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FACULTY OF MATHEMATICS AND COMPUTER
SCIENCE**

SPECIALIZATION Computer Science

DIPLOMA THESIS

Separation of concerns in cross-platform development

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2024

The goal of this thesis is to make an overview of cross-platform development. What is the current state of this software development branch, and more importantly what are the main approaches regarding it.

The relevance of this subject is marked by the evergrowing technological advancements. In the past decade more and more machines and platforms came to life that needed to be interoperable and had to communicate with each other. This became a necessity especially because all of them brought alongside different operating systems.

As a consequence, a lot of development platforms were created. With the increasing relevance for them, more transpositions of the application were needed. It was inconvenient to use an application that is available for only one platform. For the software engineers it meant more code bases that needed maintenance and also a lot more learning.

I will analyze the evolution of software development, what it meant along the decades, from the earliest days, up to the starting point of cross-platform development. This is needed, so we can see the buildup that has been created, turning it into a must-have, rather than a concept. Further on, I'll make a case for the current state of cross-platform development. What are the main features it provides, the legacies it kept from it's predecessors, how it is used today and what are the most important tools used. Then, an analysis over the principle of separating concerns will provide us with the most appreciated features, and see how they align with the needs identified earlier. I will do a breakdown of this principle, see how it has been approached already and why it is a global standard. Afterwards, I will make some regards towards the impact this principle provides, by overlooking some metrics that should provide empirical data, according to the provided examples.

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Chapter 1

Introduction

Cross-platform development is a modern approach to transitive applications. It is a domain that gained popularity along the years, due to constant innovations in the gadget realm, such as the smartphone, the tablet or the game console. Each of these took a different approach on their system design or their operating system, hence creating a multitude of "platforms", all with unique features and perspectives regarding development.

This thesis will have 4 main chapters. In the next chapter, the second one, I will take a look through the history of cross-platfrom development and the principle of separation of concerns. This is a necessary step in order to understand the current state of this domain, and see how separation of concerns can be applied to it.

In the third chapter, I will take a look at the principle of separation of concerns. This is a development principle that has been around for a long time, and it is a key factor in the development of software. A thorough analysis over the positive and negative outcomes that separation of concerns can have will be made. Then I will make a point by point cover over the advantages this principle proposes and see how it aligns with the upgrades that this branch needs. This will be done through analyzing all the conditions that it proposes for a concern to meet in order to be separated.

The fourth chapter will cover the branch of cross-platform development. I will take a look at the current state of this domain, and see how separation of concerns can be applied to it. This will be done through analyzing all the design principles that are actively used and see how they can be separated into different concerns. One key feature of the application of this principle will be design patterns. Yet another aspect that we will take a look at and see the ones used in the proof of concept application. Last but not least, we'll take a look at all the tools that are used in the development of cross-platform applications.

The fifth chapter will cover the implementation of a proof of concept application. This will be a simple application that will be developed using the principles of

separation of concerns. The application will be developed using the tools that are currently used in the development of cross-platform applications. It will follow the principles of separation of concerns, and also the aforementioned design patterns. Positive, negative and neutral outcomes will be analyzed, and the results will be presented.

The final chapter will cover the conclusions of this thesis. I will take a look at the results of the proof of concept application, and see how separation of concerns can be applied to cross-platform development. I will also take a look at the future of cross-platform development, and see how separation of concerns can be used to improve it. Finally, I will present the conclusions of this thesis, and see how separation of concerns can be used to improve cross-platform development.

Chapter 2

History

In this chapter, I will elaborate on the progresses made throughout the decades regarding designing software and the evolution of hardware, and see how we ended up with cross-platform development as a necessity. I will also discuss the first mentions of the term "cross-platform development" and the first toolkits that were created to help developers in this area. Another main aspect of this chapter is the principle of separation of concerns. I'll take a look at the history of this principle and how it was implemented in the early days of software development.

2.1 History of cross-platform development

In 1972, Dennis M. Ritchie and his team created the C programming language. To say it was revolutionary, was an understatement. This project turned Dennis Ritchie into a titan and unforgettable figure of the software world. He was a "bearded, somewhat disheveled computer scientist"[J.22] that stays at the foundation of the things we make most use of today, for exmaple the internet.

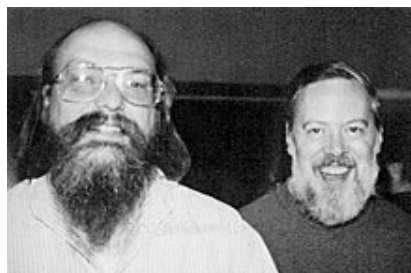


Figure 2.1: Ken Thompson and Dennis Ritchie, 1973

C is a language that derived from BCPL (Basic Combined Programming Language). It became relevant when, yet again, Dennis Ritchie decided to use it in order to re-write the source code of the UNIX operating system. Such and operation was

deemed necessary by him mainly because the U.S government categorized the capitalism of such a product as a violation the "Sherman Antitrust Act"[D.16]. Due to this, AT&T released the Operating System as royalty-free, but later however licenses became a bigger obstruction, hence the limitations in the access of the source code. Then Dennis Ritchie decided to re-write the whole OS in the high-level programming language of C, in 1973. This project, although later forked into many other operating systems such MacOS or GNU/Linux, was maintained and developed up to this day to the FreeBSD project.

A part of the legacy assembly source code of UNIX is still on GitHub, at the repository 'dspinellis/unix-history-make'. During the 80's, software design became

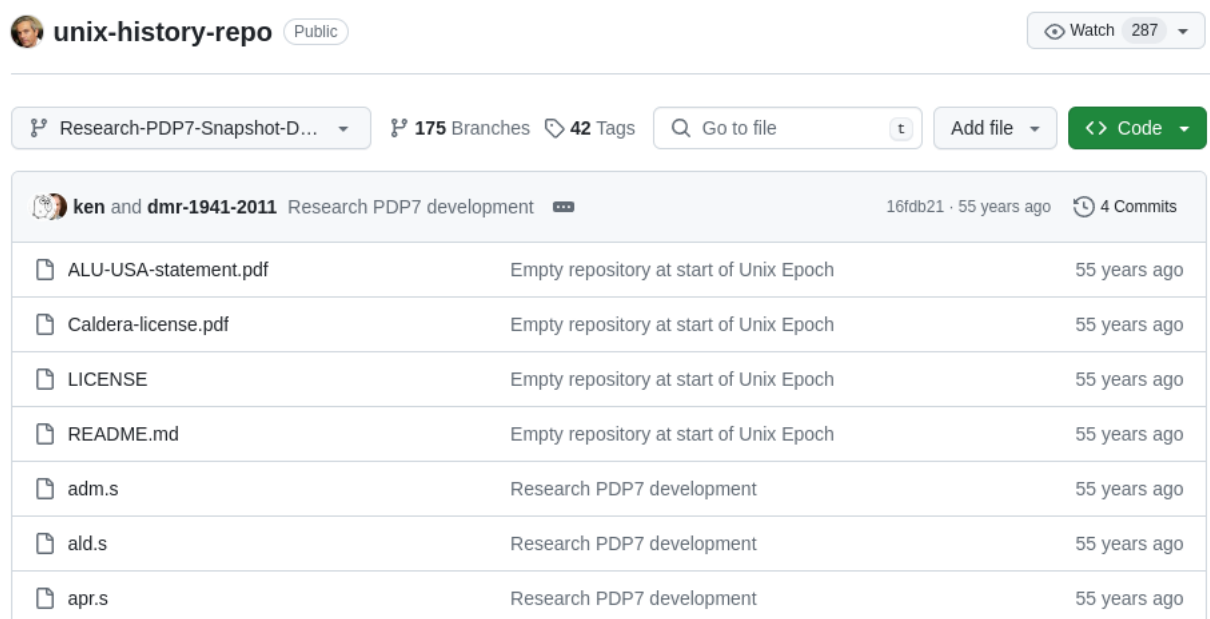


Figure 2.2: Assembly source code of UNIX on GitHub

an area on interest for most people involved in the computer science field. One of the earliest approaches of software design is the Layered architecture. This was firstly introduced as a need because of the way computer networks were operating. Now, files were getting bigger and because of that, "The programmer must maintain descriptions of how various alternative designs are distributed among files"[Bob80].

Along with these software design paradigms, this decade introduced the first implementation of a version control system. It worked quite similarly to the modern approaches. It stored the differentials of the files in a 'delta' file[Bob80]. This file was one of the deterministic factors for which version control and layered architecture were introduced.

As files grew bigger in size, the delta file associated with it was also getting clunkier, thus making reverting or alternating changes a time and memory-consuming task, and by separating the files into smaller ones, each depending on the other one,

this process would be optimized.

This decade brings the most enhancing and used tool of the modern world, the internet. Although it is believed that invented rather earlier, in the late 60's, it is in 1983 when ARPANET and DDN (Defense Data Network) switched to the TCP/IP standard, "so that computers of many kinds could communicate with each other, no matter what kind of network they were connected to in the Internet".[M.88] This was a big leap, as ARPANET was an already enormous cluster of interconnected computers, therefore the computers entering the network would have access to them.

