Fundamentals of Software Architecture

Practical guide to building resilient software and high-performance systems

Craig Risi

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Dedicated to

My wife, ***Jacqui Risi***

About the Author

A man of many talents, but no sense of how to use them. **Craig Risi** could be out changing the world but would prefer to make software instead. Probably the reason why Nick Fury refused to take his calls. He possesses a passion for software design, but more importantly software quality and designing systems that can achieve this in a technically diverse and constantly evolving tech world.

Craig has over 20 years of experience across the development, testing, and management disciplines in various software industries, but he still feels he learns something new every day. It is the continued change and evolution of the software industry that motivates him to keep learning and finding ways to improve. More than just playing with tech though, it's people that make software come together – and so Craig believes in developing people and empowering them to make a success out of the software they build.

When not playing with software he can often be found spending time with family, writing, designing board games, or running long distances for no apparent reason. He is also a massive fan of comic books and Star Wars, so if you see him concentrating intensely, he is probably just trying to use the force.

Craig is also the writer of several books and writes regular articles on his blog sites and various other tech sites around the world. He is also an international speaker on a wide range of different software development topics, though these experiences only make him even more excited about the future of the industry in South Africa.

About the Reviewer

Kartoue Mady Demdah, Ph.D., is a data scientist at Olameter Inc. with seven years of experience in data science, machine learning, and statistics. He earned his Ph.D. in Mathematics from the *University of Rennes I and the University of Pisa*.

Over the years, he has developed expertise in computer vision, graph neural networks, time series analysis, and **natural language processing (NLP)**. In addition to his Ph.D., he holds a Professional Certificate in Digital Transformation from MIT, covering AI, IoT, cloud computing, blockchain, and cybersecurity. His technical proficiency spans Python, SQL, TensorFlow, PyTorch, AWS, and Azure.

Beyond his technical skills, Kartoue is deeply committed to mentorship and community engagement. He actively participates in AI hackathons, promotes data philanthropy, and shares his expertise to support the growth of the AI community.

Acknowledgement

Thank you for taking the time to purchase this book and hopefully it will give you as much enjoyment into reading it as it did for me in writing it. The role of a software architect is one of continued learning, so no doubt even after reading this one, you will continue reading even more insightful books on different topics and continue to grow on these topics. But, for giving me so much of your time to read this – I do appreciate it.

Special thanks also go out to BPB Publications for the support and incredible editing that makes my writing come across a lot better than it really is.

This book would not have been possible without the many people in my career who have helped me understand many of the concepts in this book more clearly. So, I want to thank those many unnamed mentors, managers and colleagues who have worked with me over the years and helped me to learn many different aspects of software architecture and software development.

However, most importantly - to my loving wife – who has sacrificed the time with me in helping me put this book together. Without her support, writing this book would not have been possible and she has been the backbone in my career that has helped me to thrive. I am incredibly grateful to have someone who supports me the way she does.

Preface

This book is for all people in the software space keen to know a little bit more about what software architects do, and their importance in the software development life-cycle. The book looks at both the technical aspects of software architecture and the softer side of skills to present a well-rounded view of all the crucial skills required for people to become software architects.

The book does not require in-depth technical knowledge to be of value, though there will be some technical models and patterns discussed and why they are effective, so a basic understanding of software principles is required.

This book lays out the fundamentals of what software architecture is, what skills are required to be a skilled software architect, and some of the best practices to follow for companies to leverage software architecture the most in their companies. Too many companies place too little emphasis on the importance of proper architectural design in their software processes and through this book, we hope to teach the reader about its importance and how proper software design can have a marked improvement on the resultant developed software.

Below is an outline of all the chapters:

Chapter 1: Defining Software Architecture - This foundational chapter lays the groundwork for understanding the significance of software architecture. In this chapter, we explain why software architecture is so important to the overall development process of the software, look at the different high-level attributes of design that matter, and briefly explain the consequence of poor software architecture to further explain the importance of the practice.

Chapter 2: The Role of a Software Architect - In this chapter, we delve into the multifaceted role of a software architect, outlining key responsibilities and expectations. We explore the pivotal relationship between architects and development teams, emphasizing effective communication and collaboration for successful project outcomes. The chapter delves into the architect's crucial role in aligning technical decisions with overarching business goals, and how their choices can significantly impact the organization.

Chapter 3: Architectural Properties - This chapter looks at the different properties that form the foundation of good architectural design and represent all the things architects need to consider in order to design effective applications that meet the needs of performance, maintainability and long-term resilience.

Chapter 4: The Importance of Modularity - Before we look at the different architectural styles and patterns, we will take some time to look at modularity in software design and why it is important to be aware of these different principles and to build modularity into all aspects of software design. This means ensuring each module has well-defined responsibilities and interacts with other modules through well-defined interfaces.

