as possible and can be worked on sooner. [Sim14] [New15]

3. Correlation ID
   A request from a client is fulfilled by a number of microservices, each microservice being responsible for certain part of the whole functionality. The request passes through various microservices until it succeeds. For this reason, it is difficult to track the request as well as visualize the complete logical path. Correlation ID is an unique identification code given to the request by the microservices at the user end and passes it towards the downstream microservice. Each downstream microservice does the same and pass along the ID. It gets easier to capture a complete picture of any request in that way.

SAP Hybris uses ELK stack for monitoring and log visualization. In order to check the health status of microservices, 'uptime' tool is used. The webhook from the tool updates the central status page showing the current status of all the existing microservices. Any problem triggered by 'uptime' is also reflected in this page. Similary, a set of smoke tests are triggered from continuous integration tool such as TeamCity at regular interval. In order to track the requests at each microservices, a unique code is given to each request. The code is assigned by API-Proxy server which is the central gateway for any incoming request into YaaS.

6.4.2 Challenge: Deployment

A major advantage of microservices is that the features can updated and delivered quickly due to the autonomity and independent deployability of each microservices. However, with the increase in the number of microservices and the rate of changes that can happen in each microservice, fast deployment is not straight forward. The culture of doing deployment for monolithic application will not work perfectly on microservices. This section discusses how it can be achieved.
There are two major parts in deployment. In order to speed up deployment in microservices, approach to accomplish each part has to be changed slightly.

Techiniques

1. Continuous Integration
   It is a software development practice in which newly checked in code are followed by automated build and verification to ensure that the integration was successful.

Following continuous integration does not only automate the artifact creation process but also reduces the feedback cycle of the code providing opportunity to improving quality.
To ensure autonomy and agility in microservices, a better approach is to assign separate source code repository and separate build for each microservice as shown in Figure 6.5. Each repository is mapped to separate build in Continuous Integration server. Any changes in a microservice triggers corresponding build in Continuous Integration server and creates a single artifact for that microservice. An additional advantage of this approach is clear assignment of ownership of the repository and build responsibility to the teams, owning the microservices. [New15] [Fow06a]

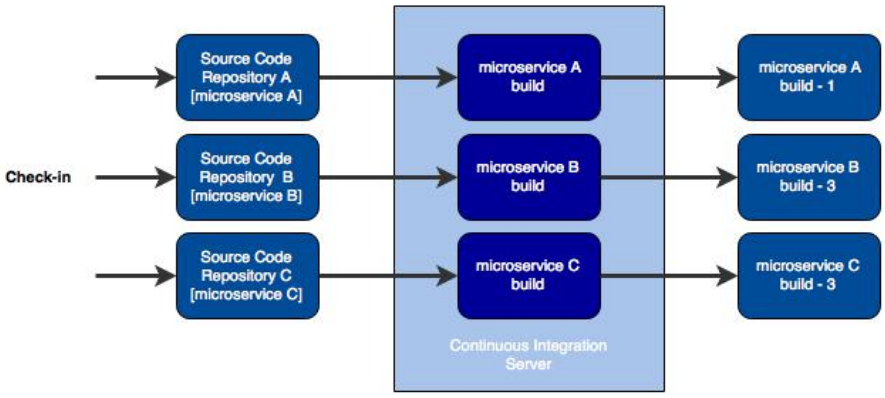


Figure 6.5: Continuous Integration [New15]

2. Continuous Delivery
   It is a discipline in which every small change is verified immediately to check deployability of the application. There are two major concepts associated with continuous delivery. First one is continuous integration of source code and creation of artifact. The artifact is then fed into a build pipeline. A build pipeline is a series of stages, each stage responsible for the verification of certain aspects of the artifact. A successful verification at each stage ensures the readiness of the artifact further close to release.

