Implementing Consumer-Driven Contract Testing in a DevOps Pipeline

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Implementing Consumer-Driven Contract Testing in a DevOps Pipeline

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# Acknowledgements

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# Abstract

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(no references in the abstract; strictly 250 words so that it works with the online repository)

# Acronyms

|  |  |  |
| --- | --- | --- |
| Acronym | Definition | Page |
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# Introduction

Technology is currently witnessing a dual transition, shifting from monolithic architectures to microservice architectures and from traditional software development life cycle (SDLC) practices to DevOps. The two transitions are interconnected as both DevOps and microservice deployment stresses on continuous integration (CI) and continuous deployment (CD). With this industry shift, it is important to ensure the speed of release cycle as well as a reliable deployment for which correct testing is required. The goal of fast and reliable testing pipelines is to be able to release software often and regularly (Nagel n.d.). One testing method that has emerged as a testing method specifically designed for microservices is consumer-driven contract (CDC) testing. Consumer-Driven Contract testing is a methodology that enables the testing of communication between services in an isolated manner (‘Testing Microservices - Contract Tests’ 2023). In this dissertation, we study how integration of contract test framework into the DevOps pipeline by executing them within containers, maximize the effectiveness of continuous testing (CT) in a distributed system. For this we design a DevOps pipeline, that incorporates multiple microservices and leverages containerization technology orchestration and deployment. This design integrates contract testing frameworks, ensuring that the interactions between microservices are thoroughly validated based on defined contracts.

## Purpose

The purpose of this dissertation stems from the growing adoption of microservice architecture and the need to ensure its successful integration within DevOps pipelines. With the increasing complexity of distributed systems, the speed and reliability of software releases have become critical (Nagel n.d.). Consumer-Driven Contract testing offer a promising solution in this regard (‘Testing Microservices - Contract Tests’ 2023). Containers, as lightweight and isolated environments, offer an ideal solution for managing and deploying microservices (‘DevOps for Microservices - Creating Change Together’ 2021). By incorporating consumer-driven contract tests into the DevOps pipeline and executing them within containers, organizations can effectively validate service contracts and identify compatibility issues early on. This approach enables teams to effectively validate service contracts, detect compatibility issues early on, and improve the overall quality and reliability of distributed software systems. This research aims to provide insights and practical guidance on integrating consumer-driven contract tests to DevOps pipeline leveraging containers to enhance integration testing within DevOps practices.

## Background

DevOps represents a transformative shift in how organizations approach software development, deployment, and maintenance, encompassing the entire software development lifecycle (SDLC) as a more collaborative process (Wickramasinghe 2023). A microservice architecture is a software design approach that involves breaking down an application into a distributed collection of loosely coupled services (Dhaduk 2022). Containers provide a standardized and lightweight method for applications to seamlessly transition between environments, containing everything required to run the application within the container object itself. This includes the code, runtime, system tools, libraries, and dependencies (‘Microservices and Containers 101 - Learn all About Microservices’ 2023). Containers offer an efficient approach for deploying microservices, as they provide a consistent and isolated environment for each individual service (‘The Role of Containers in Your Microservice Architecture’ 2021). By combining a microservices framework with containers, organizations can create a highly scalable and distributed system. This combination enables the establishment of continuous integration/continuous delivery (CI/CD) pipelines for applications, facilitating rapid and seamless development, testing, and deployment processes (‘What Are Containerized Microservices? – DreamFactory Software- Blog’ 2023). Meanwhile, when dealing with microservices, the testing process becomes more complex due to the crucial role of communication within a microservice architecture. Fortunately, there is a solution in the form of consumer-driven contract testing, which addresses the challenges specific to microservices testing. Consumer-Driven Contract testing is an approach used to verify integrations between services, where a crucial aspect is the establishment of a contract between the consumer (an application or service) and the provider (another service) when the consumer utilizes the API provided by the provider. (Lehvä 2019). There are two popular frameworks for the contract test — Spring Cloud Contract (SCC) and PACT that provide a way for contract definition and automate the test process (Fong 2022). A blend of these emerging technologies, including DevOps practices, microservices, containerization, and contract testing can have a significant impact on enabling fast and reliable software product releases (‘DevOps for Microservices - Creating Change Together’ 2021). By leveraging these technologies together, organizations can achieve enhanced scalability and maintainability in their software development and deployment processes. This integrated approach facilitates quicker iterations, smoother collaboration between teams, efficient resource utilization, and robust validation of microservice interactions, ultimately leading to accelerated and more dependable software releases.

## Problem Statement

With the rise of microservice architecture and the increasing emphasis on continuous delivery, there is a demand for ensuring the quality and reliability of software systems (‘How Contract Tests Improve the Quality of Your Distributed Systems’ 2023). However, traditional testing approaches often struggle to keep up with the speed and complexity of microservices.

The problem statement is:

Testing microservice components within a DevOps pipeline, validating the interaction between client and server, lacks a comprehensive approach that goes beyond unit testing. By implementing contract testing framework, consumers can define their expectations through contracts, enabling effective integration testing.

The objective of this dissertation is to effectively implement contract testing framework in DevOps pipeline, enabling organizations to validate service contracts, detect compatibility issues early on, and ensure the smooth and reliable deployment of microservices.

## Research Question

The research question considered in this research is:

How does the integration of contract testing frameworks, within a Container-based DevOps pipeline enhance the validation of microservice interactions?

In order to answer this research question three aims were identified. They are:

1. To explore and evaluate the viability with integration of contract testing frameworks within the designed DevOps pipeline.
2. To explore how validation of microservice interactions within containers can be carried out based on defined contracts
3. To assess the effectiveness and benefits of integrating consumer-driven contract testing within containers in terms of enhancing the quality, speed and reliability of microservice-based systems within the DevOps pipeline.

## Scope and Limitations

Outline what is or is not covered and why. This is just a short paragraph.