Chapter 5: Architectural Styles - In this chapter we talk about what makes an architectural style versus the different patterns that exist. For each style, we will break down how it works, look at the different benefits it offers, and what type of applications it would be best for.

Chapter 6: Architectural Patterns - In this chapter we dive into more detail of the different architectural patterns that can be considered, shedding light on their distinct characteristics and applications. The chapter navigates through practical examples to illustrate the decision-making process when choosing patterns, looking at the different pros and cons of each pattern and when they might be best applied in different situations.

Chapter 7: Component Architecture - After looking at architectural patterns, it is important to now delve into software components and how they also play a role in software architecture, but at a smaller level. This includes component identification and the breaking down of a system into modular and reusable elements. We will also have a look at concepts of coupling and cohesion and look at the interdependence and internal unity of components that impact system design.

Chapter 8: Architecting for Performance - This chapter provides an insightful examination of assessing software patterns for performance and designing components to operate optimally. It begins by exploring methodologies for measuring the performance of code, offering a comprehensive overview of tools and techniques used to gauge efficiency and identify potential bottlenecks.

Chapter 9: Architecting for Security - This chapter underscores the paramount importance of security in software architecture, unraveling its critical role in safeguarding systems from evolving threats. Delving into secure design patterns, the chapter explores tried-and-true methodologies for integrating security into the very fabric of software architecture. Moreover, the chapter emphasizes the significance of secure coding practices, guiding developers in crafting robust, resilient code. Through an exploration of secure coding principles, readers learn to implement defensive coding techniques that stand as a formidable line of defense against malicious exploits.

Chapter 10: Design and Presentation - This chapter looks at design principles that create robust and scalable software systems. It delves into the foundations of design thinking in software architecture, emphasizing a holistic approach that aligns technological decisions with user needs and business objectives. Readers are guided through a spectrum of design principles, exploring concepts such as modularity, reusability, and scalability, essential for crafting architectures that stand the test of time.

The chapter takes a closer look at best practices for the presentation layer, focusing on creating user interfaces that are intuitive, responsive, and user-friendly. Through real-world examples, readers gain practical insights into optimizing the user experience while adhering to design principles.

Chapter 11: Evolutionary Architecture - This chapter delves into the core principles of Evolutionary Architecture, emphasizing the importance of flexibility and adaptability. This chapter will be split up into sections of why change is necessary, some architectural strategies for dealing with change, and how teams can best update and evolve their design without interfering with system operation or incurring high levels of redevelopment costs.

Technically, this will look at designing for independence and isolation, a look at modular design principles but then also how best to navigate and handle tech debt in teams and apply them technically. A significant portion of the chapter is dedicated to continuous integration in supporting evolving architectures. Readers learn how automated integration processes can streamline development workflows, enabling architects to implement changes smoothly while maintaining system integrity.

Chapter 12: Soft Skills for Software Architects - No architect can thrive no their technical skills alone and needs to work with development teams, various product stakeholders, clients and other architects to build an effective software solution. That is why there is a chapter set aside to look at soft skills that are critical for architects to master to be able to effectively lead others and teams toward executing a successful strategy.

In this chapter, we will start looking at the core principles of an architect's role which require them to take a leadership role in companies, and then unpacking specific skills that will help them to fulfil this leadership need effectively.

Chapter 13: Writing Technical Requirements - Writing technical requirements for architects is a critical aspect of the project planning process. By carefully defining the functional, performance, and design criteria, architects can ensure that their designs meet the needs of stakeholders while adhering to industry standards and regulations. Effective communication and documentation are essential for maintaining clarity and facilitating collaboration throughout the project lifecycle.

Chapter 14: Development Practices - Software is built by development teams and so it is important in this book that we make an effort to discuss development practices and have a detailed understanding of the different development practices across the software industry and the impact they have on delivery in different ways, This is vital so that software architects can work with the various engineering teams on the correct methodologies and practices that will suit their vision for the software.

Through this chapter, we will look at different at how different Agile, DevOps, and CI/CD methodologies influence architectural decisions, and provide strategies for architects to thrive in this dynamic environment.

Chapter 15: Architecture as Engineering - This chapter explores the invaluable contributions of architecture to the broader field of software engineering. In this chapter, readers will gain a holistic understanding of architecture's role in shaping software engineering practices in a company and ensuring the success of complex projects.

This chapter is important because architects need to align in how software design and ensure they design software that allows for the software engineering processes discussed in the previous chapter. This includes looking at different design techniques that can help teams achieve repeatable results and lasting success - largely built on the foundation of a design that works effectively across the team and its skillsets

Importantly this chapter will also discuss metrics. Metrics provides architects with the ability to quantitatively assess and improve the quality of their designs. Readers learn how to leverage metrics to evaluate performance, maintainability, and other crucial aspects, enabling informed decision-making throughout the software development lifecycle.