Figure 6.6: Continuous Delivery Pipeline [New15]

A version of build pipeline is shown in Figure 6.6. Here, faster tests are performed ahead and slow tests, manual testing are performed down the line. This kind of successive verifications make it faster to identify problems, clear visibility of problems and improve the quality as well as confidence in the quality of the application.
Each microservice has an independent build pipeline. The artifact build during continuous integration triggered by any change in the microservices is fed into corresponding build pipeline for the microservice. [New15] [Fow13]

The variation of continuous integration and deployment used at SAP Hybris is already discussed in Section 5.7.

6.5 Conclusion

In this chapter, various challenges needed to handle for assuring benefits from using microservices are listed. Each challenge is further broken down into fine constraints. Then, various ways of handling those constraints are discussed. Finally, the solution in the perspective of SAP Hybris is also presented. Microservices architecture provides efficient way to develop agile software however without a good grasp in the techniques to handle the challenges cannot be a good idea to start with microservice in the first place.

7 Guidelines

7.1 Context

The major objective of the research is to devise some guidelines so that the task of approaching any complex problem domain using microservices becomes easier. On the way to that, a few research questions related to various crucial topics on microservices emerged. The research questions were taken as stepping stones for discovering guidelines. The topics are already covered in previous chapters.
At first, the concept related to granularity of microservices is studied in detail in Chapter 2. In this chapter, the semantic meaning of size along with various dimensions defining granularity are discussed. Finally, various principles to help finding the optimum size for microservices are listed.
Secondly, other quality attributes to be considered when designing good microservices were listed in Chapter 3. The quality metrices to determine each of these quality attributes are also mentioned. The various quality metrices lead to a limited list of basic metrices. Finally, various principles to qualify good services along with the way the quality attributes affect each other are recorded.
Next, the ways to decompose problem domain in order to identify microservices are discussed in Chapter 4, Chapter **??** and Chapter **??**. The methods discussed are using domain driven design and use case refactoring. The steps involved in each method are described along with an example.
Till then answers related to granularity , quality attributes and process of identifying microservices are derived from literature. In Chapter 5 attempt is made to find answeres from industry experience by studying the architecture at Hybris and conducting various interviews. With the knowledge, series of steps are shown to better visualize the process of breaking down problem domain into microservices.
Finally, the challenges which come up while implementing microservices architecture are discussed in Chapter 6. In this chapter, various ways to tackle these problems are described.

7.2 Process to Implement Microservices Architecture

As shown in the Figure 7.1, the implementation of microservices consists of two major parts, understanding each part is crucial in order to follow microservice architecture.

1. **modeling microservices**
   The core of the microservices architecture is problem domain and understanding it. Modeling microservices divides the problem domain into various components considering various internal quality attributes such as coupling, cohesion etc. The knowledge regarding quality attributes acts as an input when choosing the efficient process for identifying microservices from problem domain.

2. **operating the microservices artifacts in production environment**
   The way microservices are designed to satisfy various external quality attributes such as scalability, resilience etc. However, it also introduces critical challenges. It is not entirely possible to get the advantages from microservice architecture unless these challenges are identified and tackled appropriately. In order to achieve that, certain implementation and operational practices of microservices need to be followed.

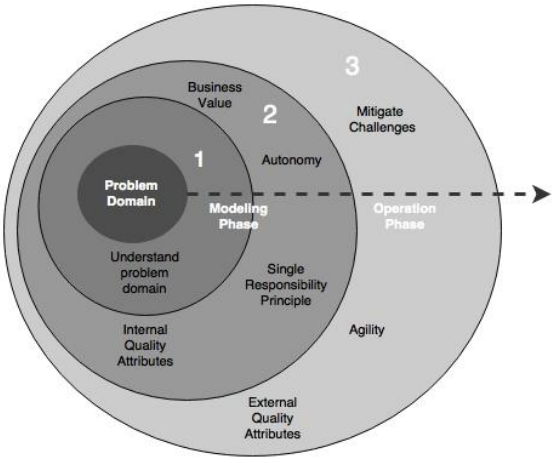


Figure 7.1: Process to microservice architecture

The microservices architecture follows a process which guides from understanding the problem domain, identifying modular components considering various attributes to implementing and operating the components to satisfy various external quality attributes. It is interesting find how process, principles and guidelines are related. A process is based upon some basic principles whereas principles helps to define guidelines based upon some specific requiement and environment. So, in order to understand the process of implementing microservices, it can be helpful to look into some broad basic principles.