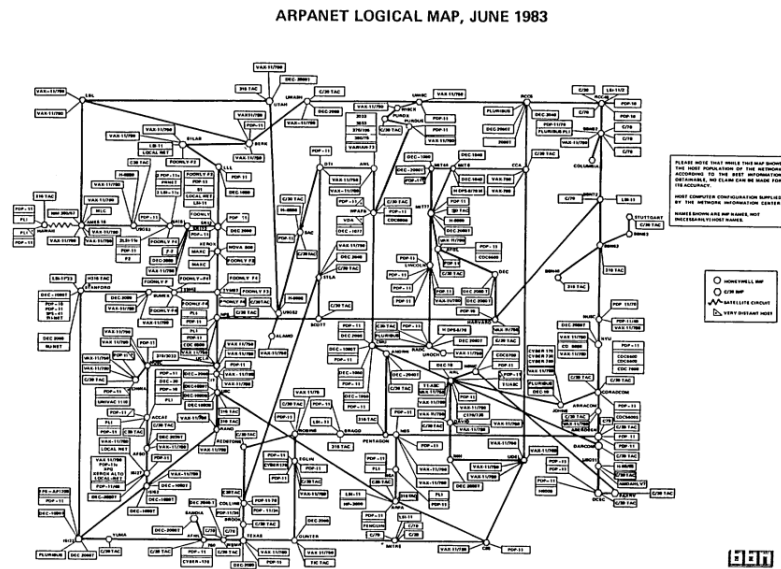


Figure 2.3: ARPANET logical map, 1983

Due to this, a doubling of household computers happened until the 90's. This meant that more people were put on the network, and, due to this, all the computer owners had access to each other's data and information, should they wanted to access it.

Year	Percentage
1980	2.8%
1982	6.2%
1983	7.3%
1984	8.4%
1986	9.5%
1988	12.5%
1989	15.0%

As you can see, the biggest jump in the percentages happened between 1980 and 1982. But, since ARPANET switched their protocols in 1983, the number of

computers in personal households has grown by a staggering 7.7%, a bit more than double.

In 1990, we see the first true creation of cross-platform software. At CERN, Switzerland, Tim Berners-Lee submits two ideas for what should be the Web, back in March 1989. Until the Christmas of 1990, he contoured the World Wide Web, making the first prototype for it. The intention of this project was to be “a pool of human knowledge”, thus allowing for ease of communication between people who were geologically disjointed[A.94].

This project offered features that are still generally available today, such as a server, HTML, the first web programming language, URL’s and the first browser.

2.1.1 First definition

Now, during this decade we can see some of the first mentions of the term “cross-platform development”. That is due to the fact that more and more “platforms” (example: Windows, MacOS) started rising and gaining popularity, and certain large applications needed to behave and act accordingly on all of them. I will refer to “platform” from now on as development environments, for example Android meaning not only the mobile phone operating system, but also the ecosystem surrounding it, such as smartwatches or TV’s.

Some of the first people that proposed this terminology were Bishop J. and Horspool N., who also gave the first definition to this development branch. They described the product of it as “software that exists in different versions so that it is available on more than one platform”[N.06], all the way back in 2006. In this definition, their meaning of platform is the same as the one I mentioned earlier, because back then the definition was a bit more general, such as “language, operating system, computer, or some combination”. In the same time-period, the Web was starting a world-conquering journey. Along with it, it brought a whole toolkit of development principles and design patterns, with component-based development being the most praised one. This is also mentioned and observed by the aforementioned authors, whom agree that component-based development has made a good impact toward satisfying “both parts of the definition.”[N.06]

2.1.2 First toolkits

The idea of cross-platform development was initially brought as a fix for one of the bigger issues developers faced at the time, and that is building graphical user interfaces (GUI’s). This in itself represented a dilemma because for every platform there were dedicated tools and specific programming languages, for example for Windows there was exclusively .NET with the C# programming language. This

inherently meant that there was no uniform way of developing such GUI's across platforms. There is also acknowledgement in this, starting with the earliest days. Due to such history, there came the stigma that cross-platform toolkits are "integral to GUI development"[N.06].

Because of this, we can also observe the rise in popularity of some toolkits that were not very seriously taken considered before this realization, such as Qt or GTK+. These are some of the first cross-platform frameworks that are still used today at a production level, and we can see them used in many well-known applications, such as Spotify for Qt, or the GNOME desktop environment for GTK+. They are trying to achieve different goals, but one thing that they have in common is that both Qt and GTK+ define a collection of widgets that should work as "platform independent"[N.06]. This then allowed for the developers to apply a "learn once, code everywhere" approach.

2.2 History of the principle of separation of concerns

The principle of separation of concerns has roots that extend back several decades, and it has been discussed and applied in various forms across different disciplines, including software engineering, information architecture, and systems design. While it's challenging to pinpoint an exact date or origin for this principle, we can explore some key moments in its history, the ones that got it started as a founding principle in software design. First we'll take a look at the structured programming era, this taking place during the 1960's-1970's timeframe.

During the structured programming era, pioneers such as Edsger W. Dijkstra and Niklaus Wirth advocated for modular programming techniques that emphasized separation of concerns to improve code clarity and maintainability. Dijkstra was the first to indirectly point towards this approach, because he argued against the unstructured use of goto statements and advocated for structured programming techniques, which inherently promote separation of concerns. He emphasized the importance of clear control flow and modular design in creating understandable and maintainable code. He believed that a so called "coordinate system"[Dji68] can be used to describe the code in a "helpful and manageable"[Dji68] manner.

Chapter 3

Separation of concerns

Now that we got to understand the origins of cross-platform development, I believe it's time for a move that's just as important for the thesis. During this chapter, I'll take a step towards a different direction. I'll take a look at the definitions, because there will be multiple, history, use cases, advantages and disadvantages of the principle of separating concerns. We'll compare and analyze the views regarding this topic, see where it originated (or all the places of its origins), check out what caused it to come into existence, and then do a thorough analysis regarding the benefits it provides, and the disadvantages they bring.

3.1 Rise in popularity

The adoption of the principle of separation of concerns gained significant momentum during the late 20th century and continued into the early 21st century. While it's challenging to pinpoint an exact time period for its increased adoption, we can identify key phases when the concept became more widely recognized and discussed:

During the emergence of object-oriented programming (OOP) in the late 1970s and 1980s, the principles of modularity and separation of concerns gained prominence. Languages like Smalltalk and Simula popularized OOP concepts such as encapsulation, inheritance, and polymorphism, which inherently promote the separation of concerns. This period laid the groundwork for the widespread adoption of modular design principles.

The 1990s saw a proliferation of publications and discussions on software design principles, design patterns, and best practices. Influential works such as "Design Patterns: Elements of Reusable Object-Oriented Software" by the Gang of Four (Erich Gamma, Richard Helm, Ralph Johnson, John Vlissides) were published in 1994. This book cataloged common design patterns, many of which emphasize separation of concerns. The 1990s also witnessed the rise of agile methodologies and

the growing importance of modular design in software development.

In the early 2000s, there was a continued focus on modular design principles, particularly within the context of domain-driven design (DDD) and agile software development. Eric Evans' book "Domain-Driven Design: Tackling Complexity in the Heart of Software" (2003) emphasized the importance of separating concerns within a software system to improve maintainability and alignment with business requirements. This period saw an increasing recognition of separation of concerns as a fundamental principle in software architecture.

From the mid-2000s to the present day, separation of concerns has remained a central tenet of software engineering practices. The advent of microservices architectures, cloud computing, and DevOps practices further underscored the importance of modular design and loose coupling. Additionally, the proliferation of open-source software projects and collaboration platforms facilitated the exchange of knowledge and best practices related to separation of concerns.

Overall, while separation of concerns has been a guiding principle in software engineering for several decades, its adoption and recognition as a fundamental design principle gained momentum during the late 20th century and continue to shape software development practices today. The most significant publications about separation of concerns were written during the 1990s and early 2000s, coinciding with the emergence of object-oriented programming and the proliferation of design patterns and agile methodologies.

3.2 Definition

Separation of concerns is a design principle in software engineering where different parts of a system are divided to handle different responsibilities. This makes the system easier to understand, maintain, and modify because each part focuses on a specific aspect of functionality, rather than trying to handle everything at once. It is a fundamental principle in software architecture that promotes modularity, maintainability, and scalability, or, as Harold Ossher and Peri Tarr put it, it's something that stands at the "core of software engineering" [Tar03].

Now we'll take an in-depth look at the founding ideas that are holding this principle high in its regard. These are: modularity, flexibility and reusability, testing and scalability. We'll take each of them apart and see what they can provide for us.

3.2.1 Modularity

Separation of concerns promotes modularity, where a system is divided into smaller, independent modules. Each module encapsulates a specific aspect of functionality.