Chapter 16: Testing in Software Architecture - This chapter focuses on the critical aspect of ensuring testability in software architecture, illuminating the importance of building systems that are robustly and effectively testable. The chapter delves into unit testing for architectural components, providing architects with a nuanced understanding of how to design and implement tests for individual components.

This chapter serves as a comprehensive guide for architects, offering practical strategies and insights to embed testability into software architecture, ensuring the reliability and quality of the final product.

Chapter 17: Current and Future Trends in Software - The chapter focuses on emerging technologies in software architecture, from blockchain to edge computing, AI and ML and providing architects with a forward-looking perspective on how these innovations might influence architectural decision-making. We will also discuss how AI/ML can inform and enhance architectural choices, from automated decision support to predictive analytics, through data-driven design techniques.

Anticipating and adapting to industry changes is a critical aspect of software architecture and so thus cater will also have a look at tips that architects can leverage to be better prepared for these industry changes and how to identify and adapt to them quicker.

Chapter 18: Synthesizing Architectural Principles - In this chapter we revisit the core themes that have underscored each chapter, emphasizing the interconnectedness of architectural decisions with project success, business impact, and user satisfaction. The importance of adaptability and agility in the face of evolving technologies and industry landscapes becomes evident, as architects are not just designers but strategic navigators steering organizations toward success.

The concluding chapter serves as a call to action, encouraging architects to continually refine their craft and embrace lifelong learning as the speed of software innovation continues to rapidly escalate and makes the role of software architecture and design increasingly more critical.

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Prologue

Once upon a time, in the bustling kingdom of Codeburg, there lived a group of talented engineers and developers who toiled day and night to build magnificent software structures that would stand the test of time. Amidst the lines of code and the hum of servers, there emerged a figure known as the Software Architect, a wise and visionary leader with the ability to shape the very foundations of the digital realm.

In the heart of Codeburg, there was a great castle known as The Repository, where the kingdom's most critical software projects were guarded. The Software Architect, a seasoned guardian of The Repository, was tasked with designing the blueprint for these projects, ensuring they were robust, scalable, and adaptable to the ever-changing winds of technology.

As the sun rose over Codeburg, casting its light upon the kingdom, the Software Architect embarked on a quest to understand the needs of the kingdom's citizens: developers, project managers, and even the elusive users. With a map of requirements in hand, the architect set out to build structures that not only met the immediate demands but also anticipated the challenges that lay ahead.

On this journey, the Software Architect encountered various challenges: dragons of technical debt, treacherous swamps of conflicting requirements, and the labyrinthine maze of legacy code. Yet, armed with the sword of architectural patterns and the shield of modular design, our protagonist persevered.

Architectural patterns were like spells in the architect's magical repertoire, enabling the creation of robust fortresses against bugs and vulnerabilities. Each line of code was carefully woven into the fabric of the architecture, forming a tapestry that told the story of both the present and the future.

In the kingdom of Codeburg, collaboration was key, and the Software Architect became a maestro orchestrating the symphony of developers. Meetings were not mere gatherings but strategic councils, where decisions were made with foresight, and everyone had a role to play in the grand design.

As the Software Architect's influence spread, so did the understanding of the importance of testability. Testing became an integral part of the architecture, ensuring that every component could withstand the fires of scrutiny. The architect, like a vigilant sentinel, introduced continuous integration and continuous delivery, forging a path where changes were seamless, and the kingdom's software evolved with grace.

The tale of the Software Architect in Codeburg became legendary. The kingdom prospered, and the architects who followed in the footsteps of their predecessors continued to build upon the legacy, adapting to new technologies and challenges.

And so, the story goes on in Codeburg, where the Software Architect remains a guardian of innovation, a weaver of digital dreams, and a beacon of wisdom in the ever-expanding landscape of software architecture.

Okay, this story above sounds more like a childhood fairy tale than an explanation of what software architecture entails, but I felt it was a fitting introduction because I think that software architecture is often not given the right importance in the software world. As a result, the idea of what a software architect does can oftentimes feel like the stuff of fantasy than what actually occurs in the average company.

I have seen it many times when companies end up suffering under the weight of incorrectly architected applications, either stuck with software that is not performant, is buggy, or is expensive to operate and maintain. These companies will then put pressure on engineering teams to try and fix the issues and turn things around while trying to deliver more features at an increasing pace, rather than revisiting their design. This leads to frustrated teams and excessive maintenance that makes the software delivery more expensive than it needs to be. Something which can be fine for many large organizations, but has killed off far too many start-ups.