7.3 Principles And Guidelines

In this section, based upon the research findings as discussed in previous chapters, various principles are presented in order to tackle modeling microservices as well as operating them in release environment. It is highly recommended to follow these principles when considering microservices.[New15]

1. **Correct Granularity**
   The dimension of granularity for microservice is given by functionality it performs, data it handles and business value it provides. 2.3 These dimensions make it pretty obvious how to make the size of a service as low as possible. However, the notion of correct granularity is rather important and should be only focus instead of attempting to make the size lowest possible.2.2 There are various factors which act together and tailor the size of microservice.
   a) One of the factors is **SRP**, which influence the functionalities and data handled by microservices to make it as small as possible. SRP encourages to focus on small set of cohesive tasks which change for same reason. [Sti14] [New15] The influence of SRP on is also verified by the result of interview which is compiled in Section 5.4.2.
   b) Another important factor is **autonomy**. According to S. Newman, a microservice should be able to be deployed and updated independently. [New15] Without any surprise, autonomy is an important quality attribute of microservice and is evaluated as the degree of control upon operations to act on its business entities only. 3.3.6 As discussed in Section 2.2, a microservice should provide transaction integrity such that it is big enough to support activities which fall under one transaction. So, autonomy tends to limit the scope of functionality and data such that the service is self-contained, self-controlling and can be self-governed.[MLS07]
   c) The act of realizing the size of microservices as small as possible comes with

a price. As the functionality of microservice is squeezed, the number of microservices needed for any application increases. The task of deploying, provisioning and governing these microservices can be challenging. So, as stated in the principles defined in Section 2.3.4, the decision regarding the size of service should be rational based upon the current **infrastructure and operational capability** to handle such large number of small microservices. It is further supported by the response of interview compilation in Section 5.4.2

d) Finally, the size of microservices according to functionality and data should also relate to ultimate **business value** and should be coincide with the business goal. It is evident from the response of interview compiled in Section 5.4.2. Also, business value being an important dimension of granularity of microservice according to Section 2.3, should be examined before choosing the functionality being performed by a service.

So, while deciding about the size of microservice the mentioned factors should be well considered.

2. **Consider quality attributes as early as possible**
The internal quality attributes such as coupling, cohesion, autonomy etc should be controlled as early as possible during modeling and development phases. Taking care of the internal qualities will eventually help to control the external qualities of the microservices in release such as reusability, reliability, resilience etc. The Table 3.8 which identifies various attributes in terms of basic metrices can be helpful. For one thing that the metrices such as scope of opertions, number of operations used in the basic metrices table are completely in disposal of the developers and teams of microservices. Secondly, it helps to identify the relationship among them as shown in Table 3.9 which assists in managing trade offs needed.

3. **Understand the problem domain**
As discussed in chapters , problem domain can be analyzed using either usecase modeling or domain driven design.
Using usecase can break down the problem domain into level of abstractions, each abstraction representing lower scope of functionality. The graphical approach used in usecase can be an effective approach in brainstorming and exploring the problem domain to find new usecases.
Another popular approach is using domain driven design to explore problem domain. The overal process looks natural and straight forward which focus on dividing the complex domain into manageable subdomains and further into modular autonomous components. Furthermore, it gives emphasis on using

ubiquitous language to find modules and define their boundaries. The chapter provides important guidelines as well as hints on ubiquitous language and to find bounded contexts.
Although the graphical approach provided by usecases are wellsuited to experience so can be faster, but they tend to focus only on SRP and scope of functionality. Following the process may likely lose grip on very important quality attribute of microservices which is autonomy.
Domain driven design on the other hand, with its approach of using ubiquitous language focus on autonomy and by dividing the problem domain into smaller manageable components also focus on autonomy. Although the whole proces seems natural, getting the boundary right is complex process. A clear understanding of the problem domain is necessary to get the bounded context right. So, it can be an iterative process starting at bigger boundaries at first and then down to smaller modular boundaries in several iterations.
The knowledge and practice of both usecase modeling and domain driven desing can be helpful. Depending upon the complexity of the problem domain and experience with it, any of them or combination of them can be used to understand the problem domain well.