## Report Outline

The thesis includes a comprehensive literature review in chapter 2, which examines the relevant research on DevOps Pipeline, Microservices and Consumer-Driven Contract (CDC) Testing. Chapters 3 and 4 focus on the design and implementation of a Container-based DevOps pipeline that incorporates contract testing frameworks. These chapters address the research question that was introduced in chapter 1. Finally, in chapter 6, the thesis concludes by discussing the implemented solution's architecture and suggesting future areas of research and development in this domain.

In some sections of the thesis an image may be required. Any image utilised must be referred to within the main body of text. In Figure 1 the ATU Donegal logo can be seen with an appropriate caption.



Figure 1.1 Atlantic Technological University Donegal Logo

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Where an image does not have a clearly defined border, one should be added. Care should be taken to ensure that all details of images are clearly visible both when in print and when in electronic format. Careful selection of colours should be considered for this purpose. Images as shown in Figure 2 should always be referred to from the main text.



Figure 1.2 ATU Donegal, Letterkenny

All text highlighted in yellow is text that you have written and are ready for me to read.

All text highlighted in grey is text you have written as notes to yourself and is not yet ready for me to read.

All text highlighted in green is something that has been reviewed and needs to be rephrased.

All text that no longer has highlight is deemed good enough for now but will be reviewed again during the last edit.

# Literature Review

In this literature review, the initial research lies on the DevOps pipeline and microservices, with a detailed exploration of key aspects such as build and integration testing, deployment, and containerization. Furthermore, the study investigates how the adoption of microservice architecture facilitates the implementation of a DevOps pipeline. Finally, it examines the emergence of Consumer Driven Contract (CDC) testing and its significance within the context of microservices and CI/CD pipeline. The subsequent focus of this dissertation is to assess the effectiveness of integrating the CDC framework into the DevOps pipeline.

## DevOps Pipeline

DevOps is a set of practices that aim to decrease the time between changing a system and transferring that change to the production environment (Balalaie *et al.* 2016). However, they also insist on maintaining software quality in terms of both code and the delivery mechanism. Any technique that enables these goals is considered a DevOps practice. (Bass *et al.* 2015; Brunnert *et al.* 2015). Similar to agile techniques, DevOps divides programming applications into particularly discreet parts or modules to speed up processing and improve quality. DevOps signs are non-stop practices, including regular shuffling, continuous testing, continuous deployment, and continuous delivery (Amrit *et al.* n.d.).

DevOps focuses on the goals, rather than the means. DevOps practices are intended to reduce the time between committing a change to a system and the change being placed into norm. The longer it takes a release to get to market, the less advantage will accrue from whatever features or quality improvements led to the release. Ideally, we want to release in a continuous manner. This is often termed continuous delivery or continuous deployment.al production, while ensuring high quality (Bass *et al.* 2015).

### 2.1.1. Build and Integration Test

In the realm of DevOps pipeline, testing holds substantial significance in achieving desired results. According to Unit (Agrawal and Rawat 2019), system, acceptance and regression test expertise are the main factors that may further promote continuous integration, continuous delivery and continuous deployment. Continuous testing identifies integration issues much earlier in the life cycle; makes defect resolution cheaper, faster; and frees tester’s precious time for exploratory testing and value-added test activities. (Angara *et al.* 2018). It is a process of testing early, testing often, testing everywhere, and automate (Agrawal and Rawat 2019).

Build is the process of creating an executable artifact from input such as source code and configuration. The goal of building is to create something suitable for deployment.The build and integration tests are performed by a continuous integration (CI) server. The input to this server should be scripts that can be invoked by a single command. This practice ensures that the build is repeatable and traceable. Repeatability is achieved because the scripts can be rerun, and traceability is achieved because the scripts can be examined to determine the origin of the various pieces that were integrated together.

As such, it primarily consists of compiling source code (if you are working with compiled languages) and packaging all files that are required for execution (e.g., the executables from the code, interpretable files like HTML, JavaScript, etc.). Once the build is complete, a set of automated tests are executed that test whether the integration with other parts of the system uncovers any errors. Integration testing is the step in which the built executable artifact is tested (Bass *et al.* 2015). The environment includes connections to external services, such as a surrogate database. Including other services requires mechanisms to distinguish between production and test requests, so that running a test does not trigger any actual transactions, such as production, shipment, or payment. This distinction can be achieved by providing mock services, by using a test version provided by the owner of the service, or—if dealing with test-aware components—by marking test messages as such by using mechanisms built into the protocol used to communicate with that service. If mock versions of services are used, it is good practice to separate the test network from the real services (e.g., by firewall rules) to make absolutely sure no actual requests are sent by running the tests.

One of the challenges in CT is the environment of heterogeneity, which will never reflect actual production environment and application architecture. (Agrawal and Rawat 2019).With teams releasing updates at their own speed, it tends to be trying to plan strong end-to-end testing, particularly when services have dependencies on different services. In addition, running a full creation cluster can be costly, so it's impossible that each team will run its own full cluster at creation scales, only for testing. (Amrit *et al.* n.d.)

Deploying and rolling back microservices in new environments independently without an excessively long-running suite of integration tests. Microservices should be deployed independently of each other, yet changes need to be compatible with other services in the same environment. Integration tests are currently being used to verify this, but as the number of microservices grows this could become a bottleneck. Investigation into concepts such as consumer-driven contracts, maintenance of metadata around test runs, and reliability of specific microservice version combinations is being done, but this is still an outstanding problem.(Bass *et al.* 2015)

Nevertheless, to become part of the actual system, the individual microservices have to interact with each other through synchronous or asynchronous messaging. To validate that these interactions work properly, testing and, in particular, integration testing is essential. Integration testing, besides security- and data storage-related issues, is stated as one of the major challenges in MSA based applications in academic and grey literature [6], [7]. It is the result of the increased complexity caused by the distribution of the system’s functionality across services and the necessary, additional infrastructure for communication. The challenge with integration tests is also rooted in the aim to run the tests in isolation (i.e., without dependent services) while validating the correctness of the interactions with exact these services. Currently, different approaches are used to tackle this discrepancy. (Fischer 2021)

### 2.1.2 Continuous Deployment

Organizations are moving beyond continuous integration to continuous delivery deployment. The reason is dynamic business requirements to respond to the market competition. The goal of the DevOps CI/CD pipeline is to deliver software faster and frequently (Victor 2023). DevOps helps to evolve and produce products at a faster rate with better quality when compared to the products that the old infrastructure management processes and traditional software development applications used to produce (‘10 Best Deployment Tools for DevOps in 2023’ 2023).

