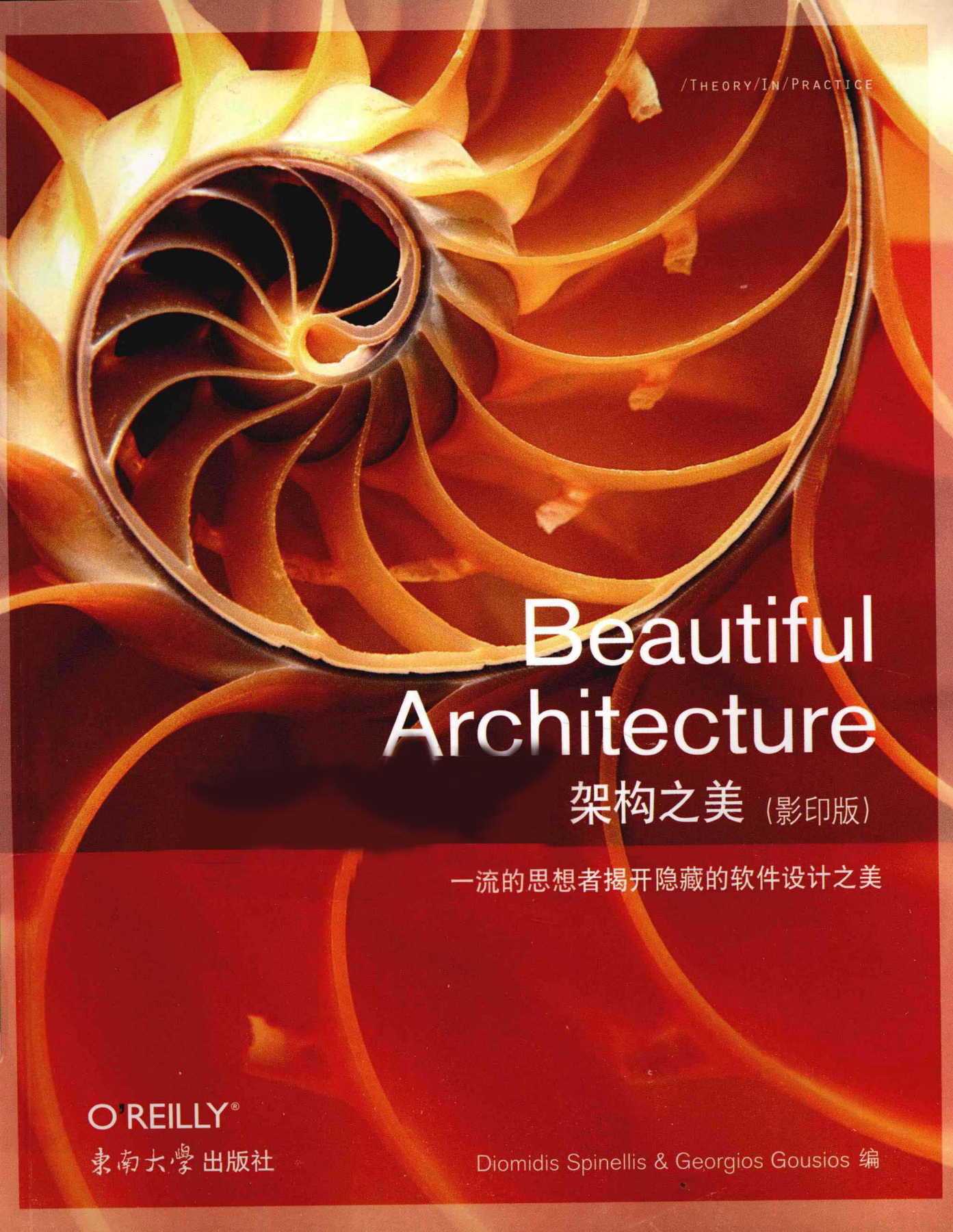
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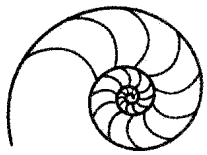
Beautiful Architecture



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Foreword

Stephen J. Mellor

THE CHALLENGES OF DEVELOPING HIGH-PERFORMANCE, HIGH-RELIABILITY, and high-quality software systems are too much for ad hoc and informal engineering techniques that might have worked in the past on less demanding systems. The complexity of our systems has risen to the point where we can no longer cope without developing and maintaining a single overarching architecture that ties the system into a coherent whole and avoids piecemeal implementation, which causes testing and integration failures.

But building an architecture is a complex task. Examples are hard to come by, due to either proprietary concerns or the opposite, a need to "sell" a particular architectural style into a wide range of environments, some of which are inappropriate. And architectures are big, which makes them difficult to capture and describe without overwhelming the reader.