4. **Culture of Automation**
With such a large number of small services, the task of managing and operating them manually can become impossible. There are three specific areas where automation can serve greatly.

   a) Automated Continuous Delivery can help building and deploying microservices frequently with consistency. Maintaining continuous integration and delivery pipeline can make sure that any new changes is consistent to old system and can be put into release in a matter of few button presses.

   b) Automated Testing is another important area to be serious when there are large number of microservices and again large number of changes in the backlog. Without automated testing in sync with delivery pipeline, it can be hard to have confidence of deploying changes to release environment without breaking existing functionalities.

   c) Infrastructure Automation and provisioning should not be neglected, especially when there can be different technology stack in different microservices and different infrastructure environments. PAAS such as CloudFoundry can be helpful to deployment and provision easily whereas various configuration management tools such as Puppet, chef etc can assist to manage different technology stacks.

5. **Hide Internal Implementation**
   Collaboration among microservices is essential however high coupling by over exposing inter details should be avoided to save autonomy.
   a) The first on the checklist is to model the APIs in right way. Rather than breaking the application into technological aspects, the problem domain should be clearly understood to discover clear boundaries and so should be modeled around business domains. The concept of bounded context can be a way to define clear APIs reducing unnecessary coupling.
   b) The APIs should be technology agnostic, which means that the technology used for collaborating between APIs should not guide the implementation of them. Using REST and some form of RPC can help to mitigate them.
   c) In microservices, database also an integral part of internal implementation. Already mentioned in Section **??**, sharing database will tightly couple microservices as it exposes internal data structure details. In order to mitigate that each microservice should atleast have its own private tables or schema per each service or at most separate database server.
   d) Additionally, in order to maintain loose coupling, the integration technology should be well thought. As already discussed in Section 6.2.2, if business requirement allows, asynchronous communication styles such as publish/-subscribe, notification, request/async response should be chosen over synchronous request/response.

6. **Decentralize**
   Autonomy should not be limited to deployment and updates only. It should be applied in team organization as well. A team should be autonomous enough to own services completely from devloping the microservices, releasing them and maintaining in the production environment all by themselves. In order to achieve that, teams should be trained to become domain-experts in the business areas which are focussed by their services. Additionaly, the architecture of microservices should follow decentralization as well. The business logic should be divided among microservices and should not be concentrated towards any specific god services and integration mechanism. With that point, the microservices should be smart enough to handle collaboration among themselves and the communication mechanism should be dumb as possible such as REST and messaging. Also, choreography should be highly applied whenever possible and orchestration should only be used if the business requirement dictates so.

7. **Deploy Independently**

Microservices should be able to be deployed independently. The Section 6.3.1 already discusses the challenges for that as well as solutions.

a) In order to avoid breaking changes, an integration technology such as REST should be used to decouple microservices and tollerant reader pattern should be used to implement consumers.

b) To find the breaking changes early during development, consumer-driven contracts should be implemented as automated test in the delivery pipeline of services. Additionally, semantic versioning can be used to clearly indicate the level of new changes.

c) When breaking changes cannot be avoided, maintaining co-existing endpoints of different versions or co-existing service versions can provide enough time and opportunity to consumers to be updated gracefully without breaking APIs.

d) Finally, the release and deployment can be decoupled using techniques such as bluegreen deployment 11.5 and canary release 11.6, so that new changes can be tested in production for confidence and can be released later to reduce the risk.