For consumer-facing businesses, it is important to discover the market needs, develop necessary features, convert the lines of code into functional features, and make it reach the users as fast as possible. One of the critical aspects of implementing Continuous Deployment is Continuous Testing(Oberoi 2023). A variety of tools exist for managing deployment. The emergence of lightweight containers and image management tools is helping developers to deploy into small-scale production-like environments more easily for testing (Bass et al. 2015). Containers are a method of building, packaging and deploying software (Pahl 2015). A container includes all the code, runtime, libraries and everything else the containerized workload needs to run (‘What is a Container Deployment? | VMware Glossary’ 2023).

## Microservices

A microservices architecture is a cloud-native architecture that aims to realize software systems as a package of small services. Each service is independently deployable on a potentially different platform and technological stack. It can run in its own process while communicating through lightweight mechanisms such as RESTful or RPC-based APIs—for example, Finagle. (REST stands for Representational State Transfer.) (Balalaie *et al.* 2016)

Migrating monolithic architectures to microservices brings in many benefits. In particular, it provides adaptability to technological changes to avoid technology lock-in and, more important, reduced time to-market and better development team structuring around services.3 (Balalaie *et al.* 2016)

Microservices are gaining momentum across industries to facilitate agile delivery mechanisms for service-oriented architecture and to migrate function-oriented legacy architectures toward highly flexible service orientation.

Cloud computing is a rapidly growing paradigm which has evolved from having a monolithic to microservices architecture (Saboor *et al.* 2022). In recent years, cloud platforms are gaining mainstream adoption as the preferred delivery and operating model for modern applications by several companies like Amazon, Microsoft and IBM (Cito *et al.* 2015) (Keni and Kak 2020). An architectural style that has become more relevant in the last years and that allows taking advantage of the benefits obtained with cloud computing is the Microservices Architecture (MSA) (Mazlami *et al.* 2017). The International Data Corporation has forecasted that by 2021, 80 percent of application development on cloud platforms will be with microservices. (Larrucea *et al.* 2018). Cloud based microservices architecture is incorporated by firms such as Netflix, Twitter, eBay, Amazon, Hailo, Groupon, and Zalando. (Saboor *et al.* 2022)

Monolithic Architecture (MA), instead, was the traditional approach to software development, used in the past by large companies like Amazon and Ebay (De Lauretis 2019). In MA, the functions are encapsulated into a single application. Monolith application, if not complicated, have their own strength, for instance, easiness of development, testing and deployment. However, when the application tends to become more complicated, the monolith structure grows in size, becoming a large, hard to manage and scale piece of software (‘From Monolith to Microservices: A Dataflow-Driven Approach | IEEE Conference Publication | IEEE Xplore’ 2023).

Cloud computing is a rapidly growing paradigm which has evolved from having a monolithic to microservices architecture. The importance of cloud data centres has expanded dramatically in the previous decade, and they are now regarded as the backbone of the modern economy.

In MSA-based applications, the system is divided into small, independent microservices (Lewis and Fowler 2023). The individual services are loosely-coupled and communicate through platform-independent interfaces with (Zimmermann 2016). Therefore, the individual microservices can be developed, tested, and deployed independently (Newman 2018) which enables the services to evolve autonomously. The video-streaming platform Netflix was one of the pioneers in migrating its system from a monolithic architecture to MSA. Today Netflix’s platform is an enormous system of hundreds of microservices (*Microservices at Netflix Scale: Principles, Tradeoffs & Lessons Learned • R. Meshenberg • GOTO 2016* 2016). Another example is the technology company Uber which is famous for its ride-sharing service. Uber’s platform is a system of circa 2200 microservices (Gluck 2020).

The autonomy of the individual microservice is one of the key principles of MSA that has to be incorporated in the complete software development life-cycle. Without autonomy, microservices cannot be independently developed and released, and the system loses its flexibility and agility. The autonomy is reflected in the system by the loosely-coupling of the microservices as well as organizational (i.e., independent development teams per microservice). (Fischer 2021)

In a microservices architecture, most testing, packaging, and deployment tasks can be automated for each service. (‘The Role of Containers in Your Microservice Architecture’ 2021). Each service is independently deployable on a potentially different platform and technological stack. It can run in its own process while communicating through lightweight mechanisms such as RESTful or RPC-based APIs—for example, Finagle. (REST stands for Representational State Transfer.) (Balalaie *et al.* 2016)

### 2.1.1. Containerization

For microservices, deployment in the development environment is difficult. Although the application code is now in isolated services, developers must also deploy the dependent services to run the isolated services on their machines. (Balalaie *et al.* 2016). As companies produce further and further microservices, their deployment surroundings are getting increasingly elaborate. Without proper configurations, a microservices road chart could snappily come unmaintainable (Amrit *et al.* n.d.).

Containerization is a concept that broadens and supplements microservices-based models in this regard (Amrit *et al.* n.d.). Containerization is a form of virtualization that attempts to achieve resource isolation with minimal overhead by sharing the kernel with the host OS (Pahl 2015). The Microservice architecture is supported by containers as each microservice can be deployed without interfering with other micro services. Containers provide suitable environment for service deployment in terms of speed, isolation and ease of deployment of new versions(Singh and Singh 2016). Bundling each help as a container picture further diminishes the intricacy while smoothing out the persistent conveyance pipeline. Administrations can go about as completely autonomous substances with every one of the conditions and necessities packaged inside the container. This makes the administration's framework rationalist and reusable while permitting them to interface with some other framework. (Amrit *et al.* n.d.)