Yet beautiful architectures exhibit a few universal principles, some of which I outline here:

One fact in one place

Duplication leads to error, so it should be avoided. Each fact must be a single, nondecomposable unit, and each fact must be independent of all other facts. When change occurs, as it inevitably does, only one place need be modified. This principle is well known to database designers, and it has been formalized under the name of *normalization.* The principle also applies less formally to behavior, under the name *factoring,* such that common functionality is factored out into separate modules.

Beautiful architectures find ways to localize information and behavior. At runtime, this manifests as *layering*, the notion that a system may be factored into layers, each representing a *layer of abstraction* or *domain*.

Automatic propagation

One fact in one place sounds good, but for efficiency's sake, some data or behavior is often duplicated. To maintain consistency and correctness, propagation of these facts must be carried out automatically at construction time.

Beautiful architectures are supported by construction tools that effect *meta-programming*, propagating one fact in one place into many places where they may be used efficiently.

Architecture includes construction

An architecture must include not only the runtime system, but also how it is constructed. A focus solely on the runtime code is a recipe for deterioration of the architecture over time.

Beautiful architectures are *reflective*. Not only are they beautiful at runtime, but they are also beautiful at construction time, using the same data, functions, and techniques to build the system as those that are used at runtime.

Minimize mechanisms

The best way to implement a given function varies case by case, but a beautiful architecture will not strive for "the best." There are, for example, many ways of storing data and searching it, but if the system can meet its performance requirements using one mechanism, there is less code to write, verify, maintain, and occupy memory.

Beautiful architectures employ a minimal set of mechanisms that satisfy the requirements of the whole. Finding "the best" in each case leads to proliferation of error-prone mechanisms, whereas adding mechanisms parsimoniously leads to smaller, faster, and more robust systems.

Construct engines

If you wish to build brittle systems, follow Ivar Jacobson's advice and base your architecture on use cases and one function at a time (i.e., use "controller" objects). Extensible systems, on the other hand, rely on the construction of virtual machines—engines that are "programmed" by data provided by higher layers, and that implement multiple application functions at a time.

This principle appears in many guises. "Layering" of virtual machines goes back to Edsger Dijkstra. "Data-driven systems" provide engines that rely on coding invariants in the system, letting the data define the specific functionality in a particular case. These engines are highly reusable—and beautiful.

O(G), the order of growth

Back in the day, we thought about the "order" of algorithms, analyzing the performance of sorting, say, in terms of the time it takes to sort a set of a certain number of elements. Whole books have been written on the subject.

The same applies for architecture. Polling, for example, works well for a small number of elements, but is a response-time disaster as the number of items increases. Organizing everything around interrupts or events works well until they all go off at once. Beautiful architectures consider the direction of likely growth and account for it.

Resist entropy

Beautiful architectures establish a path of least resistance for maintenance that preserves the architecture over time and so slows the effects of the Law of System Entropy, which states that systems become more disorganized over time. Maintainers must internalize the architecture so that changes will be consistent with it and not increase system entropy.

One approach is the Agile concept of the *Metaphor*, which is a simple way to represent what the architecture is "like." Another is extensive documentation and threats of unemployment, though that seldom works for long. Usually, however, it generally means tools, especially for generating the system. A beautiful architecture must remain beautiful.

These principles are highly interrelated. One fact in one place can work only if you have automatic propagation, which in turn is effective when the architecture takes construction into account. Similarly, constructing engines and minimizing mechanisms support one fact in one place. Resisting entropy is a requirement for maintaining an architecture over time, and it relies on the architecture including construction and support for propagation. Moreover, a failure to consider the way in which a system will likely grow will cause the architecture to become unstable, and eventually fail under extreme but predictable circumstances. And combining minimal mechanisms with the notion of constructing engines means that beautiful architectures usually feature a limited set of patterns that enable construction of arbitrary system extensions, a kind of "expansion by pattern."

In short, beautiful architectures do more with less.

As you read this book, ably assembled and introduced by Diomidis Spinellis and Georgios Gousios, you might look for these principles and consider their implications, using the specific examples presented in each chapter. You might also look for violations of these principles and ask whether the architecture is thus ugly or whether some higher principle is involved.

During the development of this Foreword, your authors asked me if I might say a few words about how someone becomes a good architect. I laughed. If we only knew that.... But then I recalled from my own experience that there is a powerful, if nonanalytic, way of becoming a

beautiful architect. That way* is never to believe that the last system you built is the only way to build systems, and to seek out many examples of different ways of solving the same type of problem. The example beautiful architectures presented in this book are a step forward in helping you meet that goal.

