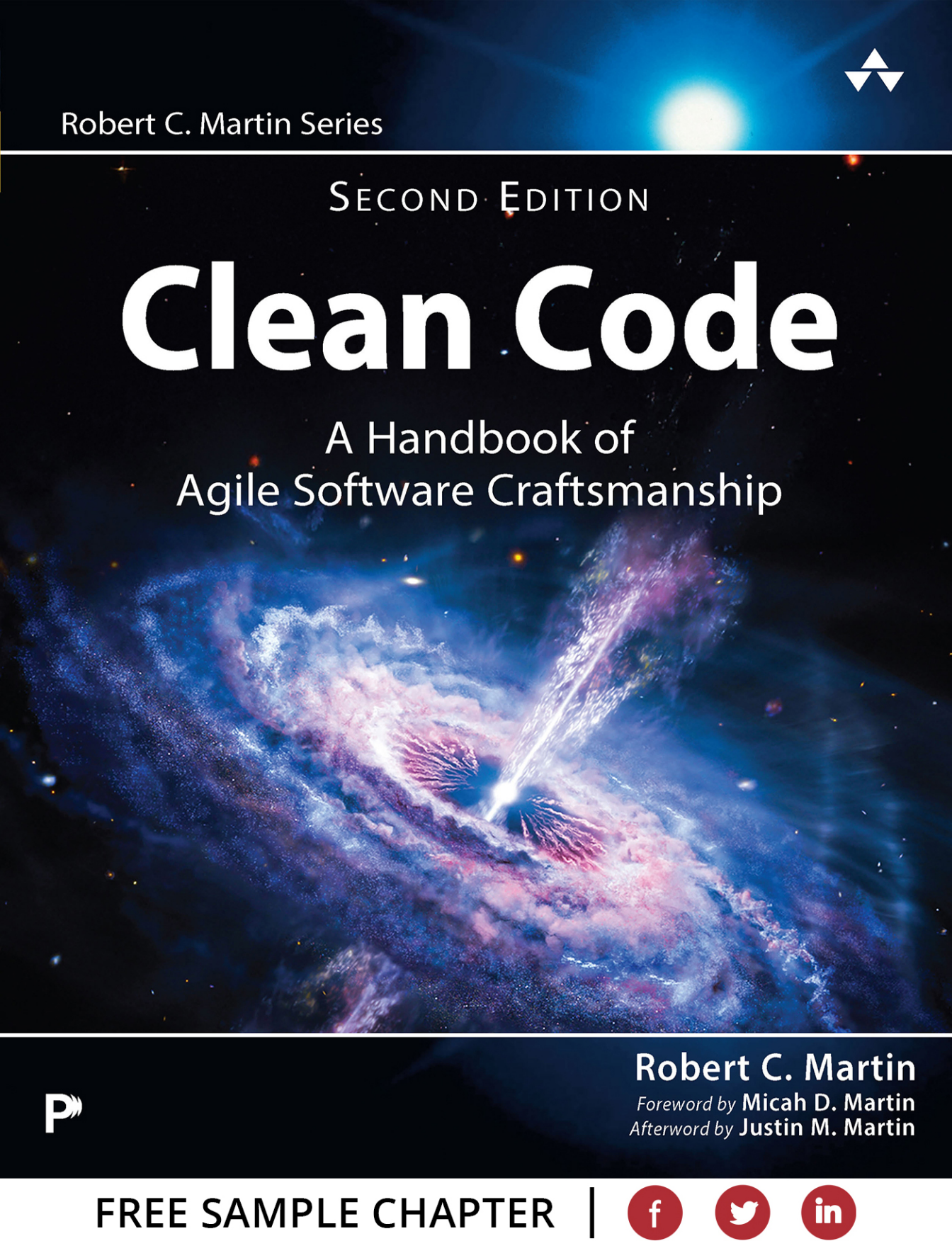
Robert C. Martin Series
SECOND EDITION
Clean Code
A Handbook of
Agile Software Craftsmanship
Robert C. Martin
Foreword by Micah D. Martin
Afterword by Justin M. Martin
FREE SAMPLE CHAPTER

Praise for the First Edition of Clean Code

"*Clean Code* has changed the way I develop and maintain software in so many ways. It defines so well how code should be written, and I have not only learnt much from this book but have also put into practice many of its gems. I can honestly say that having gone on this journey, it is once again a pleasure to develop software and look at code that you are proud to have written."

—Steve Roberts, head of IT

"Reading *Clean Code* validated my inner sense of how software should be written, while also improving the quality of my work by teaching me things I didn't know. I'm grateful for this book and others by the same author as they remain fundamental prerequisites, even in the age of AI."

—Milos Baic, developer and solution architect

"[*Clean Code*] was the single most influential thing that I encountered in my career. Provided I was in a team that adhered to it, it took a lot of stress away as the code was suddenly more understandable and thus easier to maintain. To design something with testability in mind eliminated a lot of complexity in design and maintenance. Above all, it made programming feel cozy and fun again. The feeling gets stronger when you move from poor to a cleaner code base."

—Žarko Stojanović, staff software engineer

Robert C. Martin Series

THE ROBERT C. MARTIN SERIES is directed at software developers, team leaders, business analysts, and managers who want to increase their skills and proficiency to the level of a Master Craftsman.

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Clean Code

A Handbook of Agile Software Craftsmanship

SECOND EDITION

Robert C. Martin

Addison-Wesley

Hoboken, New Jersey

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Contents

Foreword

You hold in your hand the secrets for building high-quality software—secrets that will make you better than you are, secrets that will help you become a master craftsman.

Like Antonio Stradivari (perhaps the best luthier ever), Uncle Bob has spent a lifetime curating and developing the best techniques for crafting code. Unlike Stradivari, who hoarded his secrets so that only he could craft the best violins, Uncle Bob shares his secrets willingly, openly, hoping that you too will craft masterful code.

This is the Way: the Way of Clean Code. These are my disciplines, my principles, my techniques. I strive to master them all. Why? Because they make me better. And because this is the way my father taught me.

Yes, Uncle Bob is my father. He bestowed upon me the honor of writing this foreword. Furthermore, please allow me to introduce my brother, Justin, also a

Clean Coder, who wrote the afterword. How appropriate that two second editions of Uncle Bob get to sandwich his second edition of *Clean Code*. (Yeah … that sounded cheesy as I wrote it, but I'm going with it.)

Let me tell you a little about Uncle Bob, or at least the version of him that I know as "Dad."

One of my earliest memories is riding on my dad's shoulders, playing Robot. The rules are simple. My dad was the robot, and he did whatever I told him to do … to a T.

Me: "Go to my room."

Dad: "I don't know how to do that."

Me: Thinking … "Turn."

Dad: "Which way?"

Me: "Turn right."

Dad: Starts turning clockwise. 90°… 180°… 360°… He doesn't stop turning.

Me: "STOP!"

Dad: Stops. Stands still, facing the absolute wrong direction.

Me: "Turn right … STOP!"

Dad: Turns and stops obediently. We are now facing down the hallway, the right direction.

Me: "Start walking."

Dad: "I don't know how to walk."

For the next few minutes, I teach the robot how to "walk" by lifting a leg the appropriate amount and falling forward, then repeating with the other leg. We agree to name this activity "walking."

Me: "Start walking."

Dad: Starts walking.

Me: Feeling exhausted by this ignorant robot, but also victorious that I successfully made it do my bidding, I prepare for the final maneuver, a left turn at the end of the hall. "Turn left!"

Dad: "I am still walking" … and CRASH we go into the wall. Apparently the robot was single threaded. We bounce off the wall and the robot continues to walk … CRASH we go into the wall again … and again.

Me: Laughing uncontrollably.

At that tender age of 4 or 5 years old, my dad was teaching me how to program with the Robot game. It was fun. Fast-forward 5 years, and my dad brings home a Commodore 64. "What is it?" I inquired. "A computer," my dad responded. "What is it for?" I asked, still confused. "Well, with a computer you can blah blah blah blah, blah blah, you can even play games."

"Games? Show me!" I adopted that Commodore 64, or maybe my dad gave it to me … regardless, it lived in my room and I played *lots* of games on it. There was a kid in my neighborhood who knew how to pirate games, and we'd do a weekly floppy disk exchange. Other than loading games from disks, I didn't really know how to use the computer, and anytime something went wrong, like "PRESS PLAY ON TAPE" … I'd shout "DAD! HELP!"