The use of containerization allows us to implement many of the desirable features associated with cloud platforms– elasticity, reliability, and ease of management. Microservices can be conveniently packaged into containers that are then deployed onto physical hardware, thus ensuring a consistent software execution environment from the developer to the consumer (Keni and Kak 2020). The use of containerization also allows for inherent scalability and creates a redundancy mechanism for machine failure as container instances can be added and removed on demand. (Keni and Kak 2020)

The goal of building is to create something suitable for deployment. Lightweight containers are a new phenomenon. Like VM images, lightweight containers can contain all libraries and other pieces of software necessary to run the application, while retaining isolation of processes, rights, files, and so forth. The emergence of lightweight containers and image management tools is helping developers to deploy into small-scale production-like environments more easily for testing. (Bass *et al.* 2015)

(C). In a microservices architecture, most testing, packaging, and deployment tasks can be automated for each service. As each service resides in an independent DevOps pipeline, any issues in a single automated task do not affect the other services (‘The Role of Containers in Your Microservice Architecture’ 2021)

### 2.1.2. Testing Microservices

To become part of the actual system, the individual microservices have to interact with each other through synchronous or asynchronous messaging. To validate that these interactions work properly, testing and, in particular, integration testing is essential. Integration testing, besides security- and data storage-related issues, is stated as one of the major challenges in MSA based applications in academic and grey literature (Waseem, Liang, Márquez, *et al.* 2020), (Soldani *et al.* 2018). It is the result of the increased complexity caused by the distribution of the system’s functionality across services and the necessary, additional infrastructure for communication. The challenge with integration tests is also rooted in the aim to run the tests in isolation (i.e., without dependent services) while validating the correctness of the interactions with exact these services. Currently, different approaches are used to tackle this discrepancy. (Fischer 2021)

Deploying and rolling back microservices in new environments independently without an excessively long-running suite of integration tests. Microservices should be deployed independently of each other, yet changes need to be compatible with other services in the same environment. Integration tests are currently being used to verify this, but as the number of microservices grows this could become a bottleneck. Investigation into concepts such as consumer-driven contracts, maintenance of metadata around test runs, and reliability of specific microservice version combinations is being done, but this is still an outstanding problem(Bass *et al.* 2015).

Integration and end-to-end testing with all or most microservices should be done judiciously. It can be expensive to run these tests frequently due to the involvement of a potentially large number of microservices and realistic external resources. A testing practice called Consumer Driven Contract (CDC) can be used to alleviate the problem (Bass *et al.* 2015). This topic serves as the foundation for our dissertation which will be further examined and discussed in the upcoming sections.

## Microservice Architecture Enables DevOps

DevOps is a culture that combines new or improved practices, processes, team structures and responsibilities, and tools to maximize the ability of an organization to deliver applications and services quickly (Mueller, 2018; Sánchez-Gordón and ColomoPalacios, 2018). DevOps acts as a process framework that can be used for developing, deploying, and managing MSA (Larrucea et al., 2018). The coexistence of microservices and DevOps enables reusability, decentralized data governance, automation, and built-in scalability (Balalaie et al., 2016). MSA and DevOps have many common characteristics that make them a perfect fit for each other. For instance, DevOps practices and MSA promote the idea of decomposing large problems into smaller pieces and then address them through small cross-functional teams (Watts, 2020). Containerized microservices can be realized independently because DevOps gives them a favor of continuous integration and deployment. Although it is not compulsory to design software systems based on MSA in DevOps, most of the challenges arisen in DevOps can be resolved by using MSA (Bass et al., 2015).

The structure of microservices arose from the average relevance of DevOps philosophies born in companies such as Amazon, Facebook, Google, Netflix, and SoundCloud. Microservices allow DevOps teams to develop independent features in parallel. Instead of moving code from one specialist to another (for example, from development to testing to production), cross-functional teams build, test, release, monitor, and maintain applications together. (Amrit *et al.* n.d.)

Not only are software vendors (for example, IBM and Microsoft) using microservices and DevOps practices, but also content providers (for example, Netflix and the BBC) have adopted and are using them. In addition, Google Trends reveals that both DevOps and microservices are growing concepts, with an equal rate of growth after 2014 (see Figure 1). Although DevOps can also be applied to monolithic software systems, microservices enable effective implementation of DevOps by promoting the importance of small teams. (Balalaie *et al.* 2016).

Many practitioners and researchers advocate that MSA has a natural progression of embracing DevOps (Gauna, 2018, Humble and Farley, 2010). DevOps brings additional productivity with MSA through using tools chain and a fast feedback mechanism (Stahl et al., 2017).

The DevOps goal of minimizing coordination among various teams can be achieved by using a microservice architectural style where the coordination mechanism, the resource management decisions, and the mapping of architectural elements are all specified by the architecture and hence require minimal inter-team coordination. (Bass *et al.* 2015)

DevOps practices can be applied to monolithic applications, but microservices increase the importance of small groups to enable practical DevOps execution. The microservices structure is a cloud-native structure that creates a product framework that can be a small management package. All of these can be freely deployed in different layers and machine stacks, jogging cycles through lightweight systems. (Balalaie *et al.* 2016)

As found in the literature, it can also be discovered from the interviews that it’s very hard doing DevOps with monoliths and microservices seem to be a part of a solution to allow it. (Jokinen 2020)

Microservices Architecture (MSA) is a cloud-native architectural style, which is inspired by Service-Oriented Architecture (SOA). Typically, microservices are organized as a suite of small granular services that can be implemented (developed, tested, and deployed) on different platforms through multiple technological stacks (Larrucea et al., 2018). Each service of the MSA runs on its own process and communicate with each other through, e.g., RESTful or RPC-based APIs (Balalaie et al., 2016). (D&M)

MSA has become popular in industry because of its benefits, such as availability, flexibility, scalability, loose coupling, and high velocity (Hasselbring and Steinacker, 2017) According to the International Data Corporation (IDC), by the end of 2021, 80% of cloud-based applications will be developed using by MSA (Larrucea et al., 2018). It is also argued that the worldwide DevOps market would grow to $5.6 billion in 2021 (Elliot et al., 2018). Another published report reveals that organizations may adopt MSA for different purposes (Yousif, 2016), for example, to gain agility (82%), to improve organization performance (57%), and scalability (78%). This report also shows that the motivation behind implementing MSA in 47% of organizations was DevOps (LightStep, 2018).