* Or exercise more and eat less.

Preface

THE IDEA FOR THE BOOK YOU'RE READING WAS CONCEIVED IN 2007 as a successor to the award-winning, best-selling *Beautiful Code*: a collection of essays about innovative and sometimes surprising solutions to programming problems. In *Beautiful Architecture*, the scope and purpose is different, but similarly focused: to get leading software designers and architects to describe a software architecture of their choice, peeling back the layers of their creations to show how they developed software that is functional, reliable, usable, efficient, maintainable, portable, and, yes, elegant.

To put together this book, we contacted leading architects of well-known or less-well-known but highly innovative software projects. Many of them replied promptly and came back to us with thought-provoking ideas. Some of the contributors even caught us by surprise by proposing not to write about a specific system, but instead investigating the depth and the extent of architectural aspects in software engineering.

All chapter authors were glad to hear that the work they put in their chapters is also helping a good cause, as the royalties of this book are donated to *Medécins Sans Frontières* (Doctors Without Borders), an international humanitarian aid organization that provides emergency medical assistance to suffering people.

How This Book Is Organized

We have organized the contents of this book around five thematic areas: overviews, enterprise applications, systems, end-user applications, and programming languages. There is an obvious, but not deliberate, lack of chapters on desktop software architectures. Having approached more than 50 software architects, this result was another surprise for us. Are there really no shining examples of beautiful desktop software architectures? Or are talented architects shying away from an area often driven by a quest to continuously pile ever more features on an application? We are really looking forward to hearing from you on these issues.

Part I: On Architecture

Part I of this book examines the breadth and scope of software architecture and its implications for software development and evolution.

Chapter 1, *What Is Architecture?*, by John Klein and David Weiss, defines software architecture by examining the subject through the perspectives of quality concerns and architectural structures.

Chapter 2, *A Tale of Two Systems: A Modern-Day Software Fable*, by Pete Goodliffe, provides an allegory on how software architectures can affect system evolution and developer engagement with a project.

Part II: Enterprise Application Architecture

Enterprise systems, the IT backbone of many organizations, are large and often tailor-made conglomerates of software usually built from diverse components. They serve large, transactional workloads and must scale along with the enterprise they support, readily adapting to changing business realities. Scalability, correctness, stability, and extensibility are the most important concerns when architecting such systems. Part II of this book includes some exemplar cases of enterprise software architectures.

Chapter 3, *Architecting for Scale*, by Jim Waldo, demonstrates the architectural prowess required to build servers for massive multiplayer online games.

Chapter 4, *Making Memories*, by Michael Nygard, goes through the architecture of a multistage, multisite data processing system and presents the compromises that must be made to make it work.

Chapter 5, *Resource-Oriented Architectures: Being "In the Web"*, by Brian Sletten, discusses the power of resource mapping when constructing data-driven applications and provides an elegant example of a purely resource-oriented architecture.

Chapter 6, *Data Grows Up: The Architecture of the Facebook Platform*, by Dave Fetterman, advocates data-centric systems, explaining how a good architecture can create and support an application ecosystem.

Part III: Systems Architecture

Systems software is arguably the most demanding type of software to design, partly because efficient use of hardware is a black art mastered by a selected few, and partly because many consider systems software as infrastructure that is "simply there." Seldom are great systems architectures designed on a blank sheet; most systems that we use today are based on ideas first conceived in the 1960s. The chapters in Part III walk you through four innovative systems software architectures, discussing the complexities behind the architectural decisions that made them beautiful.

Chapter 7, *Xen and the Beauty of Virtualization*, by Derek Murray and Keir Fraser, gives an example of how a well-thought-out architecture can change the way operating systems evolve.

Chapter 8, *Guardian: A Fault-Tolerant Operating System Environment*, by Greg Lehey, presents a retrospective on the architectural choices and building blocks (both software and hardware) that made Tandem the platform of choice in high-availability environments for nearly two decades.

Chapter 9, *JPC: An x86 PC Emulator in Pure Java*, by Rhys Newman and Christopher Dennis, describes how carefully designed software and a good understanding of domain requirements can overcome the perceived deficiencies of a programming system.

Chapter 10, *The Strength of Metacircular Virtual Machines: Jikes RVM*, by Ian Rogers and Dave Grove, walks us through the architectural choices required for creating a self-optimizable, self-hosting runtime for a high-level language.