At one point, he sat me down at the Commodore and introduced me to Logo, a programming language with turtle graphics. He showed me how to make the turtle turn, move forward. It was the Robot game! I played with Logo for a while and it was … boring. Back to gaming.

Then, I observed my dad working with Logo for what seemed like forever but was probably just a couple days. When he was finally done monopolizing my computer, he showed me his Lunar Lander game that he'd just built. It was a jaw-dropping moment as I realized this is how games are built. Wow! Lunar Lander was inducted into my game rotation, and I proudly showed it off to my friends.

A couple of years later, my dad brought home a brand-new Apple Macintosh. It was AMAZING. "What's that thing?" "This is a mouse." So novel. And it had more games. Better games! The Mac lived in my dad's office (basement), but when he was at work, the Mac was mine. Similar to the Lunar Lander incident, my dad spent weeks monopolizing the Mac to create a game he called "Pharaoh." Pharaoh was much bigger than Lunar Lander. You were the pharaoh, and your goal was to buy enough oxen, plant enough crops, and sustain enough workers every year to build a pyramid before you died. It was a fun game, and I could tell my dad had fun building it.

Programming is so much fun! That's the conclusion I had when I reached college age. For my whole childhood, if I wasn't having fun playing on the computers, my dad was having fun programming them. Why would I choose any other major than computer science? Programming in college was … not fun. Upon graduating, I was offered a job at ThoughtWorks and, thank goodness, my dad offered me a job working with him at Object Mentor. Of course, I accepted my dad's offer, where I got to work with some of the biggest names and best software guys in the industry. Once again, programming was fun. It was at Object Mentor where I learned the way of Clean Code from my dad, building lots of internal tools and open source projects like FitNesse, that you'll see later in this book.

Object Mentor was primarily a training and consulting business. We told people how to build good software. We didn't really write the software for them. I'll admit that after several years as a trainer, I got an itch to build software again, instead of teaching how to build software.

An opportunity arose, and Object Mentor started developing software for a client. It was great, and it turned out to be a solid business model. So, I convinced my dad that Object Mentor should do more software development contracts. He agreed. And then I tried to convince him that I should run that branch of the business. Oops … that was one step too far. His response hit me like a truck. "If you want to run things, you should start your own business." Wow! Was that his way of putting me in my place? Or was he actually suggesting I start my own business? I concluded it was the latter, so I told him, "I quit."

I created a company called 8th Light. It was (and still is) a contract software development company. Clients hired us to build software for them. What was unique about 8th Light was that we practiced the Way of Clean Code. We didn't call it that, because the first edition of *Clean Code* hadn't been written yet. But we put into practice everything that my dad had taught me. The Uncle Bob Way of Coding doesn't have the same ring. Moreover, 8th Light adopted apprenticeship, which is something we had dabbled with at Object Mentor. Everyone who joined 8th Light had to go through a 3-to-12-month apprenticeship where they learned the Way of Clean Code. We were ALL-IN on Clean Code. Did it work? Hell yeah! Demand for Clean Code went through the roof. We couldn't train apprentices fast enough. By the time of my departure from 8th Light in 2015, we had nearly a hundred team members, most of them "Clean Code" Craftsmen working on our clients' projects.

But maybe 8th Light was a fluke. In 2020, my dad and I decided to start Clean Coders Studio. This is a branch off our existing partnership, Clean Coders, where we sell educational software videos (https://cleancoders.com). However, "Studio" is our contract software development branch of the business, and yes, I do run it. Once again, we are ALL-IN on Clean Code, more than ever. Is it working? Hell yeah. Once again, we cannot train apprentices fast enough to meet demand.

The industry wants Clean Code. The industry NEEDS Clean Code. This book is your guide into the world of Clean Code.

I have some advice for you on how to best use this book.

1. **Don't rush it.** There is a lot of ground to cover in these pages. Apprentices at Clean Coders Studio take months to internalize all the material. Don't feel like you need to cram it all in a week.
2. **Use it as a reference.** You might want to stick some tabs on some of the pages. For example, the SOLID principles; you'll likely want to jump

back to that section when you're trying to debate a code smell with your peers.

3. **Read the code examples.** When Uncle Bob walks through code changes, like the Video Store, you might be tempted to skip to the end. Don't. Follow along. Ideally, you'd have Uncle Bob sitting next to you, pairing with you on this code. His walk-throughs are the next best thing.
4. **Practice.** "Calculus is not a spectator sport." I can still hear my professor recite that when he assigned homework. Coding is not a spectator sport either. You need to practice it to internalize it. Especially TDD.
5. **Have fun!** Uncle Bob has fun when he codes. Trust me, he does. So do I. *Clean Code* should help you have more fun writing code too.

—Micah Daniel Martin

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Introduction

"Code Quality is a mindset that I've seen correlate with wealth and great outcomes over and over again."

—David Heinemeier Hansson (DHH)

As I type this, it has been over a decade and a half since *Clean Code* was first published. Since then, I have participated in many discussions, podcasts, interviews, blog postings, and social network flame wars inspired by that first edition. Recently it occurred to me that there are quite a few more things I could say; and several more that I would say differently than I did in 2008.

I first proposed the *Clean Code* book in April of 2006. This was before there were iPhones. Mobile internet was mostly GPRS, or maybe EDGE. Nobody was talking about the Internet of Things. YouTube was barely one year old, and hardly anyone had heard of it—fewer took it seriously. Languages like Kotlin, Swift, Go, Dart, Rust, Elm, Elixir, and Clojure had not yet appeared. *Meet the Fockers* was the top-grossing movie up to that point.

Yeah, that was a long time ago—especially in internet time. So, it's time to take a new look at the old message of *Clean Code*. The essence of that message has not changed; but after a decade and a half our industry has—and remarkably so. After so much change, it would be irresponsible to just dust off the old manuscript and make a few simple adjustments. So, in light of that decade and a half of progress, learning, and change, I decided to significantly restate and expand the original message.

I have added many new chapters, new ideas, and new disciplines. I have added newer languages, and newer paradigms. I have also revamped the older chapters with a decade and a half of newer insights and knowledge.

I have added chapters on design, architecture, and even ethics. These were missing from the first edition, and I felt it necessary to repair that omission. In some cases, these chapters are heavily edited and abridged excerpts from my

more recent books, *Clean Architecture* and *Clean Craftsmanship*; others are entirely new.

In the original edition, I was reluctant to assert my ideas as anything more than one programmer's way of looking at things. Now, many years later, I'm a bit more confident than that. The ideas in that original edition have withstood the test of time and have quite a bit more staying power.

On the other hand, there are other very experienced programmers who have different ideas, and I thought it wise to include some of their contrary viewpoints. After all, I'm not the only one who has ideas about what it means for code to be clean. I like my ideas best, but I think all creditable ideas should be heard and considered.

On yet another hand, in the process of reviewing the newer chapters months after they had been written, I was surprised to find that I had issues with some of the examples I had posed. Rather than erasing that surprise by further "cleaning" the examples, I added some Future Bob comments so that you could see my own reaction.

Why is all this cleanliness important? What benefits do these ideas about clean code bring? Why should we be worried about code cleanliness at all?

Our civilization depends upon us. Nothing happens in our society without computers being intimately involved in virtually every aspect of our lives. Nowadays we cannot microwave a hot dog, watch TV, make a phone call, drive to the store, wash our dishes or our clothes, buy anything, sell anything, or even tell the time of day without software being smack in the middle of it all.

You and I, we programmers, rule the world. Other people think they rule the world, but then they hand those rules to us, and *we* write the rules—the software—that executes in the machines that sit in the middle of the details of billions of people's lives.

And some of the software we wrote has caused two fully loaded passenger jets to slam into the ground at near the speed of sound, cars to accelerate out of control and crash, billions of dollars to be lost in seconds, rockets to explode, spacecraft to crash into Mars, and noxious fumes to be emitted by tens of thousands of cars. Just for starters.

And with such a burden of responsibility and failure sitting upon us, we have to ask ourselves this question: Are we professionals?

A professional is someone who professes a set of standards, disciplines, and ethics. Do we? Do you? If so, can you recite them?

My goal for this book is to provide some standards of code cleanliness, some disciplines of code creation and maintenance, and the beginnings of an ethical framework to help us define a true profession. Because if we don't define and adopt that profession, others who are less able but more powerful—the politicians of the world—will define it for us and force it down our throats.

I hope there's still time for us to get there before that idea occurs to them.