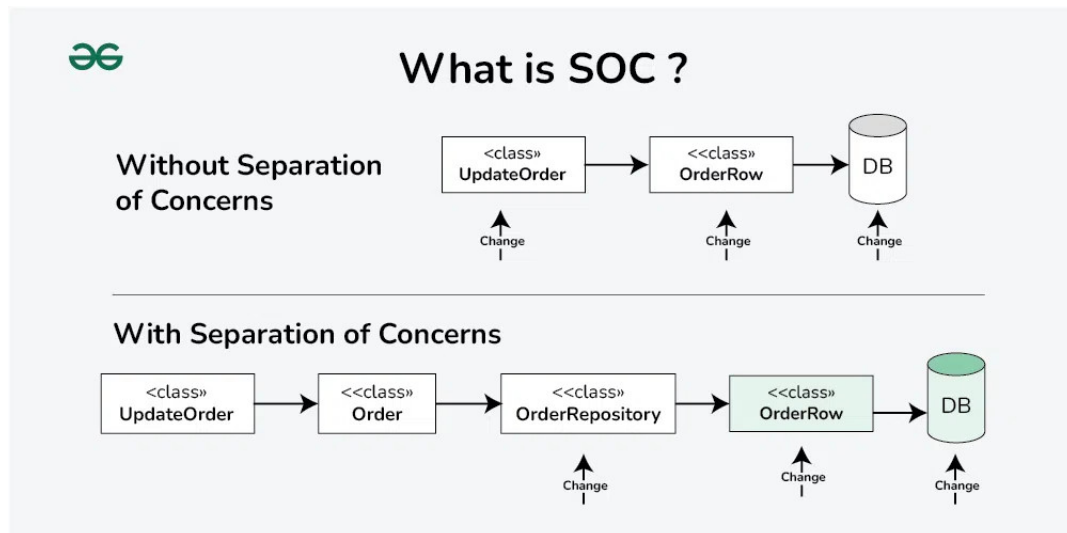


Figure 3.1: Separation of concerns definition example, source: GeekForGeeks

For example, in an application that requires extensive security, advanced separation of concerns allows for building mechanisms that "can be merged into the system in a flexible way" [Ver02].

Modularity encourages encapsulation, which involves bundling related functionality and data into cohesive units called modules. Each module represents a self-contained unit of code that hides its internal implementation details from the rest of the system. This encapsulation fosters information hiding, reducing dependencies between modules and promoting loose coupling.

Modular design emphasizes defining clear and well-defined interfaces for communication between modules. These interfaces specify how modules interact with each other, providing a contract that ensures consistent behavior and interoperability. By adhering to these interfaces, developers can swap out implementations or extend functionality without affecting other parts of the system, as long as the interface remains unchanged.

Modularity allows for varying levels of granularity in module design. Modules can be large or small, depending on the complexity and scope of the functionality they encapsulate. Decomposing a system into smaller, more manageable modules facilitates better organization and promotes code reuse. However, it's essential to strike a balance between granularity and cohesion to avoid overly fragmented or tightly coupled modules.

Overall, modularity is a key aspect of the separation of concerns principle that promotes the organization, maintainability, and extensibility of software systems. By breaking down a system into modular components with clear interfaces and well-defined responsibilities, developers can create more flexible, scalable, and reusable codebases.

3.2.2 Readability and Maintainability

By separating concerns, the code becomes easier to read and understand. This is important, because it was proven by Raymond P. L. Buse and Westley R. Weimer that “low readability correlates more strongly with this direct notion of defect density” [Wei10]. Developers can focus on one aspect of the system at a time, making it easier to debug, maintain, and modify without affecting other parts of the system. This also facilitates collaboration among team members, as each person can work on different modules independently.

Separation of concerns promotes clear code organization by dividing a system into distinct modules, each responsible for a specific aspect of functionality. This modular structure makes it easier for developers to locate and understand relevant code when working on a particular feature or fixing a bug. Clear organization reduces cognitive overload and helps developers navigate the codebase more efficiently, improving readability.

By isolating concerns into separate modules, separation of concerns reduces the complexity of individual components. Each module focuses on a specific task or responsibility, which makes the code more concise and easier to comprehend. Developers can reason about each module in isolation, without having to consider the entire system’s complexity at once, leading to improved readability.

Separation of concerns aligns with the Single Responsibility Principle (SRP), which states that a module or class should have only one reason to change. By adhering to SRP, modules become more focused and maintainable, as they are less likely to be affected by changes unrelated to their primary responsibility. This principle enhances readability by promoting a clear understanding of each module’s purpose and minimizing code churn during maintenance.

Separation of concerns facilitates modular testing, where each module can be tested independently of the rest of the system. This modular approach to testing improves maintainability by allowing developers to identify and fix bugs more efficiently. Unit tests can be written for each module to verify its behavior in isolation, making it easier to pinpoint and resolve issues without disrupting other components.

To sum it up, separation of concerns enhances readability and maintainability by promoting clear code organization, reducing complexity, adhering to the Single Responsibility Principle, isolating changes, facilitating modular testing, and encapsulating complexity. By breaking a system into modular components with well-defined responsibilities, developers can create codebases that are easier to understand, modify, and maintain over time.

3.2.3 Flexibility and Reusability

Separating concerns allows for greater flexibility and reusability of code. We need to understand that flexibility is a key aspect of software design, as it allows for adapting to changing requirements and environments. Through separation of concerns, we can ensure that we have solid base for reusability, because, as Jones T.C. mentioned, "effective reuse will require an architectural starting point" [Jon84]. Since each module is designed to handle a specific responsibility, it can be reused in different parts of the system or even in other projects altogether. For example, a module responsible for database access can be reused in multiple parts of an application without modification.

Separation of concerns enables a flexible system architecture by allowing each module to focus on a specific aspect of functionality. This modular approach means that individual modules can be modified, replaced, or extended without affecting other parts of the system. For example, if you need to change the data storage mechanism in your application, you can modify the database module without altering the modules responsible for business logic or user interface presentation.

Modular design facilitates the creation of plug-and-play components that can be easily integrated into different systems or projects. By encapsulating functionality within self-contained modules, developers can reuse these components across various applications without modification. This promotes code reuse, accelerates development, and ensures consistency across projects.

Separation of concerns encourages the creation of a library of reusable modules that can be leveraged across different projects. These modules encapsulate common functionality, such as authentication, data validation, or file handling, making them readily available for use in new projects. By building a library of reusable components, developers can reduce development time, minimize duplication of effort, and maintain consistency in software architectures.

Separation of concerns facilitates integration with third-party libraries, frameworks, or services. By encapsulating integration logic within modular components, developers can easily swap out implementations or upgrade dependencies without affecting the rest of the system. This interoperability enables software systems to leverage external resources and functionalities, enhancing their capabilities and reducing development effort.

When concerns are separated, changes and updates can be isolated to specific modules without affecting the rest of the system. This isolation minimizes the risk of unintended consequences and makes it easier to test and validate modifications. Developers can confidently refactor or extend individual modules knowing that they won't inadvertently impact other parts of the codebase, which enhances maintain-

ability.

Separation of concerns facilitates modular testing, where each module can be tested independently of the rest of the system. This modular approach to testing improves maintainability by allowing developers to identify and fix bugs more efficiently. Unit tests can be written for each module to verify its behavior in isolation, making it easier to pinpoint and resolve issues without disrupting other components.

Modular design encapsulates complexity within well-defined boundaries, making the codebase more maintainable. By hiding implementation details behind module interfaces, developers can interact with modules at a higher level of abstraction, reducing cognitive overhead. This encapsulation shields developers from unnecessary complexity, enabling them to focus on understanding and maintaining one concern at a time, which enhances readability and maintainability.

In summary, separation of concerns fosters flexibility and reusability by enabling modular, self-contained components that can be easily integrated, customized, extended, and reused across different projects and contexts. This promotes agility, reduces development time, and facilitates the creation of scalable and adaptable software systems.

3.2.4 Testing

When concerns are separated, it becomes easier to test individual modules in isolation. This allows for more targeted and comprehensive testing, as each module can be tested independently of the rest of the system. Additionally, modular code is often easier to mock or stub, which is useful for unit testing. Testing is a need that should be more enforced, because "software bugs will almost always exist" [Pan99].

Separation of concerns facilitates modular testing, where each module can be tested independently of the rest of the system. This modular approach allows developers to write focused unit tests for individual modules, verifying their behavior in isolation. By decoupling modules from their dependencies, such as external services or databases, developers can easily mock or stub these dependencies to create controlled test environments.

When concerns are separated, testing becomes more focused and targeted. Each module encapsulates a specific aspect of functionality, making it easier to identify and test individual behaviors. By isolating concerns, developers can write tests that validate the correctness of each module's behavior without having to consider the interactions with other parts of the system. This isolation simplifies testing and reduces the scope of potential failures, improving test coverage and reliability.

Separation of concerns promotes clear test scenarios by defining well-defined

boundaries between modules. Each module has a clear interface and defined inputs and outputs, making it easier to identify test cases and expected outcomes. Developers can write tests that cover various scenarios and edge cases for each module, ensuring comprehensive test coverage and robustness.

Modular design enables parallel testing, where multiple modules can be tested concurrently. Since each module operates independently of the others, developers can run tests for different modules simultaneously, reducing overall test execution time. This parallel testing approach accelerates the feedback loop and improves the efficiency of the testing process, enabling faster iteration and delivery of software updates.

Separation of concerns enhances test maintainability by minimizing the impact of changes on test suites. When concerns are isolated into separate modules, modifications to one module are less likely to affect the tests for other modules. This decoupling between modules and tests reduces the need for extensive test refactoring when making changes to the codebase, ensuring that tests remain valid and reliable over time.

While separation of concerns primarily facilitates unit testing, it also supports integration testing by providing clear interfaces between modules. Integration tests validate the interactions and collaborations between modules to ensure that they work together correctly as a cohesive system. By testing integration points and boundary conditions, developers can identify and resolve integration issues early in the development lifecycle, improving overall system reliability.

3.2.5 Scalability

Separating concerns also facilitates scalability. As the system grows and evolves, new functionality can be added. Existing functionality can be modified without affecting other parts of the system. This makes it easier to scale the system both horizontally (by adding more instances of existing modules) and vertically (by adding new modules). It also refers to the performance of an existing system, as "performance and scalability are about the scalable performance of the system" [Liu09]. Let's take a more in-depth look at how it influences scalability.