DevOps is a set of practices for developing, testing, and deploying software quickly and reliably by promoting collaboration between the developers, testers, and operators (Yousif, 2016). DevOps practices aim “to decrease the time between changing a system and transforming that change into production environment” (Balalaie et al., 2016). Many practitioners and researchers advocate that MSA has a natural progression of embracing DevOps (Gauna, 2018, Humble and Farley, 2010). DevOps brings additional productivity with MSA through using tools chain and a fast feedback mechanism (Stahl et al., 2017). (D&M)

(Waseem, Liang and Shahin 2020)

Connecting microservices with DevOps will increase software engineering’s impact and benefits.[4]. (Larrucea *et al.* 2018)

In a microservices architecture, most testing, packaging, and deployment tasks can be automated for each service. As each service resides in an independent DevOps pipeline, any issues in a single automated task do not affect the other services. Microservices architecture is tailor-made for DevOps with its services-based approach that allows organizations to break down the application into smaller services. This enables delivery teams to tackle individual services as separate entities—ultimately simplifying the development, testing, and deployment. (This doesn’t mean microservices should be used for every application, however. They do come with certain challenges.) The role microservices plays in DevOps includes streamlining the DevOps process and increasing productivity and quality of the application while moving developments to a flexible architecture. This leads to the development of cloud-native applications that are capable of fulfilling any user demand. (‘The Role of Containers in Your Microservice Architecture’ 2021)

Microservices are suited for agile development because of their independence from each other and their short deployment times. The evolutionary process is helped by having assigned each microservice to a small team. Each microservice can be developed on their own (mostly) without the need to contact big project managers for each and every decision. The mostly autonomous workflow is also helping the short cycle times. Continuous deployment is another important factor. It reduces the overhead of human interaction needed to deploy software. That means that every time a change is made and released a pipeline job will compile the software, run various tests and when this all passes the software will be deployed. (Nagel n.d.)

To be able to deliver microservices fast and reliably the continuous integration (CI) and continuous deployment (CD) pipeline have to be efficient, of good quality and optimized. This way we can ensure the maximum speed of reliable updates. To get the maximum out of the most beneficial aspect of microservices, the fast release cycle, we need to have fast testing. With the introduction of microservices in an architecture the number of interfaces that can be reached is significantly higher. Most, if not all, of the communication between microservices rely on these interfaces. This proves to be a new problem in testing. These interfaces have to be tested reliably and quick. (Nagel n.d.).

Luckily, for every challenge, we have a pattern and, in this case, it’s contract testing. Contract testing is a concept that allows testing communication (both synchronous and asynchronous) between the services in isolation. The main idea behind it is a contract. . (‘Testing Microservices - Contract Tests’ 2023).

## Consumer-Driven Contract Testing

Testing has a prominent role in revealing faults in systems that are based on Microservices-Based Architectures (MSAs). With teams releasing updates at their own speed, it tends to be trying to plan strong end-to-end testing, particularly when services have dependencies on different services. In addition, running a full creation cluster can be costly, so it's impossible that each team will run its own full cluster at creation scales, only for testing. (Amrit *et al.* n.d.). The challenge with integration tests is also rooted in the aim to run the tests in isolation (i.e., without dependent services) while validating the correctness of the interactions with exact these services (Fischer 2021).

A central discussion point in MSAs is the granularity of services, that are often in different levels of abstraction (Newman 2019). Similarly, the granularity of tests in MSAs is reflected in different test types (Vocke 2023). The individuality of microservices (Lewis and Fowler 2023), means that unit tests are part of the software development lifecycle (Newman 2018) , but the broader architectural scope of MSAs includes also other types of tests (e.g., for integration) (Waseem, Liang and Shahin 2020). To become part of the overall system, the interactions of individual microservices need to be validated and thus, integration-level, component-level and system-level testing are also crucial (Waseem, Liang, Márquez, *et al.* 2020). For instance, writing good integration test cases is ranked as the most important skill to sufficiently test microservices (‘Design, monitoring, and testing of microservices systems: The practitioners’ perspective’ 2021). Currently, different approaches are used to tackle this discrepancy. CDC testing is described as a potential addition (‘Testing Strategies in a Microservice Architecture’ 2023) to handle the challenges of integration testing. A substantial number of researches has concluded that CDC testing is the ideal choice for testing microservices (Dai *et al.* 2007; Lehvä *et al.* 2019a; Waseem, Liang, Márquez, *et al.* 2020; Fischer 2021; Ayas *et al.* 2022; Wu *et al.* 2022; Vocke 2023; Nagel n.d.; Nyman n.d.; Selleby n.d.).

Consumer-Driven Contract testing is a way to test integrations between services and ensure that all the integrations are still working after new changes have been introduced to the system (‘Consumer-Driven Contracts: A Service Evolution Pattern’ 2023). The main idea is that when an application or a service (consumer) consumes an API provided by another service (provider), a contract is formed between them (Lehvä *et al.* 2019a). The contract contains information about how the consumer calls the provider and what is being used from the responses. In the contract, the consumer states its expectations to the provider, provider then confirms that it can fulfill these expectations and they become contractual (Fischer 2021; Ayas *et al.* 2022). The contract is accessible to both parties for independent testing. By testing against contracts, the tests verify that a consumer and a provider can integrate and successfully communicate (‘Testing Microservices - Contract Tests’ 2023). However, they do not aim at testing the functionality or business logic of the respective services, just the communication between the services. Changes in the contract have to be communicated between the involved parties (Bass *et al.* 2015; Vocke 2023). CDC tests leave the scope of the individual service as they require the communication and collaboration between the interacting microservices’ teams, but the actual testing can be conducted in isolation. (Fischer 2021). As long as both of the parties obey the contract, they can both use it as a basis to verify their sides of the integration. The consumer can use it to mock the provider in its tests (Lehvä *et al.* 2019b). The provider, on the other hand, can use it to replay the consumer requests against its API.