A NOTE ABOUT OLDER CHAPTERS

I have taken a great deal of liberty with the older chapters for which I was the sole author. In many cases they have been completely rewritten, or very substantially edited.

Most of the authors of the chapters that I did not write have submitted second editions of their chapters to this effort.

THE STRUCTURE OF THIS BOOK

Possibly the greatest change between the first and second editions is the structure of the material. I have divided the book into four parts: Code, Design, Architecture, and Craftsmanship.

These parts are not independent of each other.

Part I: Code strongly depends upon Part II: Design. As you read Part I, you will find many references to design principles and design strategies that are described in Part II. I encourage you to treat Part II as a reference that you can consult while reading Part I. Then, when you are done with Part I, you should read Part II in its entirety.

Part III: Architecture is a set of deeply edited and abridged excerpts from my book *Clean Architecture*. Again, consider it a reference to assist in your understanding of Part I. However, it also stands alone as a simple introduction to higher-level architectural principles.

Part IV: Craftsmanship is, once again, a set of deeply edited and abridged excerpts from my book *Clean Craftsmanship*—specifically the chapters that have to do with the ethics of software development. It is included as a way to underscore that there is an ethical imperative to writing clean code.

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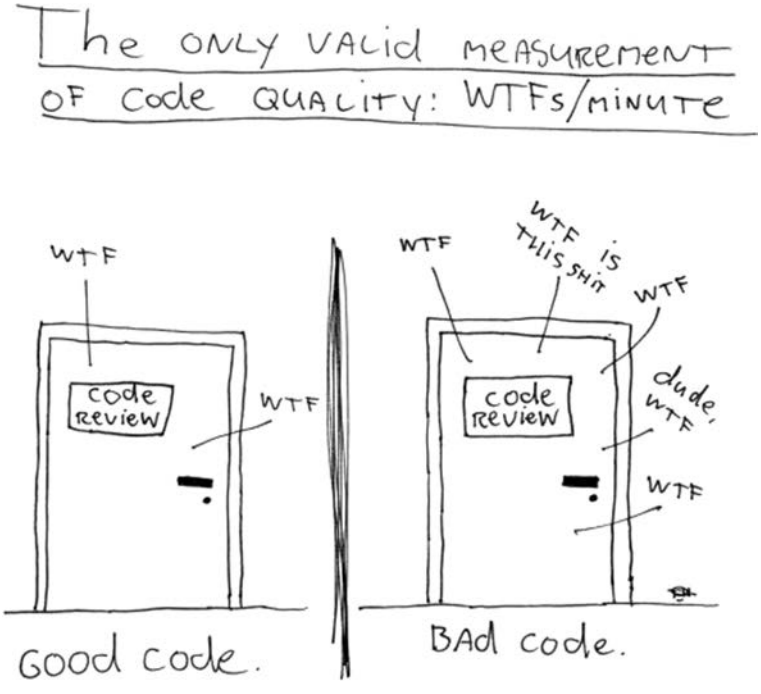
Introduction (from Long Ago)

This is the Introduction to the first edition and has been edited and abridged.



Reproduced with the kind permission of Thom Holwerda (www.osnews.com/story/19266/WTFs_m).

Look at the drawing above. Which door represents your code? Which door represents your team or your company? Why are we in that room? Is this just a normal code review or have we found a stream of horrible problems shortly after going live?

Are we debugging in a panic, poring over code that we thought worked? Are customers leaving in droves and managers breathing down our necks? How can we make sure we wind up behind the right door when the going gets tough? The answer is: craftsmanship.

There are two parts to learning craftsmanship: knowledge and work. You must gain the knowledge of principles, patterns, practices, and heuristics that a craftsman knows, and you must also grind that knowledge into your fingers, eyes, and gut by working hard and practicing.

I can teach you the physics of riding a bicycle. Indeed, the classical mathematics is relatively straightforward. Gravity, friction, angular momentum, center of mass, and so forth can be demonstrated with less than a page full of equations. Given those formulae, I could prove to you that bicycle riding is practical and give you all the knowledge you needed to make it work.

And you'd still fall down the first time you climbed on that bike.

Coding is no different. We could write down all the "feel good" principles of clean code and then trust you to do the work (in other words, let you fall down when you get on the bike), but then what kind of teachers would that make us, and what kind of student would that make you?

No. That's not the way this book is going to work.

Learning to write clean code is hard work. It requires more than just the knowledge of principles and patterns. You must *sweat* over it. You must practice it yourself, and watch yourself fail. You must watch others practice it and fail. You must see them stumble and retrace their steps. You must see them agonize over decisions and see the price they pay for making those decisions the wrong way.

Be prepared to work hard while reading this book. This is not a "feel good" book that you can read on an airplane and finish before you land. This book will make you work, *and work hard*. What kind of work will you be doing? You'll be reading code—lots of code. And you will be challenged to think about what's right about that code and what's wrong with it. You'll be asked to follow along as we (the authors) take modules apart and put them back together again. This will take time and effort; but we think it will be worth it.

About the Author

Robert C. Martin (**Uncle Bob**) has been a programmer since 1970. He is founder of Uncle Bob Consulting, LLC, and cofounder with his son Micah Martin of Clean Coders, LLC. Martin has published dozens of articles in various trade journals and is a regular speaker at international conferences and trade shows. He has authored and edited many books, including *Designing Object-Oriented C++ Applications Using the Booch Method*; *Pattern Languages of Program Design 3*; *More C++ Gems*; *Extreme Programming in Practice*; *Agile Software Development: Principles, Patterns, and Practices*; *UML for Java Programmers*; *Clean Code*; *The Clean Coder*; and *Functional Design: Principles, Patterns, and Practices*. A leader in the industry of software development, Martin served for three years as editor-in-chief of *The C++ Report*, and he served as the first chairman of the Agile Alliance.

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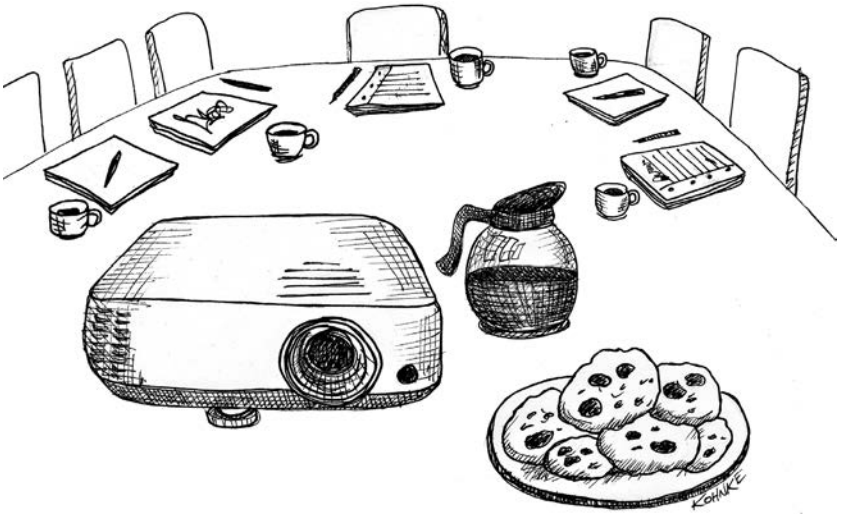
3 First Principles



If you read this chapter and grasp all the principles within, then you'll be 90% of the way toward cleaning code. The ideas presented here are old and well established. They have stood the test of time and should be part of every programmer's regimen of discipline.

Keep in mind that these are not strict laws. They are not rules that must be followed. They are, more or less, guidelines. Each should be applied in the context of the problem at hand, and every programmer should feel free to take whatever license is necessary to solve that problem.

But, when all else is equal, and all the variables are averaged out, these are the principles that I believe emanate from well-cleaned code.

If, as you read what follows, you encounter concepts that are foreign or novel, be assured that all will be explained in subsequent chapters. Indeed, when you have finished reading this book, you may wish to complete the circle by rereading this chapter.

EVERYTHING SMALL, WELL NAMED, ORGANIZED, AND ORDERED

If you stop now and read nothing more than that heading, you'll have much of the essence of what it takes to clean code.

Keep everything small. Choose names for those small elements that communicate to other programmers. Define and maintain a structure and organization that present the software in such a way that others can easily consume it. Keep the elements within that organization well-ordered so that one concept follows another in a rational and sensible way.

Remember that your own understanding of the code will likely bias your attempts at providing good names and structures; so work hard to put yourself in the headspace of those who do not understand the code.