By dividing a system into independent modules, each responsible for a specific concern, it becomes easier to manage and scale individual components. For example, in a web application, the user interface, business logic, and data storage can be separated into distinct modules. This isolation allows each part to be scaled independently based on demand. Modules can be scaled according to their specific load requirements. For instance, if the data storage module experiences heavy read/write operations, it can be scaled up by adding more database instances or

using a distributed database system, without affecting the business logic or user interface modules.

Separation of concerns allows for distributing the load across different modules running on separate servers or instances. For example, microservices architecture, which heavily relies on SoC, enables distributing microservices across different nodes. This distribution helps balance the load effectively, preventing any single component from becoming a bottleneck. Components can be replicated across multiple servers to handle increased traffic. For instance, multiple instances of a stateless service (e.g., an authentication service) can be run behind a load balancer to handle a larger number of requests concurrently.

By isolating concerns, resources such as CPU, memory, and storage can be allocated more efficiently. Each module can be optimized for its specific workload. For example, a caching module can be allocated more memory, while a computation-intensive module can be allocated more CPU resources. Cloud platforms provide features like auto-scaling, where resources are automatically added or removed based on current demand. SoC makes it easier to apply elastic scaling to individual components, ensuring that resources are used efficiently and costs are controlled.

Separation of concerns allows for optimizing the performance of individual modules without affecting the entire system. For example, performance-critical modules such as a real-time analytics engine can be highly optimized for speed and efficiency, while less critical modules can be optimized for maintainability or other factors. Separation of concerns facilitates the implementation of asynchronous processing. For example, background tasks like data processing or logging can be handled by separate modules running asynchronously, reducing the load on the main application and improving overall responsiveness.

When concerns are separated, updating or upgrading individual modules becomes simpler. New features or improvements can be added to specific modules without disrupting the entire system, making it easier to evolve and scale the system over time. Separation of concerns allows for incremental scalability, where new modules can be added to handle additional concerns as needed. This approach ensures that the system can grow organically, adapting to new requirements and scaling efficiently.

By isolating concerns, failures in one module are less likely to affect other parts of the system. For example, if the payment processing module in an e-commerce application fails, it doesn't impact the product catalog or user authentication modules. This isolation improves the overall resilience and scalability of the system. In the event of partial system failures, separation of concerns allows for graceful degradation. Non-critical modules can fail or scale down without taking down the entire system, ensuring that critical services remain operational and scalable.

In summary, separation of concerns enhances scalability by enabling modular architecture, efficient resource allocation, targeted performance optimization, easier maintainability and extensibility, and improved fault isolation and recovery. By organizing a system into distinct, manageable components, this design principle allows for focused scaling efforts, better resource utilization, and a more resilient and adaptable architecture.

3.3 Challenges

While the benefits of separating concerns are well-documented, the paradigm also introduces several challenges that developers and architects must navigate to realize its full potential. These challenges span various aspects of software development, including design complexity, increased component management, inter-module communication, dependency management, integration testing, configuration management, and team coordination. Understanding these challenges is crucial for effectively applying the principle and leveraging its advantages without succumbing to the pitfalls that can arise from increased system complexity. Now we'll take a look at the mentioned challenges and analyze them.

3.3.1 Complexity

From a design perspective, separating concerns often requires designing a system with multiple modules, each responsible for a specific aspect of the functionality. This aspect is one of the hardest to quantify, because "the base of every evaluation of the complexity of a program is an idea" [Zus98]. Taken this into consideration, we'll enforce the following definition of complexity: modular design can be complex because it involves defining clear boundaries and interfaces between modules. Ensuring that each module interacts correctly and efficiently with others can be challenging, particularly in large systems with many interdependencies. Deciding how to partition a system into separate concerns can be non-trivial. It requires a deep understanding of the domain, potential changes, and future scalability requirements. Poorly defined boundaries can lead to tight coupling between modules, defeating the purpose of SoC.

As concerns are separated, the number of components in the system increases. Managing these components, keeping track of their versions, and ensuring they are correctly integrated into the overall system can add significant complexity. Each component may have its own lifecycle, dependencies, and configuration requirements. Deploying a system composed of many separate components can be more complex than deploying a monolithic system. Each component might need to be

deployed independently, and the interactions between them must be carefully managed to ensure the system functions correctly as a whole.

When enforcing the principle, different concerns are handled by different modules, which need to communicate effectively. Managing this communication can be complex, especially when different modules are developed by different teams or even at different times. Choosing the right communication protocols and ensuring data consistency across modules are critical challenges. In a distributed system, maintaining synchronization between different modules can be difficult. Issues like data consistency, latency, and failure handling become more prominent as the number of communicating modules increases.

While it aims to reduce dependencies between modules, some level of interdependency is inevitable. Managing these dependencies and ensuring that changes in one module do not adversely affect others can be complex. Dependency injection and service discovery mechanisms can help but add another layer of complexity to the system. Keeping track of different versions of modules and ensuring compatibility between them can be challenging. This is particularly true in environments where modules are developed and released independently. In summary, to address complexity issues, we need to keep in mind an overhead of design and architectural challenges, managing an increased number of components, ensuring effective communication and synchronization between modules, handling dependencies and versioning, and managing configurations. Addressing these challenges requires careful planning, robust tooling, and effective communication among development teams.

3.3.2 Performance

When a system is divided into separate modules, these modules often need to communicate with each other. This communication, whether it's through function calls, message passing, or network requests, introduces latency. For instance, in a microservices architecture, each service call over the network adds a delay, which can accumulate and degrade overall system performance. Data exchanged between modules often needs to be serialized and deserialized, especially in distributed systems. This process can be computationally expensive and add to the latency, particularly when dealing with large volumes of data or complex data structures.

In systems where concurrency is heavily used, such as those employing multiple threads or asynchronous processing, the operating system may need to perform frequent context switches. This switching incurs overhead, as the CPU must save and restore the state of threads or processes, potentially leading to reduced performance. Separate modules may require their own resources, such as memory and CPU cycles. Inefficient use of these resources across modules can lead to increased

computational overhead. For example, if each module maintains its own data cache, it can lead to duplicated data and higher memory usage.

In distributed systems where modules communicate over a network, the amount of data transferred between modules can become significant. High network traffic can saturate the network bandwidth, reducing throughput and affecting the performance of other network-dependent operations. If a particular module becomes a communication bottleneck, it can slow down the entire system. For instance, a centralized database or a service handling authentication might become a performance bottleneck if it cannot handle the volume of requests efficiently.

Optimizing the performance of a system with separated concerns requires comprehensive profiling and monitoring across all modules. This can be complex and resource-intensive. Identifying performance bottlenecks necessitates detailed insights into the interactions and performance metrics of each module. Performance optimization often requires coordinated changes across multiple modules. For instance, optimizing a data processing pipeline might involve adjustments in both the data ingestion module and the processing module. Ensuring that these optimizations are harmonized can be challenging.

In summary, performance challenges need careful management, and by understanding and addressing these challenges, developers can create systems that leverage the advantages of separating concerns without compromising on performance.

3.3.3 Learning curve

Applying the principle in software development introduces a learning curve that can be challenging for developers, particularly those new to the paradigm or working within complex systems. Now, let's do an in-depth analysis at the specific learning curve challenges.

Separation of concerns requires developers to think differently about how they design and structure their code. Instead of creating monolithic applications, they must learn to break down functionality into distinct, loosely-coupled modules. This shift in thinking can be difficult, especially for those accustomed to traditional, tightly-coupled designs. Effective application of the principle demands a solid grasp of software architecture principles, including how to define clear interfaces, manage dependencies, and ensure proper module interactions. Developing these skills takes time and experience.

Setting up a project while keeping the principle in mind involves creating and configuring multiple modules from the outset. This can be more complex and time-consuming than starting with a monolithic approach, requiring a good understanding of project organization and configuration management. Developers need to fa-

miliarize themselves with tools and frameworks that also encourage the use of the principle. For instance, in a microservices architecture, knowledge of containerization (e.g., Docker), orchestration (e.g., Kubernetes), and service discovery tools becomes essential. The learning curve for these technologies can be steep.

The principle often relies on well-established design patterns (e.g., Observer, Strategy, Factory, MVC, the last one being later used in a demonstrated implementation). Developers need to learn these patterns and understand when and how to apply them effectively. This involves both theoretical knowledge and practical experience. Beyond design patterns, developers must also familiarize themselves with best practices for implementing SoC, such as encapsulation, loose coupling, and high cohesion. These principles are essential for creating maintainable and scalable systems.

In summary, by providing the necessary training, tools, and support, developers overcome these challenges and effectively apply the principle to create maintainable, scalable, and high-performing systems.

3.3.4 Tooling

Implementing the separation of concerns principle in software development often necessitates the use of specialized tools to manage the increased complexity of modular systems. While these tools can greatly enhance the development process, they also introduce several challenges. Now we'll dive deeper and look at the tooling challenges associated with the principle.

There is a vast array of tools available for different aspects of software development, such as version control, build automation, testing, deployment, and monitoring. Selecting the right combination of tools that work well together and support that support the principle can be daunting. Once chosen, integrating these tools into a cohesive development environment can be challenging. Ensuring that the tools communicate effectively, and that workflows are streamlined requires careful planning and configuration. Integration issues can lead to inefficiencies and disruptions in the development process.

Setting up the development environment to support separation of concerns typically involves configuring multiple tools and ensuring they are correctly set up for different modules. This setup can be time-consuming and complex, especially for large projects. Ensuring that all developers have consistent environments can be difficult. Discrepancies in tool versions, configurations, or dependencies can lead to "it works on my machine" issues, where code behaves differently on different setups.