The book DevOps a software architect’s perspective (Bass *et al.* 2015), states that if CDC is practiced properly, confidence in the microservice can be high without running many end-to-end test cases. CDC serves as a method of coordination and has implications on how user stories of a microservice should be made up and evolve over time. Consumers and microservice developers collectively make up and own the user stories. CDC definition becomes a function of the allocation of functionality to the microservice, is managed by the service owner as a portion of the coordination that defines the next iteration, and, consequently, does not delay the progress of the current iteration.

A case study (Lehvä *et al.* 2019b) of consumer-driven contract (CDC) testing conducted on an industrial system highlighted the benefits of CDC that includes isolated integration testing, improved communication between teams, flexibility for providers to adapt to consumer needs, and effective detection of breaking changes in the API. Additionally, it suggested that CDC tests can replace integration tests as they caught all the defects from the integrations that were implemented in the case study. In that light, it can be safely said that consumer-driven contract testing is a viable addition to testing strategies used to test integration-heavy systems, especially those based on microservices. (CDC). Florian Nagel has stated in his thesis paper Analysis of Consumer-driven contract tests with asynchronous communication between microservices (Nagel n.d.) that CDC testing offers faster execution with reliable results, often detecting errors before end-to-end tests. This allows for fewer end-to-end tests and reduces their intensity and necessity in the testing pipeline. Fast and reliable testing pipelines will be able to release software often and regularly which results in an effective DevOps pipeline.

According to a recent study on testing approaches for CI/CD Pipelines (‘Effective Test Automation Approaches for Modern CI/CD Pipelines’ 2023), the increasing popularity of CI/CD has brought about a significant transformation in the field of software testing. Developers now require fast feedback from pipelines to determine the success of their software updates. In order to adapt to this significant change and ensure the delivery of high-quality automated tests, the study proposes several solutions, one of which involves the use of mocks and stubs whenever feasible. To achieve more dependable test results, as well as gain better control over testing efforts and enhance coverage, the recommended approach is to incorporate mocking into the test framework and rely on stubs to intercept complex data patterns instead of relying solely on external functions. This makes CDC testing frameworks a vital suite for modern CI/CD pipelines. Lastminute.com has recently implemented contract tests to address challenges associated with system-level integration tests, aiming to enhance the feedback cycle and development process. Similarly, eBay is utilizing contract testing to facilitate the safe evolution of their internal APIs and cater to the requirements of client teams. (‘eBay and lastminute.com Adopt Contract Testing to Drive Architecture Evolution’ 2023). Lastminute.com experienced a significant positive impact on their microservice architecture and delivery process by adopting contract tests, resulting in a substantial reduction in test-execution times compared to traditional system-level tests. eBay utilizes contract testing to validate integration points within their platform, facilitating collaborative efforts and ensuring the smooth evolution of internal APIs without compatibility issues.

In this literature survey, we have encountered compelling evidence showcasing the effectiveness of CDC as the optimal testing strategy for microservices. The seamless integration of DevOps and microservices has further reinforced the importance of CDC. Additionally, various studies have highlighted the pressing need for efficient testing frameworks in modern CI/CD DevOps pipelines. In this dissertation paper, our aim is to adopt the CDC testing framework within a DevOps pipeline and investigate the deployment of reliable distributed software with enhanced efficiency.

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Begin with the wider area of interest and quickly move to the narrow field of study. Do not go back to the beginning of the Internet or the first attempts to create a database management system. Consider your audience. Talk about the area rather than individual tools. Provide an analysis of the broad area and focus down to the narrow area under research. When writing chapter 3 there should be a clear link from the broad topic area in chapter 2 to the specific tools selected in chapter 3.

The text of any given chapter may refer to an interesting idea presented in another book, paper, journal or whitepaper. On-line sources should not normally constitute more than 50% of your references. ALL of your references must be peer-reviewed or small percentage of whitepapers. Further details on this will be given in the Research Workshop and may be obtained from your supervisor. This is supported by research (Bloggs, 2022) carried out how best to reference. The idea is succinctly expressed by Murphy:

“A reference in a thesis should be of the previously demonstrated Harvard Style.” (Murphy, 2021a)

Notice that the quote has indentations on both sides and is surrounded by quotes. If the quote abstracts only part of a sentence double dots should be placed before or after to show where there is missing text. Further, where additions for clarification are used in the text square brackets should be used. According to Murphy:

“A reference in a thesis should be of… Harvard Style.” (Murphy, 2021b)

Quotes should be short. Long quotes are not considered acceptable. Neither should there be too many quotes. It is better to provide a critique of what the person has stated.

While the example above is provided for demonstration purposes it is obviously not a good idea to provide the same quote twice so for the purposes of this example, we will assume this quote was taken from a different book by the same author. Further the general use of a single or a small number of sources multiple times is referred to as ‘over-reliance on a source’ and is deemed plagiarism.

## Tables

The text of any chapter may include tabular data. To aid legibility some simple guidelines should be adhered to. Refer to Table 2.1.

Table 2.1. Table Formatting Guidelines

|  |  |
| --- | --- |
| Format | Description |
| Size | The table should be able to fit into one page and should not overrun. |
| Margins | The table should not extend past the normal margins of the page |
| Colour | Colour may be used but consideration should be given to both on screen display and printed display. |
| Design | Simple designs are best. At all times consider that the information in the table is more important than the ‘flashy’ design. |

The title for an image or code must appear directly underneath and on the same page. If this is not possible then move the item within the text to ensure that the caption remains with the item. The title for a table must appear directly above the table.

Refer to Table 2.2 for the second short table sample.

Table 2.2. Short Table Example

|  |  |
| --- | --- |
| Format | Description |
| Size | The table should be able to fit into one page and should not overrun. |

Tables should never run over from one page to another. Move or split the tables as needed. Don’t forget to refer to the table such as Table 2.2, or figure from within the main text.