FUNCTIONS

Functions should be small. Most should be just a handful of lines. This allows them to have nice, descriptive names and promotes the separation of concerns. It ensures that each function does one, and only one, thing.

Let's start with the name. If you see a snippet of lines that does something that can be reasonably named, then that snippet should be moved into a function named for what that snippet does. The name should be a verb that says what the function does and that allows the calling sequence to read "like well-written prose."[1]

As an example, consider this function, adapted from the `JCommon` library. It finds the date of a specified weekday before a given date. The weekday codes are integers 1 (Sunday) through 7 (Saturday).

```
public static Date getPreviousDayOfWeek(int weekday, Date from) {
  // check arguments…
  if (!isValidWeekdayCode(weekday)) {
    throw new IllegalArgumentException(
      "Invalid day-of-the-week code."
    );
```

1. Grady Booch, private email.

```
  }

  // find the date…
  final int adjust;
  final int baseDOW = from.getDayOfWeek();
  if (baseDOW > weekday) {
    adjust = Math.min(0, weekday - baseDOW);
  } else {
    adjust = -7 + Math.max(0, weekday - baseDOW);
  }

  return Date.addDays(adjust, from);
}
```

There are at least two snippets of code that we could extract into smaller and better-named functions. And those extractions will lead to some simplifications.

```
public static Date getPreviousDayOfWeek(int weekday, Date from) {
  checkWeekdayArgument(weekday);
  return addDays(-daysBefore(weekday, from), from);
}

private static void checkWeekdayArgument(int weekday) {
  if (!isValidWeekdayCode(weekday))
    throw new IllegalArgumentException(
      "Invalid day-of-the-week code.");
}

private static int daysBefore(int targetWeekday, Date from) {
  int fromWeekday = from.getDayOfWeek();
  int diff = fromWeekday - targetWeekday;
  return diff + (diff > 0 ? 0 : 7);
}
```

Notice how the simplified `getPreviousDayOfWeek` function reads. It's short, and it's obvious. If you need to know more, all you have to do is look down to see the extracted functions. However, most often you would not need to know more. You'd simply look at that function, agree with it, and move on. It may not read like the prose of a Crichton novel, but it reads pretty well.

FUTURE BOB: I don't like the leading minus sign. It would have been better to create a `subtractDays` function in order to get rid of it. That's a small thing, but small things matter.

A MORE SIGNIFICANT EXAMPLE

Here I present the Uncle Bob Conference Room system. Scan through it. It's not very complicated—probably.

```
——Statement.java——
package ubConferenceCenter;

import java.util.ArrayList;
import java.util.List;

public class Statement {
  public enum CatalogItem {SMALL_ROOM, LARGE_ROOM,
                           PROJECTOR, COFFEE, COOKIES}

  public record RentalItem(CatalogItem type,
                           int days,
                           int unitPrice,
                           int price,
                           int tax) {
  }

  public record Totals(int subtotal, int tax) {
  }

  private String customerName;
  private int subtotal = 0;
  private int tax = 0;
  private List<RentalItem> items = new ArrayList<>();

  public Statement(String customerName) {
    this.customerName = customerName;
  }

  public void rent(CatalogItem item, int days) {
    int unitPrice = switch (item) {
      case SMALL_ROOM -> 100;
      case LARGE_ROOM -> 150;
      case PROJECTOR -> 50;
      case COFFEE -> 10;
      case COOKIES -> 15;
    };

    boolean eligibleForDiscount = switch (item) {
      case SMALL_ROOM, LARGE_ROOM -> days == 5;
```

```
      case PROJECTOR, COFFEE, COOKIES-> false;
    };

    int price = unitPrice * days;

    if (eligibleForDiscount) price = (int) Math.round(price * .9);

    subtotal += price;
    int thisTax = switch (item) {
      case SMALL_ROOM, LARGE_ROOM, PROJECTOR ->
           (int) Math.round(price * .05);
      case COFFEE,COOKIES -> 0;
    };
    tax += thisTax;
    items.add(new RentalItem(item, days, unitPrice, price, thisTax));
  }

  public RentalItem[] getItems() {
    List<RentalItem> items = new ArrayList<>(this.items);
    boolean largeRoomFiveDays = items.stream().anyMatch(
      item -> item.type() == CatalogItem.LARGE_ROOM && item.days() == 5);
    boolean coffeeFiveDays = items.stream().anyMatch(
      item -> item.type() == CatalogItem.COFFEE && item.days() == 5);
    if (largeRoomFiveDays && coffeeFiveDays)
      items.add(new RentalItem(CatalogItem.COOKIES, 5, 0, 0, 0));
    return items.toArray(new RentalItem[0]);
  }

  public String getCustomerName() {
    return customerName;
  }

  public Totals getTotals() {
    return new Totals(subtotal, tax);
  }
}
```

I'm sure you figured it out. Users can rent small rooms, large rooms, coffee, projectors, and cookies. (How do you rent cookies?) Small rooms rent for $100 per day. Large rooms are $150. You get a 10% discount if you rent a room for the whole week. There's a 5% (rounded up) tax on all nonfood items. Coffee is $10 per day. Cookies are $15 per day. Projectors are $50 per day. And if you rent a large room and coffee for a whole week, you get one day of free cookies.

The `Statement` class represents a sales statement that includes each item rented, the price of the item, the number of days rented, the subtotal, and the tax. The `Statement` also contains the subtotals of all the items and all the tax.

Easy peasy.

This is not too hard to understand, but you can tell that it was slapped together. It's a bit unkempt, but not terrible. We could probably clean it up a bit, but would that be worth the effort?

But let me ask you. Have you ever seen a system that started out simple and then got much, much more complicated? If you've been in this business for more than a year or so, I *know* you have. Indeed, if you've been in the business for five years or more, you've likely seen a system that began a bit unkempt but grew into a horrible mess, becoming a living hell for the developers and the organization.

So let's make this example a bit more real. You don't suppose that this program started out in its current form, do you? No, at first it just rented one small room. Then, many small rooms. Then, large rooms with a different unit price. Then, coffee, with no sales tax. Then, the discount for a full week was added. And then cookies, and the bonus for renting a large room for a week.

In other words, this program *grew*.

Let's suppose that we've just gotten back from an all-hands meeting at which the CEO gave us a glowing report about how the company is expanding. There are new markets, new states, new laws to contend with. There will be new discounts and new promotions, and new tax regulations. It's going to be great for the business; but you look at this little `rent` function and you think … it's going to continue to grow, isn't it? And as it grows, it will become ever more tangled and confusing. It will degrade, like a piece of rotting meat.

So let's stop that from happening. Let's figure out a way to get ahead of the coming business growth and let this function grow without rotting from the inside out. Let's tidy it up first.[2]

Look back at the `rent` function and ask yourself what you don't like about it. Personally, I think it's a bit large and disorganized. It does several things that I can pull apart into functions that do one thing.

So first, let's just use the extract method refactoring to create functions that do one thing, and gather together the things that are related and separate the things that are different.[3]

——Statement.java——

```
…
  public void rent(CatalogItem item, int days) {
    int unitPrice = getUnitPrice(item);
    int price = calculatePrice(item, days, unitPrice);
    int thisTax = getTax(item, price);
```

2. [Tidy].

3. The Single Responsibility Principle.

```
    items.add(new RentalItem(item, days, unitPrice, price, thisTax));
    subtotal += price;
    tax += thisTax;
  }

  private int getUnitPrice(CatalogItem item) {
    return switch (item) {
      case SMALL_ROOM -> 100;
      case LARGE_ROOM -> 150;
      case PROJECTOR -> 50;
      case COFFEE -> 10;
      case COOKIES -> 15;
    };
  }

  private int calculatePrice(CatalogItem item, int days, int unitPrice) {
    boolean eligibleForDiscount = isEligibleForDiscount(item, days);
    int price = unitPrice * days;
    if (eligibleForDiscount) price = (int) Math.round(price * .9);
    return price;
  }

  private boolean isEligibleForDiscount(CatalogItem item, int days) {
    return switch (item) {
      case SMALL_ROOM, LARGE_ROOM -> days == 5;
      case PROJECTOR, COFFEE, COOKIES-> false;
    };
  }

  private int getTax(CatalogItem item, int price) {
    return switch (item) {
      case SMALL_ROOM, LARGE_ROOM, PROJECTOR ->
           (int) Math.round(price * .05);
      case COFFEE,COOKIES -> 0;
    };
  }
```


FUTURE BOB: Having used Grok3 on the `fromRoman` module in the last chapter, I thought I'd do the same here. So I told Grok3 to improve my initial implementation. It was not particularly surprising that its solution was nearly identical to mine.