Which is one of the reasons why I feel this book is so important. While most companies have software architects and rely heavily on their software architecture roadmap for their development delivery, their role is often not prioritized. Architects are often not empowered enough. Giving decision-making to managers and CTOs, who may not be skilled enough in this department, leads to them making decisions on the strategy of the company. These decisions are based on what they feel is best for the business and not necessarily based on what is right for the software solution, leaving the software and its resultant delivery in a mess. All because proper software architectural procedures were not followed, and the company likely did not listen.

The hope is that by empowering more people to understand the critical role that software architecture plays in the software delivery process, we can increase awareness across engineering teams. As more engineers grasp its importance, we can begin to see teams and companies place greater emphasis on proper software design. This, in turn, will empower architects to take the lead in driving technical decision-making within companies.

During this book, we will frequently revisit our world of *Codeburg* to explain aspects of software architecture more plainly, but we will also spend many chapters delving into technical topics that explain some architectural terms in more detail.

So, whether you come from a technical background or are new to the world of software architecture, you will hopefully be able to take something away from this book.

CHAPTER 1
Defining Software Architecture

Introduction

Upon reading the prologue of the book, you must have understood that software architecture is important and should not exist in the world of fairy tales—what is software architecture, and what does it entail?

Software architecture refers to the high-level structuring of a software system, which involves making key design decisions to ensure that the system's components work cohesively to meet the specified requirements. It encompasses various elements, such as the organization of software components, the interaction patterns among them, and the guidelines governing their design and evolution.

While other roles in the software development process are involved in the creation of specific functions, algorithms, and executable code that make the software work, the software architect is more concerned with how everything will fit together and focuses on the bigger structure of the software applications. They are also concerned about how the various components should fit together, and not just the code that will achieve the end result.

This does not mean that the software architect is not concerned with the code or involved in the coding process. A successful software architect needs to be very familiar with the coding patterns and style. They need to achieve their overall vision for the software in development and be capable enough to review and take accountability that the delivered code meets their purposes. At a high level, a software architect is focused on the various aspects of software design, which we will be discussing in the chapter ahead.

Structure

In this chapter, we will discuss the following topics:

- Structural elements
- Architectural patterns and styles
- Architectural decision making
- Architecture in software development lifecycle

Objectives

By the end of this chapter, you will be able to understand the role of software architecture in the software development landscape and how it fits across all other processes. This chapter sets the basis for topics that we will discuss in later chapters.

Structural elements

These are different types of software components that are required to work together to create a final cohesive application or user experience. We will look at each of these aspects in more detail in *Chapter 7, Architectural Components*:

- **Components:** The modular building blocks of a system that encapsulate specific functionalities.
- **Connectors**: The mechanisms that enable communication and interaction between components (for example, APIs, messaging protocols).
- **Data**: The way information is stored, accessed, and managed within the system.

Architectural patterns and styles

Patterns represent bigger design processes that are followed across an application's design. They help us understand how certain structural elements fit together and provide a cohesive flow of data and information between the different structural elements. The following are some important attributes that need to be considered in software architecture:

- **Design patterns**: Reusable solutions for common design problems that help in creating flexible and maintainable software.
- **Architectural styles**: High-level patterns that define the overall organization and structure of a system (for example, client-server, microservices, monolithic).

- **Quality attributes**: Software architecture focuses not just on trying to solve for the existing functional purposes of an application, but also needs to keep in mind various quality aspects to ensure the software meets the long-term needs.

  We will unpack some of these important quality attributes in *Chapter 3, Architectural Properties*.

  Some high-level considerations in this area are outlined as follows:

  - **Performance**: How well the system responds to user inputs and handles load.
  - **Scalability**: The system's ability to grow and handle increased demand.
  - **Reliability**: The system's ability to consistently perform as expected under various conditions.
  - **Maintainability**: How easily the system can be updated, extended, or modified.
  - **Security**: Measures taken to protect the system against unauthorized access and data breaches.

- **Design principles**: Along with building the bigger patterns in how applications work, it is also important for software architecture to focus on important design principles that ensure the software can meet the quality attributes design.

  The following is an example of two different design principles, though we will unpack these in more detail in later chapters on architectural styles and architectural patterns:

  - **SOLID principles**: A set of five design principles for writing maintainable and scalable software.
  - **Separation of Concerns**: Dividing a software system into distinct sections, each addressing a different concern. This is something we will unpack further in *Chapter 4, The Importance of Modularity*, when we speak about design modularity.

- **Service-oriented architecture** (**SOA**): Designing software as a set of loosely coupled, independently deployable services.
- **Microservices**: Breaking down a system into small, independent services that can be developed, deployed, and scaled independently.

Architectural decision making

Often when designing software, you will come across times when there is no one best approach to design your application or part of an application. Architects will then be