8. **Consumer First**
Microservices are made in order to serve its consumers, so consumers should be the priority when designing them.

a) APIs should be designed considering its consumers. It should be easy to understand, use and extend. The name as well as link should be self intuitive. Additionally, documentation should be provided which should be helpful to follow and use API. In order help with these, there are various tools available such as swagger, RAML etc. The tools not only make it easy to design and document APIs but also enable to try them.[Blo16] [Bla08]

b) Another important concept is to make it easy for consumers to find the microservice itself. There are various service discovery tools such as zookeeper, etcd, consul etc which can be used.

9. **Isolate Failures**
Microservices are build on the top of distributed system and it is not false to say they are not reliable.[Fac14] With the consent regarding amount of microservices and collaboration among them, the system should not be affected until all the microservices fail. The solutions are discussed in Section 6.3.2.

a) Timeout should be implemented realizing the fact that remote calls are

different than local calls and they can be slow. A realistic value of timeout should be chosen based on the use case scenario.

b) In order to avoid leaking failures and affecting the whole system as a result, bulkhead should be used to segregate the resources and a thereshold value should be maintained for each group of resources.

c) For reducing latency, circuit breaker should be implemented which detaches a failed node after certain attempts and reattemts automatically. In this way, it not only removes unnecessary roundtrip time or waiting time but also saves network resource.

d) Finally, fallback mechanism can be used in conjunction with timeouts and circuit breaker to provide alternative mechanism such as serving from cache. It not only isolates failure but also serves the reques.

10. **Highly Observable**
It can be difficult to observice the status of each microservice on each provisioned hosts given the number of microservices. The Section 6.4.1 points out some ideas which can be used to make it easier.

a) Use semantic monitoring to check the current behaviour of services such as availability, response time etc. An example of tools to accomplish that is uptime. Additionally, trigger certain tests to verify important logic of microservice in regular basis. One way to achieve that is to trigger smoke tests automatically.

b) In order to get the overal picture of the whole application at one place, use logs aggregation and visualization tools such as logstash and kibana.

c) Finally, use correlation ids to get a semantic picture of related requests branched out along many downstream microservices.

8 Conclusion

Architecture gives a set of principles to guide the process of decomposing a system into modules. Additionally, it defines interaction amongst the individual modules. Defining architecture is thus an important part in software development. So, irrespective of any architecture, there should be precise guidelines to implement the architecture. Moreover, architecture has evolved a long way from one approach to another.
One of the basic architectural approach is monolithic architecture in which an application is deployed as a single artifact. With this architecture, development, deployment and scaling is simple to some extent. However, as the application gets big and complex, the architecture faces various disadvantages including limited agility, decrease in productivity, longterm commitment to technology stack, limited scalability etc. This is where, a different architectural style 'Microservices' comes into play. In this approach, an application is composed using different independent, autonomous components, each component fulfils a single functionality and can be deployed as well as updated independently. However, there are various concepts related to the definitions of microservices such as collaboration, granularity, mapping of business capability etc that are not clearly communicated. Moreover, there are no proper guidelines how to follow microservices architecture. This is the motivation of the current research. The objective of the research is to clarify various concepts related to microservices and finally create a precise guidelines.
In order to achieve that, various definitions provided by different authors are taken as starting point. A list of keywords and areas are selected from them, which are further investigated during research. Furthermore, quality attributes, constraints and principles are considered the building block of any architecture. So, these areas are also considered for research to create guidelines.
Granularity of microservice is considered as an important concept and is discussed a lot. Granularity is not a one dimensional entity but has three distinct dimensions which are functionality, data and business value. Increase in any of these dimension will increase granularity. Also, it is important to consider the concept of 'Appropriate' granularity rather than 'Minimum' size. Appropriate granularity of any microservice is given by three basic concepts.