Perhaps you look at this and think that it's more code. But it's not more *executable* code; it's just more names and more structure. That extra structure makes room for growth. For example, if the tax rules become more complicated, it is not the `rent` function that will grow; instead, in all likelihood, it will be the `getTax` function that grows.

This is an example of the Single Responsibility Principle (SRP)[4] in action. The stakeholders of our system who are most concerned about taxation will most probably be the only ones asking for changes to the `getTax` function, whereas the stakeholders who are interested in discounts will most likely be the only ones affecting the `calculatePrice` and `isEligibleForDiscount` functions.

This is helpful to us because, after this change, we are not very likely to break the discounts when the taxes change, or break the taxes when the price calculation changes. The farther we can keep these different stakeholders' responsibilities apart and isolated, the safer our code will be when changes are made.

If we ignore the SRP, then we risk the symptom of *fragility*. A fragile system breaks in unexpected ways; for example, when a stakeholder asks us to modify taxes and we inadvertently break discounts. Such occurrences are terrifying to our stakeholders, managers, and users because it gives them a glimpse of what's under the hood; and they don't like what they see.

Our stakeholders have the right to expect that a change to taxes will not break discounts. When we violate that expectation, the only conclusion they can draw is that we've lost control of the system and don't really know what the hell we are doing.

Now look at that new code. What don't you like about it? One thing we might focus on are those `switch` statements.

`Switch` statements aren't intrinsically bad. However, if the number of cases is likely to grow, then they violate the Open–Closed Principle (OCP).

The OCP suggests that when we add a new feature, we should add that new feature in one place, not in many places. Right now, if we were to add a new `CatalogItem`, like `NotePads`, we'd have to add those changes to as many as five different places in the code. We can reduce this down to two by turning the `CatalogItems` into data structures and replacing the `switch` statements with accesses of those data structures.

——Statement.java——

```
…
public enum CatalogItem {
  SMALL_ROOM(100, .05),
  LARGE_ROOM(150, .05),
```

4. See Chapter 19, "The SOLID Principles."

```
  PROJECTOR(50, .05),
  COFFEE(10, 0),
  COOKIES(15, 0);

  private double taxRate;
  private int unitPrice;

  CatalogItem(int unitPrice, double taxRate) {
    this.unitPrice = unitPrice;
    this.taxRate = taxRate;
  }
}
…
public void rent(CatalogItem item, int days) {
  int unitPrice = item.unitPrice;
  int price = calculatePrice(item, days, unitPrice);
  int thisTax = (int) Math.round(price * item.taxRate);
  items.add(new RentalItem(item, days, unitPrice, price, thisTax));
  subtotal += price;
  tax += thisTax;
}
…
```

This is better—I have to say that I like that Java's `enum`s are actually classes, and that each enumerator is an instance. Now when we add `NotePads`, we'll only have to change the enum, and, perhaps, the `getItems` function. However, the OCP tells us to keep new changes out of old modules. So it would be better, from an OCP point of view, to get that `enum` out of the `Statement` module altogether so that when we add `NotePads`, we can leave the `Statement` module untouched.

——CatalogItem.java——

```
package ubConferenceCenter;

public enum CatalogItem {
  SMALL_ROOM(100, .05),
  LARGE_ROOM(150, .05),
  PROJECTOR(50, .05),
  COFFEE(10, 0),
  COOKIES(15, 0);

  public double taxRate;
  public int unitPrice;

  CatalogItem(int unitPrice, double taxRate) {
    this.unitPrice = unitPrice;
    this.taxRate = taxRate;
```

```
  }
}
```

We're doing pretty well here. We've isolated the `CatalogItem` enums, and we've gotten rid of the `switch` statements. The SRP and the OCP are pretty happy. But there's another principle that is sounding an alarm.

What modules ought to be recompiled if we add `NotePads` to `CatalogItem`? Answer: `CatalogItem.java` (of course) and probably[5] `Statement.java` because it depends upon `CatalogItem.java`. Now ask yourself whether `Statement.java` *should have* to be recompiled.

I contend that at least the `rent` function of `Statement.java` should not have to be recompiled when we add `NotePads`, because nothing within that function needs to know anything about `NotePads`.

This is a violation of the Dependency Inversion Principle (DIP). This principle is violated when high-level policies directly depend on low-level details. The addition of `NotePads` is a low-level detail that the `rent` function should not depend upon.

You may not think this is a big issue. Recompiling a module is quick and easy, and why should you care if you compile more modules than is required? For small projects, you could be right to make that decision. But for larger projects, the recompile and redeployment burden can get pretty large. This is especially true for JavaScript applications where redeployments are downloaded into browsers. There's also the cognitive burden of trying to remember which modules depend on which others. So let's assume that this project is becoming large enough for those issues to be a concern. How can we invert the dependencies to reduce the recompilation, redeployment, and cognitive burdens?

The SRP will help us here. The `Statement.java` module is doing two major things. The `rent` method adds `CatalogItems`, and the `getItems` method totals them and computes the cookie bonus. Hmmm, `getItems` isn't the best name, is it? We'll take care of that momentarily. First, we should separate those two major behaviors.

The first step is to pull out the `RentalItem` record into its own module.

```
——RentalItem.java___
package ubConferenceCenter;

public record RentalItem(CatalogItem type,
                         int days,
                         int unitPrice,
                         int price,
```

5. The Java compiler is often smart enough to determine whether or not upstream modules need to be recompiled based on downstream changes. The safe bet, however, is to assume that those modules will be recompiled.

```
                        int tax) {
}
```

Next, we'll create a new module for the `ItemList`.

```
——ItemList.java——
package ubConferenceCenter;

import java.util.ArrayList;
import java.util.List;

public class ItemList {
  private List<RentalItem> items = new ArrayList<>();

  public void add(CatalogItem item, int days, int unitPrice,
                  int price, int thisTax) {
    items.add(new RentalItem(item, days, unitPrice, price, thisTax));
  }

  public RentalItem[] getItems() {
    boolean largeRoomFiveDays = items.stream().anyMatch(
      item -> item.type() == CatalogItem.LARGE_ROOM && item.days() == 5);
    boolean coffeeFiveDays = items.stream().anyMatch(
      item -> item.type() == CatalogItem.COFFEE && item.days() == 5);
    if (largeRoomFiveDays && coffeeFiveDays)
      items.add(new RentalItem(CatalogItem.COOKIES, 5, 0, 0, 0));
    return items.toArray(new RentalItem[0]);
  }
}
```

We'll have to come back to this module because that `getItems` method gives me the willies.[6] It smells of an SRP violation. But for now, all that remains is to make a few adjustments to the `Statement.java` module.

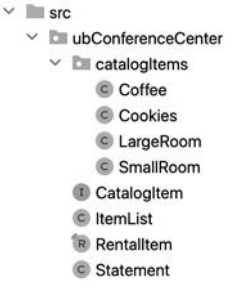
```
…
public class Statement {
  …
  private ItemList items = new ItemList();
  …

  public RentalItem[] getItems() {
    return items.getItems();
  }
  …
}
```

6. An archaic term that means nervous, uneasy, or creeped out. (According to Grok.)

Again, you may be concerned that we're chopping this up into too many pieces, and that all those pieces will make the code harder to understand. But our assumption has been that this code is going to grow, and that we're trying to make room for that growth. In any case, if you look at the directory structure, you'll see that there's a nice road map that will help anyone understand the organization.

Looking at this, you can see that the names may not be perfect, but we'll come back to that when we understand more about where this reorganization is going. In the meantime, we still have to reduce the recompile and redeployment burden.