In summary, by selecting the right tools, providing comprehensive training and documentation, automating setup processes, maintaining tools regularly, streamlin-

ing debugging, and planning for scalability, organizations can effectively mitigate these challenges and leverage the full benefits of this principle.

3.3.5 Debugging

Applying the separation of concerns principle introduces several debugging challenges due to the modular and often distributed nature of the system. Debugging is a step that's quite often met in the development process, because it "typically happens during three activities" [P.02] of this process. Let's take a look at these challenges.

In a system where concerns are separated into distinct modules or services, identifying the source of an issue can be challenging. A bug in one module might manifest as an error in another, leading to confusion about where the problem actually lies. Debugging issues that span multiple modules requires understanding the interactions and dependencies between them. This complexity increases with the number of modules and their interconnections.

Each module might have its own logging mechanism, making it difficult to trace the flow of events across the entire system. Consolidating logs from different modules into a centralized logging system is essential but can be complex to set up and maintain. Maintaining context (such as transaction IDs or user session information) across module boundaries is crucial for effective tracing. Ensuring this context is consistently propagated throughout the system can be challenging.

Reproducing issues in a modular system can be difficult due to differences in development, testing, and production environments. Ensuring consistency across these environments is key but can be resource-intensive. Each module may manage its own state, making it harder to reproduce issues that depend on specific states across multiple modules. Capturing and restoring these states for debugging purposes adds complexity.

Different modules might have different error handling strategies, leading to inconsistencies in how errors are reported and propagated. Ensuring a unified error handling approach across modules is essential for effective debugging. Debugging asynchronous operations, such as those involving message queues or background processing, adds another layer of complexity. Tracing the lifecycle of an asynchronous task across modules requires specialized tools and techniques.

In summary, by employing centralized logging, distributed tracing, consistent environments, effective state management, integrated debugging tools, performance considerations, and standardized error handling, developers can mitigate these challenges and enhance their ability to debug complex modular systems effectively.

Chapter 4

Current state of cross-platform development

4.1 Overview

Cross-platform software is designed to operate on multiple computing platforms, such as different operating systems (Windows, macOS, Linux) or device types (desktop computers, mobile devices, web browsers). The primary goal of cross-platform development is to write a single codebase that can run on various platforms with minimal modifications, thereby reducing development time and cost while maximizing reach and usability. Now we will take a look at some key-features of this type of development.

4.1.1 Code Reusability

This development area can be best categorized into two types of codebases: single codebase and shared libraries and frameworks.

Developing with a single codebase means that the same code can be reused across multiple platforms, reducing duplication and making maintenance easier. Also, due to this approach, the need for dependency checking is eliminated, as it is one of the most daunting tasks regarding cross-platform development. A good scenario, for example, is to know that your application's server is dependent on an Object-Relational Mapping (ORM) framework, or a wrapper for one to be more specific, and to find that it is being discontinued. This is where single codebase comes in, as it is not dependent on a framework, a package or a library, but on the code itself, thus making it more reliable and easier to maintain. The disadvantage of this approach is that it can be more time-consuming and expensive to develop, as it requires more effort to write and test the code.

Utilizing shared libraries and frameworks, such as .NET Core, Flutter, or JavaScript

frameworks (e.g., React Native, Electron), helps streamline development. These libraries and frameworks provide pre-built components and tools that can be used across multiple platforms, reducing the amount of code that needs to be written and tested. However, the downside of this approach is that it can be more challenging to maintain and update the codebase, as changes to the library or framework may require modifications to the application code. In addition, the performance of the application may be affected by the overhead of the library or framework. This is why it is important to consider certain aspects of the framework, such as “popularity”, “ease of use” and “longevity”, because these are the frameworks that “you can try out with little investments” [Sat18] and can decide early of their fit for the job.

4.1.2 Platform Abstraction

Platform abstraction refers to building an abstraction layer that isolates the application logic from the platform-specific code (e.g. Kernel interactions). It is necessary, due to the multitude of platforms that exist today, each with its own set of features and requirements. This is usually done through a hardware abstraction API, that gives “an abstraction of underlying HW (hardware) architecture, i.e. processor local architecture” [A.A03].

Abstraction layers allow developers to write platform-agnostic code that interfaces with platform-specific functionality through standardized APIs. They are also one of the core features of separating concerns, as they provide a clear separation between the application logic and the platform-specific code. This allows developers to focus on writing the core functionality of the application without having to worry about the underlying platform details. In addition, abstraction layers can help improve code maintainability and portability, as changes to the platform-specific code can be isolated and managed more easily.

Middleware provides a layer between the application and the operating system, handling differences in platform-specific operations. It can be used to abstract away platform-specific details, such as file system access, network communication, and user interface interactions. Middleware can also provide additional functionality, such as caching, logging, and error handling, that can be shared across multiple applications. However, middleware can introduce additional complexity and overhead, as it adds an extra layer of abstraction between the application and the platform.

4.1.3 Conditional Compilation and Code

Conditional compilation is a technique used to include or exclude code based on the target platform or configuration. This involves writing code that compiles differ-

ently depending on the target platform, often using preprocessor directives or build configurations. Sometimes, platform-specific code is necessary to handle unique features or limitations of each platform. This is necessary especially on the application's user interface, as each platform has its own design guidelines and user experience expectations.

4.2 Legacy paradigms that are present today

We will take a look at all the features that cross-platform development kept from its predecessors, and see how they align with the needs identified earlier.

Despite the evolution of software development practices, several legacy design principles have remained relevant and continue to be applied in modern cross-platform development. These principles provide a foundation for creating robust, maintainable, and scalable applications. Here are some key legacy design principles still in use today.

4.2.1 Separation of Concerns

This sounds confusing now, but the principle is implemented in a very shallow and basic way, as it is not a global standard. This can be observed in the lower levels of the application, where the concerns are separated into platform-specific and platform-agnostic code. However, this separation is not always clear or consistent, as platform-specific code may be mixed with platform-agnostic code, leading to dependencies and coupling between different components. This can make it difficult to maintain and update the codebase, as changes to one component may require modifications to other components as well. It is also worth mentioning that the principle is not used as intended in the higher levels of the application, where the concerns are mixed together, leading to increased complexity.

4.2.2 Single Responsibility Principle (SRP)

The Single Responsibility Principle (SRP) states that a class should have only one reason to change. This principle is relevant in cross-platform development, as it helps to create more modular and maintainable code. By separating concerns into individual classes or components, developers can isolate changes to specific areas of the codebase. It is mostly used in "three levels of granularity: (a) method-, (b) class-, and (c) package-level" [A.19].

This makes it easier to understand, test, and modify the code, as each component has a clear and well-defined purpose. However, the SRP is not always followed in

cross-platform development, as classes or components may have multiple responsibilities.

4.2.3 DRY (Don't Repeat Yourself)

The DRY principle states that code should not be duplicated, but instead should be reused or abstracted into shared components. This principle is relevant in cross-platform development, as it helps to reduce redundancy. By reusing code across multiple platforms, developers can save time and effort, as changes only need to be made in one place. However, the DRY principle is not always followed in cross-platform development, as code duplication can occur due to platform-specific requirements or limitations.

4.2.4 Open/Closed Principle

The Open/Closed Principle states that classes should be open for extension but closed for modification. It is mostly used when designing "modules that never change" [Mar00]. This principle is relevant in cross-platform development, as it helps to create more flexible and maintainable code. By designing classes to be extensible, developers can add new functionality without modifying existing code. This makes it easier to adapt the codebase to changing requirements or new platforms.

4.2.5 Liskov Substitution Principle

The Liskov Substitution Principle states that objects of a superclass should be replaceable with objects of a subclass without affecting the correctness of the program. This is mostly used for components superclassing, because when it is applied correctly we enforce "inheritance hierarchies that are easy to understand and extend" [AA01]. This principle is relevant in cross-platform development, as it helps to ensure that code is reusable and interoperable across different platforms. By designing classes to be substitutable, developers can create more flexible and scalable code. However, the Liskov Substitution Principle is not always followed in cross-platform development, as platform-specific code may not be interchangeable with platform-agnostic code.

4.2.6 Dependency Injection (DI)

Dependency Injection (DI) is a design pattern that allows objects to be injected into a class rather than created internally. It mainly refers to the use case of a service "that

is required by another object to fulfill its function” [Pra09], or, in our case, it can be referred to API handlers that need ORM’s (*Object Relational Mappers*) for example. This pattern is relevant in cross-platform development, as it helps to decouple components and reduce dependencies. By injecting dependencies into classes, developers can create more modular and testable code. However, DI is not always used in cross-platform development, as it can add complexity and overhead to the codebase.

4.2.7 Lack of separation of concerns

In order to understand why the lack of this principle is an issue, we should take a brief look at the predecessors of cross-platform development. The first software applications were developed as monolithic systems, where all the code was tightly coupled and interdependent. This made it difficult to make changes or updates to the codebase, as any modification could have unintended consequences elsewhere in the application.

Also, due to this, a modification on a base layer would imply a cascade of changes on the upper layers, thus making the maintenance process a lot more difficult. As software systems grew in size and complexity, it became clear that a more modular and flexible approach was needed to manage the codebase effectively. This is where the separation of concerns principle comes in, as it provides a clear and structured way to organize the codebase and manage dependencies between different components.

4.3 Frequently used design patterns

In this section, I will analyze the design patterns that are found most commonly in cross-platform development. I will also do a more thorough analysis on the design patterns of my choice for the companion app that will support this thesis.