1. **Single Responsibility Principle**

2. **Autonomy**, and

3. **Infrastructure capability**

Adding to that, other quality attributes such as coupling, cohesion, autonomy etc are as important as granularity. For that purpose, a list of basic metrices are created to evaluate each quality attributes easily. The quality attributes are not mutually exclusive but affect eachother. The relationship among them is clarified so that it becomes easy to determine the appropriate tradeoffs when necessary.
Another important concept which is not clearly communicated is the identification of microservices and mapping of business capability to microservices. Two different approaches are discussed which are

1. **Using UseCase Refactoring** and

2. **Using Domain Driven Design**

. UseCase Refactoring uses use cases to breakdown a problem domain and refactor them based on various concepts such as similarity in functionality, similarity on entities they act etc. A discrete set of rules for usecase refactoring are also present. On the other hand, domain driven design uses the concept of ubiquitous language and bounded context to break down a problem domain. A detailed step for each phase is also presented. Furthermore, a case study is broken down into microservices using each approach.
Usecase Refactoring is comparatively easier since architects and developers are more familiar with the concept. Domain Driven Design on the other hand is a complex and iterative procedure. Furthermore, Usecase Refactoring considers an entity as a single source of truth for all sub-domains in entire system. Using this approach does not necessarily produce autonomous microservices but focus more on functionality. However, domain driven design using the concept of ubiquitous language and bounded context creates autonomous microservices with single responsibility.
After conducting research along various literature, another important part is determining the process followed in industry for which SAP Hybris is chosen. Firstly, various available documents are studied which suggested goals and principles as being the driving force for the process. In order to understand indepth, interviews are conducted with various key personnels related to YaaS. A major outcome of the interview is that, in addition to factors such as autonomy, infrastructure capability and Single Responsibility Principle, **Business Value** of the microservices plays significant role when identifying microservices and defining the optimum granularity. Finally, the workflow followed during deployment of microservices in SAP Hybris is also studied in order to clarify the operational approach in addition to modeling process.

Understanding constraints is another important driver of architecture. The approach to handle various constraints can be helpful in defining guidelines. Microservices architecture has various advantages such as strong modularity, agility, independent deployment however also presents various challenges for maintaining these advantages. The challenges can be kept into three distinct groups.

1. **Distributed System Complexity**
2. **Integration**, and
3. **Operational Complexity**

Different challenges along each group are discussed. Additionally, the various techniques which can be used to tackle each are listed based on the litereature. Finally, the techniques used in SAP Hybris to handle each challenge are also mentioned.
With all the studies done, the process of microservices architecture can be disected along two phases.

1. **Modeling Phase** and
2. **Operation Phase**

During modeling phase, problem domain is studied, various internal quality attributes along with business value and infrastructure capability are considered. Whereas during operational phase, various challenges are tackled. The effectiveness of modeling phase is visible across various external quality attributes in this phase. Again, principles are major driving factor for creating architectural guidelines. The principles along both modeling and operation phase are listed based on the previous findings of current research. Finally, for each principles, a set of guidelines are presented. The guidelines are one of the major outcomes of the research.

9 Related Work

Microservices is quite new architecture and it is not surprising that there are very few research attempts regarding the overal process of modeling them. Although there are a lot of articles which share the experience of using microservices, only few of them actually share how they achieved the resulting architecture. According to process described in [LTV14], firstly database tables are divided into various business areas and then business functionalities and corresponding tables they act upon, are grouped together as microservices. It may only be used in special cases because an assumption is made that there exist a monolith system which has to be broken down into components as microservices and analysing the codebase is one of the necessary steps followed to relate business function with database tables. Furthermore, it does not provide any clear explanation regarding how to break the data into tables handling autonomy. Also, there is no idea about how different quality attributes will be managed when breaking the monolith into various business areas. Another research paper [Brü+13] also share its process of finding microservices but does not provide enough explanation except that the microservices are mapped from product or features of the system.
The approach applied in the current research, as already defined in section 1.4, takes quality attributes and modeling process into account. It would also be interesting to see the related works on these two topics.
Looking back to component oriented architecture can also be helpful to identify some concepts. The research paper [Lee+01] describes process of using coupling and cohesion to indentify individual components. In the process, a single usecase is mapped to a component such that interaction among the objects inside components is decreased. Althoug the whole process may not be used for services but the idea of usecase can be applied.
[Ma+09] defines an iterative process evaluating portfolio of services around various quality metrices in order get the better quality services. It takes various quality attributes such as cohesion, coupling, size etc into consideration to find out their overal metrics value. The process is iterated until the services are obtained with satisfied values. The consideration of quality attributes and evaluating them is well thought in this process but the process of coming up with the initial set of services from business domain is not well documented. Additionally there are a lot of methodology standards based around SOA to model the services. Some of these methodologies are SOAF, SOMA,