To do this, we'll change the `CatalogItem` from an `enum` to an `interface`, with each enumeration becoming a derived class. This creates several new classes and makes the directory look like this.




```
——CatalogItem.java——
package ubConferenceCenter;

public interface CatalogItem {
  boolean isEligibleForDiscount(int days);
  int getUnitPrice();
  double getTaxRate();
  String getName();
}
```

This represents a significant change in the way the application works. Now instead of using `switch` and `if` statements to check for enumerators, we defer

to the polymorphic methods of the `CatalogItem` interface. The `getTaxRate` and `getUnitPrice` methods are familiar, but the other two are new. You can see how they are used in the `Statement.java` and `ItemList.java` modules.

```
——Statement.java——
package ubConferenceCenter;

public class Statement {
  …
  public void rent(CatalogItem item, int days) {
    int unitPrice = item.getUnitPrice();
    int price = calculatePrice(item, days, unitPrice);
    int thisTax = (int) Math.round(price * item.getTaxRate());
    items.add(item, days, unitPrice, price, thisTax);
    subtotal += price;
    tax += thisTax;
  }

  private int calculatePrice(CatalogItem item, int days, int unitPrice)
{
    boolean eligibleForDiscount = item.isEligibleForDiscount(days);
    int price = unitPrice * days;
    if (eligibleForDiscount) price = (int) Math.round(price * .9);
    return price;
  }
 …
}

——ItemList.java——
package ubConferenceCenter;

import java.util.ArrayList;
import java.util.List;

public class ItemList {
  private List<RentalItem> items = new ArrayList<>();

  public void add(CatalogItem item, int days, int unitPrice,
                  int price, int thisTax) {
    items.add(new RentalItem(item.getName(), days,
              unitPrice, price, thisTax));
  }

  public RentalItem[] getItems() {
    boolean largeRoomFiveDays = items.stream().anyMatch(
```

```
      item -> item.type().equals("LARGE_ROOM") && item.days() == 5);
    boolean coffeeFiveDays = items.stream().anyMatch(
      item -> item.type().equals("COFFEE") && item.days() == 5);
    if (largeRoomFiveDays && coffeeFiveDays)
      items.add(new RentalItem("COOKIES", 5, 0, 0, 0));
    return items.toArray(new RentalItem[0]);
  }
}
```

Notice that the `type` field of the `RentalItem` record has been changed from the `enum` to a `String`. This was necessary because, when we abandoned the `enum`, we needed some kind of token to represent the `CatalogItem` type; and a `String` seemed the most obvious choice. However, using that string means that we've had to sacrifice a bit of static type safety. The compiler cannot check that those names are correct. This minor loss of static type safety always accompanies the effort to reduce the recompile and redeployment burden, and the isolation of low-level details from high-level policy.

——RentalItem.java——

```
package ubConferenceCenter;

public record RentalItem(String type,
                         int days,
                         int unitPrice,
                         int price,
                         int tax) {
}
```

With the exception of the `getItems` method of the `ItemList` class, the last few listings above represent the high-level policy of the application. We're going to have to do something about that `getItems` method. For now, let's look at how the low-level details have been isolated in the derivatives of `CatalogItem`.

——SmallRoom.java——

```
package ubConferenceCenter.catalogItems;

import ubConferenceCenter.CatalogItem;

public class SmallRoom implements CatalogItem {
  public String getName() {
    return "SMALL_ROOM";
  }

  public boolean isEligibleForDiscount(int days) {
    return days == 5;
```

```
  }

  public int getUnitPrice() {
    return 100;
  }

  public double getTaxRate() {
    return 0.05;
  }
}

——LargeRoom.java——
package ubConferenceCenter.catalogItems;

import ubConferenceCenter.CatalogItem;

public class LargeRoom implements CatalogItem {
  public boolean isEligibleForDiscount(int days) {
    return days == 5;
  }

  public int getUnitPrice() {
    return 150;
  }

  public double getTaxRate() {
    return 0.05;
  }

  public String getName() {
    return "LARGE_ROOM";
  }
}

——Coffee.java——
package ubConferenceCenter.catalogItems;

import ubConferenceCenter.CatalogItem;

public class Coffee implements CatalogItem {
  public boolean isEligibleForDiscount(int days) {
    return false;
  }
```

```
  public int getUnitPrice() {
    return 10;
  }

  public double getTaxRate() {
    return 0;
  }

  public String getName() {
    return "COFFEE";
  }
}

——Cookies.java——
package ubConferenceCenter.catalogItems;

import ubConferenceCenter.CatalogItem;

public class Cookies implements CatalogItem {
  public boolean isEligibleForDiscount(int days) {
    return false;
  }

  public int getUnitPrice() {
    return 15;
  }

  public double getTaxRate() {
    return 0;
  }

  public String getName() {
    return "COOKIES";
  }
}
```

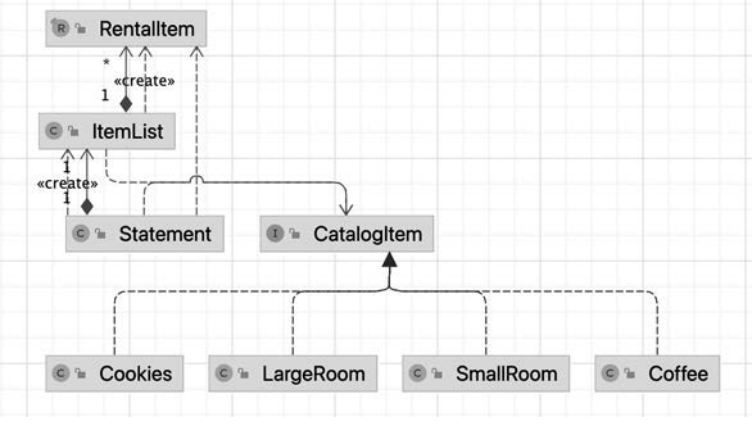
One of the people who commented on the first edition of this book looked at code like this and called it *"just dreadful."* You might be feeling that now too. But remember, we are expecting business growth, and we have decided that it is necessary to make room in this code for that growth.

Some folks might charge us with violating YAGNI. They think it stands for You Aren't Going to Need It. But the original intent of YAGNI was to ask yourself: "What if you aren't going to need it?" It was a way of asking us to

count the cost before we invested in making room in our code for things we might not need.

But given the enthusiasm of the CEO and the kinds of markets he is courting, we have decided we need to make this room. So, in our case, we've decided to answer YAGNI's question with: *"Yes, we are going to need it."*

Why is this code better? Let's look at the dependency diagram generated by my IDE.



The four classes that represent our high-level policy—`RentalItem`, `ItemList`, `Statement`, and `CatalogItem`—are tied together with a rat's nest of dependencies. We'll deal with that later. But look at how well isolated the low-level details are. The previous dependencies have been inverted. Nothing within the high-level policy depends upon the low-level details. The low-level details depend only on the `CatalogItem`. Just say this to yourself, over and over: *High-level policy should not depend on low-level details.*

This means that if any of the low-level details are changed, nothing in the high-level policy ought necessarily to be recompiled or redeployed. Nor will changes to the high-level policy force recompilation and redeployment of the low-level details.

Let me say that differently. If the unit price of `Cookies` changes, or if the tax rate of `Coffee` changes, or if the discount for `SmallRoom` changes, none of the classes in the high-level policy will need to be recompiled or redeployed. Changes to those low-level details are completely isolated from the high-level policy.

Indeed, the low-level details have become a *plug-in* to the high-level policy. Or, at least they are in a position to become such a plug-in.

But now we need to do something about the rat's nest that's caused by the `ItemList`.

We called this class `ItemList` because initially it contained our list of items, and we needed a place to put that bonus code. Now I want to take that bonus code out of there and do to it what we did to the `CatalogItems`. So I'll create a `Bonus` interface and have the `CookieBonus` implement it. The `ItemList` can contain a list of `Bonus` instances and simply iterate through all of them to add all the bonuses. That means that the `ItemList` *finalizes* all the bonuses. And that suggests that the `ItemList` should be renamed something like `RentalReceipt`, since it represents the final state of the order.