Part IV: End-User Application Architectures

End-user applications are those that we interact with in our everyday computing lives, and the software that our CPUs burn the most cycles to execute. This kind of software normally does not need to carefully manage resources or serve large transaction volumes. However, it does need to be usable, secure, customizable, and extensible. These properties can lead to popularity and widespread use and, in the case of free and open source software, to an army of volunteers willing to improve it. In Part IV, the authors dissect the architectures and the community processes required to evolve two very popular desktop software packages.

Chapter 11, *GNU Emacs: Creeping Featurism Is a Strength*, by Jim Blandy, explains how a set of very simple components and an extension language can turn the humble text editor into ~~an operating system~~* the Swiss army knife of a programmer's toolchest.

* As some die-hard users say, "Emacs is my operating system; Linux just provides the device drivers."

Chapter 12, *When the Bazaar Sets Out to Build Cathedrals,* by Till Adam and Mirko Boehm, demonstrates how community processes such as sprints and peer-reviews can help software architectures evolve from rough sketches into beautiful systems.

Part V: Languages and Architecture

As many people have pointed out in their works, the programming language we use affects the way we solve a problem. But can a programming language also affect a system's architecture and, if so, how? In the architecture of buildings, new materials and the adoption of CAD systems allowed the expression of more sophisticated and sometimes strikingly beautiful designs; does the same also apply to computer programs? Part V, which contains the last two chapters, investigates the relationship between the tools we use and the designs we produce.

Chapter 13, *Software Architecture: Object-Oriented Versus Functional,* by Bertrand Meyer, compares the affordances of object-oriented and functional architectural styles.

Chapter 14, *Rereading the Classics,* by Panagiotis Louridas, surveys the architectural choices behind the building blocks of modern and classical object-oriented software languages.

Finally, in the thought-provoking Afterword, William J. Mitchell, an MIT Professor of Architecture and Media Arts and Sciences, ties the concept of beauty between the building architectures we encounter in the real world and the software architectures residing on silicon.

Principles, Properties, and Structures

Late in this book's review process, one of the reviewers asked us to provide our personal opinion, in the form of commentary, on what a reader could learn from each chapter. The idea was intriguing, but we did not like the fact that we would have to second-guess the chapter authors. Asking the authors themselves to provide a meta-analysis of their writings would lead to a Babel tower of definitions, terms, and architectural constructs guaranteed to confuse readers. What was needed was a common vocabulary of architectural terms; thankfully, we realized we already had that in our hands.

In the Foreword, Stephen Mellor discusses seven principles upon which all beautiful architectures are based. In Chapter 1, John Klein and David Weiss present four architecture building blocks and six properties that beautiful architectures exhibit. A careful reader will notice that Mellor's principles and Klein's and Weiss's properties are not independent of each other. In fact, they mostly coincide; this happens because great minds think alike. All three, being very experienced architects, have seen many times in action the importance of the concepts they describe.

We merged Mellor's architectural principles with the definitions of Klein and Weiss into two lists: one containing principles and properties (Table P-1), and one containing structures (Table P-2). We then asked the chapter authors to mark the terms they thought applied to their chapters, and produced a corresponding legend for each chapter. In these tables, you can see the definition of each principle, property, or architectural construct that appears in the chapter legend. We hope the legends will guide your reading of this book by giving you a clean overview of the contents of each chapter, but we urge you to delve into a chapter's text rather than simply stay with the legend.

TABLE P-1. Architectural principles and properties

Principle or property	**The ability of an architecture to...**
Versatility	...offer "good enough" mechanisms to address a variety of problems with an economy of expression.
Conceptual integrity	...offer a single, optimal, nonredundant way for expressing the solution of a set of similar problems.
Independently changeable	...keep its elements isolated so as to minimize the number of changes required to accommodate changes.
Automatic propagation	...maintain consistency and correctness, by propagating changes in data or behavior across modules.
Buildability	...guide the software's consistent and correct construction.
Growth accommodation	...cater for likely growth.
Entropy resistance	...maintain order by accommodating, constraining, and isolating the effects of changes.

TABLE P-2. Architectural structures

Structure	**A structure that...**
Module	...hides design or implementation decisions behind a stable interface.
Dependency	...organizes components along the way where one uses functionality of another.
Process	...encapsulates and isolates the runtime state of a module.
Data access	...compartmentalizes data, setting access rights to it.

Conventions Used in This Book

The following typographical conventions are used in this book:

Italic
: Indicates new terms, URLs, email addresses, filenames, and file extensions.

`Constant width`

Used for program listings, as well as within paragraphs to refer to program elements such as variable or function names, databases, data types, environment variables, statements, and keywords.

`Constant width bold`

Shows commands or other text that should be typed literally by the user.

`Constant width italic`

Shows text that should be replaced with user-supplied values or by values determined by context.

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