## Code and Formulae

Where code requires listing within the text it should be treated as an image in that it is sectioned off with a border and has a caption directly underneath. Refer to Code Listing 1.1 below. The full code listing should be included in electronic format through a repository. It should not be included in printed format in the main document. Code listings, tables and images should not run over multiple pages.

…

name: CI

# Run this workflow every time a commit gets pushed to main or a pull request gets opened against main

on:

push:

branches:

- main

pull\_request:

branches:

- main

jobs:

build:

name: Call Azure Pipeline

runs-on: ubuntu-latest

steps:

- name: Azure Pipelines Action

uses: Azure/pipelines@v1

with:

azure-devops-project-url: https://dev.azure.com/organization/project-name

azure-pipeline-name: 'My Pipeline'

Code Listing 2.1 GitHub YAML calling Azure

Notice that only minimal commenting is provided within the text. The code is shown in Cambria, 10 point. This reduces the overall text size and clearly distinguishes it from the main text.

If a single line of formula is required it can be referred to within the text as formula (Equation 1) for example with the formula example shown slightly indented and with the formula number to the far right.

Equation 1

A single line space above and below the formula (Tsiolkovsky, 2000) also aids legibility. Note also that the font size is increased by one point. A further item to note is that equations may also be referenced.

## Chapter Conclusions

Make sure that each chapter has a one paragraph chapter conclusions. Make sure this paragraph somehow relates to the research question. Make sure that the last line in the summary introduces the next chapter by relating it to the last chapter.

# Design Introduction

The design of the system should be presented succinctly. Justification for the selection of the design elements should be considered. The titles of the chapters are only samples. However, it is important that the background to the problem, the review of existing work in the area, design, results and conclusions are all discussed in some format.

The selection of tools and techniques are often best served by providing a high-level diagram early in this chapter. This helps the reader to understand where each element of the system is applied. In particular, it is often helpful to use the broad technology terminology from chapter 2 in this high-level diagram at the beginning of the chapter. At the end of the chapter a similar diagram with the exact technologies chosen can then be presented. This is not a requirement but may be considered helpful.

If the dissertation is focused on analytics rather then technology describe the process including, data ingress, etl, analytics, etc.

## Design Considerations

Describe the frameworks, methods, laws or other considerations prior to describing the system.

## System Context Diagram

Describe the solution very briefly by providing a simplified graphical image of the system. This is a high level diagram used to set the context for the technologies you will talk about. This should not be a UML diagram but something that can be easily understood.

In a cyberpsychology example a method may be shown as a flow chart.

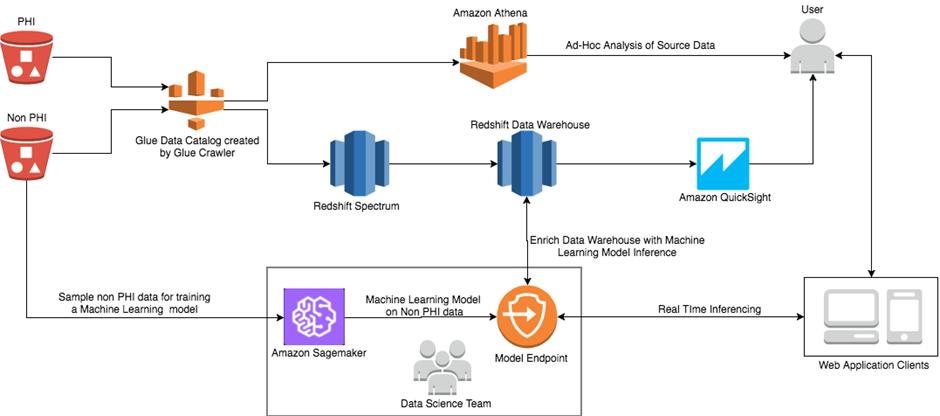


Figure 3.1 Top Level Context/System Diagram

## Specific Technology/Concept 1 (can you use one of your keywords in this title?)

Describe commercial implementations available for the Broad Technology in Chapter 2. This could also be a concept you wish to investigate. Mention the options. Mention how you evaluated them. What was your final choice and why. For example, when speaking of technology this time talk about Docker as an implementation of containers. Do this for each of the technologies, algorithms or concepts selected.

### Commercial Technology/narrow scope Example1

Why is this a good example? How do you evaluate the best? Why did you or did you not pick this technology or concept. How is the scope narrowed by using this example.

### Commercial Technology/narrow scope Example2

Why is this a good example? How do you evaluate the best? Why did you or did you not pick this technology or concept. How is the scope narrowed by using this example.

## Specific Technology/Concept 2

Describe commercial implementations available for the Broad Technology in Chapter 2. This could also be a concept you wish to investigate. Mention the options. Mention how you evaluated them. What was your final choice and why. For example, when speaking of technology this time talk about Docker as an implementation of containers. Do this for each of the technologies, algorithms or concepts selected.

### Commercial Technology/narrow scope Example1

Why is this a good example? How do you evaluate the best? Why did you or did you not pick this technology or concept. How is the scope narrowed by using this example.

### Commercial Technology/narrow scope Example2

Why is this a good example? How do you evaluate the best? Why did you or did you not pick this technology or concept. How is the scope narrowed by using this example.

## Framework or other relevant title

Make sure that the broad areas include the key words mentioned in the research question and in the individual aims.

## Chapter Conclusions

Provide specific conclusions relating back to key words mentioned in the research questions and in the individual aims.

# Implementation

The implementation chapter may describe a case study, interviews, observations, combinations of technologies or code structure depending on the type of dissertation you wish to carry out.

The implementation should be presented succinctly. Clearly define how the system/algorithm/process works in practice showing the most important parts and how they relate to each other. Describe your specific contribution making it clear what is yours and what api’s you used from elsewhere.