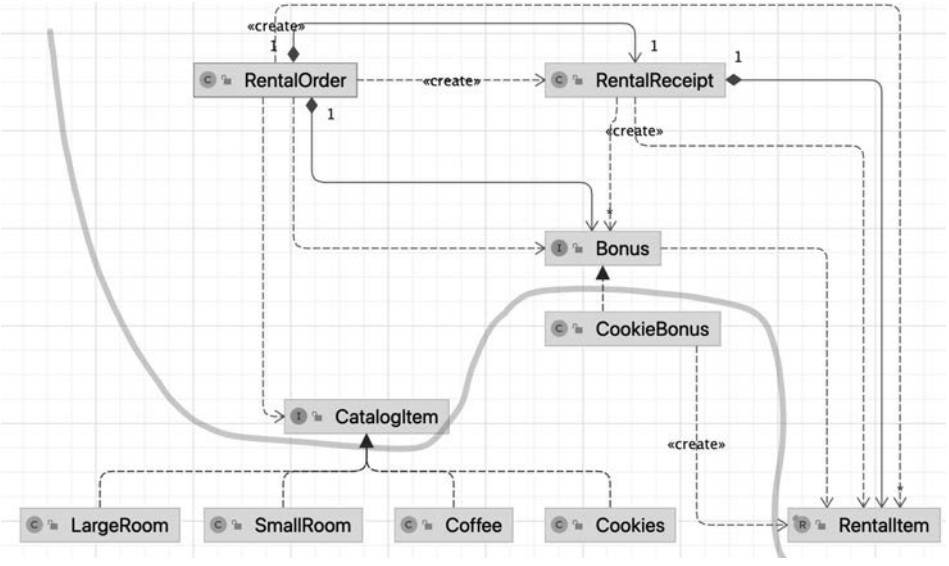
That name change suggests that `Statement` should be renamed something like `RentalOrder`. These name changes are important. As we pick apart the design and start making room for growth, we gain insights into what's really going on. When the problem is small, names can afford to be inconsistent or vague because there aren't that many concepts to keep track of. But as the problem grows, names become much more important because they help us keep the concepts straight in our heads.

So with those changes in place, here's the directory structure:

The diagram is shown below. The `RentalOrder` depends on the `RentalReceipt`, but not vice versa. Both depend upon the `Bonus`, but the `CookieBonus` is an independent low-level detail.

The lowest-level detail is the `RentalItem` record. That's a bit of a concern because it is so concrete. If it gets changed in any way, then pretty much everything has to recompile and redeploy. There are ways to resolve that—but I think that's a battle for another day.

Notice the curvy border line. That line divides the project into two components. One contains the high-level policy, and the other contains the low-level details. All dependencies cross that line in one direction, toward the higher-level component. That line is an *architectural boundary* that separates those two components—and the rule for architectural boundaries is that dependencies cross only toward the higher-level side.



First, let's look at the code within the high-level component.

——RentalOrder.java——

```
package ubConferenceCenter;

import java.util.ArrayList;
import java.util.List;

public class RentalOrder {
  public record Totals(int subtotal, int tax) {
  }

  private String customerName;
  private int subtotal = 0;
  private int tax = 0;
  private RentalReceipt receipt = new RentalReceipt();
  private List<Bonus> bonuses = new ArrayList<>();

  public RentalOrder(String customerName) {
    this.customerName = customerName;
  }

  public void addBonus(Bonus bonus) {
    bonuses.add(bonus);
  }
```

```
  public void rent(CatalogItem item, int days) {
    int unitPrice = item.getUnitPrice();
    int price = item.getDiscountedPrice(days);
    int thisTax = (int) Math.round(price * item.getTaxRate());
    receipt.add(new RentalItem(item.getName(), days,
             unitPrice, price, thisTax));
    subtotal += price;
    tax += thisTax;
  }

  public RentalItem[] getReceipt() {
    return receipt.finalize(bonuses);
  }

  public String getCustomerName() {
    return customerName;
  }

  public Totals getTotals() {
    return new Totals(subtotal, tax);
  }
}
```

Notice that virtually all of the business rules have fled this module. The only ones that remain are the tax and total calculations. But the discount and bonus calculations have been moved into the appropriate derivatives of `CatalogItem` and `Bonus`.

——RentalReceipt.java——

```
package ubConferenceCenter;

import java.util.ArrayList;
import java.util.List;

public class RentalReceipt {
  private List<RentalItem> items = new ArrayList<>();

  public void add(RentalItem item) {
    items.add(item);
  }

  public RentalItem[] finalize(List<Bonus> bonuses) {
    List<RentalItem> finalItems = new ArrayList<>(this.items);
    finalItems.addAll(addBonuses(bonuses));
    return finalItems.toArray(new RentalItem[0]);
  }
```

```
  private List<RentalItem> addBonuses(List<Bonus> bonuses) {
    List<RentalItem> bonusItems = new ArrayList<>();
    for (Bonus bonus : bonuses)
      bonus.checkAndAdd(items, bonusItems);
    return bonusItems;
  }
}
```

The `RentalReceipt` class walks through and applies the bonuses; but it does not know any of the details about those bonuses. It creates a finalized receipt with the bonuses added to all the items.

Next come the two interfaces that inverted the dependencies between the high-level policy and the low-level detail.

```
——CatalogItem.java——
package ubConferenceCenter;

public interface CatalogItem {
  int getDiscountedPrice(int days);
  int getUnitPrice();
  double getTaxRate();
  String getName();
}

——Bonus.java——
package ubConferenceCenter;

import java.util.List;

public interface Bonus {
  void checkAndAdd(List<RentalItem> items, List<RentalItem> bonusItems);
}
```

The last module in the high-level component is the `RentalItem`. This is a simple concrete data structure.

```
——RentalItem.java——
package ubConferenceCenter;

public record RentalItem(String type,
                         int days,
                         int unitPrice,
                         int price,
                         int tax) {
}
```

As previously stated, this module is somewhat problematic. Any changes made to this data structure will force recompilation and redeployment of both components. And changes to this data structure are not at all unlikely.

There are ways of dealing with this. For example, we could turn the `RentalItem` into a hash map. But that's probably going well beyond our current goal of making room for growth. We'll keep that idea in our back pocket for now.

Now let's look at the low-level component.

```
——SmallRoom.java——
package ubConferenceCenter.catalogItems;

import ubConferenceCenter.CatalogItem;

public class SmallRoom implements CatalogItem {
  public String getName() {
    return "SMALL_ROOM";
  }

  public int getDiscountedPrice(int days) {
    double discountRate = (days == 5) ? 0.9 : 1.0;
    return (int) Math.round(getUnitPrice() * days * discountRate);
  }

  public int getUnitPrice() {
    return 100;
  }

  public double getTaxRate() {
    return 0.05;
  }
}

——LargeRoom.java___
package ubConferenceCenter.catalogItems;

import ubConferenceCenter.CatalogItem;

public class LargeRoom implements CatalogItem {
  public int getDiscountedPrice(int days) {
    double discountRate = (days == 5) ? 0.9 : 1.0;
    return (int) Math.round(getUnitPrice() * days * discountRate);
  }
```

```
  public int getUnitPrice() {
    return 150;
  }

  public double getTaxRate() {
    return 0.05;
  }

  public String getName() {
    return "LARGE_ROOM";
  }
}

——Coffee.java——
package ubConferenceCenter.catalogItems;

import ubConferenceCenter.CatalogItem;

public class Coffee implements CatalogItem {
  public int getDiscountedPrice(int days) {
    return getUnitPrice() * days;
  }

  public int getUnitPrice() {
    return 10;
  }

  public double getTaxRate() {
    return 0;
  }

  public String getName() {
    return "COFFEE";
  }
}

——Cookies.java——
package ubConferenceCenter.catalogItems;

import ubConferenceCenter.CatalogItem;

public class Cookies implements CatalogItem {
  public int getDiscountedPrice(int days) {
    return getUnitPrice() * days;
  }
```

```
  public int getUnitPrice() {
    return 15;
  }

  public double getTaxRate() {
    return 0;
  }

  public String getName() {
    return "COOKIES";
  }
}
```

——CookieBonus.java——

```
package ubConferenceCenter.bonuses;

import ubConferenceCenter.Bonus;
import ubConferenceCenter.RentalItem;

import java.util.List;

public class CookieBonus implements Bonus {
  public void checkAndAdd(List<RentalItem> items,
                          List<RentalItem> bonusItems) {
    boolean largeRoomFiveDays = items.stream().anyMatch(
      item -> item.type().equals("LARGE_ROOM") && item.days() == 5);
    boolean coffeeFiveDays = items.stream().anyMatch(
      item -> item.type().equals("COFFEE") && item.days() == 5);
    if (largeRoomFiveDays && coffeeFiveDays)
      bonusItems.add(new RentalItem("COOKIES", 5, 0, 0, 0));
  }
}
```

As you can see, all the business rules have been tucked away into their corresponding derivatives. If a new discount is needed for coffee, we can place it in the `Coffee` class. If a new bonus is needed for small rooms, we can create a `Bonus` derivative for that. If we want to add `NotePads` or `Projectors`, we can do that by adding those classes to the low-level component. None of those changes will cause the high-level component to be recompiled or redeployed. We have achieved that isolation by conforming to the DIP.