SOAD and others. The paper [RDS16] presents a detail list and comparision of these methodologies. Most of them are not yet implemented in industries and others not compatible with agile practices.

10 Future Directions

The current thesis research is conducted on the basis of various academic as well as industrial researches. It would be interesting if the current research could create opportunities for new researches.
The Table 3.8 listed some basic metrices which can be used to evaluate the quality of microservices. The very first thing which can be done is to find the threshold range that can classify good and bad microservices. A certain number of microservices can be taken as sample from which microservices with high scalability, reusability or other external quality attributes can be filtered out from non performing microservices with low scalability and reusability. Then basic metrices tables can be filled along with their corresponding values for each microservice. These tables can used to find threshold values. The threshold values can be verified further by using them while creating new microservice and checking if their external quality attributes meet the expectations.
Another direction of the research can be finding the priority sequence of quality attributes for microservices. From literature, the quality attributes to focus are coupling, cohesion and autonomy. During the interview conducted with SAP Hybris, the quality attributes such as scalability and reusability were given priority when mapping functionalities to microservices. It can be valuable to research further in literature as well as in other industries regarding the priority of quality attributes they choose to identify microservices.
Furthermore, the basic metrices table can be leveraged to create a graphical tool which representes various microservices as nodes and connections between them as lines between nodes. It would be benefical if various basic metrices can be evaluated only with API definitions internally. Then, the graphical tool can be used to show the various quality attributes using the basic metrices. Depending upon the expected quality, API definition can be changed.
Finally, the report can always be used as a base to conduct research on other similar industries as SAP Hybris. It can be interesting to view the result obtained from the study at various different industries.

11 Appendices

11.1 CAP Theorem

CAP Theorem was published by scientist Eric Brewer and also called as Brewer's Theorem. There are three major requirements for deploying an application in a distributed environment.

1. **Consistency**
   A functionality of a service is accomplished as a whole or not at all. All the nodes accessing any data see the same version at any given time.

2. **Availability**
   The functionalities provided by a service are available and working.

3. **Partition Tolerance**
   The partitions which occurs due to problems in the network does not affect the operations of the system unless the whole network fails.

According to the theorem, as the system scales across a number of nodes and the volume of requests increase, it becomes difficult to achieve all the three qualities but to compromise any one of them. [Bro09] Network partitions cannot be avoided completely due to the very nature of distributed system and so is the quality of partition tolerance has to be maintained. The choice is the trade off between availability and consistency. It is completely dependent upon business requirement which one to choose. [BG13]

11.2 Eventual Consistency

It is a weaker form of consistency which guarantees all read to a data item return the same value eventually, if no additional updates are performend to the same data item. For any update, only the nodes which are viable and reachable at the moment are updated and the remaining nodes are updated when they are back. [BG13]

11.3 Command Query Responsibility Segregation(CQRS)

In this pattern as shown in the figure 11.1, the conceptual model is divided into two separate models, each one for update and read. It refers to creating different object model handled by different logical processes. The database can be shared, where it acts as integration point but can have different database as well.