4.3.1 MVC

The Model-View-Controller (MVC) design pattern is a software architecture pattern that separates an application into three main concerns: the Model, the View, and the Controller. It’s mostly used when we keep into account “the role of objects and the communications between those objects” [Buc09]. This is a design pattern that is highly compatible with most REST APIs, as it provides a clear separation between the application logic and the user interface.

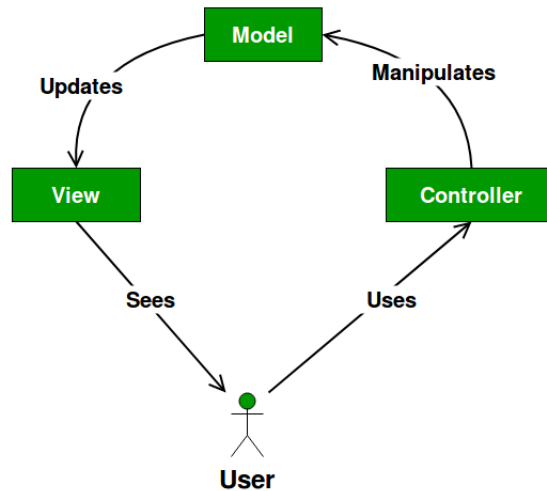


Figure 4.1: MVC pattern visualized, source: Pushar Baichwal

The Model concern represents the data and business logic of the application. It encapsulates the application's data and the access to the said data. It is tightly coupled with the View concern, as it notifies it for any changes in data.

The View concern deals with the UI (User Interface) of our application. Its role is to display the data and handle user interactions. Because of this, it is tightly coupled to the Controller concern.

The Controller concern is used as a connecting piece between the View and the Model concerns. It is the layer that interprets the user input and makes calls to the model objects. Its main purpose is to update the Model and select the proper View display.

4.3.2 Singleton

Singleton is a creational design pattern that lets you ensure that the "need for one - and only one - instance of a class" [J.11] is met. The Singleton pattern solves two problems at the same time, violating the Single Responsibility Principle.

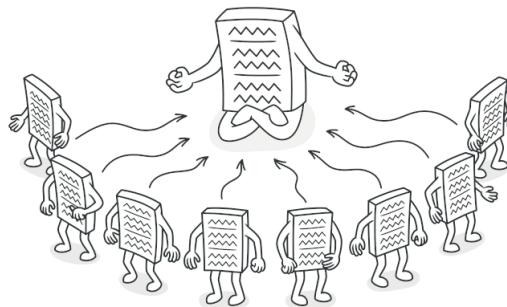


Figure 4.2: Singleton pattern visualized, source: Refactoring Guru

The Singleton pattern introduces a global state, which can make it harder to track and reason about the behavior of the system. Changes to the Singleton instance can affect other application parts, potentially resulting in hidden bugs and unintended side effects. As the Singleton instance is directly accessed throughout the application, the use of Singleton can lead to tight coupling between classes. This can make it more difficult to modify or replace the Singleton in the future with a different implementation.

It is worth mentioning that this pattern is great for server-side development. Some real-world examples of the Singleton pattern include: database connections, logging, caching, thread pools, and configuration settings. These are things that are not supposed to be instantiated more than once, as they can lead to memory leaks or other issues. Also, due to their nature, they should not be handled in the client-side part.

This is a design pattern I avoided using in the companion app, as it is not recommended for use in modern software development due to its drawbacks. Also, because of the spawn of global state, it could result in some slowdowns in the application, as the Singleton instance is directly accessed throughout the application.

4.3.3 MVVM

MVVM is a design pattern that separates into the following concerns: the Model, the View, and the ViewModel. All the concerns have their own responsibility and are specific handlers for some use cases. This design pattern is considered one of the best, as “regardless of how you implement the pattern, doing so is good practice” [C.12]. Below we will take a look at each concern and see how it is implemented in the companion app. This design pattern is used in almost all cross-platform frameworks to provide a clear separation between the application logic and the user interface.

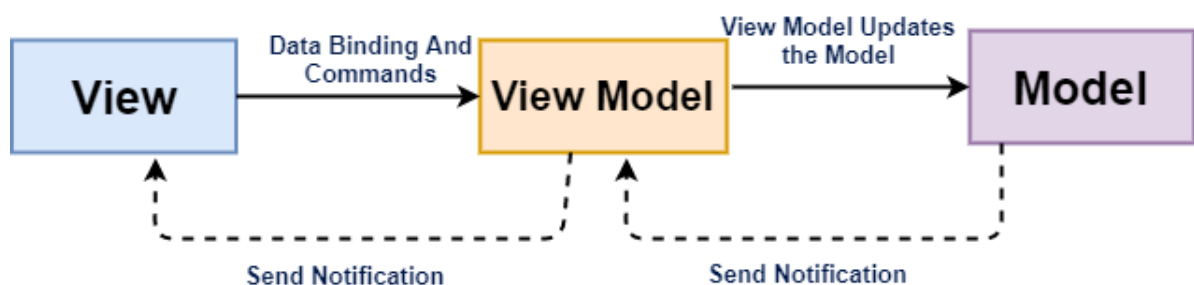


Fig: MVVM Pattern

Figure 4.3: MVVM pattern visualized, source: Tutorialspoint

The Model concern represents the data and business logic of the application. It

encapsulates the application's data and the rules that govern access to and updates of this data. It is responsible for fetching data from the database or any other data source, and it ensures that the data is valid. This is notable in the companion app as well, by providing *Service* and *Provider* layers, each being themselves separated into units that are responsible for handling the functionality of a single entity.



Figure 4.4: Service and Provider layers (Model concern)

The View concern deals with the UI (User Interface) of our application. Its role is to display the data and handle user interactions, by sending them to the ViewModel concern. This is observable in the companion app through widget trees.

```

9  @override
8  Widget build(BuildContext context) {
7    return Scaffold(
6      appBar: AppBar(title: const Text('Chat Page')),
5      body: Center(
4        child: Column(
3          children: <Widget>[
2            Expanded(child: Consumer<ChatProvider>(
1              builder: (context, chatProvider, child) {
26             chatProvider.initChats();
1             _partnerId = chatProvider.partnerId;
2             return ListView.builder(
3               itemCount: chatProvider.chats.length,
4               itemBuilder: (context, index) {
5                 return Padding(
6                   padding: const EdgeInsets.fromLTRB(20.0, 0, 20.0, 0),
7                   child: Row(
8                     mainAxisAlignment: MainAxisAlignment.spaceBetween,
9                     children: [
10                      ChatWithPartner(
11                        chat: chatProvider.chats[index],
12                        partnerId: chatProvider.partnerId,
13                        chatName: chatProvider.chats[index].chatName,
14                      ) // ChatWithPartner
15                    ],
16                  )); // Padding // Row
17              }); // ListView.builder
18            }); // Expanded // Consumer
19          ], // <Widget>[]
20        ), // Column
21      ), // Center

```

Figure 4.5: Widget tree (View concern)

The ViewModel is the liant between the View and the Model concerns, as the name suggests. Its primary role is to update the Model based on the inputted user interactions. It is usually the concern that handles state management, but since our companion app is mostly stateless, this turns our *Provider* layer into a ViewModel concern handler.

Data binding is a key feature of MVVM that allows automatic synchronization

of data between the View and ViewModel. Changes in the ViewModel are automatically reflected in the View and vice versa. Most of the current cross-platform frameworks have a built-in data binder, so there is almost no need to build it. This is important, because it means that less code needs maintenance, due to the framework's maintenance being done internally.

4.3.4 Observer

The Observer design pattern is a behavioral design pattern that defines a one-to-many dependency between objects so that when one object changes state, all its dependents are notified and updated automatically. It was first codified by "a group of IBM researchers" [Eag05] in the 1994 book *Design Patterns*. It is used to establish a subscription mechanism to allow multiple objects (*Observers*) to listen and react to events or changes in another object (*Subject*).

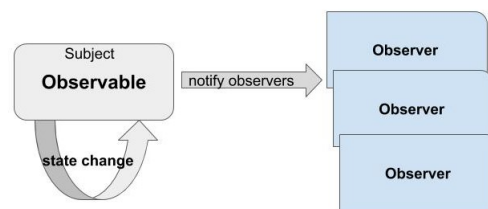


Figure 4.6: Observer pattern visualized, source: Gustavo Peiretti

The Observer defines a one-to-many relationship between objects so that when one object changes state, all its dependents are notified and updated automatically. This is useful for building loosely coupled systems, where objects can interact without having direct references to each other. The Observer pattern is commonly used in event-driven programming, where objects can subscribe to events and receive notifications when the events occur. It is a good fit for separating concerns, as it provides a clear separation between the object that generates events and the objects that react to the events.

The Observer pattern is also used in the companion app to notify the UI when the data changes. This is done by using the *Provider* layer, which is a state management solution that allows the UI to listen for changes in the data and update accordingly. This turns the Provider object into a Subject, and all the notified objects into Observers. Such an implementation of the Observer allows for a responsive, and most importantly "stateless" UI, in the sense that traditional "states" (such as the ones in React or Flutter) are not being used, due to them being runtime heavy.