You might be concerned about one thing, though. Perhaps you are wondering where all those derivatives are getting instantiated. I never showed you my tests, did I? That's where all that work was done. Here they are.

```
———RentalOrderTest.java———
package ubConferenceCenter;

import org.junit.jupiter.api.BeforeEach;
import org.junit.jupiter.api.Test;
import ubConferenceCenter.RentalOrder.Totals;
import ubConferenceCenter.bonuses.CookieBonus;
import ubConferenceCenter.catalogItems.Coffee;
import ubConferenceCenter.catalogItems.Cookies;
import ubConferenceCenter.catalogItems.LargeRoom;
import ubConferenceCenter.catalogItems.SmallRoom;

import static org.junit.jupiter.api.Assertions.assertEquals;

public class RentalOrderTest {
  private final SmallRoom SMALL_ROOM = new SmallRoom();
  private final LargeRoom LARGE_ROOM = new LargeRoom();
  private final Coffee COFFEE = new Coffee();
  private final Cookies COOKIES = new Cookies();
  private RentalOrder order;

  @BeforeEach
  void setUp() {
    order = new RentalOrder("Customer Name");
    order.addBonus(new CookieBonus());
  }

  private void assertTotalAndTax(int subtotal, int tax) {
    Totals totals = order.getTotals();
    assertEquals(subtotal, totals.subtotal());
    assertEquals(tax, totals.tax());
  }

  private void assertTypeDaysUnitTotalTax(RentalItem item, String type,
                                          int days, int unitPrice,
                                          int price, int tax) {
    assertEquals(type, item.type());
    assertEquals(days, item.days());
    assertEquals(unitPrice, item.unitPrice());
    assertEquals(price, item.price());
    assertEquals(tax, item.tax());
  }
```

```
@Test
public void oneSmallRoomForOneDay() throws Exception {
  assertEquals("Customer Name", order.getCustomerName());
  order.rent(SMALL_ROOM, 1);
  RentalItem[] receipt = order.getReceipt();
  assertEquals(1, receipt.length);
  assertTypeDaysUnitTotalTax(receipt[0], "SMALL_ROOM", 1, 100, 100, 5);
  assertTotalAndTax(100, 5);
}

@Test
public void oneSmallRoomForTwoDays() throws Exception {
  order.rent(SMALL_ROOM, 2);
  RentalItem[] receipt = order.getReceipt();
  assertEquals(1, receipt.length);
  assertTypeDaysUnitTotalTax(receipt[0], "SMALL_ROOM", 2, 100, 200, 10);
  assertTotalAndTax(200, 10);
}

@Test
public void oneLargeRoomForThreeDays() throws Exception {
  order.rent(LARGE_ROOM, 3);
  RentalItem[] receipt = order.getReceipt();
  assertEquals(1, receipt.length);
  assertTypeDaysUnitTotalTax(receipt[0], "LARGE_ROOM", 3, 150, 450, 23);
  assertTotalAndTax(450, 23);
}

@Test
public void oneSmallRoomForOneWeek() throws Exception {
  order.rent(SMALL_ROOM, 5);
  RentalItem[] receipt = order.getReceipt();
  assertEquals(1, receipt.length);
  assertTypeDaysUnitTotalTax(receipt[0], "SMALL_ROOM", 5, 100, 450, 23);
  assertTotalAndTax(450, 23); /* 10% discount */
}

@Test
public void twoSmallRoomsForOneDay() throws Exception {
  order.rent(SMALL_ROOM, 1);
  order.rent(SMALL_ROOM, 1);
  RentalItem[] receipt = order.getReceipt();
  assertEquals(2, receipt.length);
  assertTypeDaysUnitTotalTax(receipt[0], "SMALL_ROOM", 1, 100, 100, 5);
  assertTypeDaysUnitTotalTax(receipt[1], "SMALL_ROOM", 1, 100, 100, 5);
```

```
  assertTotalAndTax(200, 10);
}

@Test
public void oneSmallRoomAndCoffeeForOneDay() throws Exception {
  order.rent(SMALL_ROOM, 1);
  order.rent(COFFEE, 1);
  RentalItem[] receipt = order.getReceipt();
  assertEquals(2, receipt.length);
  assertTypeDaysUnitTotalTax(receipt[0], "SMALL_ROOM", 1, 100, 100, 5);
  assertTypeDaysUnitTotalTax(receipt[1], "COFFEE", 1, 10, 10, 0);
  assertTotalAndTax(110, 5); /* No tax on coffee */
}

@Test
public void oneSmallRoomAndCookiesForOneDay() throws Exception {
  order.rent(SMALL_ROOM, 1);
  order.rent(COOKIES, 1);
  RentalItem[] receipt = order.getReceipt();
  assertEquals(2, receipt.length);
  assertTypeDaysUnitTotalTax(receipt[0], "SMALL_ROOM", 1, 100, 100, 5);
  assertTypeDaysUnitTotalTax(receipt[1], "COOKIES", 1, 15, 15, 0);
  assertTotalAndTax(115, 5); /* No tax on cookies */
}

@Test
public void oneSmallRoomCookiesCoffeeForFiveDays() throws Exception {
  order.rent(SMALL_ROOM, 5);
  order.rent(COFFEE, 5);
  order.rent(COOKIES, 5);
  RentalItem[] receipt = order.getReceipt();
  assertEquals(3, receipt.length);
  assertTypeDaysUnitTotalTax(receipt[0], "SMALL_ROOM", 5, 100, 450, 23);
  assertTypeDaysUnitTotalTax(receipt[1], "COFFEE", 5, 10, 50, 0);
  assertTypeDaysUnitTotalTax(receipt[2], "COOKIES", 5, 15, 75, 0);
  /* 10% discount on room but not on coffee */
  assertTotalAndTax(575, 23);
}

@Test
public void oneLargeRoomAndCoffeeForWeekGetsCookies() throws Exception {
  order.rent(LARGE_ROOM, 5);
  order.rent(COFFEE, 5);
  RentalItem[] receipt = order.getReceipt();
  assertEquals(3, receipt.length);
```

```
    assertTypeDaysUnitTotalTax(receipt[0], "LARGE_ROOM", 5, 150, 675, 34);
    assertTypeDaysUnitTotalTax(receipt[1], "COFFEE", 5, 10, 50, 0);
    assertTypeDaysUnitTotalTax(receipt[2], "COOKIES", 5, 0, 0, 0);
  }
}
```

These tests were written before any of the refactoring in this chapter had begun. At each step of that refactoring, I kept these tests passing. Some of the changes made to the production code caused changes to the tests, but I was able to minimize them by keeping the tests and production code decoupled and by isolating the details of the production code from the details of the tests. For example, the final fields named for the `CatalogItems` replaced the old enumerations without too much fuss.

INDEPENDENT DEPLOYABILITY

Our design now has a strong architectural boundary that separates it into two components. Those two components can be independently deployed. They can be compiled into two separate `jar` files. When one component changes, only that `jar` changes, and the other does not need to be redeployed.

Imagine that this code was written in JavaScript as opposed to Java. Imagine that it will be sent to a browser to run there. The fact that we have divided it into two components has a very specific advantage. If one of those two components changes, and if the browser maintains a cache of those components, then only the component that changed needs to be reloaded into the browser. On slow network connections, that could be a big advantage.

A FINAL THOUGHT

This major cleaning will greatly facilitate the growth of the project. The time it took will be paid back many times over simply because there's a clear and obvious place to put the needed changes; and those changes aren't likely to interfere with each other or with the overall flow of the system.

However, the new structure is not cost free. Those who complain that it is harder to read because of all the different modules and all the indirection are not without a point. Yes, adding structure adds complexity—and that complexity is not free. There's a cognitive price to pay. But we knew that the cognitive load was going to grow, and so our goal was to minimize that growth by creating an organization that would accept it gracefully.

What about performance? Is the new structure slower than the old one? Probably so. There are a few more references that need to be followed, and `switch` statements are easier for compilers to optimize than polymorphic

dispatch. But the difference in performance is probably so tiny that you could not easily measure it. For most applications, that tiny decrease in performance would be of no concern at all.

FUTURE BOB: Grok3, good as it is, did not drive the design of the original code to the level of depth we just saw. Grok3 did not invert the dependencies, nor did it attempt to separate high-level policy from low-level detail. Large language models (LLMs)/AIs have their uses; but they are not human and are not adept at understanding higher architectural goals.

This chapter, and the chapter before, were a whirlwind tour through the low-hanging fruit of clean code. But now that tour is over, and it's time to get down to the basics. And, of course, we begin with names.

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Index

B

C

D

F

J

P

Q

R

S

T

U

V