Show snips of code/configuration/questionnaire or similar. This may include screengrabs of your implementation if a software or hardware artifact is involved. Relate the implementation elements to the sections described in the literature survey. Be very careful to end each second level heading with a statement showing how the section relates to the research question.

## Some Title with keyword from RQ

Some text.

## Some Title with keyword from RQ

Some text.

## Chapter Conclusions

Provide specific conclusions relating back to key words mentioned in the research questions and in the individual aims.

# Test Strategy, Results and Analysis

Test strategy and how it aligns to the problem statement and hypothesis should be provided. This can be integrated with the results chapter or can be separate. This depends on the type of dissertation. Results can be quantitative or qualitative. Discuss this using appropriate, high level terminology.

Results of tests carried out should be presented. Where extensive testing is carried out the majority of the results should be moved to the appendix. Each graph should include values on the axes and should be appropriately labelled. All graphs/tables must be referred to and explained within the main text. Refer to all graphs in the main text. See Figure 5.1

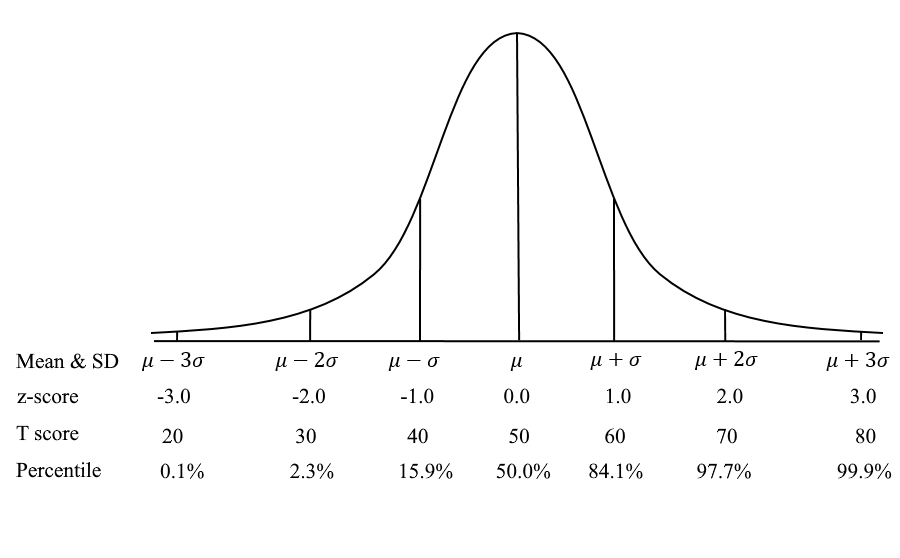


Figure 5.1 A graph showing Z score, t score and percentile information

## Test Strategy

Describe the type of tests that were selected as part of the test strategy. Why are these types of tests considered important?

Remember that these graphs cannot simply be the sum or average of figures obtained. You need to carry out detailed analysis and that takes time.

## Test Type 1 (Name linked to keyword in RQ/Aims)

Describe the type of test carried out. Say why it is an important type of test. What were the inputs and outputs. State how many times the test was run or the confidence factor for the test. State the facts drawn from the tests but do not give an opinion on the importance of the result. Repeat for each test type.

## Test Type 1 (Name linked to keyword in RQ/Aims)

Ensure that there is a dozen or so test types each with appropriate graphs or similar demonstration of practical tests. Include tables, graphs and screen shots as needed. Average is not sufficient as a mechanism to evaluate data.

## Chapter Conclusions

Describe how the test strategy included all appropriate test types as could be covered in the time allowed. Describe general observations on the results.

# Conclusions

Each week write at least one or two lines of notes to yourself as to what you might say in the conclusions chapter. You will forget when you get to the end, so it is really important to write this as you go along.

Conclusions should not introduce new material. The conclusions section should present your final thoughts in an organised manner. Try to organise your conclusions into logical paragraphs where points surround a given topic.

It could be argued that references should not appear in this chapter as that would indicate new material other than your own work. Similarly, it could be argued that images should not appear in the conclusions chapter.

Note that the number of pages in the conclusions should generally balance with the number of pages in the introduction. This is because the introduction is created to introduce the problem whilst the conclusions determine the validity of the hypothesis

## Conclusions on Theoretical Research

Try to organise your thoughts under headings as that will help you focus. Jot down your thoughts as you go along rather than waiting until the end to write the conclusions. You may find that you will forget a lot of the important conclusions if you don’t do this. The last statement on each of these topics should relate directly to the research question.

For example:

Bloggs, et al. showed that…indicating a need for research in this area…link to RQ

Smith, et al. described an experiment where…However, they did not consider…link to RQ

From the survey of existing literature has been found that a gap exists where….Link to RQ

## Conclusions on Practical Research

Focus on your practical element to test our hypothesis here. Focus strongly on why this is new.

### X Discussion (name linked to keyword 1 in RQ/Aim)

Discussion on how the theory from chapter 2 relates to the practical work in the remaining chapters. Show how your work agreed with, disagreed with or extended what was already known.

### X Discussion (name linked to keyword 2 in RQ/Aim)

Discussion on how the theory from chapter 2 relates to the practical work in the remaining chapters. Show how your work agreed with, disagreed with or extended what was already known.

### X Discussion (name linked to keyword 3 in RQ/Aim)

Discussion on how the theory from chapter 2 relates to the practical work in the remaining chapters. Show how your work agreed with, disagreed with or extended what was already known.

### Some other Technology Example Heading

Always relate the theory to the practical element when discussing conclusions.

## Limitations

Very short recap on limitations outlining any new discoveries on limitations. How would limitations be overcome if you had more time. Don’t just list the limits. Keep this very short as you don’t want the work to seem unfinished.

## Chapter Conclusions

Discussion on why this is so good there is some further work to be done. Relate your answer to why this can be applied in other domains. Relate to social/real world examples.

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# Appendices

# Appendix A: Code Listing Location

Some description or essential code snips can go here.

Code for this dissertation can be found in the repository listed below. To ensure that the code is accessible the repo must be a public repo.

<https://github.com/studentlnumber/reponame.git>