The Observer pattern is a good fit for building cross-platform applications, as it provides a flexible and scalable way to manage dependencies between objects. The

```

@override
Widget build(BuildContext context) {
  // Use the Consumer widget to get the messages from the Mess
  // We'll also use the consumer widget to add messages
  return Expanded(child: Consumer<MessagesProvider>(
    builder: (context, messagesProvider, child) {
      messagesProvider.initMessages(widget.chatId);
      return ListView.builder(
        controller: widget.scrollController,
        itemCount: messagesProvider.messages.length,
        itemBuilder: (context, index) {
          return Container(
            padding: const EdgeInsets.all(2),
            alignment: messagesProvider.messages[index].sender
              ? Alignment.centerRight
              : Alignment.centerLeft,
            child: ChatText(
              text: messagesProvider.messages[index].text,
              isSentByUser:
                messagesProvider.messages[index].senderId ==
              ), // ChatText
            ); // Container
          }, // ListView.builder
        ); // Expanded // Consumer
      }
    }
  )
}

```

```

class MessagesProvider extends ChangeNotifier {
  MessagesProvider({required this.messagesApiService});

  List<Message> _messages = [];
  final MessagesApiService messagesApiService;

  List<Message> get messages => _messages;

  Future<void> initMessages(int chatId) async {
    _messages = await messagesApiService.getMessages(chatId);
    notifyListeners();
  }

  Future<void> addMessage(Message message) async {
    int id = await messagesApiService.addMessage(message);
    if (id != 0) {
      // We have to unpack all of this because the param is
      _messages.add(Message(
        messageId: id,
        chatId: message.chatId,
        senderId: message.senderId,
        text: message.text,
        isRead: message.isRead,
        dateSent: message.dateSent,
      ));
      notifyListeners();
    }
  }
}

```

Figure 4.7: Consumer/Observer on left, and Provider/Subject on right

MVVM design pattern follows, in a way, the Observer pattern, as the ViewModel concern acts as an Observer that listens for changes in the Model and updates the View accordingly. This is a good example of how the Observer pattern can be used to create a responsive and interactive user interface in a cross-platform application. Also, with it, we can achieve a good separation of concerns, as the ViewModel concern is responsible for updating the Model based on the user interactions, and the View concern is responsible for displaying the data and handling user interactions.

4.4 Tools

By tools, we refer to the software and libraries that are used in cross-platform development. This includes frameworks, libraries, and development environments that help streamline the development process and provide essential functionality for building cross-platform applications. Here are some of the most popular tools used in cross-platform development today.

4.4.1 Flutter

Flutter is an open-source UI toolkit for building natively compiled applications for mobile, web, and desktop from a single codebase. It provides a rich set of pre-built components and tools that can be used to create responsive and interactive user interfaces. This enables Flutter to stick to the “write once, deploy everywhere”

[Win20] paradigm. Flutter uses the Dart programming language, which is designed for building modern, object-oriented applications. It also provides a hot reload feature that allows developers to quickly see changes to the code reflected in the application without restarting the app. It is a popular choice for building cross-platform applications due to its ease of use, performance, and flexibility. By being very easily adaptable to the separation of concerns principle, as it provides a clear separation between the application logic and the user interface, this would be a good choice for a cross-platform development tool, hence the use of this tool for the case study. Distinct features of Flutter include:

- Hot reload
- Rich set of pre-built components
- Support for mobile, web, and desktop platforms
- Dart programming language, designed for building modern, object-oriented applications, and also very easy to learn.

4.4.2 React Native

React Native is an open-source framework for building natively compiled applications for mobile devices from a single codebase. It is also performant, run time wise, due to its "asynchronous calls to the underlying mobile OS" [Bod17]. It uses the React JavaScript library to create user interfaces and provides a rich set of pre-built components and tools for building cross-platform applications. React Native is a popular choice for building mobile applications due to its ease of use, performance, and flexibility. It also provides the hot reload feature aforementioned. React Native is a good choice for building cross-platform applications due to its support for a wide range of platforms and devices.

4.4.3 Xamarin

Xamarin is an open-source framework for building natively compiled applications for mobile devices from a single codebase. It is a descendant of the "open source Mono Project that brought .NET to Linux" [?]. It uses the C# programming language and the .NET framework to create cross-platform applications. Xamarin provides a rich set of pre-built components and tools for building mobile applications, including support for iOS, Android, and Windows devices. It also provides a hot reload feature that allows developers to quickly see changes to the code reflected in the application without restarting the app.

Chapter 5

Implementation

During this chapter I will elaborate on the practical implementation of an application that will be used to prove the concept of the research. The application is implemented in Flutter, a cross-platform framework developed by Google. Due to the nature of the research and my hardware, the application is developed for Android and Linux devices only, and it will use a self-implemented server, rather than a third party service such as Firebase.

The server is implemented in Golang, a statically typed language developed by Google. It will be used to store the data of the application, and to provide the necessary data to the application. The server connects to a MSSQL database, which is used to store the data. This was also chosen due to nature of the research, as it represents a more realistic scenario, where the data is stored in a company's database. Due to its ownership by Microsoft, a well-known brand, it is more likely to be used in a company's environment. This is a good opportunity to test the application in a more realistic scenario, where the so-called 'frontend' and the 'backend' are not part of the same ecosystem.

Let's now take a look at how the server and the application are implemented.

5.1 Server

The server is separated into the following main layers: Models, Database Operations, Controllers, and Middleware. They are meant to provide core functionality to the server, and to separate the concerns of the application. The middle layers are: Globals, Initializers, and Utils. They are meant to provide support to the main layers, so that we can effectively separate the concerns. The purpose of having side layers is that we can easily declutter the main layers, and make the code more readable and maintainable. Let's take for example the above utils function that helps us to display the error messages in a response body. This will help us reduce boilerplate

code, that is repeatable and makes the code harder to read.

```

5 package utils
4
3 import (
2     "github.com/gin-gonic/gin"
1 )
6
1 func ErrorCheckerHttpResponse(c *gin.Context, http_status int, err error, err_msg string) {
2     if err != nil {
3         c.AbortWithStatus(http_status)
4         c.JSON(http_status, gin.H{"error": err_msg})
5     }
6 }

```

Figure 5.1: Utils layer

The Models layer contains the structs that represent the entities of the application. The structs are used to store the data of the application, and to provide a way to interact with the data. They also provide a schema of the database, as they are used for mapping the results of the database queries. Another use for them is to validate the data that is sent to the server, so that we can ensure that the data is correct.

The Database Operations layer contains the functions that interact with the database. They perform CRUD operations on the database, and to provide the necessary data to the application. It is the layer that is responsible for the communication between the server and the database. It's only functionality is the one mentioned above. Other logic, such as validation or error handling, is done elsewhere. An advantage of writing this layer, instead of choosing an ORM (Object Relational Mapping) library, is that we have more control over the queries that are sent to the database. This makes the server feel more responsive.

```

1  ./
1  chats.go
2  credentials.go
3  db_instance.go
4  messages.go
5  partners.go
6  pcconnections.go
7  user.go

```

Figure 5.2: Database Operations layer

The Middleware layer goes between the Controllers and the endpoints calls. It

handles the logic that is common to all the endpoints, such as authentication, logging, and error handling. This makes it easier to add new endpoints, as we don't have to write the same logic for each endpoint. Also, the handlers for the endpoints can be easily replaced or removed, as they are not tied to the endpoints themselves.

```
3 func CreateUserGrouping(router *gin.Engine) {  
2     router.Group("/user")  
1     {  
236         router.POST("/user/signup", signup)  
1         router.POST("/user/login", login)  
2         router.GET("/user/validate", middleware.RequireAuth, validateToken)  
3         router.GET("/user/get/chats", middleware.RequireAuth, getUserChats)  
4         router.GET("/user/get/id", middleware.RequireAuth, getIdFromToken)  
5     }  
6 }
```

Figure 5.3: Middleware layer

The Controllers layer contains the functions that handle the requests from the client. They are used to provide the necessary data to the client, and to handle the data that is sent to the server. It is the main layer of the server, as they are the ones that interact with the client. A key point of this layer is that it is not tied to the database, as it only interacts with the Database Operations layer. I also chose to implement the controllers in a model-based way, as it makes the code more readable and maintainable.

```
1  . ./  
1  chats_controller.go  
2  credentials_controller.go  
3  messages_controller.go  
4  partners_controller.go  
5  user_controller.go
```

Figure 5.4: Controllers layer

5.2 Main focus

The main entity around which the application is built is the *Partner* class, as seen below.

```

22 class Partner {
21   int id;
20   String businessName;
19   String address;
18   String phoneNumber;
17   String contactPerson;
16   String email;
15   int reach;
14
13   Partner(
12     {required this.id,
11     required this.businessName,
10     required this.address,
9     required this.phoneNumber,
8     required this.contactPerson,
7     required this.email,
6     required this.reach});
5
4   factory Partner.fromJson(Map<String, dynamic> json) {
3     return Partner(
2       id: json['partner_id'],
1       businessName: json['business_name'],
23  address: json['address'],
1       phoneNumber: json['phone_number'],
2       contactPerson: json['contact_person'],
3       email: json['email'],
4       reach: json['reach'],
5     );
6   }
7
8   Map<String, dynamic> toJson() {
9     return {
10      'partner_id': id,
11      'business_name': businessName,
12      'address': address,
13      'phone_number': phoneNumber,
14      'contact_person': contactPerson,
15      'email': email,
16      'reach': reach,
17    };
18  }
19 }

```

Figure 5.5: Main entity of the application

This entity is a substitute for the User class, as the User is just a Partner connected with a Credential entity from the DB. Partner is also connected to the entity Chat, which by itself is connected to Message. This enforces a good separation of the functionality, and also allows for efficient queries and server responses. Although this is the main entity, the way it is build, with the additional methods of *fromJson* and *toJson*, allows for easy extension of the application. This will be present across all the other entities, to manage more easily the bodies of the sent requests.