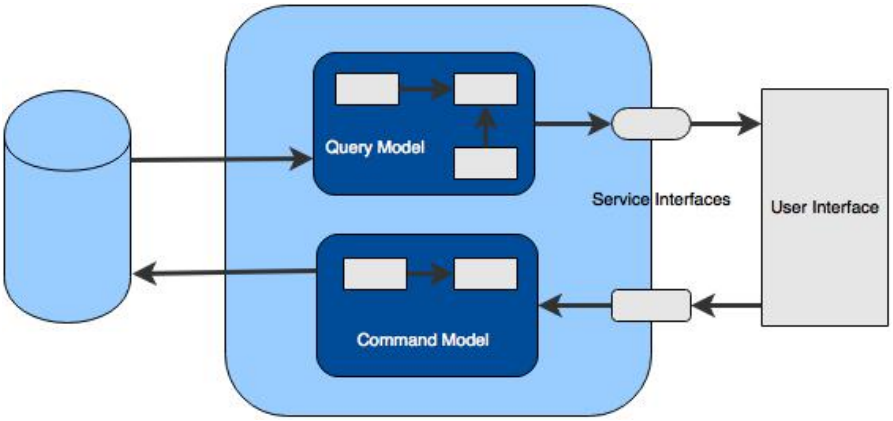


Figure 11.1: CQRS [[Fow11a]]

11.4 Single Responsibility Principle

Responsibility is inferred as a reason to change. According to the principle, a service should have a single reson to change. In order to achieve that, a service should perform functionalities which change for the same reason. [Mar09] [Sti14]

11.5 BlueGreen Deployment

Continuous Delivery focus on rolling out the changes as fast as possible from development to production. However, during the process of releasing there can be subtle amount of downtime or possibility of errors. With the intention to tackle that, bluegreen deployment introduces an approach to create two identical production environments "blue" and "green" with one active at a time "blue". At this time a routing mechanism points all traffic towards "blue" environment. Whenever any change has to be rolled out, it is done in "green" environment. As soon as the environment is fully tested, the routing mechanism points all traffic towards "green" environment. In this way, there

is negligible amount of downtime and in the event of any problem, the traffic can be routed back to old "blue" environment.

11.6 Canary Release

Canary Relase is an approach to minimize the risk of releasing faulty application to all users. Similar to BlueGreen deployment, there are two identical production environments. As one environment is serving live requests, another environment is used to deploy new changes. After the changes are tested properly, the routing mechanism exposes few selected users to the new environment to minimize the risk. As the new system gains confidence, it is rolled out to large group of users and ultimately to all users.

Acronyms

API Application Programming Interface.

AWS Amazon Web Services.

CQRS Command Query Responsibility Segregation.

CRUD create, read, update, delete.

DEP Dependency.

HCP Hana Cloud Platform.

IDE Integrated Development Environment.

IFBS International Financial and Brokerage Services.

ISCI Inter Service Coupling Index.

ODC Operation Data Granularity.

ODG Operation Data Granularity.

OFG Operation Functionality Granularity.

PAAS Platform as a Service.

RCS Relative Coupling of Services.

REST Representational State Transfer.

RIS Relative Importance of Services.

RPC Remote Procedure Call.

SCG Service Capability Granularity.

SDG Service Data Granularity.

SDLC Software Development Life Cycle.

SFCI Service Functional Cohesion Index.

SIDC Service Interface Data Cohesion.

SIUC Service Interface Usage Cohesion.

SIUC Service Sequential Usage Cohesion.

SLC Self Containment.

SMCI Service Message Coupling Index.

SOA Service Oriented Architecture.

SOAD Service Oriented Analysis and Design.

SOAF Service Oriented Architecture Framework.

SOCI Service Operational Coupling Index.

SOG Service Operations Granularity.

SOMA Service Oriented Modeling and Architecture.

SRI Service Reuse Index.

SRP Single Responsibility Principle.

SWIFT Society for Worldwide Interbank Financial Telecommunication.

UML Unified Modeling Language.

YaaS Hybris as a Service.

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