Now, we'll take a look at how a few components are built, and how their state is managed. This will contain some good and bad examples, and see how they impact the development of the application, and also the developer experience.

5.3 Example Components

5.3.1 Good example

The first component we'll take a look at is a *Partner list* component. To be more specific, the below picture is part of the component that renders the top five partners by reach, a field which represents the average number of clientele.

```
return ListView.builder(
  itemCount: partnersProviders.topFive.length,
  itemBuilder: (context, index) {
    return ListTile(
      title: Row(
        children: [
          Icon(
            Icons.business,
            size: 30,
            color: Theme.of(context).primaryColor,
          ), // Icon
          const SizedBox(width: 10),
          Text(partnersProviders.topFive[index].businessName)
        ],
      ), // Row
      subtitle: Row(
        children: [
          Icon(Icons.email,
            size: 20,
            color: Theme.of(context).colorScheme.secondary), // Icon
          const SizedBox(width: 10),
          Text(partnersProviders.topFive[index].email),
        ],
      ), // Row
      trailing: Text(
        'Reach: ${partnersProviders.topFive[index].reach.toString()}', // Text
      ), // ListTile
    );
  }, // ListView.builder
);
```

Figure 5.6: List component

Here we can note the good use of states, as the component is stateless, and the state is managed by the provider component. This is a good practice, as it allows for a more efficient rendering of the component, and also for a more readable code. Each child sits under a *Consumer* widget, which listens for changes in the provider, and rebuilds the child when the state changes. By doing so, the component is more efficient, as only the child that needs to be rebuilt is rebuilt, and not the whole component. Also, it removes for the need of passing the state as a parameter to the child. Due to the simple nature of the entity it overwatches, it eliminates the need for a websocket. This is a good example of how to build a component, and how to manage the state of the component, for simple operations on simple entities.

5.3.2 Bad example

The second component we'll take a look at is a *Login* component. This component is used to log in the user, and to provide the necessary data to the application. In the picture below, we can see that the component is stateful, through the use of controllers. This is a bad practice, as it makes the component easy to read, but prone to mistakes, due to repetitive coding.

```
// Username text field
CustomTextField(
  controller: _usernameController,
  label: 'Username',
  hint: 'Enter your username',
  isTextObscured: false,
  icon: const Icon(Icons.person),
), // CustomTextField
const SizedBox(height: 25),

// Password text field
CustomTextField(
  controller: _passwordController,
  label: 'Password',
  hint: 'Enter your password',
  isTextObscured: true,
  icon: const Icon(Icons.lock),
), // CustomTextField
const SizedBox(height: 25),
```

Figure 5.7: Login component

This is as much avoided as possible, through the makings of custom widgets, that eliminate boilerplate as much as possible. It is easily observable in the picture below, where *CustomTextField* is used to create a text field, with a custom design, and a custom controller. Everything under the *Widget build* method would be repeated for each text field, and would make the code harder to read and maintain.

```
26 class CustomTextField extends StatefulWidget {
27   const CustomTextField({
28     super.key,
29     required this.label,
30     required this.hint,
31     required this.controller,
32     required this.isTextObscured,
33     required this.icon,
34   });
35   final String label;
36   final String hint;
37   final TextEditingController controller;
38   final bool isTextObscured;
39   final Icon icon;
40
41   @override
42   State<CustomTextField> createState() => _CustomTextFieldState();
43 }
44
45 class _CustomTextFieldState extends State<CustomTextField> {
46   @override
47   Widget build(BuildContext context) {
48     return SizedBox(
49       width: 300,
50       height: 50,
51       child: TextFormField(
52         decoration: InputDecoration(
53           border: const OutlineInputBorder(),
54           labelText: widget.label,
55           hintText: widget.hint,
56           suffixIcon: widget.icon,
57         ), // InputDecoration
58         cursorWidth: 2,
59         obscureText: widget.isTextObscured,
60         style: const TextStyle(color: Colors.black),
61         controller: widget.controller,
62       ), // TextFormField
63     ); // SizedBox // TextFormField
64   }
65 }
```

Figure 5.8: Custom text field

5.3.3 Neutral example

The last component we'll take a look at is a *User Details* component. This component is used to display the details of a user, such as the name, email, and phone number. It also allows the user to edit the details, and to save the changes. In the picture below, we can see that the component is stateless, and the state is managed by the *Partners Provider*.

```

_customText(
  '${partnersProvider.currentPartner?.businessName}',
  Icon(
    Icons.business,
    color: Theme.of(context).colorScheme.secondary,
  ), // Icon
const SizedBox(height: 30),
_customText(
  '${partnersProvider.currentPartner?.email}',
  Icon(
    Icons.email,
    color: Theme.of(context).colorScheme.secondary,
  ), // Icon
const SizedBox(height: 30),
_customText(
  '${partnersProvider.currentPartner?.phoneNumber}',
  Icon(
    Icons.phone,
    color: Theme.of(context).colorScheme.secondary,
  ), // Icon
const SizedBox(height: 30),
_customText(
  '${partnersProvider.currentPartner?.address}',
  Icon(
    Icons.location_pin,
    color: Theme.of(context).colorScheme.secondary,
  ), // Icon
const SizedBox(height: 30),
_customText(
  '${partnersProvider.currentPartner?.reach}',
  Icon(
    Icons.groups_3,
    color: Theme.of(context).colorScheme.secondary,
  ), // Icon
const SizedBox(height: 30),
_customText(
  '${partnersProvider.currentPartner?.contactPerson}',
  Icon(
    Icons.person_3,
    color: Theme.of(context).colorScheme.secondary,
  ), // Icon

```

Figure 5.9: User Details component

This is a bad practice, as it makes the component harder to read, and harder to maintain. Also, it makes the component less efficient, as there is no need for the whole component to be rebuilt when the provider notifies for changes. This example, although it is a simple one, shows how not to build a component, and how not to manage the state of the component. This represents a tricky example, because it looks like a bad mapping, because it is done manually. In reality, it provides a way to improve the design of the application, by giving custom icons to the inner components. We can notice this in the picture below.

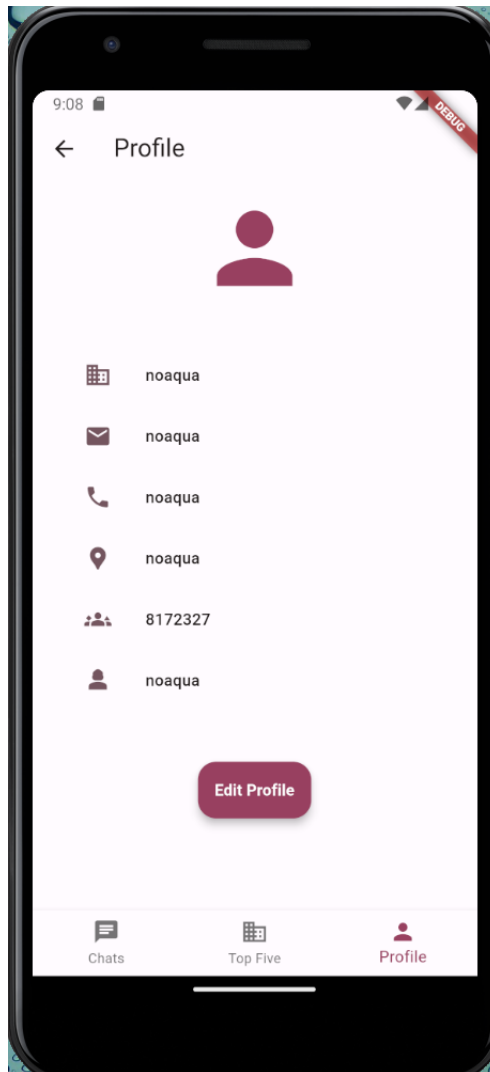


Figure 5.10: User Details UI

Chapter 6

Conclusions

The research has shown that the use of a cross-platform framework can be beneficial for companies that want to develop applications for multiple platforms. It can reduce the development time, as the code can be shared between the platforms. This can also reduce the costs of development, as the developers don't have to learn multiple languages and frameworks. The research has also shown that the use of a self-implemented server can be beneficial for companies that want to have more control over their data. It can provide a more realistic scenario, where the data is stored in a company's database, rather than in a third party service.

As noticed in the examples above, the server is separated into different layers, each with its own responsibilities. The frontend is also separated into different layers, but it requires some manual tweaking in certain use cases. Both have proven that this separation of concerns can make the code more readable and maintainable, through good and bad examples. This separation of concerns can also make it easier to add new features to the application, as the code is more organized.

Through the practical implementation of the application, I have learned that the use of a cross-platform framework can be beneficial for companies that want to develop applications for multiple platforms. Not only that, but the reduction in code duplication can also reduce the development time and costs. By making use of thoughtful separation of concerns, the code can be more readable and maintainable, and it can be easier to add new features to the application.

It is important to note that the research has some limitations. The application is developed for Android and Linux devices only, and it uses a self-implemented server. This means that the application is not available for iOS devices, and it does not use a third party service such as Firebase. This can limit the reach of the application, as it is not available for all devices. It can also limit the scalability of the application, as the server is not as robust as a third party service. But even with these limitations considered, we can still see the benefits of using a cross-platform framework and a self-implemented server, with separation of concerns.

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